MISCELLANEOUS PAPER C-70-17

TESTS OF ROCK CORES
WARREN II STUDY AREA, WYOMING

by

K. L. Saucier

September 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
<table>
<thead>
<tr>
<th>Report No.</th>
<th>Title</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>MP C-69-3</td>
<td>Tests of Rock Cores, Warren Area, Wyoming</td>
<td>March 1969</td>
</tr>
<tr>
<td>MP C-69-16</td>
<td>Tests of Rock Cores, Castle Study Area, California</td>
<td>October 1969</td>
</tr>
<tr>
<td>MP C-70-4</td>
<td>Tests of Rock Cores, Bergstrom Study Area, Texas</td>
<td>February 1970</td>
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<tr>
<td>MP C-70-6</td>
<td>Tests of Rock Cores, Scott Study Area, Missouri</td>
<td>May 1970</td>
</tr>
<tr>
<td>MP C-70-7</td>
<td>Tests of Rock Cores, Plattsburgh Study Area, New York</td>
<td>June 1970</td>
</tr>
<tr>
<td>MP C-70-9</td>
<td>Tests of Rock Cores, Duluth-Vermillion Study Area, Minnesota</td>
<td>June 1970</td>
</tr>
<tr>
<td>MP C-70-10</td>
<td>Tests of Rock Cores, Michigamme Study Area, Michigan</td>
<td>June 1970</td>
</tr>
<tr>
<td>MP C-70-11</td>
<td>Tests of Rock Cores, Pease Study Area, New Hampshire</td>
<td>July 1970</td>
</tr>
<tr>
<td>MP C-70-14</td>
<td>Tests of Rock Cores, Pembine Study Area, Michigan and Wisconsin</td>
<td>August 1970</td>
</tr>
<tr>
<td>MP C-70-16</td>
<td>Tests of Rock Cores, Machias Study Area, Maine</td>
<td>August 1970</td>
</tr>
</tbody>
</table>

Destroy this report when no longer needed. Do not return it to the originator.

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.
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.

Laura Hanisee said following MP's were to be changed to Statement A:

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

Laboratory tests were conducted on rock core samples received from five holes from Natrona and Fremont Counties, Wyoming (Warren II Study Area). Results were used to determine the quality and uniformity of the rock to depths of 200 feet below ground surface.

The rock core was petrographically identified as predominantly granite and biotite gneiss. Several specimens of amphibolite gneiss and biotite schist were also identified.

The wide area represented by the five drill holes and the complex nature of the material preclude assessment of the area on a hole-to-hole basis. The overall appearance of the area is one of a complex rock mass with quite variable physical properties. However, based on the limited data available, the area offers possibilities as a competent hard rock medium if poor quality schist can be avoided. Except for the schist, poorer quality rock is predominantly in the upper elevations, but one may expect to remove up to 70 feet of material in some areas before competent rock is reached. A more extensive investigation will be required to identify the most promising hard rock areas.
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, Norton Air Force Base, California. The work was accomplished during the period August 1969 through May 1970 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. C. R. Hallford was responsible for the petrographic work. Mr. Saucier performed the majority of the program analysis and prepared this report.

Directors of the WES during the investigation and the preparation and publication of this report were COL Levi A. Brown, CE, and COL Ernest D. Peixotto, CE. Technical Director was Mr. F. R. Brown.
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5.1 Discussion

5.2 Conclusions

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APPENDIX C DATA REPORT - HOLE W2-CR-5, 26 AUGUST 1969

APPENDIX D DATA REPORT - HOLE W2-CR-14, 28 AUGUST 1969

APPENDIX E DATA REPORT - HOLE W2-CR-26, 20 AUGUST 1969

REFERENCES

REFERENCES
CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

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

<table>
<thead>
<tr>
<th>Multiply</th>
<th>By</th>
<th>To Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>inches</td>
<td>25.4</td>
<td>millimeters</td>
</tr>
<tr>
<td>feet</td>
<td>0.3048</td>
<td>meters</td>
</tr>
<tr>
<td>feet per second</td>
<td>0.3048</td>
<td>meters per second</td>
</tr>
<tr>
<td>pounds</td>
<td>0.45359237</td>
<td>kilograms</td>
</tr>
<tr>
<td>pounds per square inch</td>
<td>0.070307</td>
<td>kilograms (force) per square centimeter</td>
</tr>
<tr>
<td></td>
<td>6.894757</td>
<td>kilonewtons per square meter</td>
</tr>
<tr>
<td>square miles</td>
<td>2.58999</td>
<td>square kilometers</td>
</tr>
</tbody>
</table>
CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

The purpose of this study was to supplement the information being obtained for the area evaluation study by the U. S. Air Force Space and Missile Systems Organization (SAMSO). It was necessary to determine the properties of the specific materials for evaluation of the area as a hard rock medium and, as necessary, for design of structures in the medium. Results of tests on cores from Natrona and Fremont Counties in Wyoming, designated the Warren II area, 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 as indicated in the following paragraph on samples received from the field. 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) unconfined compression (conventional and cyclic compression), and (4) dynamic elastic properties. Special tests conducted, respectively, to determine the degree of anisotropy of the sampled rock and 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. A limited petrographic examination was also made.

1.4 SAMPLES

Samples were received from five holes in the Warren II area. These holes were designated W2-CR-1, -4, -5, -14, and -26. All samples were NX size cores (nominal 2-1/8-inch diameter). Test specimens of the required dimensions as presented 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.

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 E.

The core descriptions originally given in the data reports (Appendixes A through E) were frequently taken from the core logs received with the sample shipments. These descriptions have been changed, where necessary, to reflect the results of the petrographic examination and analysis performed at a later date.
<table>
<thead>
<tr>
<th>Test</th>
<th>Specimen Size</th>
<th>Test Equipment</th>
<th>Recording Equipment</th>
<th>Measured Properties</th>
<th>Computed Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative hardness</td>
<td>1 diameter by 2 diameters</td>
<td>Schmidt hammer</td>
<td>--</td>
<td>Relative hardness</td>
<td>--</td>
</tr>
<tr>
<td>Specific gravity</td>
<td></td>
<td>Scales</td>
<td>--</td>
<td>Specific gravity</td>
<td>Density</td>
</tr>
<tr>
<td>Indirect tension</td>
<td></td>
<td>440,000-pound test machine</td>
<td>--</td>
<td>Tensile strength</td>
<td>--</td>
</tr>
<tr>
<td>Direct tension</td>
<td></td>
<td>30,000-pound test machine</td>
<td>--</td>
<td>Tensile strength</td>
<td>--</td>
</tr>
<tr>
<td>Unconfined compression</td>
<td></td>
<td>440,000-pound test machine</td>
<td>X-Y recorder</td>
<td>Compressive strength</td>
<td>--</td>
</tr>
<tr>
<td>Cyclic compression</td>
<td></td>
<td>440,000-pound test machine</td>
<td>X-Y recorder</td>
<td>Compressive strength</td>
<td>Young's, shear, and bulk moduli and Poisson's ratio</td>
</tr>
<tr>
<td>Ultrasonic velocity</td>
<td></td>
<td>Pulse generator, amplifiers</td>
<td>Oscilloscope</td>
<td>Compressional and shear velocities</td>
<td>Young's, shear, and bulk moduli and Poisson's ratio</td>
</tr>
<tr>
<td>Dynamic elastic moduli</td>
<td></td>
<td>Pulse generator, amplifiers</td>
<td>Oscilloscope</td>
<td>Compressional and shear velocities</td>
<td>--</td>
</tr>
<tr>
<td>Petrographic examination</td>
<td>Variable</td>
<td>Microscopes, X-ray diffraction</td>
<td>--</td>
<td>Appearance, texture, and mineralogy</td>
<td>--</td>
</tr>
<tr>
<td>Anisotropy</td>
<td>1 diameter by 1 diameter</td>
<td>Pulse generator, amplifiers</td>
<td>Oscilloscope</td>
<td>Compressional and shear velocities</td>
<td>Young's, shear, and bulk moduli and Poisson's ratio</td>
</tr>
</tbody>
</table>
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 TESTS

3.1 TESTS UTILIZED

Based on past experience with tests on samples received from areas previously evaluated, the following tests were selected for use in determining the quality and uniformity of the Warren II area rock: compressional wave velocity, unconfined compressive strength, Schmidt number, and specific gravity.

Core samples from the five holes in the Warren II area were petrographically identified as predominantly biotite gneiss and granite. Several specimens of the core were identified as amphibolite gneiss and biotite schist. A few of the granite specimens were weathered. 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:

1 A list of associated reports is given on the inside front cover of this report.
<table>
<thead>
<tr>
<th>Group</th>
<th>Rock Quality</th>
<th>Compressive Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Poor</td>
<td>&lt;8,000</td>
</tr>
<tr>
<td>2</td>
<td>Marginal</td>
<td>8,000 to 12,000</td>
</tr>
<tr>
<td>3</td>
<td>Good to excellent</td>
<td>12,000 and above</td>
</tr>
</tbody>
</table>

3.2 POOR QUALITY ROCK

The incompetent rock (compressive strength less than 8,000 psi) was predominantly schist and gneiss as given below. The description denotes the field-given names unless the petrographic work dictated a different nomenclature.

<table>
<thead>
<tr>
<th>Hole No.</th>
<th>Specimen No.</th>
<th>Description</th>
<th>Specific Gravity</th>
<th>Schmidt No.</th>
<th>Compressive Strength</th>
<th>Compressional Wave Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>W2-CR-4</td>
<td>4</td>
<td>Biotite schist (^a)</td>
<td>2.906</td>
<td>--</td>
<td>3,500</td>
<td>8,995</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Biotite schist (^a)</td>
<td>2.858</td>
<td>--</td>
<td>2,800</td>
<td>11,625</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>Amphibolite gneiss (^a)</td>
<td>2.916</td>
<td>14.0</td>
<td>1,210</td>
<td>7,225</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>Amphibolite gneiss (^a)</td>
<td>3.070</td>
<td>21.8</td>
<td>5,990</td>
<td>11,675</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>Granite gneiss</td>
<td>2.986</td>
<td>43.2</td>
<td>6,240</td>
<td>16,655</td>
</tr>
</tbody>
</table>

Average: 2.947 26.3 3,950 11,235

\(^a\) Petrographic description.
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 specific gravity results in the above tabulation are very high for rock, but the other physical tests indicate rather incompetent material.

Poor quality rock comprised 10 percent of the material tested. 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).

<table>
<thead>
<tr>
<th>Hole No.</th>
<th>Specimen No.</th>
<th>Description</th>
<th>Specific Gravity</th>
<th>Schmidt No.</th>
<th>Compressive Strength</th>
<th>Compressional Wave Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>W2-CR-4</td>
<td>193</td>
<td>Granite gneiss</td>
<td>2.597</td>
<td>55.8</td>
<td>8,400</td>
<td>17,140</td>
</tr>
<tr>
<td>W2-CR-4</td>
<td>16</td>
<td>Granite gneiss</td>
<td>2.589</td>
<td>--</td>
<td>10,650</td>
<td>16,185</td>
</tr>
</tbody>
</table>

(Continued)
<table>
<thead>
<tr>
<th>Hole No.</th>
<th>Specimen No.</th>
<th>Description</th>
<th>Specific Gravity</th>
<th>Schmidt No.</th>
<th>Compressive Strength</th>
<th>Compressional Wave Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>W2-CR-4</td>
<td>17</td>
<td>Amphibolite gneiss&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.095</td>
<td>--</td>
<td>9,170</td>
<td>16,055</td>
</tr>
<tr>
<td>W2-CR-5</td>
<td>2</td>
<td>Biotite gneiss</td>
<td>2.655</td>
<td>32.1</td>
<td>--&lt;sup&gt;b&lt;/sup&gt;</td>
<td>--&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Biotite gneiss</td>
<td>2.670</td>
<td>57.8</td>
<td>11,510</td>
<td>19,300</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>Biotite gneiss</td>
<td>2.704</td>
<td>46.8</td>
<td>10,940</td>
<td>17,205</td>
</tr>
<tr>
<td>W2-CR-14</td>
<td>1</td>
<td>Weathered granite</td>
<td>2.620</td>
<td>40.3</td>
<td>11,340</td>
<td>8,590</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Average</td>
<td>2.709</td>
<td>46.6</td>
<td>10,335</td>
</tr>
</tbody>
</table>

<sup>a</sup> Petrographic description.
<sup>b</sup> Specimen broke during preparation.

Although the strength results indicate the rock quality to be marginal, the Schmidt number and the compressional wave velocity results are not definitive. 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 TO EXCELLENT QUALITY ROCK

Most of the rock described as intact gneiss or granite was good to excellent quality material, depending on the strengths obtained. Results are given as follows.
<table>
<thead>
<tr>
<th>Hole No.</th>
<th>Specimen No.</th>
<th>Description</th>
<th>Schmidt Spec. No.</th>
<th>Compressional Gravity</th>
<th>Strength psi</th>
<th>Wave Velocity fps</th>
</tr>
</thead>
<tbody>
<tr>
<td>W2-CR-1</td>
<td>2</td>
<td>Diorite, critically fractured&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.764</td>
<td>12,420</td>
<td>15,730</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Granite porphyry&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.736</td>
<td>21,210</td>
<td>20,400</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Granite porphyry</td>
<td>2.765</td>
<td>22,550</td>
<td>20,705</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Granite porphyry, incipient fracture&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.739</td>
<td>22,180</td>
<td>20,610</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Granite porphyry</td>
<td>2.655</td>
<td>21,060</td>
<td>20,760</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Granite porphyry</td>
<td>2.767</td>
<td>25,000</td>
<td>20,730</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>Granite porphyry, incipient fracture</td>
<td>2.639</td>
<td>35,760</td>
<td>20,850</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Granite porphyry</td>
<td>2.635</td>
<td>48,180</td>
<td>20,435</td>
<td></td>
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<tr>
<td></td>
<td>10</td>
<td>Granite porphyry, fine grained</td>
<td>2.649</td>
<td>28,030</td>
<td>20,260</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>Pink granite, fine grained</td>
<td>2.739</td>
<td>24,240</td>
<td>20,610</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>Granite porphyry</td>
<td>2.671</td>
<td>13,640</td>
<td>20,955</td>
<td></td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>Granite porphyry, fractured</td>
<td>2.681</td>
<td>21,670</td>
<td>20,155</td>
<td></td>
</tr>
<tr>
<td>W2-CR-4</td>
<td>10</td>
<td>Amphibolite gneiss</td>
<td>3.024</td>
<td>25,860</td>
<td>22,715</td>
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<td></td>
<td>12</td>
<td>Amphibolite gneiss</td>
<td>3.014</td>
<td>19,520</td>
<td>21,865</td>
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<tr>
<td></td>
<td>18</td>
<td>Granite</td>
<td>2.684</td>
<td>15,950</td>
<td>18,195</td>
<td></td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>Granite</td>
<td>2.670</td>
<td>25,380</td>
<td>19,795</td>
<td></td>
</tr>
<tr>
<td>W2-CR-5</td>
<td>9</td>
<td>Biotite gneiss</td>
<td>2.677</td>
<td>20,480</td>
<td>18,505</td>
<td></td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>Biotite gneiss</td>
<td>2.726</td>
<td>22,090</td>
<td>18,955</td>
<td></td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>Biotite gneiss</td>
<td>2.692</td>
<td>22,120</td>
<td>19,820</td>
<td></td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>Biotite gneiss, vertically fractured</td>
<td>2.692</td>
<td>18,180</td>
<td>19,945</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>Biotite gneiss, vertically fractured</td>
<td>2.678</td>
<td>12,550</td>
<td>19,430</td>
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<td></td>
<td>21</td>
<td>Biotite gneiss</td>
<td>2.732</td>
<td>23,340</td>
<td>20,235</td>
<td></td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>Biotite gneiss</td>
<td>2.703</td>
<td>15,300</td>
<td>20,035</td>
<td></td>
</tr>
<tr>
<td>W2-CR-14</td>
<td>5</td>
<td>Slightly weathered granite</td>
<td>2.640</td>
<td>22,790</td>
<td>18,655</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Slightly weathered granite</td>
<td>2.640</td>
<td>22,910</td>
<td>18,630</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>Slightly weathered granite</td>
<td>2.644</td>
<td>22,510</td>
<td>18,575</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Slightly weathered granite</td>
<td>2.644</td>
<td>21,400</td>
<td>18,425</td>
<td></td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>Slightly weathered granite</td>
<td>2.639</td>
<td>17,300</td>
<td>18,875</td>
<td></td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>Unweathered granite</td>
<td>2.645</td>
<td>24,360</td>
<td>18,935</td>
<td></td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>Unweathered granite</td>
<td>2.646</td>
<td>21,880</td>
<td>18,110</td>
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<tr>
<td></td>
<td>21</td>
<td>Unweathered granite</td>
<td>2.641</td>
<td>23,880</td>
<td>19,140</td>
<td></td>
</tr>
<tr>
<td>W2-CR-26</td>
<td>2</td>
<td>Vertically fractured granite</td>
<td>2.645</td>
<td>28,700</td>
<td>18,225</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Vertically fractured granite</td>
<td>2.666</td>
<td>27,270</td>
<td>17,280</td>
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<tr>
<td></td>
<td>5</td>
<td>Intact granite</td>
<td>2.648</td>
<td>29,700</td>
<td>19,415</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Intact granite</td>
<td>2.646</td>
<td>28,790</td>
<td>18,760</td>
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<tr>
<td></td>
<td>9</td>
<td>Intact granite</td>
<td>2.636</td>
<td>25,230</td>
<td>18,140</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Intact granite</td>
<td>2.630</td>
<td>31,670</td>
<td>18,660</td>
<td></td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>Intact granite</td>
<td>2.639</td>
<td>39,000</td>
<td>18,560</td>
<td></td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>Intact granite</td>
<td>2.636</td>
<td>30,160</td>
<td>18,000</td>
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<tr>
<td></td>
<td></td>
<td>Average</td>
<td>2.691</td>
<td>23,800</td>
<td>19,395</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Petrographic description.
Only six of the specimens yielded compressive strengths of less than 18,000 psi, the lower limit of what may be considered excellent quality rock. The remainder of the specimens, representing 66 percent of the specimens tested from this area, gave strengths approximating 25,000 psi—an acceptable level of confidence for the better rock. Compressional wave velocities were sufficiently high to indicate few, if any, flaws in the good to excellent quality material.
4.1 COMPARATIVE TENSILE TESTS

Five 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 4.1. Generally, the direct tensile strength averaged approximately 80 percent of the tensile splitting strength. The gneiss and the brown (possibly weathered) granite yielded strengths significantly lower than the better granite.

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.

Examination of the stress-strain curves in the data reports reveals that the intact granite is predominantly linear-elastic to approximately half of the ultimate strength. However, significant hysteresis and residual strain are evident in most of the gneiss specimens even under small stresses. 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 ANISOTROPY TESTS

To determine the degree of anisotropy, five rock specimens were selected and prepared for determination of compression (dilatational) and shear velocities in three directions according to the ASTM proposed "Standard Method of Test for Laboratory Determination of Ultrasonic Pulse Velocities and Elastic Constants of Rock." The NX-diameter specimens were cut to lengths of approximately 2 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. Compressive and shear velocities were determined in three directions, on one vertical and two mutually perpendicular lateral axes. The velocities, densities, and dimensions were measured as specified in the proposed test method. Results of the velocity determinations are given in Table 4.3.

All of the material yielded compressive and shear velocities indicative of competent rock. The shear velocities consistently averaged approximately 60 percent of the compressive velocities. Specimen W2-CR-5-16, described as quartz biotite gneiss, yielded velocities which would indicate a high degree of anisotropy in the gneissic material from this area.

A compilation of the elastic properties computed from the compressive and shear velocities and the specific gravity is given in Table 4.4. However, discretion must be used in utilizing the moduli results since experimental errors are introduced when 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 2 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.
4.4 PETROGRAPHIC EXAMINATION

4.4.1 Samples. Five boxes of NX core from holes in Fremont and Natrona Counties, Wyoming, were received in August 1969 for testing. Each box contained about 15 feet of core which represented several depths to 200 feet.

The cores were inspected to select representative pieces from all significant rock types for petrographic examination. The cores are described below:

Hole W2-CR-1. The core was brownish-gray and white, coarse-grained rock, logged as granite porphyry; gray and white medium-grained rock, logged as diorite; and pink, fine-grained rock, logged as fine-grained granite. The entire core appeared to be unweathered and very massive. A few high-angle fractures were present.

Sections 1, 3 through 10, 12 through 17, and 20 through 26 were light brownish-gray, coarse-grained porphyritic rock. This rock contained medium-grained phases that appeared to be assimilated diorite.

Sections 11, 18, and 19 were pink, fine-grained rock which was logged as granite.

Section 2 was diorite, which may have been assimilated by the granite.

Hole W2-CR-4. There were three rock types in this hole: a biotite schist, an amphibole gneiss, and a coarse-grained rock logged
as granite. Sections 1 through 6 were weathered and the rest of the sections were fresh.

Sections 2 through 6 were weathered, medium-grained biotite schist. The biotite was slightly altered to chlorite. This rock contained several randomly oriented fractures.

Sections 1, 9, 16, 18, 21, and 22 were pink and white, coarse-grained, massive rock.

Sections 7, 8, 10 through 15, 17, 19, and 20 were black and white, medium-grained amphibolite gneiss. There were a few fractures and joints present.

Hole W2-CR-5. The entire core was fine- to coarse-grained biotite gneiss and schist.

Sections 1 through 13 were fine-grained biotite gneiss and the remainder of the core was coarse-grained biotite schist and gneiss.

Section 15 contained a granitic inclusion. Most of the sections contained minor sealed fractures.

Hole W2-CR-14. The entire core was brownish-gray, coarse-grained rock, logged as granite.

Sections 1 through 8 were weathered. Fractures were not common in these sections or in the remainder of the core.

Hole W2-CR-26. The entire core was brownish-gray, coarse-grained rock, logged as granite. All sections were fresh and only Sections 2 and 3 contained fractures.
### 4.4.2 Specimens Selected.

The specimens selected for petrographic examination were:

<table>
<thead>
<tr>
<th>Hole No.</th>
<th>CD Serial No.</th>
<th>Specimen No.</th>
<th>Approximate Depth (feet)</th>
<th>Rock Description (Colors According to Reference 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W2-CR-1</td>
<td>SAMSO-8, DC-1</td>
<td>11</td>
<td>90</td>
<td>Pale red (10R 6/2) aplite</td>
</tr>
<tr>
<td></td>
<td></td>
<td>21</td>
<td>168</td>
<td>Light brownish-gray (5YR 6/1) and white (N9) to light brownish-gray (5YR 6/1) and black (N1) tonalite</td>
</tr>
<tr>
<td></td>
<td></td>
<td>26</td>
<td>200</td>
<td>Light brownish-gray (5YR 6/1) and white (N9) granite</td>
</tr>
<tr>
<td>W2-CR-4</td>
<td>SAMSO-8, DC-3</td>
<td>6</td>
<td>68</td>
<td>Greenish-black (5G 2/1) hornblende-biotite schist</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>103</td>
<td>Greenish-black (5GY 2/1) hornblende-plagioclase gneiss</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9</td>
<td>109</td>
<td>Grayish-pink (SR 8/2) tonalite pegmatite</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20</td>
<td>182</td>
<td>Black (N1) amphibolite gneiss</td>
</tr>
<tr>
<td>W2-CR-5</td>
<td>SAMSO-8, DC-4</td>
<td>6</td>
<td>57</td>
<td>Medium gray (N5) biotite gneiss</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
<td>130</td>
<td>Greenish-black (5GY 2/1) biotite schist</td>
</tr>
</tbody>
</table>

(Continued)
### Table 1: Rock Description

<table>
<thead>
<tr>
<th>Hole No.</th>
<th>CD Serial No.</th>
<th>Specimen No.</th>
<th>Approximate Depth</th>
<th>Rock Description (Colors According to Reference 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W2-CR-14</td>
<td>SAMSO-8, DC-5</td>
<td>12</td>
<td>123</td>
<td>Light gray (N7) and dark yellowish-orange (10YR 6/6) granite</td>
</tr>
<tr>
<td>W2-CR-26</td>
<td>SAMSO-8, DC-2</td>
<td>17</td>
<td>173</td>
<td>Medium light gray (N6) and white (N9) granite</td>
</tr>
</tbody>
</table>

### 4.4.3 Test Procedure

Each piece of core was sawed axially. One sawed surface of each piece was polished and photographed. Composite samples were obtained from the whole length or from selected portions from the remaining half of each piece. The composite samples were ground to pass a No. 325 sieve (44µ). X-ray diffraction (XRD) patterns were made of each sample as a tightly packed powder. All XRD patterns were made using an XRD-5 diffractometer with nickel-filtered copper radiation. The samples X-rayed are listed as follows:

<table>
<thead>
<tr>
<th>Hole No.</th>
<th>Specimen No.</th>
<th>Description of X-Ray Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>W2-CR-1</td>
<td>11</td>
<td>Entire length of core was sampled</td>
</tr>
<tr>
<td></td>
<td>21a</td>
<td>Coarse-grained half was sampled</td>
</tr>
<tr>
<td></td>
<td>21b</td>
<td>Medium-grained half was sampled</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>Entire length was sampled</td>
</tr>
</tbody>
</table>

(Continued)
<table>
<thead>
<tr>
<th>Hole No.</th>
<th>Specimen No.</th>
<th>Description of X-Ray Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>W2-CR-4</td>
<td>6</td>
<td>Entire length was sampled</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>Entire length was sampled</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Entire length was sampled</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>Entire length was sampled</td>
</tr>
<tr>
<td>W2-CR-5</td>
<td>6</td>
<td>Entire length was sampled</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>Entire length except for granitic inclusion was sampled</td>
</tr>
<tr>
<td>W2-CR-14</td>
<td>12</td>
<td>Entire length was sampled</td>
</tr>
<tr>
<td>W2-CR-26</td>
<td>17</td>
<td>Entire length was sampled</td>
</tr>
</tbody>
</table>

Small portions of the powdered samples were tested with dilute hydrochloric acid and with a magnet to determine whether carbonate minerals or magnetite were present.

The polished surface of each section was examined with a stereo-microscope. Thin sections were prepared from each section of core and examined with a polarizing microscope. A point-count modal analysis was made on each thin section, in which 500 points were counted.

4.4.4 Results. The cores examined from the Warren II area can be divided into five groups: porphyritic granites (Reference 4), tonalites (Reference 4), aplite granites (Reference 4), biotite gneisses and schists, and amphibolite schists and gneisses. The
cores were taken from pre-Cambrian rocks in the Sweet Water or Granite Mountains uplift (Reference 5) of central Wyoming, and are very similar to the Sherman Granite Facies (Reference 6) of the southern Laramie Range. The rock types are discussed below. The modal composition of each type is shown in Table 4.5 and the bulk composition by X-ray diffraction in Table 4.6.

**Granites.** Cores W2-CR-14 and -26 and parts of Core W2-CR-1 were granites which contained phenocrysts of microcline, perthite, and microperthite in a coarse-grained matrix of equigranular quartz, plagioclase, and biotite (Figures 4.1 and 4.2). The phenocrysts had a maximum diameter of 1.5 inches and were euhedral to subhedral. The microcline was unaltered, while plagioclase was usually severely altered to sericite. Biotite was slightly altered to chlorite. Primary flow structures were not detected in any of the sections. Microfractures were common in the granites and were prominent in the phenocrysts of potash feldspar. Alteration of the minerals was greatest along these fractures.

Section 26 of Core W2-CR-1 was typical of the granite in this core. The plagioclase, containing 18 percent anorthite, was moderately altered to sericite; the microcline was not altered. The quartz had been strained and fractured, and hematitic stain had been introduced along the fractures, giving the quartz and the rock an unusual brown color.
Section 12 of Core W2-CR-14 contained more microcline than the other two granite sections, but the texture and degree of alteration are similar to Section 26 of W2-CR-1. The majority of the plagioclase was oligoclase, except for the plagioclase in the perthite, which was very fresh andesine containing 33 percent anorthite.

Section 17 of Core W2-CR-26 was similar to Section 26 of W2-CR-1, except that it was more altered. Plagioclase and biotite were often broken and severely altered. Microcline did not show the effects of the alteration.

**Tonalites.** Tonalites (parts of Cores W2-CR-1 and -4) were less abundant than granites and were not porphyritic (Figure 4.3). The tonalites were identified on the field logs as granites. They were classified in this investigation as tonalites (Reference 4) because they contained more plagioclase than the granites and more plagioclase than microcline. Plagioclase comprised about 40 percent of the rock, with microcline and quartz comprising about 28 percent each. Biotite was the dominant ferromagnesian mineral in the rocks.

Section 21 of Core W2-CR-1 was medium- to coarse-grained biotite tonalite (Figure 4.3). The medium-grained part of the section contained more biotite than the coarse-grained part and was darker in color. The medium-grained part (21b) had a weak planar structure that dipped at about 45 degrees from the vertical (Figure 4.3). This structure was not apparent in the coarse-grained part (21a).
from the slight difference in amount of biotite (Table 4.5), the two parts of the section had similar compositions.

The microcline was very fresh and was perthitic. The quartz had been severely strained and fractured. The plagioclase was severely altered to sericite. The degree of alteration increased in the medium-grained part of the section.

Section 9 of Hole W2-CR-4 was typical of the tonalite in this hole and was markedly different from the tonalite in Hole W2-CR-1 (Figure 4.3). It was very coarse-grained and contained a trace of biotite and bands of garnet. The plagioclase contained 33 percent anorthite and was more calcic than the plagioclase in the other tonalites. The rock may be a dike rock.

**Aplitic Granites.** Parts of Core W2-CR-1 were accurately identified on the field log as fine-grained granite. Their equigranular texture and the absence of dark minerals cause them to be classified as aplitic granites in the Shand system (Reference 4). Section 11 of Core W2-CR-1 was representative of this rock type. Its composition was similar to that of Section 12 of Core W2-CR-1 \(^4\) (granite), but it was fine-grained (Figure 4.4), and had a cataclastic texture. This rock may have been originally similar to that granite but was later granulated. The minerals are altered and the grain boundaries are sutured.

**Amphibolites.** Parts of Core W2-CR-4 were rocks which ranged
from hornblende-mica to hornblende-plagioclase rocks (Figures 4.5 and 4.6). Euhedral to subhedral hornblende, near to edenite, was the predominant mineral in these rocks. All were medium-grained, foliated, and fairly dark colored. The hornblende showed only slight alteration to chlorite.

Section 6 of Core W2-CR-4 was very porous and severely weathered. It contained a large amount of highly altered biotite and no plagioclase or quartz. The biotite was altered to chlorite but the hornblende was very fresh. There were many fractures at random angles (Figure 4.5).

Section 8 of Core W2-CR-4 was similar to Core W2-CR-4, Section 20 (described in next paragraph), but contained less quartz and a less calcic andesine plagioclase \( (\text{An}_{36}) \). The hornblende was very fresh and the plagioclase was severely altered to sericite. High-angle and horizontal fractures were present. A pegmatite dike followed an earlier high-angle fracture.

Section 20 of Core W2-CR-4 contained a calcic plagioclase (andesine containing \( 47 \) percent anorthite) that was severely altered to sericite. Quartz was present as interstitial grains that exhibited straight extinction. There were several horizontal fractures that paralleled the schistosity. A quartz vein cut the rock at an angle of about 40 degrees from the vertical (Figure 4.6).

Biotite Gneisses and Schists. The majority of the sections of
Core W2-CR-5 were fine- to coarse-grained biotite, plagioclase gneiss (Figure 4.7). A few scattered sections of biotite schist were present in the core. The gneisses were very fresh while the schists were severely altered.

Section 6 of Hole W2-CR-5 was typical of the gneiss. It had a well-developed nearly horizontal foliation that was paralleled by numerous sealed fractures (Figure 4.7). The plagioclase was fresh oligoclase (An$_8$). Quartz appeared unstrained, not fractured, and exhibited straight extinction. Biotite was very fresh.

Section 15 of Hole W2-CR-5 was a coarse-grained biotite, quartz schist in which the biotite altered to chlorite (Figure 4.7). Quartz formed composite grains, with straight extinction and non-sutured borders, which suggested recrystallization of the quartz.

4.4.5 Summary. Petrographic examination of eleven sections of core from five holes in the Sweetwater Mountains area of central Wyoming revealed that five rock types were represented: granite porphyry, tonalite, aplite granite, amphibolite, and biotite gneiss and schist. The granites and gneisses were the most abundant rock types in the cores. Differences in compressive strength and elastic properties among the rocks of each type seem to have arisen from the number and inclination of fractures, whether the fractures were open or sealed, and degree of alteration due to weathering. The mineral
compositions are summarized in Tables 4.5 and 4.6, and the sections examined are illustrated in Figures 4.1 through 4.7.
TABLE 4.1 TENSILE STRENGTH DETERMINATIONS

<table>
<thead>
<tr>
<th>Hole No.</th>
<th>Specimen No.</th>
<th>Depth feet</th>
<th>Tensile Strength (psi)</th>
<th>Rock Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>W2-CR-1</td>
<td>24</td>
<td>192</td>
<td>1,110</td>
<td>Porphyritic granite</td>
</tr>
<tr>
<td>W2-CR-5</td>
<td>16</td>
<td>137</td>
<td>555</td>
<td>Quartz biotite gneiss</td>
</tr>
<tr>
<td>W2-CR-14</td>
<td>3</td>
<td>44</td>
<td>665</td>
<td>Brown granite</td>
</tr>
<tr>
<td>W2-CR-14</td>
<td>17</td>
<td>170</td>
<td>990</td>
<td>Gray granite</td>
</tr>
<tr>
<td>W2-CR-26</td>
<td>13</td>
<td>133</td>
<td>1,180</td>
<td>Gray granite</td>
</tr>
</tbody>
</table>

Average 80
<table>
<thead>
<tr>
<th>Hole No.</th>
<th>Specimen No.</th>
<th>Description</th>
<th>Dynamic Modulus</th>
<th>Static Modulus</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Young's Bulk</td>
<td>Static Bulk</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Shear</td>
<td>Shear</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$10^6$ psi</td>
<td>$10^6$ psi</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$10^6$ psi</td>
<td>$10^6$ psi</td>
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<tr>
<td>Poor and Marginal Quality Rock:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W2-CR-4</td>
<td>1</td>
<td>Granite gneiss</td>
<td>6.6 7.1 2.5 6.9</td>
<td>3.1 3.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Biotite schist</td>
<td>3.6 3.4 1.4 2.0</td>
<td>1.3 0.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Amphibolite gneiss</td>
<td>4.8 3.0 2.0 2.0</td>
<td>1.3 0.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Amphibolite gneiss</td>
<td>8.2 6.5 3.2 2.0</td>
<td>6.9 3.1</td>
</tr>
<tr>
<td>W2-CR-5</td>
<td>7</td>
<td>Biotite gneiss</td>
<td>10.0 7.6 4.4 8.1</td>
<td>3.6 3.6</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>Biotite gneiss</td>
<td>8.5 6.4 3.3 6.6</td>
<td>3.7 2.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td>7.0 5.7 2.6 5.9</td>
<td>2.9 2.6</td>
</tr>
<tr>
<td>Good and Excellent Quality Rock:</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W2-CR-1</td>
<td>2</td>
<td>Fractured diorite</td>
<td>8.0 4.9 3.5 --</td>
<td>--  --  --</td>
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<tr>
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<td>4</td>
<td>Granite porphyry</td>
<td>12.6 8.6 5.0 9.2</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Granite porphyry</td>
<td>11.3 9.8 4.4 9.1</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>Pink granite</td>
<td>12.7 7.9 5.2 10.5</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>Granite porphyry</td>
<td>11.9 8.2 4.7 --</td>
<td>--  --  --</td>
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<tr>
<td>W2-CR-4</td>
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<td>13.0 12.9 4.9 12.3</td>
<td>6.2 5.3</td>
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<tr>
<td>W2-CR-5</td>
<td>21</td>
<td>Biotite gneiss</td>
<td>12.7 8.2 5.1 10.4</td>
<td>6.2 4.3</td>
</tr>
<tr>
<td>W2-CR-14</td>
<td>5</td>
<td>Slightly weathered granite</td>
<td>8.7 8.0 3.3 7.8</td>
<td>4.8 3.2</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Slightly weathered granite</td>
<td>9.2 7.4 3.5 8.2</td>
<td>5.4 3.3</td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>Unweathered granite</td>
<td>10.0 6.3 4.1 8.9</td>
<td>7.4 3.4</td>
</tr>
<tr>
<td>W2-CR-26</td>
<td>3</td>
<td>Fractured granite</td>
<td>9.1 5.9 3.6 7.8</td>
<td>4.4 3.2</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Intact granite</td>
<td>8.3 7.5 3.2 7.1</td>
<td>5.2 2.8</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>Intact granite</td>
<td>8.9 6.9 3.4 8.3</td>
<td>5.6 3.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td>10.5 7.9 4.1 9.0</td>
<td>5.6 3.7</td>
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### TABLE 4.3 VELOCITY DETERMINATIONS

<table>
<thead>
<tr>
<th>Hole W2-CR-1, Specimen 24:</th>
<th>Compressional</th>
<th>Shear</th>
</tr>
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<tbody>
<tr>
<td>Porphyritic granite</td>
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<td></td>
</tr>
<tr>
<td>Depth: 192 feet</td>
<td>21,380 fps</td>
<td>11,530 fps</td>
</tr>
<tr>
<td>Specific gravity: 2.68</td>
<td>20,580</td>
<td>11,920</td>
</tr>
<tr>
<td>Compressive deviation: b 2.1 pct</td>
<td>20,870</td>
<td>11,940</td>
</tr>
<tr>
<td></td>
<td>Average 20,940</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11,800</td>
<td></td>
</tr>
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<table>
<thead>
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<th>Hole W2-CR-5, Specimen 16:</th>
<th>Compressional</th>
<th>Shear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz biotite gneiss</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth: 137 feet</td>
<td>18,660 fps</td>
<td>11,820 fps</td>
</tr>
<tr>
<td>Specific gravity: 2.77</td>
<td>20,890</td>
<td>11,030</td>
</tr>
<tr>
<td>Compressive deviation: 15.5 pct</td>
<td>15,520</td>
<td>9,960</td>
</tr>
<tr>
<td></td>
<td>Average 18,360</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10,940</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hole W2-CR-14, Specimen 3:</th>
<th>Compressional</th>
<th>Shear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown granite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth: 44 feet</td>
<td>20,130 fps</td>
<td>11,240 fps</td>
</tr>
<tr>
<td>Specific gravity: 2.68</td>
<td>19,320</td>
<td>11,090</td>
</tr>
<tr>
<td>Compressive deviation: 3.6 pct</td>
<td>18,850</td>
<td>10,760</td>
</tr>
<tr>
<td></td>
<td>Average 19,430</td>
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<tr>
<td></td>
<td>11,030</td>
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</table>

<table>
<thead>
<tr>
<th>Hole W2-CR-14, Specimen 17:</th>
<th>Compressional</th>
<th>Shear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray granite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth: 170 feet</td>
<td>18,830 fps</td>
<td>11,360 fps</td>
</tr>
<tr>
<td>Specific gravity: 2.69</td>
<td>18,210</td>
<td>10,360</td>
</tr>
<tr>
<td>Compressive deviation: 3.0 pct</td>
<td>17,800</td>
<td>10,130</td>
</tr>
<tr>
<td></td>
<td>Average 18,280</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10,720</td>
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</table>

<table>
<thead>
<tr>
<th>Hole W2-CR-26, Specimen 13:</th>
<th>Compressional</th>
<th>Shear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray granite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth: 133 feet</td>
<td>18,680 fps</td>
<td>11,070 fps</td>
</tr>
<tr>
<td>Specific gravity: 2.68</td>
<td>19,120</td>
<td>10,370</td>
</tr>
<tr>
<td>Compressive deviation: 3.8 pct</td>
<td>17,850</td>
<td>10,490</td>
</tr>
<tr>
<td></td>
<td>Average 18,550</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10,640</td>
<td></td>
</tr>
</tbody>
</table>

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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.
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<th>Hole No.</th>
<th>Specimen No.</th>
<th>Moduli</th>
<th>Poisson's Ratio</th>
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<td></td>
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<td>Bulk $10^6$ psi</td>
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<td>W2-CR-1</td>
<td>24</td>
<td>12.40</td>
<td>10.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12.80</td>
<td>8.44</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12.90</td>
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<td>12.70</td>
<td>9.14</td>
</tr>
<tr>
<td>W2-CR-5</td>
<td>16</td>
<td>12.10</td>
<td>6.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11.80</td>
<td>10.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.52</td>
<td>4.06</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>10.81</td>
<td>6.77</td>
</tr>
<tr>
<td>W2-CR-14</td>
<td>3</td>
<td>11.60</td>
<td>8.55</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11.10</td>
<td>7.56</td>
</tr>
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<td></td>
<td></td>
<td>10.50</td>
<td>7.24</td>
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<tr>
<td>Average</td>
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<td>11.07</td>
<td>7.78</td>
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<td>6.22</td>
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<td>10.29</td>
<td>6.55</td>
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<td>10.80</td>
<td>6.69</td>
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<td></td>
<td></td>
<td>10.00</td>
<td>8.02</td>
</tr>
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<td>9.82</td>
<td>6.21</td>
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<tr>
<td>Average</td>
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<td>10.21</td>
<td>6.97</td>
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TABLE 4.5 MODAL COMPOSITION OF ROCKS FROM WARREN II AREA

Modes are based on 500 point counts per thin section.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Granite</th>
<th>Tonalite</th>
<th>Aplitic W2-CR-1</th>
<th>Amphibolite</th>
<th>Biotite</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Section</td>
<td>Section</td>
<td>Section</td>
<td>Section</td>
<td>Section</td>
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<td>Quartz</td>
<td>30</td>
<td>24</td>
<td>30</td>
<td>28</td>
<td>28</td>
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<tr>
<td>Plagioclase (Anorthite content of plagioclase)</td>
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<td>28</td>
<td>30</td>
<td>40</td>
<td>37</td>
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<tr>
<td>Microcline</td>
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<td>43</td>
<td>33</td>
<td>26</td>
<td>27</td>
</tr>
<tr>
<td>Biotite</td>
<td>5</td>
<td>Trace</td>
<td>Trace</td>
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<td>Trace</td>
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<td>Muscovite</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>Trace</td>
<td>Trace</td>
</tr>
<tr>
<td>Hornblende</td>
<td>1</td>
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<td>None</td>
<td>None</td>
<td>None</td>
</tr>
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<td>Epidote</td>
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<td>Trace</td>
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<td>None</td>
<td>None</td>
<td>None</td>
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<td>Trace</td>
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<td>Garnet</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Magnetite</td>
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<td>Trace</td>
<td>1</td>
<td>Trace</td>
<td>Trace</td>
</tr>
<tr>
<td>Hematite</td>
<td>Trace</td>
<td>None</td>
<td>None</td>
<td>Trace</td>
<td>Trace</td>
</tr>
<tr>
<td>Kaolinite</td>
<td>1</td>
<td>None</td>
<td>Trace</td>
<td>Trace</td>
<td>Trace</td>
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</tbody>
</table>
### TABLE 4.6  BULK COMPOSITION OF ROCKS FROM WARREN II AREA

Based on X-ray diffraction results and compared to W2-CR-1, Section 26. ND = none detected.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Granite</th>
<th>Tonalite</th>
<th>Aplite W2-CR-1</th>
<th>Amphibolite</th>
<th>Biotite</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>W2-CR-1 Section 26</td>
<td>W2-CR-14 Section 12</td>
<td>W2-CR-1 Section 21a</td>
<td>W2-CR-1 Section 21b</td>
<td>W2-CR-4 Section 9</td>
</tr>
<tr>
<td>Quartz</td>
<td>Abundant</td>
<td>Abundant</td>
<td>Abundant</td>
<td>Abundant</td>
<td>Abundant</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>Abundant</td>
<td>Abundant</td>
<td>Slightly more</td>
<td>Abundant</td>
<td>Abundant</td>
</tr>
<tr>
<td>Microcline</td>
<td>Abundant (Plagioclase/microcline) (1/1)</td>
<td>Abundant (3/2)</td>
<td>Slightly more</td>
<td>Abundant</td>
<td>Abundant</td>
</tr>
<tr>
<td>Biotite</td>
<td>Common</td>
<td>Common</td>
<td>Common</td>
<td>Much</td>
<td>ND</td>
</tr>
<tr>
<td>Chlorite</td>
<td>Minor</td>
<td>Much</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Hornblende</td>
<td>ND</td>
<td>ND</td>
<td>Minor</td>
<td>ND</td>
<td>Minor</td>
</tr>
<tr>
<td>Magnetite</td>
<td>Minor</td>
<td>Minor</td>
<td>Minor</td>
<td>Minor</td>
<td>Minor</td>
</tr>
<tr>
<td>Hematite</td>
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<td>Slightly more</td>
<td>Slightly</td>
<td>ND</td>
</tr>
<tr>
<td>Kaolinite</td>
<td>Minor</td>
<td>ND</td>
<td>Minor</td>
<td>Minor</td>
<td>ND</td>
</tr>
</tbody>
</table>
Figure 4.1 Granite specimen, Core W2-CR-1, Section 26, showing typical porphyritic texture of the granites from the Warren II area. White specks near the black biotite are kaolinite. The large fractured grains are phenocrysts of microcline.
Figure 4.2 Granite specimens, Cores W2-CR-26, Section 17, and W2-CR-14, Section 12. W2-CR-26, Section 17, shows lack of porphyritic texture. Minute white lines are fractures. W2-CR-14, Section 12, is sheared and altered granite. Gray areas are hematite-stained quartz. White specks are kaolinite.
Figure 4.3 Tonalite specimens, Cores W2-CR-4, Section 9, and W2-CR-1, Section 21. W2-CR-4, Section 9, is coarse-grained tonalite. Dark band to the left of center is a garnet band along a sealed fracture. White lines are partially sealed fractures. The left portion of W2-CR-1, Section 21 (designated 21a in Tables 4.5 and 4.6), is coarse-grained porphyritic tonalite with phenocrysts of microcline. The right portion (21b) is medium-grained, biotite-rich tonalite, with biotite defining a strong foliation. Small white rhombs are kaolinite.
Figure 4.4 Aplitic granite specimen, Core W2-CR-1, Section 11, showing fine-grained texture. Narrow white lines are sealed fractures.
Figure 4.5 Amphibolite specimens, Core W2-CR-4, Sections 6 and 8. Section 6 is weathered hornblende-biotite schist with well-developed schistose structure. Section 8 is hornblende-plagioclase gneiss. Schistosity is in the same plane as that in Section 6. Fractures are at right angles and also serve as zone of weakness along which the quartz dike intruded.
Figure 4.6 Amphibolite specimen, Core W2-CR-4, Section 20, showing horizontal foliation and nearly parallel fractures. Quartz dike (right) cuts the foliation.
Figure 4.7 Biotite gneiss and schist specimens, Core W2-CR-5, Sections 6 and 15. Section 6 is highly fractured, well-foliated gneiss. Small white lines are fractures. Section 15 is highly fractured schist. White lines are partially sealed fractures. This rock may be an inclusion in the gneiss.
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 1,200 mi^2. The core is predominantly pink to gray granitic igneous rock; however, variations in grain size, mineral constituents, and degree of fracturing and weathering of the granite and the presence of several other rock types prevent classification as a uniform material. A rock quality chart based on compressive strength divided into three categories (poor, marginal, and good to excellent) was prepared (Figure 5.2). Except in Hole W2-CR-4, which contained very incompetent gneiss and schist scattered throughout, marginal quality rock occurs predominantly near the top of the holes, i.e., down to depths of 60 to 70 feet.

As mentioned previously, the physical properties are expectedly quite variable, in such a complex rock mass. The densest materials, the schists and some of the gneisses, were 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, including specimens which contained contacts
of the several rock types. Only 10 percent of the compressive specimens were classified as poor quality material and an additional 14 percent as marginal by the criteria utilized herein. Only 6 of 51 specimens had compressive wave velocities of less than 15,000 fps. Therefore, overall appearance of the area is one of a complex rock mass but within the complexity, a fairly 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 complex geologic area. Five general types of material were identified: porphyritic granite, tonalite, aplitic granite, amphibolite, and biotite gneiss and schist. The predominant materials were granite and biotite gneiss.

2. Based on physical characteristics, three groups of material were present: poor, marginal, and good to excellent quality rock.

3. If 12,000-psi compressive strength is taken as the acceptable minimum of competence, 24 percent of all tested material would be classified as incompetent (compared to 17 percent in the Bergstrom area and 33 percent in the Castle area). Twelve percent of the specimens tested had compressive wave velocities below 15,000 fps.

4. The wide area represented by the five drill holes and the
complex nature of the material preclude assessment on a hole-to-hole basis. Except for the schist, poorer quality rock is predominantly in the upper elevation. One may expect to remove up to 70 feet of material in some areas before competent rock is reached.

5. Three-dimensional compressional wave velocity tests on representative samples indicate that the granite is rather isotropic; however, the one gneiss specimen varied 15 percent in velocity measurements, which would indicate the gneiss to be very anisotropic.

6. Except for the schist, the material from this area was rather brittle, exhibiting little or no plastic deformation prior to failure. Hysteresis and residual strain were evident in the elasto-plastic behavior of the schist.

7. Based on the limited data available, the area offers possibilities as a competent hard rock medium if the schist can be avoided. A more extensive investigation will be required to identify the most promising hard rock areas.
Figure 5.1 Field investigation sites.
Figure 5.2 Depth versus quality for individual holes.
APPENDIX A
DATA REPORT
Hole W2-CR-1

21 August 1969

Hole Location: Natrona County, Wyoming
Township 32N, Range 88W, Section 35
900' W/EL, 650' N/SL, SE 1/4 SE 1/4

Core

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

<table>
<thead>
<tr>
<th>Core Piece No.</th>
<th>Approximate Depth, ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
</tr>
<tr>
<td>3</td>
<td>31</td>
</tr>
<tr>
<td>4</td>
<td>42</td>
</tr>
<tr>
<td>5</td>
<td>44</td>
</tr>
<tr>
<td>6</td>
<td>54</td>
</tr>
<tr>
<td>7</td>
<td>59</td>
</tr>
<tr>
<td>8</td>
<td>69</td>
</tr>
<tr>
<td>9</td>
<td>79</td>
</tr>
<tr>
<td>10</td>
<td>87</td>
</tr>
<tr>
<td>11</td>
<td>90</td>
</tr>
<tr>
<td>12</td>
<td>98</td>
</tr>
<tr>
<td>13</td>
<td>107</td>
</tr>
<tr>
<td>14</td>
<td>116</td>
</tr>
<tr>
<td>15</td>
<td>122</td>
</tr>
<tr>
<td>16</td>
<td>130</td>
</tr>
<tr>
<td>17</td>
<td>142</td>
</tr>
<tr>
<td>18</td>
<td>149</td>
</tr>
<tr>
<td>19</td>
<td>151</td>
</tr>
<tr>
<td>20</td>
<td>160</td>
</tr>
<tr>
<td>21</td>
<td>168</td>
</tr>
<tr>
<td>22</td>
<td>178</td>
</tr>
<tr>
<td>23</td>
<td>186</td>
</tr>
<tr>
<td>24</td>
<td>192</td>
</tr>
<tr>
<td>25</td>
<td>196</td>
</tr>
<tr>
<td>26</td>
<td>200</td>
</tr>
</tbody>
</table>

Description

2. The samples received were pink- to white-colored porphyritic granite and gray and white diorite, as identified by the field log received with the core. Piece Nos. 1 and 2 appeared somewhat weathered. Piece Nos. 5, 8, 10, 11, 13, 16, 18, and 20 contained fractures, some open, and some incipient.
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:

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Description</th>
<th>Core Depth</th>
<th>Sp Gr</th>
<th>Schmidt No.*</th>
<th>Comp Strg, psi</th>
<th>Comp Wave Vel, fps</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Gray, Fine Grained, Critical Angle Fracture</td>
<td>24</td>
<td>2.764</td>
<td>--</td>
<td>12,420</td>
<td>15,730</td>
</tr>
<tr>
<td>3</td>
<td>Gray Diorite, Intact</td>
<td>31</td>
<td>2.736</td>
<td>--</td>
<td>21,210</td>
<td>20,400</td>
</tr>
<tr>
<td>4</td>
<td>Pink Granite, Intact</td>
<td>42</td>
<td>2.652</td>
<td>61.8</td>
<td>22,580</td>
<td>20,705</td>
</tr>
<tr>
<td>5</td>
<td>Gray Diorite, Vertical Incipient Fracture</td>
<td>44</td>
<td>2.729</td>
<td>61.1</td>
<td>18,180</td>
<td>20,610</td>
</tr>
<tr>
<td>8</td>
<td>Pink Granite, Vertical Incipient Fracture</td>
<td>69</td>
<td>2.655</td>
<td>63.2</td>
<td>31,060</td>
<td>20,760</td>
</tr>
<tr>
<td>9</td>
<td>Pink Granite, Intact</td>
<td>79</td>
<td>2.767</td>
<td>61.4</td>
<td>25,000</td>
<td>20,730</td>
</tr>
<tr>
<td>10</td>
<td>Pink Granite, Vertical Incipient Fracture</td>
<td>87</td>
<td>2.639</td>
<td>60.8</td>
<td>35,760</td>
<td>20,850</td>
</tr>
<tr>
<td>11</td>
<td>Pink Granite, Fine Grained, Vertical Incipient Fracture</td>
<td>90</td>
<td>2.635</td>
<td>--</td>
<td>48,180</td>
<td>20,435</td>
</tr>
<tr>
<td>12</td>
<td>Pink Granite, Intact</td>
<td>98</td>
<td>2.649</td>
<td>--</td>
<td>28,030</td>
<td>20,240</td>
</tr>
<tr>
<td>15</td>
<td>Gray Diorite, Intact</td>
<td>122</td>
<td>2.739</td>
<td>59.2</td>
<td>24,240</td>
<td>20,610</td>
</tr>
<tr>
<td>20</td>
<td>Pink Granite, Critical Angle Fracture</td>
<td>160</td>
<td>2.671</td>
<td>60.7</td>
<td>13,640</td>
<td>20,055</td>
</tr>
<tr>
<td>23</td>
<td>Gray Diorite, Intact</td>
<td>186</td>
<td>2.681</td>
<td>64.2</td>
<td>21,670</td>
<td>20,155</td>
</tr>
</tbody>
</table>

Average of Specimens with Critical Angle Fractures (2) 2.718 60.7 13,030 17,890

Average of All Other Specimens (10) 2.688 61.7 27,590 20,550

* Schmidt hammer test not conducted on several specimens due to possibility of breakage.
4. Of the fractured specimens tested, the two containing critical angle fractures failed along these fractures and exhibited significantly lower unconfined compressive strengths. The vertical incipient fracturing appeared to have little affect on physical properties of the material from this hole.

5. All but two of the specimens tested were medium grained. One of the fine grained specimens (No. 2) failed along a critical angle fracture at a comparatively low compressive stress. The other (No. 11) yielded a very high compressive strength, characteristic of fine grained, competent, intact rock.

Moduli of deformation

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

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Young's Modulus, psi x 10^{-6}</th>
<th>Bulk Shear</th>
<th>Shear Velocity, fps</th>
<th>Poisson's Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>8.0</td>
<td>4.9</td>
<td>3.5</td>
<td>9,340</td>
</tr>
<tr>
<td>4</td>
<td>12.6</td>
<td>8.6</td>
<td>3.0</td>
<td>11,860</td>
</tr>
<tr>
<td>5</td>
<td>11.3</td>
<td>9.8</td>
<td>4.4</td>
<td>10,880</td>
</tr>
<tr>
<td>11</td>
<td>12.7</td>
<td>7.9</td>
<td>5.2</td>
<td>12,075</td>
</tr>
<tr>
<td>20</td>
<td>11.9</td>
<td>8.2</td>
<td>4.7</td>
<td>11,470</td>
</tr>
</tbody>
</table>

(Continued)
(Continued)

Specimen Modulus, psi x 10^-6

<table>
<thead>
<tr>
<th>No.</th>
<th>Specimen</th>
<th>Young's</th>
<th>Bulk</th>
<th>Shear</th>
<th>Shear Velocity, fps</th>
<th>Poisson's Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td></td>
<td>9.2</td>
<td>5.3</td>
<td>3.8</td>
<td>--</td>
<td>0.21</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>9.1</td>
<td>5.1</td>
<td>3.8</td>
<td>--</td>
<td>0.20</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>10.5</td>
<td>6.2</td>
<td>4.3</td>
<td>--</td>
<td>0.22</td>
</tr>
</tbody>
</table>

7. All of the rock tested herein is apparently rather rigid material exhibiting slight hysteresis. The initial erratic behavior of the vertical stress-strain relations for specimen Nos. 4 and 5 was possibly due to location of the vertical gages over a fracture along which lateral displacement occurred during the early stages of loading.

Conclusions

8. The core received for testing from hole W-2-CR-1 was identified as pink to white-colored porphyritic granite and gray and white diorite by the field log received with the core. Incipient fracturing was present in several specimens, some oriented of critical angles, some vertical. The critical angle fractures significantly weakened the rock; failure occurring along these fractures and of much lower compressive stresses. All other specimens exhibited conical modes of failure, higher compressive strengths, and higher dynamic moduli.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Critical Angle Fractures</th>
<th>All Other Specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>2.718</td>
<td>2.688</td>
</tr>
<tr>
<td>Schmidt No.</td>
<td>60.7</td>
<td>61.7</td>
</tr>
<tr>
<td>Compressive Strength, psi</td>
<td>13,030</td>
<td>27,590</td>
</tr>
<tr>
<td>Compressional Wave Velocity, fps</td>
<td>17,890</td>
<td>20,550</td>
</tr>
<tr>
<td>Young's Modulus, psi x 10^-6</td>
<td>--</td>
<td>9.6</td>
</tr>
</tbody>
</table>
Stress-Strain Curve
Unconfined Compression
Specimen W-2-CR-1-4
Comp. Str. 22,580 psi

Stress, psi

0  1000  2000  3000  4000

Strain, microin/in.

Horizontal
Vertical
Stress-Strain Curve
Unconfined Compression
Specimen W-2-CR-1-5
Comp. Str. 18,180 psi

PLATE A2
Stress-Strain Curve
Unconfined Compression
Specimen W-2-CR-1-11
Comp. Str. 48,180 psi

Strain, microin./in.

0 1000 2000 3000 4000

Stress, psi

0 10,000 20,000 30,000 40,000 50,000 60,000 70,000

Horizontal

Vertical

61-62

PLATE A3
APPENDIX B

DATA REPORT

Hole W2-CR-4

25 August 1969

Hole Location: Fremont County, Wyoming
Township 31N, Range 91W, Section 31
1100' E/WL, 900' N/SL, SW 1/4 SW 1/4

Core

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

<table>
<thead>
<tr>
<th>Core Piece No.</th>
<th>Approximate Depth, ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21</td>
</tr>
<tr>
<td>2</td>
<td>32</td>
</tr>
<tr>
<td>3</td>
<td>40</td>
</tr>
<tr>
<td>4</td>
<td>58</td>
</tr>
<tr>
<td>5</td>
<td>66</td>
</tr>
<tr>
<td>6</td>
<td>68</td>
</tr>
<tr>
<td>7</td>
<td>84</td>
</tr>
<tr>
<td>8</td>
<td>103</td>
</tr>
<tr>
<td>9</td>
<td>109</td>
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<tr>
<td>10</td>
<td>116</td>
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<tr>
<td>11</td>
<td>122</td>
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<tr>
<td>12</td>
<td>132</td>
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<td>13</td>
<td>137</td>
</tr>
<tr>
<td>14</td>
<td>146</td>
</tr>
<tr>
<td>15</td>
<td>155</td>
</tr>
<tr>
<td>16</td>
<td>156</td>
</tr>
<tr>
<td>17</td>
<td>168</td>
</tr>
<tr>
<td>18</td>
<td>172</td>
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<tr>
<td>19</td>
<td>175</td>
</tr>
<tr>
<td>20</td>
<td>182</td>
</tr>
<tr>
<td>21</td>
<td>191</td>
</tr>
<tr>
<td>22</td>
<td>194</td>
</tr>
</tbody>
</table>

Description

2. The samples received were identified by the field log received with the core as granite gneiss, pyroxene hornfels, chlorite-biotite schist, hematite, quartz-porphyry gneiss, and chlorite schist. Piece Nos. 2, 3, 4, 5, 7, 8, 10, 19, 20, and 22 contained fractures, some open and some healed.
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:

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Core Log Description</th>
<th>Core Depth</th>
<th>Sp Gr</th>
<th>Schmidt No.*</th>
<th>Comp Strg, psi</th>
<th>Comp Wave Vel, fps</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Granite Gneiss</td>
<td>21</td>
<td>2.633</td>
<td>55.8</td>
<td>8,405</td>
<td>17,140</td>
</tr>
<tr>
<td>4</td>
<td>Chlorite Schist</td>
<td>58</td>
<td>2.906</td>
<td>--</td>
<td>3,505</td>
<td>8,995</td>
</tr>
<tr>
<td>5</td>
<td>Chlorite Schist</td>
<td>66</td>
<td>2.858</td>
<td>--</td>
<td>2,800</td>
<td>11,625</td>
</tr>
<tr>
<td>10</td>
<td>Pyroxene Hornfels</td>
<td>116</td>
<td>3.024</td>
<td>58.8</td>
<td>25,860</td>
<td>22,715</td>
</tr>
<tr>
<td>12</td>
<td>Pyroxene Hornfels</td>
<td>132</td>
<td>3.014</td>
<td>--</td>
<td>19,520</td>
<td>21,865</td>
</tr>
<tr>
<td>13</td>
<td>Chlorite-Biotite Schist</td>
<td>137</td>
<td>2.916</td>
<td>14.0</td>
<td>1,210</td>
<td>7,225</td>
</tr>
<tr>
<td>15</td>
<td>Chlorite-Biotite Schist</td>
<td>154</td>
<td>3.070</td>
<td>21.8</td>
<td>5,990</td>
<td>11,675</td>
</tr>
<tr>
<td>16</td>
<td>Granite Gneiss</td>
<td>166</td>
<td>2.589</td>
<td>--</td>
<td>10,650</td>
<td>16,185</td>
</tr>
<tr>
<td>17</td>
<td>Chlorite-Biotite Schist</td>
<td>168</td>
<td>3.095</td>
<td>--</td>
<td>9,170</td>
<td>16,055</td>
</tr>
<tr>
<td>18</td>
<td>Quartz-Porphyry Gneiss</td>
<td>172</td>
<td>2.684</td>
<td>--</td>
<td>15,955</td>
<td>18,195</td>
</tr>
<tr>
<td>21</td>
<td>Granite Gneiss</td>
<td>191</td>
<td>2.996</td>
<td>43.2</td>
<td>6,240</td>
<td>16,655</td>
</tr>
<tr>
<td>22</td>
<td>Granite Gneiss</td>
<td>194</td>
<td>2.670</td>
<td>60.4</td>
<td>25,380</td>
<td>19,795</td>
</tr>
</tbody>
</table>

Average Chlorite Schist (2) 2.882 -- 3,150 10,310
Average Pyroxene Hornfels (2) 3.019 58.8 22,690 22,290
Average Granite Gneiss (4) 2.704 53.1 12,670 17,445
Average Chlorite-Biotite Schist (3) 3.027 17.9 5,455 11,550
Average Quartz-Porphyry Gneiss (1) 2.684 -- 15,955 18,195

* Schmidt hammer test not conducted on several specimens due to possibility of breakage.
4. Due to the large variation of material received from hole W-2-CR-4, the specimens were grouped for testing according to core log descriptions. Physical test results substantiated this grouping, specimens of the same core log description exhibiting similar test results.

5. Generally, the schists exhibited rather low strength, the average for both groups being only 4300 psi. The gneisses and hornfels were considerably stronger, all groups yielding average strengths greater than 10,000 psi. There was, however, considerable variation within groups, some individual specimens being considerably weaker than the average.

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 gauges affixed to the specimens, Nos. 1, 12, and 15. Stress-strain curves are given in plates 1, 2, and 3. Specimens 12 and 15 were cycled at 14,000 and 5000 psi, respectively. Results are given below.

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Modulus, psi x 10^-6</th>
<th>Shear Velocity, fps</th>
<th>Poisson's Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Young's</td>
<td>Bulk</td>
<td>Shear</td>
</tr>
<tr>
<td>1</td>
<td>6.6</td>
<td>7.1</td>
<td>2.5</td>
</tr>
<tr>
<td>5</td>
<td>3.6</td>
<td>3.4</td>
<td>1.4</td>
</tr>
<tr>
<td>12</td>
<td>13.0</td>
<td>12.9</td>
<td>4.7</td>
</tr>
<tr>
<td>15</td>
<td>4.8</td>
<td>3.0</td>
<td>2.0</td>
</tr>
<tr>
<td>17</td>
<td>8.2</td>
<td>6.5</td>
<td>3.2</td>
</tr>
</tbody>
</table>

(Continued)
Specimen Modulus, psi x 10^{-6} Shear Poisson's

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Young's</th>
<th>Bulk</th>
<th>Shear</th>
<th>Shear Velocity, fps</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.9</td>
<td>3.1</td>
<td>3.1</td>
<td>--</td>
<td>0.13</td>
</tr>
<tr>
<td>12</td>
<td>12.3</td>
<td>6.2</td>
<td>5.3</td>
<td>--</td>
<td>0.17</td>
</tr>
<tr>
<td>15</td>
<td>2.0</td>
<td>1.3</td>
<td>0.8</td>
<td>--</td>
<td>0.24</td>
</tr>
</tbody>
</table>

7. Most of the rock tested herein is apparently rather rigid material exhibiting little hysteresis. Specimen No. 15, however, a chlorite-biotite schist, exhibited considerable hysteresis. The hysteresis loops for this specimen remained open, indicating the presence of a relatively large amount of residual strain (950 microin./in.). This specimen exhibited plastic behavior over practically the entire range of loading.

Conclusions

8. The core received from hole W-2-CR-4 was quite variable, identified by the field log received with the core as granite gneiss, pyroxene hornfels, chlorite-biotite schist, hematite, quartz-porphyry gneiss, and chlorite schist. Fracturing was present in some specimens. Generally, physical properties were quite variable, the schists yielding rather low physical properties, the gneisses and hornfels exhibiting strength generally over 10,000 psi.
<table>
<thead>
<tr>
<th>Property</th>
<th>Chlorite Schist</th>
<th>Pyroxene Hornfels</th>
<th>Granite Gneiss</th>
<th>Chlorite-Biotite Schist</th>
<th>Quartz-Porphyry Gneiss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>3.982</td>
<td>3.019</td>
<td>2.704</td>
<td>3.027</td>
<td>2.484</td>
</tr>
<tr>
<td>Schmidt No.</td>
<td>--</td>
<td>58.8</td>
<td>53.1</td>
<td>17.9</td>
<td>--</td>
</tr>
<tr>
<td>Compressive Strength, psi</td>
<td>3.150</td>
<td>22.690</td>
<td>12.670</td>
<td>5.455</td>
<td>15.955</td>
</tr>
<tr>
<td>Compressional Wave Velocity, fps</td>
<td>10,310</td>
<td>22,290</td>
<td>17,445</td>
<td>11,550</td>
<td>18,195</td>
</tr>
<tr>
<td>Young's Modulus, psi x 10^-6</td>
<td>--</td>
<td>12.3</td>
<td>6.9</td>
<td>2.0</td>
<td>--</td>
</tr>
</tbody>
</table>
STRESS-STRAIN CURVE
Unconfined Compression
Specimen: W-2-CR-4-1
Comp Strg: 8405 psi

Strain, microin./in.

PlATE Bl
STRESS-STRAIN CURVE
Unconfined Compression
Specimen: W-2-CR-4-12
Comp Strg: 19,520 psi

Strain, microin./in.
STRESS-STRAIN CURVE

Unconfined Compression
Specimen: W-2-CR-4-15
Comp Strg: 5990 psi

Vertical

Horizontal

Strain, microin./in.

PLATE B3
APPENDIX C

DATA REPORT

Hole W2-CR-5

26 August 1959

Hole Location: Fremont County, Wyoming
Township 31N, Range 90W, Section 12
900' W/EL, 950' N/SL, SE 1/4 SE 1/4

Core

1. The following core was received on 5 August 1959 for testing:

<table>
<thead>
<tr>
<th>Core Piece No.</th>
<th>Approximate Depth, ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>2</td>
<td>26</td>
</tr>
<tr>
<td>3</td>
<td>37</td>
</tr>
<tr>
<td>4</td>
<td>39</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
</tr>
<tr>
<td>6</td>
<td>57</td>
</tr>
<tr>
<td>7</td>
<td>56</td>
</tr>
<tr>
<td>8</td>
<td>71</td>
</tr>
<tr>
<td>9</td>
<td>85</td>
</tr>
<tr>
<td>10</td>
<td>95</td>
</tr>
<tr>
<td>11</td>
<td>104</td>
</tr>
<tr>
<td>12</td>
<td>112</td>
</tr>
<tr>
<td>13</td>
<td>118</td>
</tr>
<tr>
<td>14</td>
<td>122</td>
</tr>
<tr>
<td>15</td>
<td>130</td>
</tr>
<tr>
<td>16</td>
<td>137</td>
</tr>
<tr>
<td>17</td>
<td>146</td>
</tr>
<tr>
<td>18</td>
<td>157</td>
</tr>
<tr>
<td>19</td>
<td>164</td>
</tr>
<tr>
<td>20</td>
<td>176</td>
</tr>
<tr>
<td>21</td>
<td>184</td>
</tr>
<tr>
<td>22</td>
<td>197</td>
</tr>
</tbody>
</table>

Description

2. The samples received were gray to black-gray-colored rock identified as quartz-biotite gneiss and quartz-mica gneiss by the field log received with the core. Piece Nos. 1, 3, 11, 15, 16, 19, and 20 contained fractures, most of which were tightly closed.
Quality and uniformity tests

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

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Description</th>
<th>Core Depth</th>
<th>Sp Gr</th>
<th>Schmidt No.*</th>
<th>Comp Strg, psi</th>
<th>Comp Wave Vel, fps</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Quartz Biotite Gneiss</td>
<td>26</td>
<td>2.655</td>
<td>32.1</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>7</td>
<td>Quartz Biotite Gneiss</td>
<td>66</td>
<td>2.670</td>
<td>57.8</td>
<td>11,515</td>
<td>19,300</td>
</tr>
<tr>
<td>9</td>
<td>Biotite Gneiss</td>
<td>86</td>
<td>2.677</td>
<td>60.8</td>
<td>20,480</td>
<td>18,505</td>
</tr>
<tr>
<td>11</td>
<td>Gneiss</td>
<td>104</td>
<td>2.704</td>
<td>46.8</td>
<td>10,940</td>
<td>17,205</td>
</tr>
<tr>
<td>14</td>
<td>Biotite Gneiss</td>
<td>122</td>
<td>2.726</td>
<td>45.6</td>
<td>22,090</td>
<td>18,095</td>
</tr>
<tr>
<td>18</td>
<td>Biotite Gneiss, Medium Grained</td>
<td>157</td>
<td>2.691</td>
<td>--</td>
<td>22,120</td>
<td>19,920</td>
</tr>
<tr>
<td>19</td>
<td>Biotite Gneiss, Vertical Fractures</td>
<td>166</td>
<td>2.691</td>
<td>57.2</td>
<td>18,180</td>
<td>19,945</td>
</tr>
<tr>
<td>20</td>
<td>Biotite Gneiss, Vertical Fractures</td>
<td>176</td>
<td>2.728</td>
<td>--</td>
<td>12,550</td>
<td>19,430</td>
</tr>
<tr>
<td>21</td>
<td>Biotite Gneiss, Coarse Grained</td>
<td>184</td>
<td>2.732</td>
<td>58.4</td>
<td>21,335</td>
<td>20,235</td>
</tr>
<tr>
<td>22</td>
<td>Biotite Gneiss, Coarse Grained</td>
<td>197</td>
<td>2.703</td>
<td>56.3</td>
<td>16,300</td>
<td>20,085</td>
</tr>
<tr>
<td></td>
<td>Average of All Specimens Tested</td>
<td></td>
<td>2.598</td>
<td>51.9</td>
<td>17,280</td>
<td>19,180</td>
</tr>
</tbody>
</table>

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

** Specimen was broken during determination of compressional wave velocity; compressive strength test was not conducted.
4. The results of unconfined compressive tests were rather variable, probably due to the variation in grain size, foliation, and incipient fracturing. The specimens containing fracturing and planes of foliation oriented at critical angles (Nos. 7, 11, 19, 20, and 22) sheared along these planes. The ultimate stress for these specimens fell somewhat below average.

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. 7, 11, and 21. Stress-strain curves are given in plates 1, 2, and 3. Specimens 7 and 21 were cycled at 10,000 psi; specimen 11 was cycled at 5000 psi.

Results are given below.

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Modulus, psi x 10^-6</th>
<th>Shear Velocity, fps</th>
<th>Poisson's Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Young's</td>
<td>Bulk</td>
<td>Shear</td>
</tr>
<tr>
<td>7</td>
<td>10.0</td>
<td>7.6</td>
<td>4.4</td>
</tr>
<tr>
<td>11</td>
<td>8.5</td>
<td>6.4</td>
<td>3.3</td>
</tr>
<tr>
<td>21</td>
<td>12.7</td>
<td>8.2</td>
<td>5.1</td>
</tr>
</tbody>
</table>

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

6. The core received for testing from hole W-2-CR-5 was identified as quartz-biotite gneiss and quartz-mica gneiss by the field log received with the core. The specimens were gray to black-gray in color; some fracturing was present. Compressive strengths varied from 10,000 to 22,000 psi, the lower strengths exhibited by specimens which failed along well-developed critical angle planes of foliation or fracturing.

<table>
<thead>
<tr>
<th>Property</th>
<th>Average of All Specimens Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>2.698</td>
</tr>
<tr>
<td>Schmidt No.</td>
<td>51.9</td>
</tr>
<tr>
<td>Compressive Strength, psi</td>
<td>17,820</td>
</tr>
<tr>
<td>Compressional Wave Velocity, fps</td>
<td>19,180</td>
</tr>
<tr>
<td>Young's Modulus, psi x 10^5</td>
<td>8.4</td>
</tr>
</tbody>
</table>
STRESS-STRAIN CURVE
Unconfined Compression
Specimen: W-2-CR-5-7
Comp Strg: 11,515 psi

Strain, microin./in.
STRESS-STRAIN CURVE
Unconfined Compression
Specimen: W-2-CR-5-11
Comp Strg: 10,940 psi

PLATE C2
Unconfined Compression
Specimen: W-2-CR-5-21
Comp Strg: 21,335 psi

STRESS-STRAIN CURVE

Strain, microin./in.

Stress, psi

PLATE C3
77-78
Hole Location: Fremont County, Wyoming
Township 29N, Range 90W, Section 6
1350' E/WL, 800' N/SL, SW 1/4 SW 1/4

Core

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

<table>
<thead>
<tr>
<th>Core Piece No.</th>
<th>Approximate Depth, ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24</td>
</tr>
<tr>
<td>2</td>
<td>35</td>
</tr>
<tr>
<td>3</td>
<td>44</td>
</tr>
<tr>
<td>4</td>
<td>44</td>
</tr>
<tr>
<td>5</td>
<td>53</td>
</tr>
<tr>
<td>6</td>
<td>63</td>
</tr>
<tr>
<td>7</td>
<td>74</td>
</tr>
<tr>
<td>8</td>
<td>83</td>
</tr>
<tr>
<td>9</td>
<td>93</td>
</tr>
<tr>
<td>10</td>
<td>104</td>
</tr>
<tr>
<td>11</td>
<td>113</td>
</tr>
<tr>
<td>12</td>
<td>123</td>
</tr>
<tr>
<td>13</td>
<td>134</td>
</tr>
<tr>
<td>14</td>
<td>141</td>
</tr>
<tr>
<td>15</td>
<td>149</td>
</tr>
<tr>
<td>16</td>
<td>159</td>
</tr>
<tr>
<td>17</td>
<td>170</td>
</tr>
<tr>
<td>18</td>
<td>179</td>
</tr>
<tr>
<td>19</td>
<td>181</td>
</tr>
<tr>
<td>20</td>
<td>190</td>
</tr>
<tr>
<td>21</td>
<td>200</td>
</tr>
</tbody>
</table>

Description

2. The samples received were brown- to gray-colored rock identified as granite by the field log received with the core. Piece Nos. 1 through 7 appeared somewhat weathered.
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:

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Description</th>
<th>Core Depth</th>
<th>Sp Gr</th>
<th>Schmidt No.*</th>
<th>Comp Strg. psi</th>
<th>Comp Wave Vel, fps</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Moderately Weathered</td>
<td>24</td>
<td>2.520</td>
<td>40.3</td>
<td>11,335</td>
<td>8,590</td>
</tr>
<tr>
<td>5</td>
<td>Slightly Weathered</td>
<td>53</td>
<td>2.540</td>
<td>56.6</td>
<td>22,790</td>
<td>18,655</td>
</tr>
<tr>
<td>7</td>
<td>Slightly Weathered</td>
<td>74</td>
<td>2.640</td>
<td>--</td>
<td>20,910</td>
<td>18,630</td>
</tr>
<tr>
<td>8</td>
<td>Slightly Weathered</td>
<td>83</td>
<td>2.644</td>
<td>56.2</td>
<td>22,515</td>
<td>18,575</td>
</tr>
<tr>
<td>10</td>
<td>Slightly Weathered</td>
<td>104</td>
<td>2.544</td>
<td>56.0</td>
<td>21,395</td>
<td>18,425</td>
</tr>
<tr>
<td>14</td>
<td>Slightly Weathered</td>
<td>141</td>
<td>2.639</td>
<td>--</td>
<td>17,305</td>
<td>18,875</td>
</tr>
<tr>
<td>16</td>
<td>Unweathered</td>
<td>159</td>
<td>2.545</td>
<td>61.3</td>
<td>24,355</td>
<td>18,930</td>
</tr>
<tr>
<td>19</td>
<td>Unweathered</td>
<td>181</td>
<td>2.646</td>
<td>60.1</td>
<td>21,880</td>
<td>18,110</td>
</tr>
<tr>
<td>21</td>
<td>Unweathered</td>
<td>200</td>
<td>2.641</td>
<td>51.5</td>
<td>23,875</td>
<td>19,140</td>
</tr>
<tr>
<td></td>
<td>Average of Slightly Weathered Specimen (1)</td>
<td></td>
<td>2.520</td>
<td>40.3</td>
<td>11,335</td>
<td>8,590</td>
</tr>
<tr>
<td></td>
<td>Average of Slightly Weathered to Unweathered Specimens (8)</td>
<td></td>
<td>2.642</td>
<td>58.6</td>
<td>21,880</td>
<td>18,665</td>
</tr>
</tbody>
</table>

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

Specimens 8, 10, and 14 were limenite stained. The specimens which sustained slight weathering were apparently not significantly different from the unaltered 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. 5, 10, and 19. Stress-strain curves are given in plates 1, 2, and 3. Specimens 10 and 19 were cycled at 15,000 psi; specimen 5 was cycled at 10,000 psi. Results are given below.

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Modulus, psi x 10^6</th>
<th>Shear Velocity, fps</th>
<th>Poisson's Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Young's</td>
<td>Bulk</td>
<td>Shear</td>
</tr>
<tr>
<td>Dynamic Tests</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>8.7</td>
<td>8.0</td>
<td>3.3</td>
</tr>
<tr>
<td>10</td>
<td>9.2</td>
<td>7.4</td>
<td>3.5</td>
</tr>
<tr>
<td>19</td>
<td>10.0</td>
<td>6.3</td>
<td>4.1</td>
</tr>
<tr>
<td>Static Tests</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>7.8</td>
<td>4.8</td>
<td>3.2</td>
</tr>
<tr>
<td>10</td>
<td>8.2</td>
<td>5.4</td>
<td>3.3</td>
</tr>
<tr>
<td>19</td>
<td>8.9</td>
<td>7.4</td>
<td>3.4</td>
</tr>
</tbody>
</table>

5. All of the rock tested herein is apparently rather rigid material, exhibiting slight hysteresis. The hysteresis loops remained open, indicative of the presence of small amounts of residual strain.
Conclusions

5. The core received for testing from hole W-2-CR-14 was identified as brown to gray granite by the field log received with the core. Some weathering was present in the upper regions of the hole. Test results for the slightly weathered to unweathered material were relatively uniform, compressive strength ranging from 17,305 to 23,875 psi and compressional wave velocity ranging from 18,110 to 19,140 fps. Generally, compressive strength for the unweathered to slightly weathered rock was approximately twice that exhibited by the moderately weathered material. In no instance, however, did compressive strength fall below 10,000 psi.

<table>
<thead>
<tr>
<th>Property</th>
<th>Moderately Weathered Specimen</th>
<th>Slightly Weathered to Unweathered Specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>2.620</td>
<td>2.642</td>
</tr>
<tr>
<td>Schmidt No.</td>
<td>40.3</td>
<td>58.6</td>
</tr>
<tr>
<td>Compressive Strength, psi</td>
<td>11,335</td>
<td>21,980</td>
</tr>
<tr>
<td>Compressional Wave Velocity, fps</td>
<td>8,590</td>
<td>18,665</td>
</tr>
<tr>
<td>Static Young's Modulus, psi x 10^-6</td>
<td>--</td>
<td>9.3</td>
</tr>
</tbody>
</table>

82
STRESS-STRAIN CURVE
Unconfined Compression
Specimen: W-2-CR-14-5
Comp Strg: 22,790 psi

Strain, microin./in.

PLATE D1
STRESS-STRAIN CURVE
Unconfined Compression
Specimen: W-2-CR-14-10
Comp Strg: 21,395 psi

Strain, microin./in.

Stress, psi

PLATE D2
STRESS-STRAIN CURVE
Unconfined Compression
Specimen: W-2-CR-14-19
Comp Strg: 21,880 psi

Stress, psi

Strain, microin./in.

Horizontal
Vertical

PLATE D3

85-86
APPENDIX E

DATA REPORT

Hole W2-CR-26

20 August 1969

Hole Location: Natrona County, Wyoming

Township 30N, Range 88W, Section 21

950' W/EL, 800' S/NL, NE 1/4 NE 1/4

Core

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

<table>
<thead>
<tr>
<th>Core Piece No.</th>
<th>Approximate Depth, ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>22</td>
</tr>
<tr>
<td>3</td>
<td>32</td>
</tr>
<tr>
<td>4</td>
<td>41</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
</tr>
<tr>
<td>6</td>
<td>60</td>
</tr>
<tr>
<td>7</td>
<td>71</td>
</tr>
<tr>
<td>8</td>
<td>81</td>
</tr>
<tr>
<td>9</td>
<td>93</td>
</tr>
<tr>
<td>10</td>
<td>103</td>
</tr>
<tr>
<td>11</td>
<td>114</td>
</tr>
<tr>
<td>12</td>
<td>124</td>
</tr>
<tr>
<td>13</td>
<td>133</td>
</tr>
<tr>
<td>14</td>
<td>144</td>
</tr>
<tr>
<td>15</td>
<td>154</td>
</tr>
<tr>
<td>16</td>
<td>164</td>
</tr>
<tr>
<td>17</td>
<td>173</td>
</tr>
<tr>
<td>18</td>
<td>183</td>
</tr>
<tr>
<td>19</td>
<td>194</td>
</tr>
</tbody>
</table>

Description

2. The samples received were light-gray-colored rock identified as granite by the field log received with the core. Piece Nos. 2 and 3 contained vertical incipient 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:

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Description</th>
<th>Core Depth</th>
<th>Sp Gr</th>
<th>Schmidt No.*</th>
<th>Comp Strg, psi</th>
<th>Comp Wave Vel, fps</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Vertical Incipient Fracture</td>
<td>22</td>
<td>2.645</td>
<td>--</td>
<td>28,700</td>
<td>18,225</td>
</tr>
<tr>
<td>3</td>
<td>Vertical Incipient Fracture</td>
<td>32</td>
<td>2.648</td>
<td>--</td>
<td>27,270</td>
<td>17,280</td>
</tr>
<tr>
<td>5</td>
<td>Intact Rock</td>
<td>50</td>
<td>2.648</td>
<td>52.8</td>
<td>29,700</td>
<td>19,415</td>
</tr>
<tr>
<td>6</td>
<td>Intact Rock</td>
<td>60</td>
<td>2.648</td>
<td>49.8</td>
<td>28,790</td>
<td>18,750</td>
</tr>
<tr>
<td>9</td>
<td>Intact Rock</td>
<td>93</td>
<td>2.636</td>
<td>48.7</td>
<td>25,230</td>
<td>18,140</td>
</tr>
<tr>
<td>10</td>
<td>Intact Rock</td>
<td>103</td>
<td>2.630</td>
<td>48.6</td>
<td>31,670</td>
<td>18,660</td>
</tr>
<tr>
<td>14</td>
<td>Intact Rock</td>
<td>144</td>
<td>2.639</td>
<td>49.9</td>
<td>30,075</td>
<td>18,560</td>
</tr>
<tr>
<td>18</td>
<td>Intact Rock</td>
<td>183</td>
<td>2.635</td>
<td>49.8</td>
<td>30,160</td>
<td>18,000</td>
</tr>
<tr>
<td>Average of All Specimens Tested (8)</td>
<td></td>
<td></td>
<td>2.644</td>
<td>49.9</td>
<td>28,950</td>
<td>18,380</td>
</tr>
</tbody>
</table>

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

4. The rock from hole W-2-CR-26 was found to be unusually uniform, exhibiting a range in unconfined compressive strength of only 6440 psi with an average strength of 28,950 psi. Apparently, the vertical incipient.
fractures in specimen Nos. 2 and 3 had very little, if any, effect on the physical properties of these specimens. Specific gravities, Schmidt numbers, and compressive wave velocities were also relatively uniform for all specimens tested.

**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, 9, and 18. Stress-strain curves are given in plates 1, 2, and 3. Specimens 3, 9, and 18 were cycled at 20,000 psi. Results are given below.

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Modulus, psi x 10^6</th>
<th>Shear Velocity, fps</th>
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<tr>
<td></td>
<td>Young's</td>
<td>Bulk</td>
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<tr>
<td>Dynamic Tests</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>9.1</td>
<td>5.9</td>
</tr>
<tr>
<td>9</td>
<td>8.3</td>
<td>7.5</td>
</tr>
<tr>
<td>18</td>
<td>8.9</td>
<td>6.9</td>
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</table>

<table>
<thead>
<tr>
<th>Static Tests</th>
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<tr>
<td>3</td>
<td>7.8</td>
<td>4.4</td>
</tr>
<tr>
<td>9</td>
<td>7.1</td>
<td>5.2</td>
</tr>
<tr>
<td>18</td>
<td>8.3</td>
<td>5.6</td>
</tr>
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</table>

6. All of the rock tested herein is apparently rather rigid material exhibiting some hysteresis. The hysteresis loops were not closed, i.e., residual strain was induced in the specimens by the cyclic stressing.

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Conclusions

7. The core received for testing from hole W-2-CR-26 was identified as granite by the field log received with the core. All of the core was light-gray colored. Physical tests indicated that the core was unusually uniform, yielding an average unconfined compressive strength of 28,950 psi and a range of only 6440 psi. Vertical incipient fractures in two specimens apparently had no effect on the specimens' physical properties. Both specimens exhibited compressive strengths very close to the average for the group.

<table>
<thead>
<tr>
<th>Property</th>
<th>Average of All Specimens Tested</th>
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<tbody>
<tr>
<td>Specific Gravity</td>
<td>2.544</td>
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<tr>
<td>Schmidt No.</td>
<td>49.9</td>
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<tr>
<td>Compressive Strength, psi</td>
<td>28,950</td>
</tr>
<tr>
<td>Compressional Wave Velocity, fps</td>
<td>18,380</td>
</tr>
<tr>
<td>Young’s Modulus, psi x 10^9</td>
<td>7.7</td>
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</tbody>
</table>
STRESS-STRAIN CURVE
Unconfined Compression
Specimen: W-2-CR-26-3
Comp Strg: 27,270 psi

[Graph showing stress-strain curve with labels for horizontal and vertical strains.]
STRESS-STRAIN CURVE
Unconfined Compression
Specimen: W-2-CR-26-9
Comp Strg: 25,230 psi
STRESS-STRAIN CURVE
Unconfined Compression
Specimen: W-2-CR-23-13
Comp Strg: 30,160 psi

Strain, microin./in.

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<tr>
<td>0</td>
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<td>5,000</td>
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<tr>
<td>10,000</td>
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<td>15,000</td>
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<tr>
<td>20,000</td>
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<tr>
<td>25,000</td>
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<td>30,000</td>
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PLATE E3

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REFERENCES


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


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Laboratory tests were conducted on rock core samples received from five holes from Natrona and Fremont Counties, Wyoming (Warren II Study Area). Results were used to determine the quality and uniformity of the rock to depths of 200 feet below ground surface. The rock core was petrographically identified as predominantly granite and biotite gneiss. Several specimens of amphibolite gneiss and biotite schist were also identified. The wide area represented by the five drill holes and the complex nature of the material preclude assessment of the area on a hole-to-hole basis. The overall appearance of the area is one of a complex rock mass with quite variable physical properties. However, based on the limited data available, the area offers possibilities as a competent hard rock medium if poor quality schist can be avoided. Except for the schist, poorer quality rock is predominantly in the upper elevations, but one may expect to remove up to 70 feet of material in some areas before competent rock is reached. A more extensive investigation will be required to identify the most promising hard rock areas.
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