REC-ERC-74-10

# ROCK MECHANICS PROPERTIES OF TYPICAL FOUNDATION ROCK TYPES

## Summarizing Physical and Mechanical Tests of Rock Samples from Several Types of Foundation Sites


Engineering and Research Center
Bureau of Reclamation



July 1974

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J. R. Brandon


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Tests of physical and mechanical properties of representative rock core samples from several project foundation sites are summarized in rock data sheets. The summary includes location and geologic occurrence and a petrographic description of the rock types. Properties listed include: absorption; specific gravity; secant elastic modulus; compressive strength; tensile strength; and shear strength, including cohesion and coefficient of angle of internal friction. The work covers 43 typical rock types from sites of dams, powerplants, tunnels, and other Bureau structures.


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# ROCK MECHANICS PROPERTIES OF TYPICAL FOUNDATION ROCK TYPES

## Summarizing Physical and Mechanical Tests of Rock Samples from Several Types of Foundation Sites



by

J. R. Brandon

July 1974

Earth Sciences Branch
Division of General Research
Engineering and Research Center
Denver, Colorado

UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION

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# INTRODUCTION

The Bureau of Reclamation performs laboratory tests on rock core from projects it is investigating and occasionally from projects of other agencies and foreign countries. This report contains a summary of physical and mechanical properties of representative rock cores as determined from some of the tests. This summary is a continuation of an initial collection of data on several rock types, which is contained in Laboratory Report No. SP-39, "Physical Properties of Some Typical Foundation Rocks," August 1953. The test data for 43 rock types contained herein are tabulated on individual rock data sheets. This summary brings the total number of typical rock types reported to 81. Test results from additional rock cores will be presented in future reports.

One of the main purposes of grouping rock properties into this format is to provide a convenient summary of test results from previous foundation investigations for use in preliminary location and design studies of new Bureau projects. Since about 1920, data on rock properties have been documented by numerous investigators and agencies in the United States, but have not always been readily available, or in some cases, the information was not comprehensive enough. Further, test conditions for obtaining some of the basic properties have varied significantly, thus reducing the value of the data reported. In the Bureau's investigations of foundation rock types, efforts have been made to maintain uniform test procedures to obtain data which are consistent with previous results.

# TEST PROCEDURES

Although the test procedures employed in the laboratory investigations basically are similar to those described in the previous SP-39 report, an additional test standard has been added and some minor changes in procedures have been incorporated. These are as follows:

The direct tension test has been utilized and results for this test, where performed, are included on the rock data sheets. Using either a hollow cone grip of steel with a wedge of sulfur clay mix to hold each end of extra-long specimens or steel caps cemented to the cut ends of standard specimens (L/D = 2), a direct tension load was applied through link chains by means of a standard testing machine. Figures 1 through 3 show the test setups for these two tension arrangements. Both procedures are used; however, the cemented end cap method is limited to the cement bond strength, which is approximately 2,000 psi. The cone-grip assembly, in contrast, has a much greater load capacity for rock material in tension, and has been used to test NX-size amphibolite rock cores to 4,900 psi.

In performing the absorption and specific gravity tests, the specimens are weighed air dried* rather than ovendried. Additionally, all core specimens are tested for absorption properties, rather than a few. This provides a better comparison of absorption data with other rock properties.

## DESCRIPTION OF ROCK DATA SUMMARY SHEETS

The format of the test data summarized herein has been designed to provide the maximum information on the rock types investigated. The key features included on the Rock Data Sheets (RDS) are described as follows:

Rock type.—The basic designation of the rock type is given in the upper right-hand corner, along with the petrographic sample number assigned to the rock group being summarized. The RDS sheets are arranged in alphabetical order of the rock types for convenient indexing.

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*The air-dry condition is obtained by subjecting the core to the warm, dry atmosphere of the laboratory at $70^{o}$-$75^{o}$ F.

Location and geologic occurrence.—The geographic location is given of the foundation site from which the core samples were taken. Also stated for most rock types are the basic features of the site being investigated, including the formation identification.

Petrographic description.—This section includes a brief summary of the significant mineral composition, structure, texture, and condition of the rock, as determined by accepted petrographic procedures. More complete petrographic reports for most of the rock types are contained in Bureau files.

Engineering properties of rock core samples.—The primary test data are arranged for ease of reading and to provide all information possible. For each average test value or set of values, the number of specimens tested is given. The secant modulus of elasticity data are recorded for the first cycle of axial loading. The elastic stress-strain curve is shown for each rock type. The data presented are for rock tested at a moisture condition of 75 percent of full saturation, except where otherwise indicated. An air-dry test condition is used for rocks such as shales and clay siltstones which are adversely affected by saturation.

This report also includes, as an appendix, a set of three reference tables[1] which give classifications for mineralogic and textural identification of igneous, sedimentary, and metamorphic rock types, as used by the Bureau of Reclamation.

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[1] Taken from "Petrography and Engineering Properties of Rock," R. C. Mielenz, Engineering Monograph No. 1, USBR, 1961 rev.

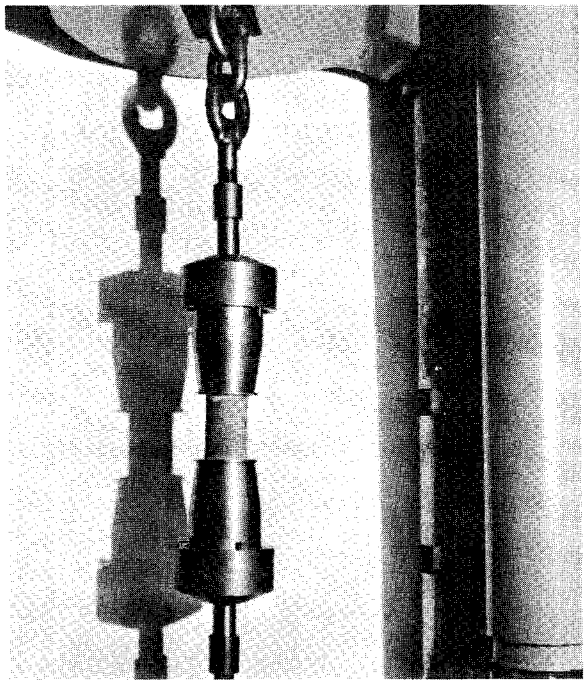


Figure 1. Direct tension test utilizing hollow steel cone grips. Flexible chain section prevents eccentric loading. Photo P859-D-68103

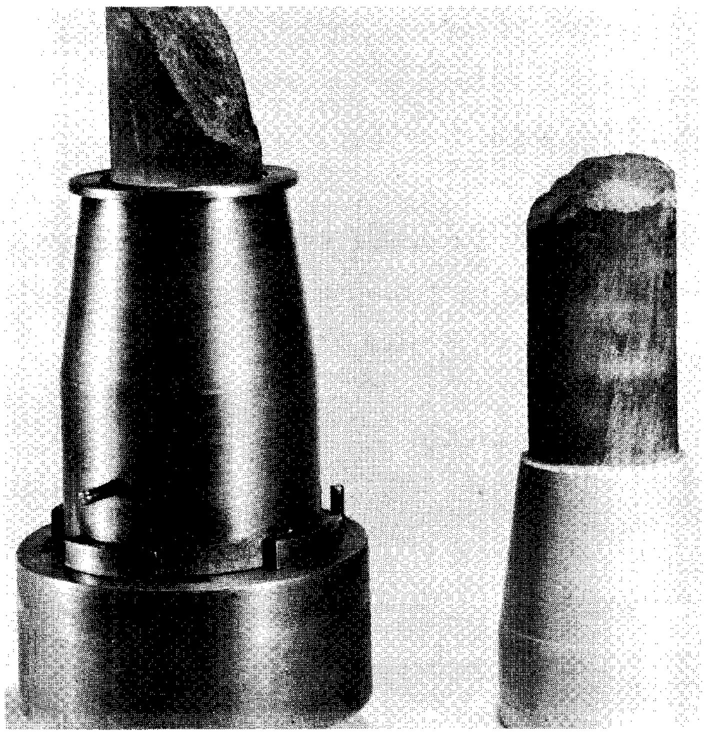


Figure 2. Cone grip assembly with ruptured specimen portion encased; and extracted specimen portion showing sulfur-clay wedge. Photo P859-D-61I04

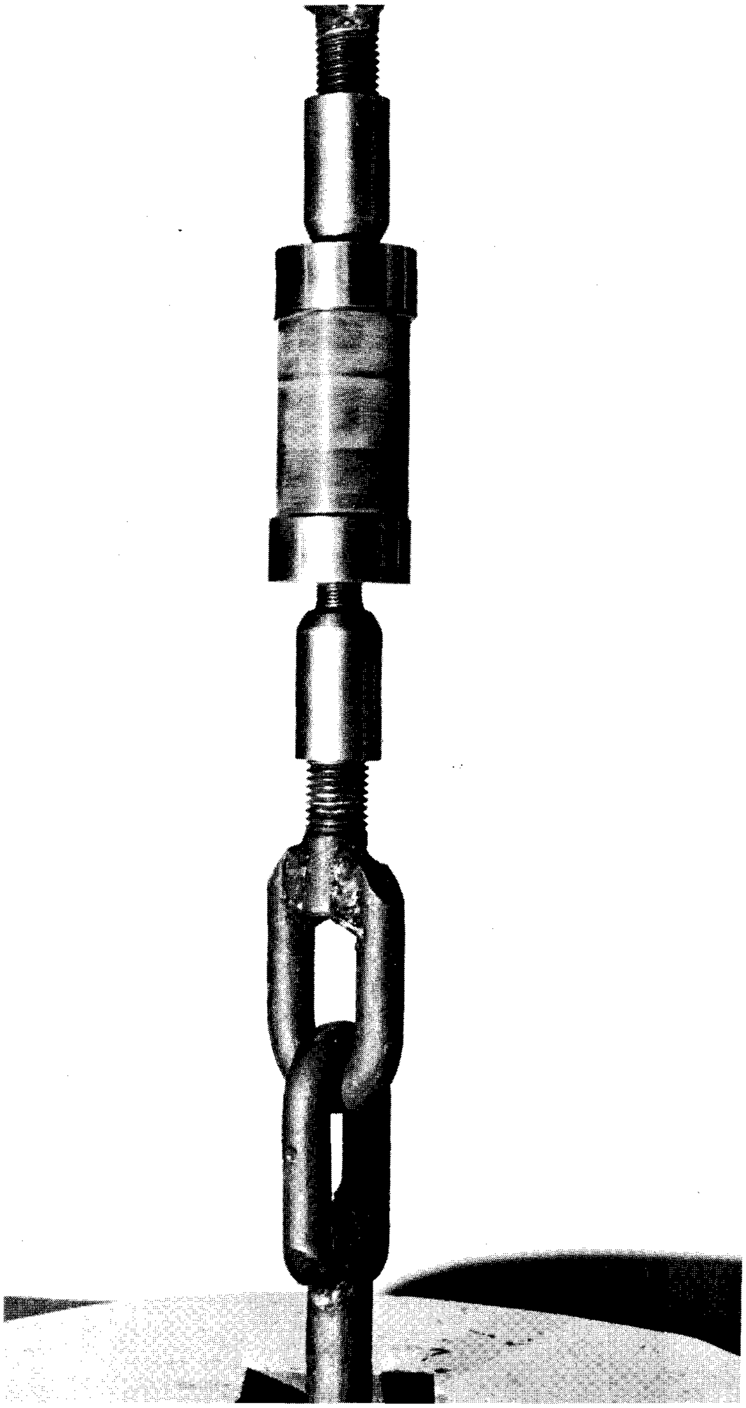


Figure 3. Direct tension test utilizing steel end caps cemented to end surfaces of rock. Photo PX-D-74673

## INDEX TO ROCK DATA SUMMARY SHEETS

INDEX TO ROCK DATA SUMMARY SHEETS—Continued

# ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

The BX samples are from the proposed Bridge Canyon damsite, located on the Colorado River about 2-1/2 miles below Bridge Canyon in Mohave County, Arizona. Foundation rock at the site consists mainly of gneisses, schists, amphibolites, and granites of Precambrian age and sandstones of the Tapeats formation (Cambrian). Pegmatite dikes cut the abutment at various angles.

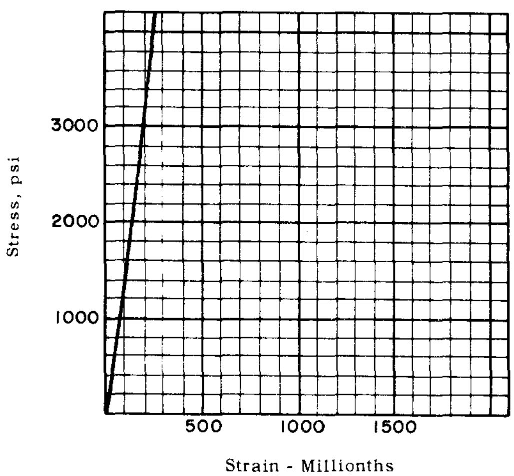
## PETROGRAPHIC DESCRIPTION

The samples are hard, mottled gray and black, massive, and coarse-grained. The rock is composed mainly of hornblende with lesser amounts of labradorite, both occurring as subhedral crystals, but occasionally in anhedral form. Of the minor components, biotite is present in small amounts, and quartz crystals constitute about 1 percent of the rock. Tremolite, magnetite, and apatite occur in trace amounts. Most of the labradorite crystals are very slightly altered to sericite. The crystals generally appear to be well interlocked. Hornblende crystals range from 0.2 to 2 mm, and labradorite crystals range much smaller, from 0.1 to 0.4 mm in size.
The rock is a massive amphibolite.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-1000 | 14.6 | .13 | (2) |
| 0-2000 | 15.2 | .16 | |
| 0-3000 | 16.1 | .19 | |
| 0-4000 | 15.9 | .19 | |




### SPECIFIC GRAVITY / ABSORPTION,%

| Specific gravity avg | Specific gravity range | Absorption,% avg | Absorption,% range | No. spec. |
|---|---|---|---|---|
| 3.06 | 0.16 | 0.12 | 0.10 | (4) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 22300 | 7000 | (2) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 12.4\ S_3 + 22000$ (4)

Equation of Mohr's envelope

$Y = 1.6\ X + 3200$ (4)

### TENSILE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 2000 | 1600 | (2) |

# AMPHIBOLITE
P-6411

ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

The NX samples are from Oroville damsite on the Feather River, about 5 miles northeast of Oroville, California. The samples are from a metamorphic remnant in the Sierra batholith of late Jurassic age. The core samples were taken from Drill Holes 84L and 85R.

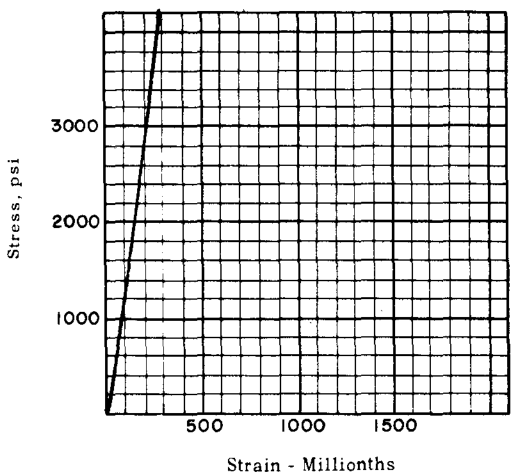
## PETROGRAPHIC DESCRIPTION

The samples are hard, gray-green, fresh, and dense. The rock is fine- to medium-grained, and shows a number of quartz and calcite-healed fractures. Megascopic schistosity occurs but is not prominent. The rock exhibits unequigranular texture, with irregularly shaped grains of plagioclase feldspar, prismatic grains of hornblende with ragged ends, and inclusions of magnetite. Chlorite occurs as green, irregularly shaped grains, ranging from 0.03 to 1.45 mm in diameter. Crystal grain size in the matrix is commonly 0.19 to 0.37 mm. The hornblende and feldspar appear in equal amounts, and chlorite, quartz, epidote, and magnetite are present in minor amounts.
The rock is an amphibolite.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-2000 | 13.5 | .18 | |
| 0-4000 | 13.8 | .20 | (3) |
| 0-6000 | 13.2 | .21 | |
| 0-8000 | 12.9 | .21 | |




### SPECIFIC GRAVITY / ABSORPTION, %

| Specific gravity avg | Specific gravity range | Absorption, % avg | Absorption, % range | No. spec. |
|---|---|---|---|---|
| 2.94 | 0.16 | 0.1 | 0.1 | (3) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 40300 | 20200 | (3) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 15.4\ S_3 + 42500$ (12)

Equation of Mohr's envelope

$Y = 1.8\ X + 5400$ (12)

### TENSILE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 3300 | 1600 | (3) |

# ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

The NX samples are from Devil Canyon damsite, which is located on the Susitna River, about 150 miles north of Anchorage, in the Talkeetna Mountains, Alaska. The geologic occurrence is an area of highly dipping stratified rocks, which have been subjected to folding, faulting, and metamorphism.

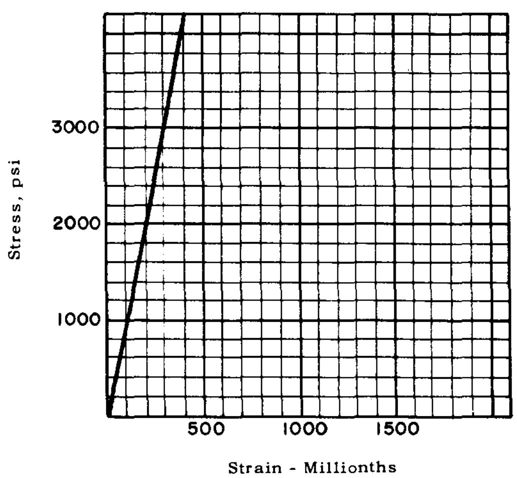
## PETROGRAPHIC DESCRIPTION

The rock is hard, dark, brittle, slightly porous, fine-grained, and fractured. The major constituents are quartz and biotite, with minor amounts of iron oxide, amphibole, calcite, chlorite, and altered biotite. The rocks are banded and slightly weathered, and when struck with a hammer, tend to split along old bedding planes. The bedding is not uniform, and contains intermittent granitic intrusions and fractures. Fractures are thin and show some slickenside structure and most are healed with quartz. The size of the grains in the matrix ranges from 0.01 to 0.08 mm, averaging 0.03 mm.
The rock is an argillite.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-1000 | 9.7 | .16 | |
| 0-2000 | 9.8 | .21 | (4) |
| 0-3000 | 9.9 | .24 | |
| 0-4000 | 10.0 | .25 | |




### SPECIFIC GRAVITY / ABSORPTION, %

| Specific gravity avg | Specific gravity range | Absorption avg | Absorption range | No. spec. |
|---|---|---|---|---|
| 2.73 | 0.03 | 0.07 | 0.05 | (3) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 16900 | 9000 | (4) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

—

Equation of Mohr's envelope

—

### TENSILE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 420 | 280 | (3) |

# BASALT

Vesicular
P-6327

ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

The NX cores were obtained from exploration drill holes at Koyna damsite, Bombay, India. The rock is representative of the Deccan Plateau area (Cretaceous-Eocene). Three rock types are found in the damsite foundation. Tuff breccia overlies a vesicular basalt, which is underlain by massive basalt.

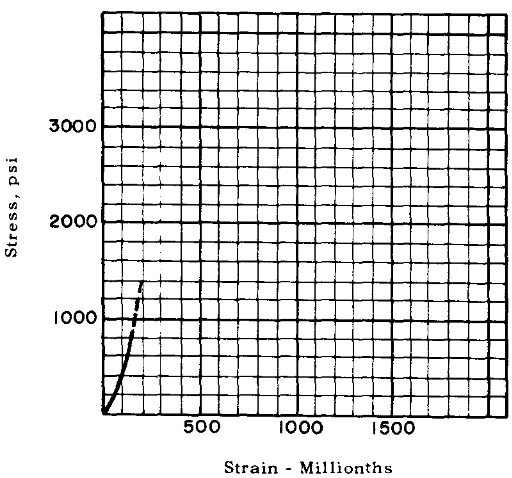
## PETROGRAPHIC DESCRIPTION

The rock is hard, dull gray to pink, compact, but porous and vesicular. The rock is composed of feldspar crystals which are present in a groundmass of granular augite and altered glass. The feldspar crystals are fine-grained, lath-shaped, and in some portions account for 50 percent of the rock composition. Magnetite occurs as an accessory mineral. The secondary minerals are hematite, zeolite, and montmorillonite. In the groundmass the augite is highly altered and fractured, and in some cases penetrates the crystal grains and fills the fractures. Most of the cavities are filled by zeolites. The high percentage of vesicules and clay present has lowered the density of the rock.
The rock is a vesicular basalt.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-200 | 4.4 | .11 | |
| 0-400 | 5.3 | .13 | (3) |
| 0-600 | 5.5 | .14 | |
| 0-800 | 5.8 | .15 | |




### SPECIFIC GRAVITY / ABSORPTION,%

| Specific gravity avg | Specific gravity range | Absorption, % avg | Absorption, % range | No. spec. |
|---|---|---|---|---|
| 2.54 | 0.59 | 5.7 | 8.5 | (4) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 9900 | 8700 | (3) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 6.8\ S_3 + 9000$ (10)

Equation of Mohr's envelope

$Y = 1.1\ X + 1900$

### TENSILE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 320 | 410 | (6) |

# BASALT
Glassy
P-5470

ROCK DATA SUMMARY

LOCATION & GEOLOGIC OCCURRENCE

The NX samples are from Black Canyon damsite, Boise Project, Boise, Idaho, on the Payette River about 7 miles east from Emmett, Idaho. The Payette formation consists of an interbedded basalt flow underlain by a well-cemented sandstone.

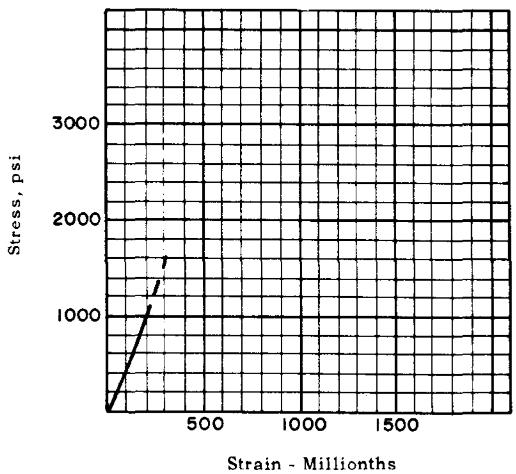
PETROGRAPHIC DESCRIPTION

The rock is hard, dark gray to black, very fine-grained, slightly to moderately porous, and moderately fractured. The rock is composed mainly of a brown basaltic glass matrix surrounding crystals of augite and labradorite feldspar. These occur as small lath-shaped crystals, some of which show complete crystal outlines, but most having ragged terminations. Moderate amounts of small magnetite crystals are present. The fractures in the rock are filled with opal and chalcedony. The labradorite crystals range from 0.03 to 0.07 mm, and the augite ranges from 0.04 to 0.11 mm in length.
The rock is a glassy basalt.

ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-250 | 4.4 | .08 | |
| 0-500 | 4.6 | .09 | |
| 0-750 | 4.8 | .10 | (6) |
| 0-1000 | 4.9 | .11 | |




SPECIFIC GRAVITY / ABSORPTION,%

| Specific gravity avg | Specific gravity range | Absorption, % avg | Absorption, % range | No. spec. |
|---|---|---|---|---|
| 2.62 | 0.16 | 1.4 | 0.7 | (10) |

COMPRESSIVE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 8400 | 5700 | (3) |

SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 8.3 S_3 + 10900$ (14)

Equation of Mohr's envelope

$Y = 1.3 X + 1900$ (14)

TENSILE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 460 | 100 | (2) |

# BASALT

P-5429

## ROCK DATA SUMMARY

### LOCATION & GEOLOGIC OCCURRENCE

The NX cores were obtained from South Coulee Damsite, Columbia Basin Project, Washington. The rock is from basalt flows of the Columbia River or Yakima basalt sequence. Lavas accumulated as nearly horizontal fissure eruptions (Miocene) with little explosive action. The basalt flows, a maximum of 1,000 feet thick, thin out northward in 25 to 50 miles to an irregular terminus, where the underlying granite (Colville batholith) is exposed.

### PETROGRAPHIC DESCRIPTION

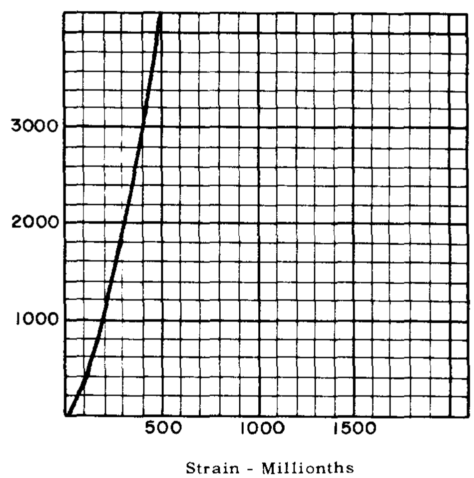
The samples are hard, dark gray, dense, fine-grained, and slightly porous. The rock is composed mostly of random labradorite laths and subhedral augite, with the interstices filled by brown glass. The glass contains crystals of ilmenite and minute octahedrons, and scales of magnetite. A small amount of this interstitial glass is partially devitrified to crystal aggregates and feldspar cyrstallites. Most of the labradorite laths and the few equant crystals vary in length from 0.09 to 0.85 mm. The crystals are moderately well interlocked.

The rock is a basalt.

### ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

#### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-1000 | 6.2 | .14 | |
| 0-2000 | 7.2 | .17 | (3) |
| 0-3000 | 7.7 | .19 | |
| 0-4000 | 8.3 | .21 | |




#### SPECIFIC GRAVITY / ABSORPTION, %

| Specific gravity avg | Specific gravity range | Absorption, % avg | Absorption, % range | No. spec. |
|---|---|---|---|---|
| 2.81 | 0.13 | 1.0 | 1.1 | (5) |

#### COMPRESSIVE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 24900 | - | (1) |

#### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 6.7\ S_3 + 28400$ (6)

Equation of Mohr's envelope

$Y = 1.1\ X + 5500$ (6)

#### TENSILE STRENGTH, PSI

| avg | range |
|---|---|
| — | |

# BASALT

Vesicular

ROCK DATA SUMMARY

P-5407 (group A)

## LOCATION & GEOLOGIC OCCURRENCE

The NX cores were taken from South Coulee Damsite, Columbia Basin Project, Washington. The rock is from basalt flows of the Columbia River or Yakima basalt sequence. Lavas accumulated as nearly horizontal fissure eruptions (Miocene) with little explosive action. These basalt flows, a maximum of 1,000 feet thick, thin out northward in 25 to 50 miles to an irregular terminus, where the underlying granite (Colville batholith) is exposed.

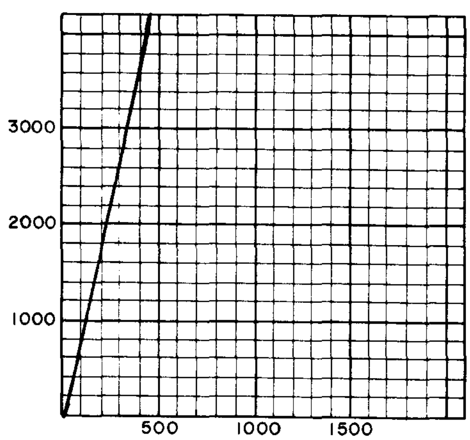
## PETROGRAPHIC DESCRIPTION

The rock samples are hard, dark bluish gray, fine-grained, and highly vesicular. Most of the vesicles present range from 0.25 to 1.50 mm, averaging 0.50 mm in size. The rock is composed essentially of labradorite laths and augite crystals. The interstices are filled with green or brown glass which contains slender apatite crystals. Basaltic hornblende occurs in very small amounts and is usually associated with augite. A few vesicles are as large as 4 mm. Most of the vesicles are lined with films of palagonite, usually mixed with small amounts of montmorillonite.
The rock is a vesicular basalt.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-1000 | 8.6 | .19 | |
| 0-2000 | 8.6 | .21 | (6) |
| 0-3000 | 8.6 | .22 | |
| 0-4000 | 8.7 | .22 | |




### SPECIFIC GRAVITY / ABSORPTION,%

| Specific gravity avg | Specific gravity range | Absorption,% avg | Absorption,% range | No. spec. |
|---|---|---|---|---|
| 2.62 | 0.04 | 3.3 | 0.3 | (10) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 13900 | 6400 | (3) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 7.6\ S_3 + 16800$ (12)

Equation of Mohr's envelope

$Y = 1.2\ X + 3000$ (12)

### TENSILE STRENGTH, PSI

avg range

—

# BASALT

**Vesicular**
**P-5407 (group B)**

ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

The NX cores were obtained from South Coulee Damsite, Columbia Basin Project, Washington. The rock is from basalt flows of the Columbia River or Yakima basalt sequence. Lavas accumulated as nearly horizontal fissure eruptions (Miocene) with little explosive action. These basalt flows, a maximum of 1,000 feet thick, thin out northward in 25 to 50 miles to an irregular terminus, where the underlying granite (Colville batholith) is exposed.

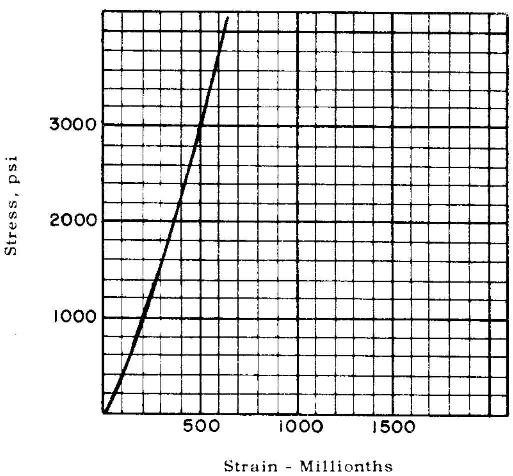
## PETROGRAPHIC DESCRIPTION

The rock samples are hard, dark bluish gray, fine-grained, and highly vesicular. The rock is composed mainly of labradorite laths and augite crystals, and the interstices are filled with glass, which contains slender apatite crystals. Basaltic hornblende occurs in very small amounts and is usually with augite. Most of the vesicles range from 0.25 to 2 mm, averaging 1 mm in diameter; a few, however, are about 9 mm. The vesicles are mostly lined with films of palagonite, which is usually mixed with small amounts of montmorillonite. The rock samples are very similar to the basalt of Group A, but have more vesicles, which accounts for the lower values of elasticity, strength, and specific gravity.
The rock is a highly vesicular basalt.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-1000 | 4.8 | .11 | |
| 0-2000 | 5.4 | .13 | (5) |
| 0-3000 | 5.9 | .15 | |
| 0-4000 | 6.3 | .16 | |




### SPECIFIC GRAVITY / ABSORPTION,%

| Specific gravity avg | Specific gravity range | Absorption avg | Absorption range | No. spec. |
|---|---|---|---|---|
| 2.58 | 0.04 | 4.7 | 1.9 | (6) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 11900 | 5500 | (2) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 8.2 \quad S_3 + 14700$ (9)

Equation of Mohr's envelope

$Y = 1.3 \quad X + 2600$ (9)

### TENSILE STRENGTH, PSI

| avg | range |
|---|---|
| — | |

# BASALT

**Vesicular**
**P-5374**

ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

The NX samples are from South Coulee damsite, Columbia Basin Project, Washington. The rock is from basalt flows of the Columbia River or Yakima basalt sequence. Lavas accumulated as nearly horizontal fissure eruptions (Miocene) with little explosive action. The basalt flows, a maximum of 1,000 feet thick, thin northward in 25 to 50 miles to an irregular terminus, where the underlying granite (Colville batholith) is exposed.

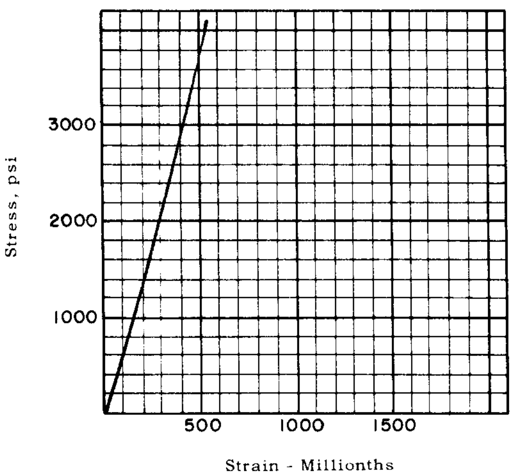
## PETROGRAPHIC DESCRIPTION

The rock is hard, dark gray, fine-grained, vesicular, and contains white phenocrysts. The rock is composed mainly of labradorite laths about 0.18 mm in length, in a volcanic glass matrix containing large amounts of illmenite, magnetite, and some hematite. Basaltic hornblende occurs in small amounts, as does irregularly shaped grains of augite. Vesicles range from 0.25 to 30 mm in diameter. These vesicles are lined with films of palagonite and/or a montmorillonite. The few phenocrysts present are intermediate between labradorite and plagioclase, and the crystals are moderately interlocked.
The rock is a vesicular basalt.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-1000 | 5.8 | .16 | |
| 0-2000 | 6.0 | .18 | (6) |
| 0-3000 | 6.2 | .20 | |
| 0-4000 | 6.4 | .22 | |




### SPECIFIC GRAVITY / ABSORPTION, %

| Specific gravity avg | Specific gravity range | Absorption avg | Absorption range | No. spec. |
|---|---|---|---|---|
| 2.47 | 0.24 | 5.6 | 3.1 | (12) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 8900 | 1020 | (3) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 3.2\ S_3 + 12400$ (15)

Equation of Mohr's envelope

$Y = 0.6\ X + 3400$

### TENSILE STRENGTH, PSI

| avg | range |
|---|---|
| — | |

# BRECCIA

Andesite
P-6571

ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

The BX samples are from Tunnel N-4, Hoover Dam foundation, which is located in Black Canyon on the Colorado River. In the north wall of the canyon, the andesite breccia is overlain by the Boulder Wash group which consists of younger volcanic and intrusive rocks.

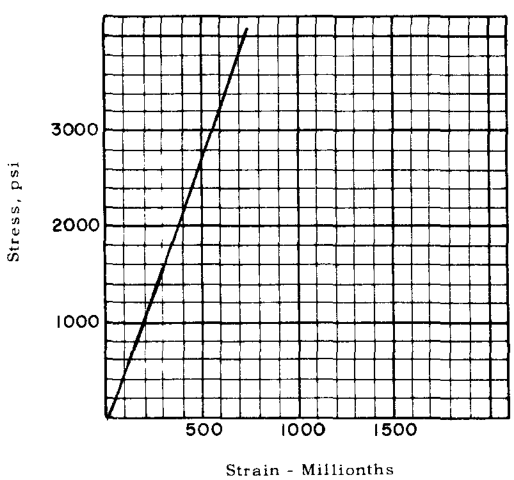
## PETROGRAPHIC DESCRIPTION

The rock is medium hard, red-brown, coarse, porous, with angular fragments in a fine-grained reddish brown groundmass. The groundmass is a mixture of very fine hematite, iron oxide, calcite, and clay. The clastic fragments consist of andesite, with lesser granite and limestone. Mineral grains consist of quartz, feldspar, calcite, clay, mica, hematite, hornblende, and magnetite. The fragments are angular and fine- to coarse-grained. Contact of the grains and fragments vary from direct to no contact. The quartz and feldspar grains contain small fractures. Some fragments show signs of being crushed to smaller particles. Clay is present in the feldspar. The matrix is softer than the rock fragments. The rock is andesite breccia.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-1000 | 5.3 | .22 | |
| 0-3000 | 5.4 | .23 | (5) |
| 0-5000 | 5.4 | .25 | |




### SPECIFIC GRAVITY / ABSORPTION,%

| Specific gravity avg | Specific gravity range | Absorption,% avg | Absorption,% range | No. spec. |
|---|---|---|---|---|
| 2.37 | - | 2.8 | - | (1) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 14900 | 6000 | (5) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 3.7\ S_3 + 18100$ (16)

Equation of Mohr's envelope

$Y = 0.7\ X + 4700$ (16)

### TENSILE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 1050 | 510 | (10) |

# BRECCIA

**Basaltic**
**P-6320**

ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

The NX cores were obtained from exploration drill holes at Koyna damsite, Bombay, India. The rock is representative of the Deccan Plateau area (Cretaceous-Eocene). Three rock types are found in the damsite foundation. Tuff breccia overlies a vesicular basalt, which is underlain by massive basalt.

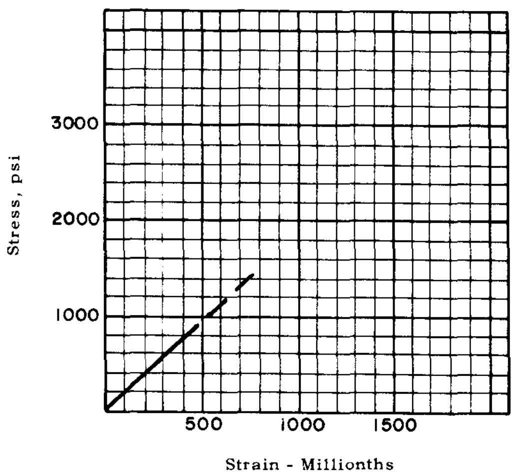
## PETROGRAPHIC DESCRIPTION

The rock is soft, reddish gray, weathered, porous with angular to subround fragments. The breccia has a nonuniform matrix composed of small laths of labradorite feldspar, grains of augite, palagonite, and altered glass. The rock has a fine-grained texture and is highly weathered and altered, and contains a high proportion of glass and ash material. Zeolites are significant as cavity and fracture fillings. Fragments are not in contact with each other and are variably cemented. Mixed quantities of hematite and montmorillonite occur between the fragments as aggregate masses. Abundance of clays has lowered the density of the rock.
The rock is a basaltic breccia.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-200 | 1.9 | .05 | |
| 0-400 | 1.9 | .08 | |
| 0-600 | 1.9 | .10 | (3) |
| 0-800 | 1.9 | .11 | |




### SPECIFIC GRAVITY / ABSORPTION, %

| Specific gravity avg | Specific gravity range | Absorption, % avg | Absorption, % range | No. spec. |
|---|---|---|---|---|
| 2.01 | 0.62 | 16.5 | 10.7 | (9) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 2600 | 1200 | (4) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$$S_1 = 5.0\ S_3 + 2650 \quad (9)$$

Equation of Mohr's envelope

$$Y = 0.9\ X + 600 \quad (9)$$

### TENSILE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 210 | 240 | (4) |

# ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

The rock is from Palisades damsite on the Snake River in Idaho. Stratified sediments of sandstones, claystones, and siltstones occur at the site. Andesite outcrops in a large body on the left abutment and disappears downward beneath the river.

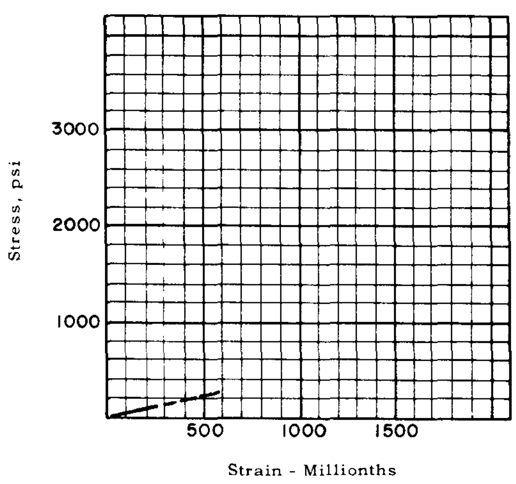
## PETROGRAPHIC DESCRIPTION

**The rock is medium hard, buff to pink, friable, porous, and is weathered. It is composed of a calcareous montmorillonite clay matrix, surrounded by fine (greater than 0.01 mm), subround, separated grains of quartz, and of calcite. Iron oxide is present in minor amounts.**
**The rock is weathered claystone.**

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES*

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-40 | 0.41 | .04 | |
| 0-60 | 0.41 | .04 | (8) |
| 0-80 | 0.41 | .03 | |
| 0-100 | 0.41 | .03 | |




### SPECIFIC GRAVITY / ABSORPTION, %

| Specific gravity avg | Specific gravity range | Absorption, % avg | Absorption, % range | No. spec. |
|---|---|---|---|---|
| 2.20 | 0.61 | 7.6 | 1.8 | (2) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 1200 | 1000 | (5) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 10.6\, S_3 + 1400$ (16)

Equation of Mohr's envelope

$Y = 1.5\, X + 220$ (16)

### TENSILE STRENGTH, PSI

| avg | range |
|---|---|
| — | |

*Tested air dry

# CLAYSTONE

**Calcareous**
**P-5643**

ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

The NX rock cores are from left abutment spillway site, Sanford Damsite, Canadian River Project, Texas. Geologically, the site is within a subsidence basin in which the Alibates dolomite beds are downwarped. Overlying beds of silty shale and sandstone of the Quartermaster formation have been preserved within the basin.

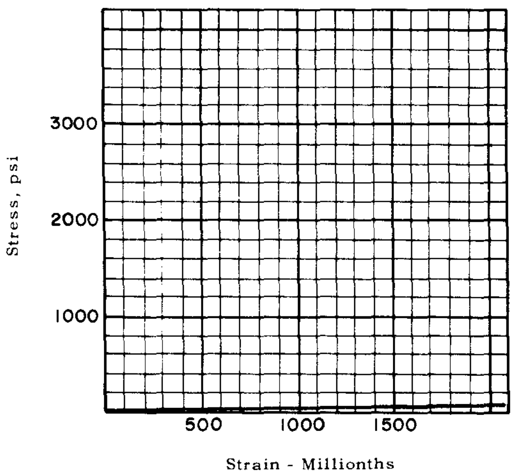
## PETROGRAPHIC DESCRIPTION

The rock is soft to firm, reddish brown, fine-grained, porous, moderately friable, and exhibits slickensides and shrinkage cracks. The rock is composed of very fine-grained vermiculite intimately mixed with small amounts of iron oxide, montmorillonite and sericite. The specimens also contain moderate amounts of silt-sized particles of quartz, feldspar, and chalcedony, and small amounts of dolomite, magnetite, chlorite, and illite. The material slakes rapidly in water. Portions of the rock exhibit crude laminations which are normal to the core axis. Rounded grains do not contact each other generally, and are poorly cemented.
The rock is a calcareous claystone.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES*

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0–25 | 0.04 | – | |
| 0–50 | 0.04 | – | (2) |
| 0–75 | 0.03 | – | |




### SPECIFIC GRAVITY / ABSORPTION, %

| Specific gravity avg | Specific gravity range | Absorption, % avg | Absorption, % range | No. spec. |
|---|---|---|---|---|
| 1.8 | - | 22.0 | - | (1) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 270 | 10 | (2) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 4.2\ S_3 + 230$ (9)

Equation of Mohr's envelope

$Y = 0.8\ X + 60$ (9)

### TENSILE STRENGTH, PSI

avg range

—

*Tested air dry

# CONGLOMERATE

ROCK DATA SUMMARY P-6303

## LOCATION & GEOLOGIC OCCURRENCE

The NX rock core samples are from Flaming Gorge damsite, located north of Vernal, Utah, on the Green River, near the Utah-Wyoming border. The geologic occurrence is of the Uinta formation, which is composed of interbedded quartzites, quartzose sandstones, and conglomerates. In addition, beds of shale and siltstone occur intermittently.

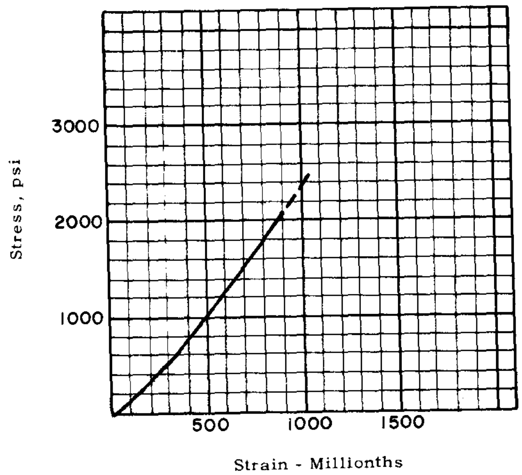
## PETROGRAPHIC DESCRIPTION

The rock is hard, medium- to coarse-grained, and slightly altered. The rock is composed of quartz and orthoclase grains and pebbles in a matrix of fine-grained quartz particles cemented with silica and hematite. The quartz and feldspar grains are angular to sub-round and are occasionally fractured. Cementing material consists primarily of secondary quartz with locally varying amounts of hematite. Much of this cementing material occurs as solution contact between grains and as secondary intergrowths of individual grains. These secondary intergrowths constitute a strong bond between the original sand grains. Grain sizes range from 0.13 to 4.0 mm.
The rock is a conglomerate.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-500 | 1.7 | .01 | |
| 0-1000 | 2.0 | .02 | (10) |
| 0-1500 | 2.2 | .03 | |
| 0-2000 | 2.3 | .05 | |




### SPECIFIC GRAVITY / ABSORPTION,%

| Specific gravity avg | Specific gravity range | Absorption avg | Absorption range | No. spec. |
|---|---|---|---|---|
| 2.54 | 0.03 | 2.1 | 0.6 | (6) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 12800 | 3600 | (9) |

### SHEAR STRENGTH, TRIAXIAL

Principal stress relation

$S_1 = 10.5\ S_3 + 14000$ (25)

Equation of Mohr's envelope

$Y = 1.5\ X + 2400$ (25)

### TENSILE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 430 | 440 | (10) |

# CONGLOMERATE
**P-4504**

## ROCK DATA SUMMARY

### LOCATION & GEOLOGIC OCCURRENCE

The BX samples are from McDowell damsite, Central Arizona Project, Arizona, and located approximately 28 miles northeast of Phoenix, Arizona, on the Salt River. The foundation rocks include Pre-cambrian granite and four overlying sedimentary series.

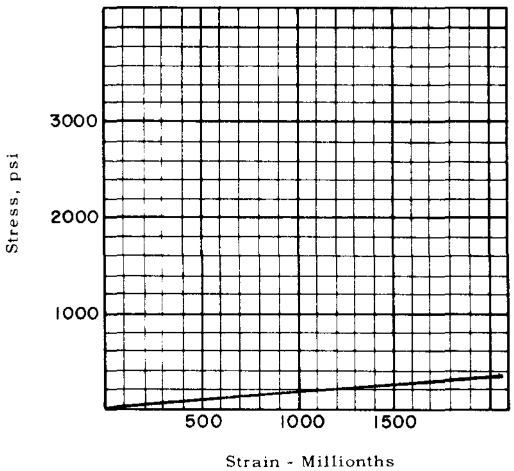
### PETROGRAPHIC DESCRIPTION

The samples are moderately hard, porous, and coarse-grained. The rock is composed of fragments of granite gneiss, quartz, orthoclase, microcline, epidote, and biotite, which are embedded in a matrix of fine sand and silt size particles. The matrix is cemented by iron oxide and small amounts of a clay mineral. The granite gneiss fragments are usually deeply fractured. The rocks are generally penetrated by many healed fractures. Fractures are filled with white and clear calcite intermixed with crushed angular silt-sized particles and some hematite. Biotite is slightly altered to chlorite. The rock fragments range from 1 by 1 mm to 15 by 25 mm in size.
The rock is a conglomerate.

### ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

#### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-200 | 0.21 | 0.15 | |
| 0-300 | 0.18 | 0.12 | (2) |
| 0-400 | 0.17 | 0.12 | |
| 0-500 | 0.17 | 0.11 | |




#### SPECIFIC GRAVITY / ABSORPTION,%

| Specific gravity avg | Specific gravity range | Absorption,% avg | Absorption,% range | No. spec. |
|---|---|---|---|---|
| 2.47 | - | 3.6 | - | (1) |

#### COMPRESSIVE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 4400 | 2400 | (3) |

#### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 1.7\ S_3 + 4900$ (8)

Equation of Mohr's envelope

$Y = 0.3\ X + 1900$ (8)

#### TENSILE STRENGTH, PSI

| avg | range |
|---|---|
| -- | |

# CONGLOMERATE

**Calcareous**
**P-5669**

ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

The NX and BX size samples are from Bhakra damsite, (BR-9), Bhakra Project, East Punjab, India. The foundation rock includes various sediments of the middle Miocene-Dagdsha series. The cores are from Drill Holes 6 and 7A.

## PETROGRAPHIC DESCRIPTION

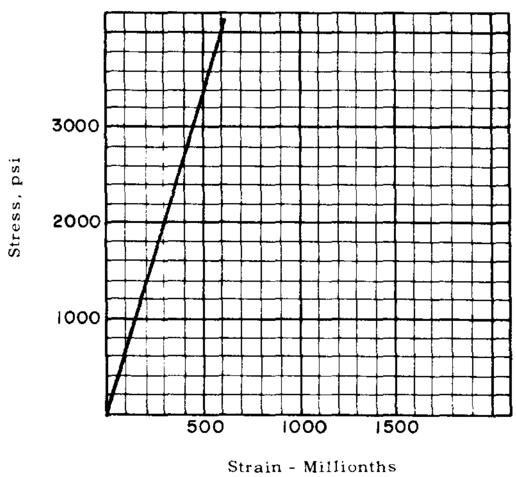
The rock is hard, gray to green, and dense. The rock is composed of large fragments of limestone and silty and sandy limestones, which are embedded in the coarse-grained matrix. The limestone fragments are fine-grained and contain rare to moderate amounts of silt-to-sand size of angular quartz grains with muscovite and biotite shreds. The matrix consists of interlocking, angular-grained quartz, oligoclase and chert, with fragments of sericite and chlorite-schist, basalt, and shale. Platy particles of muscovite, biotite, and chlorite are also present. Calcite is common in the matrix and occurs between and around the granular components. Matrix grains range from 0.08 to 0.50 mm in diameter.

The rock is a calcareous conglomerate.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-1000 | 6.7 | .13 | |
| 0-2000 | 6.7 | .14 | (4) |
| 0-3000 | 6.7 | .16 | |
| 0-4000 | 6.7 | .17 | |




### SPECIFIC GRAVITY / ABSORPTION,%

| Specific gravity avg | Specific gravity range | Absorption avg | Absorption range | No. spec. |
|---|---|---|---|---|
| 2.70 | 0.01 | 0.5 | 0.3 | (4) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 15300 | 3000 | (2) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 8.1\ S_3 + 17200$ (4)

Equation of Mohr's envelope

$Y = 2.5\ X + 6000$ (4)

### TENSILE STRENGTH, PSI

| avg | range |
|---|---|
| — | |

ROCK DATA SUMMARY

# DIORITE
Quartz
P-5823

## LOCATION & GEOLOGIC OCCURRENCE

The BX samples are from the proposed Bridge Canyon damsite, located on the Colorado River about 2-1/2 miles below Bridge Canyon in Mohave County, Arizona. Foundation rock at the site consists mainly of gneisses, schists, amphibolites, and granites of Precambrian age, and sandstones of the Tapeats formation (Cambrian). Pegmatite dikes cut the abutment at various angles.

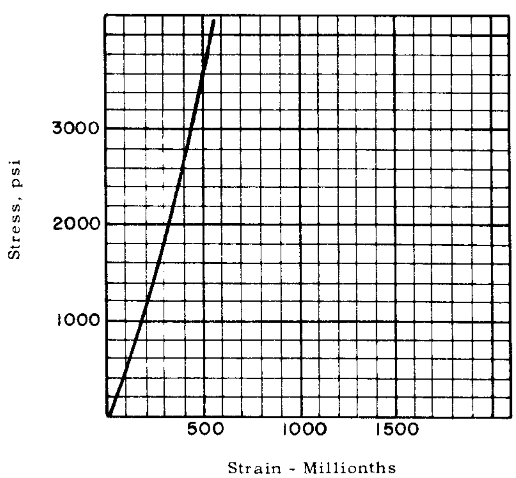
## PETROGRAPHIC DESCRIPTION

The samples are hard, white with black, coarse-grained and massive. The rock is composed mainly of oligoclase and quartz, with lesser amounts of biotite, muscovite, apatite, zircon, and chlorite. The rock has a typical granitic texture. The plagioclase crystals are subhedral to anhedral, and quartz present is always anhedral. The quartz, however, is strained and slightly to moderately fractured. Oligoclase is slightly to moderately altered to sericite and calcite. The oligoclase crystals range from 1 by 2 up to 3 by 5 mm in size. Quartz grains range from 0.3 to 2 mm in size. Boundaries of the grains are generally poorly interlocked. A few biotite crystals are partially altered to chlorite.
The rock is a quartz diorite.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-1000 | 6.2 | .05 | |
| 0-2000 | 6.7 | .06 | (2) |
| 0-3000 | 7.1 | .08 | |
| 0-4000 | 7.4 | .09 | |




### SPECIFIC GRAVITY / ABSORPTION,%

| Specific gravity avg | Specific gravity range | Absorption avg | Absorption range | No. spec. |
|---|---|---|---|---|
| 2.71 | 0.15 | 0.4 | 0.2 | (5) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 17200 | 2800 | (2) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 9.1\ S_3 + 12500$ (5)

Equation of Mohr's envelope

$Y = 1.3\ X + 2100$ (5)

### TENSILE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 1190 | 540 | (2) |

## GNEISS
Quartz-Diorite
P-5740

# ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

The BX samples are from the proposed Bridge Canyon damsite, located on the Colorado River about 2-1/2 miles below Bridge Canyon in Mohave County, Arizona. Foundation rock at the site consists mainly of gneisses, schists, amphibolites, and granites of Precambrian age, and sandstones of the Tapeats formation (Cambrian). Pegmatite dikes cut the abutment at various angles.

## PETROGRAPHIC DESCRIPTION

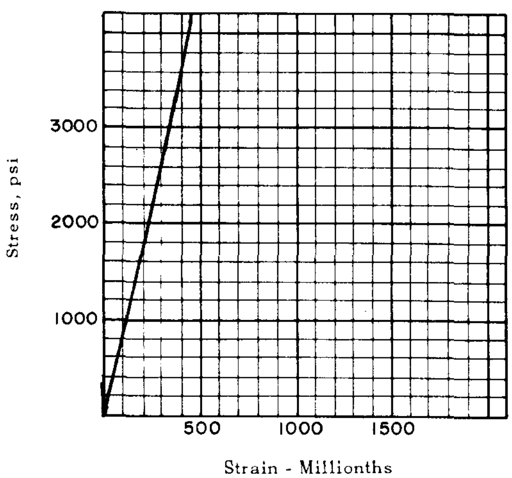
The rock is hard, gray and black, coarse-grained, nonporous, and slightly fractured. The rock is composed of subhedral crystals of andesite with anhedral crystals of orthoclase and quartz. A small amount of biotite is also present. Augen-like masses are common and enclosed by thin bands of biotite, and granular masses of garnet are scattered through the rock. Quartz is commonly strained and fractured. Most of the feldspar crystals are fresh with a few slightly to moderately altered to sericite and calcite. Sericite-filled fractures penetrate through the quartz and feldspar crystals.

The rock is a quartz-diorite gneiss.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-1000 | 9.0 | .10 | |
| 0-2000 | 8.7 | .10 | (4) |
| 0-3000 | 9.0 | .12 | |
| 0-4000 | 9.1 | .13 | |




| SPECIFIC GRAVITY avg | SPECIFIC GRAVITY range | ABSORPTION,% avg | ABSORPTION,% range | No. spec. |
|---|---|---|---|---|
| 2.83 | 0.09 | 0.2 | 0.1 | (9) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 11800 | 1900 | (3) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 6.5\ S_3 + 14600$ (9)

Equation of Mohr's envelope

$Y = 1.1\ X + 2900$ (9)

### TENSILE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 1960 | 390 | (3) |

# ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

The BX samples are from the proposed Bridge Canyon damsite, located on the Colorado River about 2-1/2 miles below Bridge Canyon in Mohave County, Arizona. Foundation rock at the site consists mainly of gneisses, schists, amphibolites, and granites of Precambrian age, and sandstones of the Tapeats formation (Cambrian). Pegmatite dikes cut the abutment at various angles.

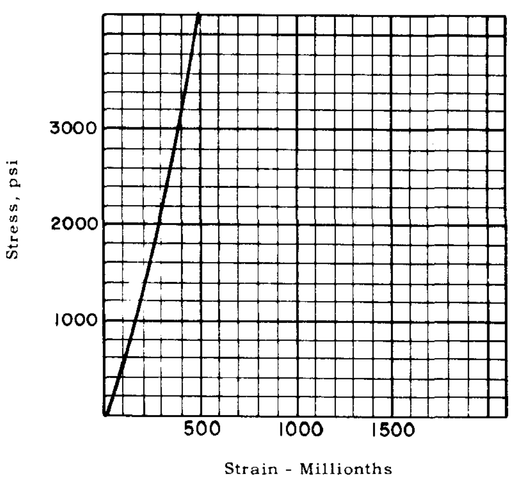
## PETROGRAPHIC DESCRIPTION

The rock is hard, speckled white, pink, and black, massive, and coarse-grained. The rock is composed mainly of quartz, orthoclase, microcline, and oligoclase, with lesser amounts of biotite, muscovite, apatite, magnetite, and calcite. The quartz, orthoclase, and microcline grains are commonly anhedral, and most of the oligoclase grains are subhedral. Between many of the large feldspar grains are biotite and muscovite flakes and small grains of quartz and feldspar. The quartz crystals are strained and the boundaries are sinuous and slightly notched. Feldspars, with similar boundary conditions, contain sericite-filled fractures.
The rock is a granite.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-1000 | 7.4 | .06 | |
| 0-2000 | 7.8 | .08 | (5) |
| 0-3000 | 8.0 | .09 | |
| 0-4000 | 8.1 | .10 | |




### SPECIFIC GRAVITY / ABSORPTION, %

| Specific gravity avg | Specific gravity range | Absorption, % avg | Absorption, % range | No. spec. |
|---|---|---|---|---|
| 2.66 | 0.06 | 0.1 | 0.1 | (15) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 21000 | 9600 | (4) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation
$S_1 = 9.3\ S_3 + 24700$ (14)

Equation of Mohr's envelope
$Y = 1.4\ X + 4100$ (14)

### TENSILE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 810 | 280 | (4) |

# GRANITE
P-5351

## ROCK DATA SUMMARY

### LOCATION & GEOLOGIC OCCURRENCE

**The samples are NX rock cores from Valencia County, New Mexico, in Sec. 13, R 12 W, T 10 N. The samples are from random depths, and the rock is in the Zuni Uplift. The investigation was performed in cooperation with the Colorado School of Mines Research Foundation.**

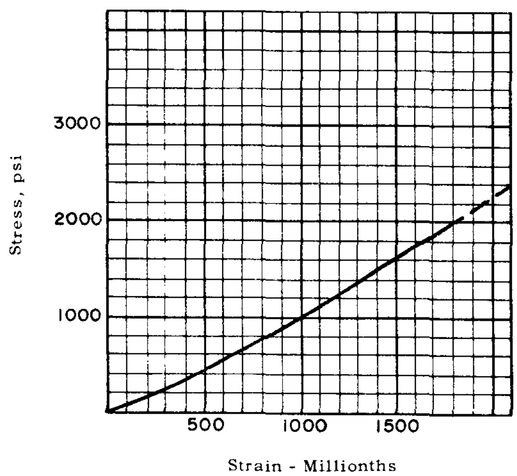
### PETROGRAPHIC DESCRIPTION

**The rock is hard, light colored, coarse-grained, weathered, and massive. The main constituents are quartz and feldspar, and the minor constituents are biotite, sericite, calcite, chlorite, and clay. Quartz fills the interstices between the grains. The boundaries of the grains generally are sinuous to straight and the grains are poorly interlocked. The feldspars are moderately altered to sericite and clay. Both quartz and feldspar show some fracturing. Quartz grains occasionally are crushed and granulated. Biotite occurs as platy crystals and as altered grains scattered throughout the rock. The grain size ranges from 0.13 to 1.45 mm in diameter.**
**The rock is a granite.**

### ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-500 | 0.9 | .06 | |
| 0-1000 | 1.0 | .06 | (2) |
| 0-1500 | 1.1 | .07 | |
| 0-2000 | 1.1 | .08 | |




| SPECIFIC GRAVITY avg | SPECIFIC GRAVITY range | ABSORPTION,% avg | ABSORPTION,% range | No. spec. |
|---|---|---|---|---|
| 2.59 | 0.06 | 2.4 | 0.8 | (2) |

COMPRESSIVE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 3700 | 1400 | (2) |

SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 5.4\ S_3 + 4900$ (3)

Equation of Mohr's envelope

$Y = 0.9\ X + 1100$ (3)

TENSILE STRENGTH, PSI

| avg | range |
|---|---|
| — | |

# GRANITE
P-5352

## ROCK DATA SUMMARY

### LOCATION & GEOLOGIC OCCURRENCE

The samples are NX rock cores from Valencia County, New Mexico, in Sec 13, R 12 W, T 10 N. The samples are from random depths, and the rock is in the Zuni Uplift. The investigation was performed in cooperation with the Colorado School of Mines Research Foundation.

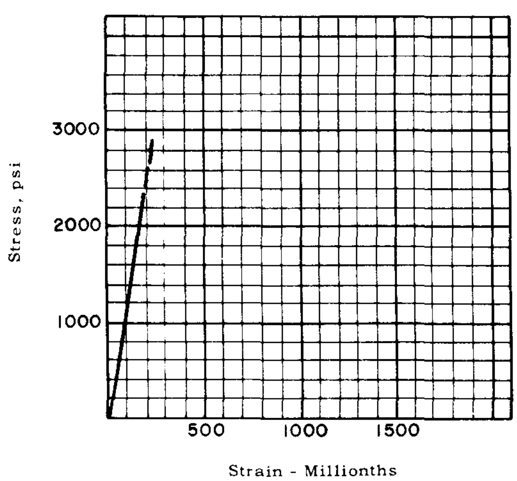
### PETROGRAPHIC DESCRIPTION

The rock is hard, light colored, coarse-grained, and massive. The main constituents are quartz and alkali feldspars. Minor minerals include mica and calcite. Quartz and biotite occur as anhedral grains, and the feldspars vary from subhedral to anhedral grains. Biotite shows a great amount of deformation. The feldspars are somewhat fractured and crushed. The presence of elongated biotite indicates deformation as a result of pressures exerted by the quartz. Calcite and epidote are present in the interstices between the quartz grains. The grain size ranges from 0.4 to 1.4 mm.
The rock is a coarse-grained granite.

### ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-500 | 11.8 | .20 | |
| 0-1000 | 11.1 | .18 | (2) |
| 0-1500 | 11.1 | .18 | |
| 0-2000 | 11.4 | .19 | |




SPECIFIC GRAVITY / ABSORPTION,%

| Specific gravity avg | Specific gravity range | Absorption avg | Absorption range | No. spec. |
|---|---|---|---|---|
| - | - | - | - | |

COMPRESSIVE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 22400 | 5000 | (2) |

SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 6.0\ S_3 + 23600$ (8)

Equation of Mohr's envelope

$Y = 1.0\ X + 4800$ (8)

TENSILE STRENGTH, PSI

| avg | range |
|---|---|
| — | |

# ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

The samples source is from Tumut Pond damsite, Snowy Mountains Project, Australia. The cores are from various depths in the foundation and are 2.5 inches in diameter. New Maragle granites and gneissic granites (Rough Creek) are within the damsite area. The Rough Creek granite is probably younger and intrusive.

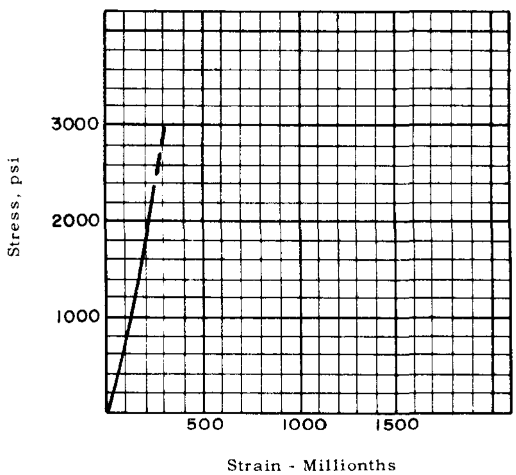
## PETROGRAPHIC DESCRIPTION

The rock is hard, dark gray and black, coarse-grained, massive, and slightly fractured. The main constituents are quartz, orthoclase, microperthite, and altered oligoclase. Minor minerals are biotite, chlorite, and muscovite. Narrow veinlets of quartz and orthoclase penetrate the rock. Quartz occurs slightly strained, anhedral, and fractured. Orthoclase and microperthite crystals are slightly altered to sericite along narrow fractures, and oligoclase is variably altered to sericite. Biotite is variably altered to chlorite.
The rock is a granodiorite.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-500 | 9.0 | .16 | |
| 0-1000 | 9.1 | .16 | (6) |
| 0-1500 | 9.2 | .16 | |
| 0-2000 | 9.3 | .16 | |




### SPECIFIC GRAVITY / ABSORPTION, %

| Specific gravity avg | Specific gravity range | Absorption, % avg | Absorption, % range | No. spec. |
|---|---|---|---|---|
| 2.71 | 0.05 | 0.1 | 0.2 | (14) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 18400 | 7300 | (3) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 8.4\ S_3 + 18500$ (18)

Equation of Mohr's envelope

$Y = 1.3\ X + 3200$ (18)

### TENSILE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 210 | 140 | (3) |

# GRAYWACKE
P-6331

ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

The NX and BX samples submitted are from Shihmen damsite at Shihmen on Takenkan Creek, 52 kilometers from Taipei, Taiwan. The rocks are from the Shihmen sandstones of the Nanking formation, which is of the Miocene age.

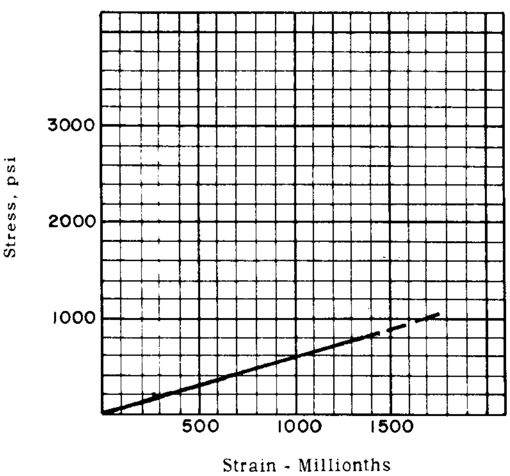
## PETROGRAPHIC DESCRIPTION

The rock is moderately hard, gray, fine-grained, and calcareous. The samples are composed primarily of angular to subround grains of quartz, chert, siltstone, chalcedony, feldspar, and calcite, in a fine-grained matrix. Grain size ranges from 0.04 to 0.15 mm. Quartz, and to a lesser extent calcite and feldspar, dominate the large grain sizes and constitute the major portion of the rock. The minor constituents, which occur primarily in the fine-grained material, consist of illite, chlorite, muscovite, biotite, and sericite. In trace amounts heavy minerals include magnetite, limonite, and tourmaline. The grains are generally well compacted and cemented with euhedral calcite and partly by clay.
The rock is a fine-grained graywacke.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-200 | 0.7 | .03 | (18) |
| 0-400 | 0.6 | .06 | |
| 0-600 | 0.6 | .07 | |
| 0-800 | 0.6 | .09 | |




### SPECIFIC GRAVITY / ABSORPTION, %

| Specific gravity avg | Specific gravity range | Absorption, % avg | Absorption, % range | No. spec. |
|---|---|---|---|---|
| 2.50 | 0.19 | 3.4 | 3.1 | (9) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 8000 | 7300 | (11) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 7.9\ S_3 + 8400$ (44)

Equation of Mohr's envelope

$Y = 1.2\ X + 1500$ (44)

### TENSILE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 290 | 140 | (9) |

# GRAYWACKE

ROCK DATA SUMMARY P-6555

## LOCATION & GEOLOGIC OCCURRENCE

The NX rock cores are from Devil Canyon damsite, located on the Susitna River, about 150 miles north of Anchorage in the Talkeetna Mountains, Alaska. The damsite is in an area of highly dipping stratified rocks, which have been subjected to folding, faulting, and metamorphism.

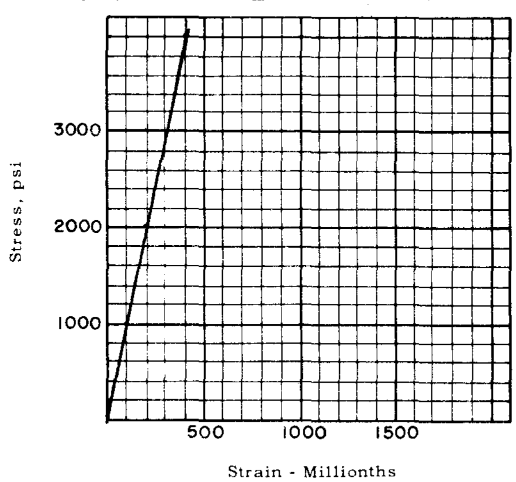
## PETROGRAPHIC DESCRIPTION

The sample is hard, gray-brown, fine-grained, slightly weathered, and porous. The rock is composed of quartz, feldspar and biotite, with minor constituents including iron oxides, pyrite, and organic material. The rock has been subjected to considerable intrusion by granitic solutions. Irregular strata are visible in the hand specimens. The grains generally appear equigranular and subrounded. The grain size ranges from 0.02 to 0.17 mm, grains 0.03 mm in diameter being the most common. Interlocking grains of quartz and feldspar constitute the main portion of the intruded rock. The rock is a graywacke.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-1000 | 9.8 | .15 | |
| 0-2000 | 10.0 | .17 | (3) |
| 0-3000 | 9.9 | .17 | |
| 0-4000 | 10.0 | .18 | |




### SPECIFIC GRAVITY / ABSORPTION, %

| Specific gravity avg | Specific gravity range | Absorption, % avg | Absorption, % range | No. spec. |
|---|---|---|---|---|
| 2.77 | 0.03 | 0.1 | 0.1 | (3) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 32100 | 8000 | (3) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

—

Equation of Mohr's envelope

—

### TENSILE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 800 | 240 | (3) |

# HORNFELS
**Hornblende**
**P-5742**

## ROCK DATA SUMMARY

### LOCATION & GEOLOGIC OCCURRENCE

The BX samples are from the proposed Bridge Canyon damsite, located on the Colorado River about 2-1/2 miles below Bridge Canyon in Mohave County, Arizona. Foundation rock at the site consists mainly of gneisses, schists, amphibolites, and granites of Precambrian age, and sandstones of the Tapeats formation (Cambrian). Pegmatite dikes cut the abutment at various angles.

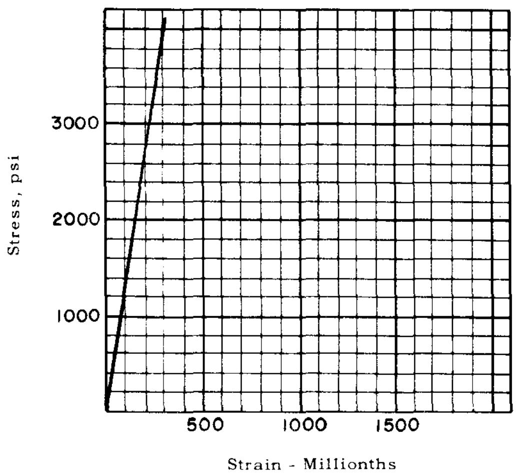
### PETROGRAPHIC DESCRIPTION

The rock is hard, black, medium-grained, and massive. Samples are composed primarily of subhedral to anhedral grains of hornblende. Biotite, diopside, and epidote occur in minor amounts. Thin fractures are filled with magnetite, chlorite, and calcite. The hornblende and biotite are commonly fresh; however, a few of the crystals are slightly altered to chlorite. Hornblende crystal boundaries are commonly straight, with only a slight penetration of one crystal into another. Magnetite and some chlorite occur between the hornblende crystals. The rock fabric is generally mosaic. Hornblende ranges from 0.08 to 0.23 mm in size.
The rock is a hornblende hornfels.

### ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-1000 | 13.4 | .13 | |
| 0-2000 | 13.5 | .16 | (2) |
| 0-3000 | 13.5 | .17 | |
| 0-4000 | 13.3 | .18 | |




SPECIFIC GRAVITY / ABSORPTION,%

| Specific gravity avg | Specific gravity range | Absorption avg | Absorption range | No. spec. |
|---|---|---|---|---|
| 3.04 | 0.16 | 0.1 | 0.1 | (3) |

COMPRESSIVE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 19300 | - | (1) |

SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 6.3\ S_3 + 19300$ (3)

Equation of Mohr's envelope

$Y = 1.1\ X + 3800$ (3)

TENSILE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 2100 | - | (1) |

HORNFELS
Lime-Silicate
P-6475

# ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

The BX cores are from Bhumiphol damsite on the Ping River, 40 miles from Tak in northwest Thailand. The site lies in a wide band of extremely hard rock which dips 85° SE.

## PETROGRAPHIC DESCRIPTION

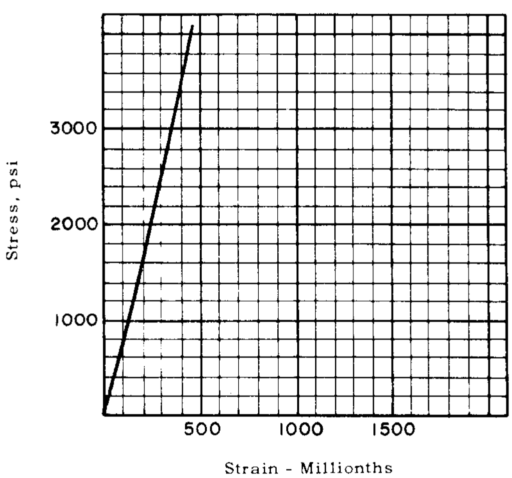
The rock is hard, fine- to medium-grained, fresh, and dense. Samples are composed primarily of quartz, calcite, and diopside. Irregular grains of scapolite, zoisite, and biotite are scattered through the rock. The rock is slightly absorptive and exhibits a mosaic texture. The color variations among the individual bands are actually laminae. Cordierite occurs in the form of large crystals with many small inclusions. Zircon is found in minor quantities. Grain shape varies from anhedral to euhedral, and the major minerals are usually euhedral.

The rock is a lime-silicate hornfels.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-1000 | 8.1 | .15 | |
| 0-2000 | 8.4 | .17 | (10) |
| 0-3000 | 8.6 | .18 | |
| 0-4000 | 8.8 | .19 | |




### SPECIFIC GRAVITY / ABSORPTION,%

| Specific gravity avg | Specific gravity range | Absorption avg | Absorption range | No. spec. |
|---|---|---|---|---|
| 2.82 | 0.32 | 0.3 | 0.4 | (6) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 11300 | 980 | (4) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 13.1\ S_3 + 11900$ (10)

Equation of Mohr's envelope

$Y = 1.7\ X + 1600$ (10)

### TENSILE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 670 | 610 | (3) |

# ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

The source of the samples is Hungry Horse damsite on the South Fork of the Flathead River, about 12 miles east of Columbia Falls, Montana. The foundation is within the Siyeh formation which is of Precambrian age. The rock cores are nominally 4-1/3 inches in diameter.

## PETROGRAPHIC DESCRIPTION

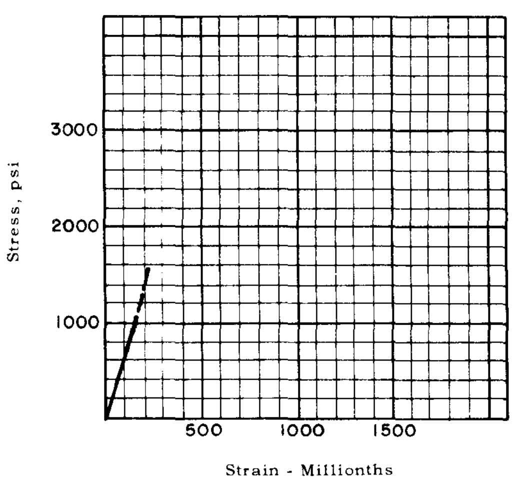
Samples are hard, dark gray, fine-grained, dense with many fractures. The rock is composed of very fine aggregate grains, both in the matrix and in the healed fractures. The major constituents are calcite, dolomite, and clay, with lesser amounts of quartz and carbonaceous material. The healed fractures appear as whitish stringers winding along the vertical axis of the core, in an irregular pattern. The rock exhibits a low percent of absorption, and is slightly weathered. Euhedral grains of quartz are scattered throughout the matrix and in some of the healed veins. Grain sizes in the matrix and the veins are commonly 0.01 mm in diameter.

The rock is an argillaceous limestone.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-400 | 6.0 | .19 | |
| 0-600 | 6.0 | .18 | (3) |
| 0-800 | 6.1 | .18 | |
| 0-1000 | 6.3 | .18 | |




### SPECIFIC GRAVITY / ABSORPTION,%

| Specific gravity avg | Specific gravity range | Absorption,% avg | Absorption,% range | No. spec. |
|---|---|---|---|---|
| 2.75 | - | 0.4 | - | (1) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 6700 | 5900 | (4) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 9.9\ S_3 + 8900$ (19)

Equation of Mohr's envelope

$Y = 1.4\ X + 1400$ (19)

### TENSILE STRENGTH, PSI

| avg | range |
|---|---|
| — | |

# QUARTZITE

P-6318

ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

The samples are from the Flaming Gorge damsite, located north of Vernal, Utah, on the Green River, near the Utah-Wyoming border. The geological area is of the Unita formation, which is composed of interbedded quartzites, sandstones, and conglomerates. Intermittent beds of shale and siltstone occur in varying thicknesses.

## PETROGRAPHIC DESCRIPTION

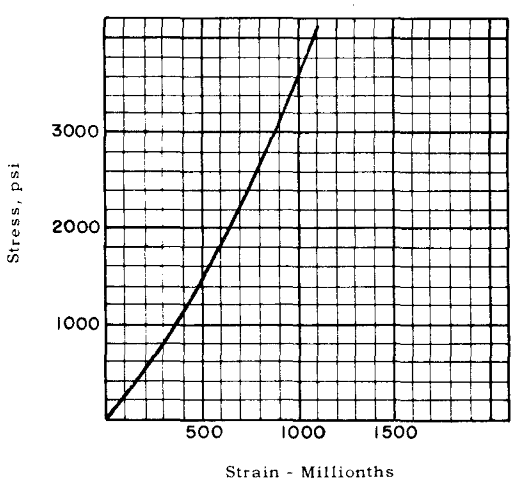
The samples are hard, dense, and fine-grained. The rock is primarily composed of well sorted, fine-grained, subround to round quartz grains well cemented together with silicious materials. Mica, sericite, and amphibole occur in minor amounts. The quartz grain sizes range from 0.17 to 0.2 mm. Hematite occurs as a cloudy dispersion in the cement and infrequently as filling materials in voids, with thin coatings on the grains. The cementing material is mostly secondary quartz with locally varying amounts of hematite; but a considerable amount occurs as a solution contact between grains and as secondary intergrowths of the grains.

The rock is a quartzite.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-1000 | 2.7 | .05 | |
| 0-2000 | 3.0 | .07 | (8) |
| 0-3000 | 3.4 | .08 | |
| 0-4000 | 3.7 | .09 | |




### SPECIFIC GRAVITY / ABSORPTION, %

| Specific gravity avg | Specific gravity range | Absorption, % avg | Absorption, % range | No. spec. |
|---|---|---|---|---|
| 2.55 | 0.13 | 2.1 | 2.0 | (11) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 21500 | 8300 | (10) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 12.5\ S_3 + 18400$ (26)

Equation of Mohr's envelope

$Y = 1.6\ X + 2600$ (26)

### TENSILE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 500 | 480 | (9) |

# QUARTZITE

**Schistose**
**P-4658**

## ROCK DATA SUMMARY

### LOCATION & GEOLOGIC OCCURRENCE

The NX and BX samples are from Kosi damsite, Kosi Project, in Nepal, India. The rock at the site consists of quartzite from the Kosi series, of Carboniferous age (Damuda).

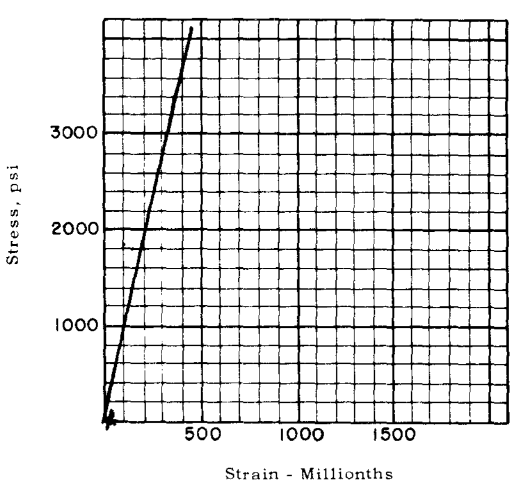
### PETROGRAPHIC DESCRIPTION

The rock is hard, medium to dark gray, medium-grained, dense, and slightly fractured. Samples are composed of elongated subangular and subround grains of quartz with small amounts of plagioclase feldspar and chalcedony in a hard, fine-grained matrix. The matrix of the rock is composed essentially of very fine grains of recrystallized quartz, with moderate amounts of sericite and chlorite. Also present are calcite, hornblende, and chalcedony. Quartz grains in the matrix are from 0.16 to 0.23 mm in diameter.
The rock is a schistose quartzite.

### ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

#### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-2000 | 9.4 | .08 | |
| 0-4000 | 9.0 | .08 | (6) |
| 0-6000 | 8.9 | .08 | |




#### SPECIFIC GRAVITY / ABSORPTION, %

| Specific gravity avg | Specific gravity range | Absorption, % avg | Absorption, % range | No. spec. |
|---|---|---|---|---|
| 2.60 | - | 0.1 | - | (1) |

#### COMPRESSIVE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 31400 | 19000 | (3) |

#### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 5.7\ S_3 + 26300$ (8)

Equation of Mohr's envelope

$Y = 1.0\ X + 5500$ (8)

#### TENSILE STRENGTH, PSI

avg range

—

# SANDSTONE
P-4012

ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

The samples are from Coconino damsite, Coconino Project, Arizona, located on the Little Colorado River, 8 miles downstream from Cameron. The foundation is of Permian age, and includes Coconino formation sandstones and Kaibab limestones. At the abutments the formations appear nearly horizontal and form steep walls.

## PETROGRAPHIC DESCRIPTION

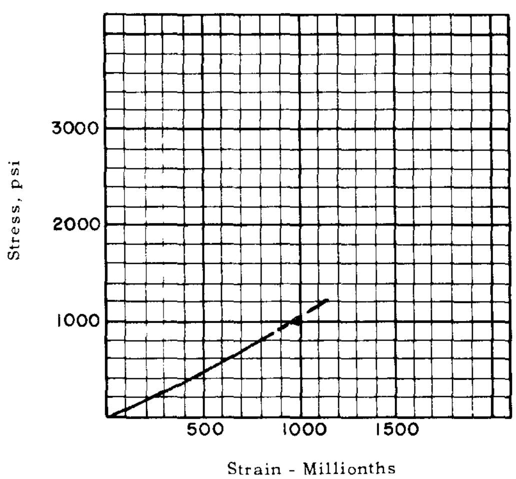
The rock is medium hard, fine-grained, buff colored, moderately porous, sandstone. The rock is composed principally of subround to subangular quartz grains with smaller amounts of plagioclase (oligoclase), chalcedony, biotite, sericite, and hematite. Most of the plagioclase feldspars have a dusty appearance due to moderate alteration. Sericite is found in the interstices surrounding the quartz grains. The grains average about 0.15 mm in size. Small laminae about 0.10 mm in width and varying from 1.5 to 30 mm in length cut across the core axis at an angle of from 10 to 20 degrees.

The rock is a fine-grained sandstone.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-200 | 0.9 | - | |
| 0-400 | 0.9 | - | (2) |
| 0-600 | 1.0 | - | |
| 0-800 | 1.0 | - | |




### SPECIFIC GRAVITY / ABSORPTION,%

| Specific gravity avg | Specific gravity range | Absorption avg | Absorption range | No. spec. |
|---|---|---|---|---|
| 2.35 | 0.08 | 7.5 | 3.1 | (2) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 11400 | 900 | (3) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 + 2.8\ S_3 + 13700$ (16)

Equation of Mohr's envelope

$Y = 0.5\ X + 4600$ (16)

### TENSILE STRENGTH, PSI

| avg | range |
|---|---|
| — | |

# ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

The specimens are BX cores from Palisades damsite on the Snake River in Idaho. Stratified sediments of sandstones, claystones, and siltstones occur at the site. Andesite outcrops in a large body on the left abutment and disappears downward beneath the river.

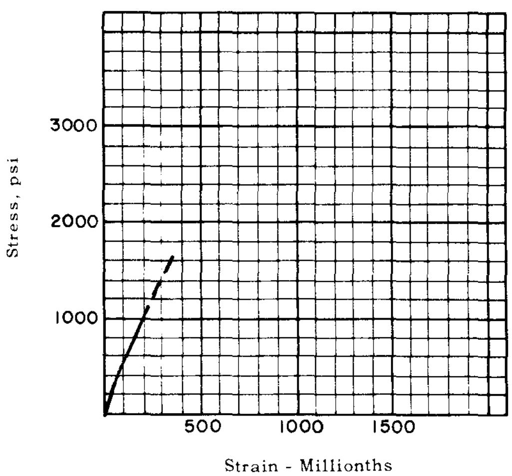
## PETROGRAPHIC DESCRIPTION

The specimens are medium hard, dark gray, massive to banded, and calcareous. Rock specimens are composed of sedimentary rocks including sandstones, siltstones, and claystones, which have been indurated, and some of which have been partially recrystallized and/or fused. Grains of sand are observed in an isotropic or fine-grained matrix consisting of fused and partially recrystallized material. Grain boundaries are smooth and well cemented. Minute prisms of secondarily developed pyroxene are present. Voids are common and may be as large as 3.0 mm in diameter, they are lined or sometimes partially filled with a zeolite. The voids and zeolite and montmorillonite present have lowered the density of the rock.
The rock is a sandstone.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-400 | 5.3 | .24 | |
| 0-600 | 5.1 | .22 | (5) |
| 0-800 | 5.1 | .20 | |
| 0-1000 | 5.1 | .21 | |




### SPECIFIC GRAVITY / ABSORPTION, %

| Specific gravity avg | Specific gravity range | Absorption, % avg | Absorption, % range | No. spec. |
|---|---|---|---|---|
| 1.87 | - | 16.4 | - | (1) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 4600 | 420 | (2) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation
$S_1 = 17.4\ S_3 + 6100$ (8)

Equation of Mohr's envelope
$Y = 2.0\ X + 730$ (8)

### TENSILE STRENGTH, PSI

| avg | range |
|---|---|
| — | |

# ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

The specimens are NX cores from the Dakota formation, Valencia County, New Mexico. In Sec. 6, R 9 W, T 8 N. The cores were taken from varying depths, and the work was a cooperative project with the Colorado School of Mines Research Foundation.

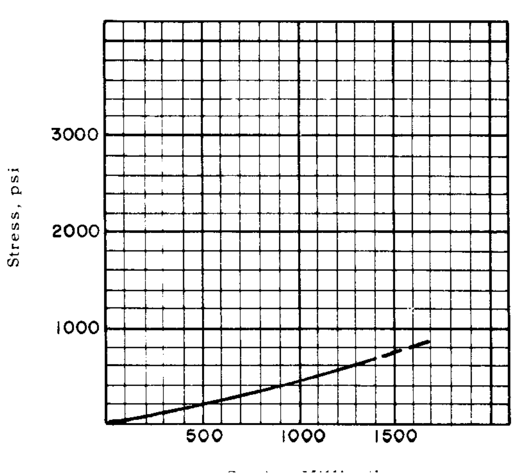
## PETROGRAPHIC DESCRIPTION

The rock is medium hard, white, fine-grained, friable, massive, and quartzose. The samples are porous, and are weathered. The main constituent is quartz, with minor amounts of siltstone, feldspar, chalcedony, and lesser amounts of iron oxide. Silica is the cementing material at points of contact of the grains, which are angular to subround. Feldspar grains are partly altered to sericite and clay. Iron oxide occurs as coatings on the quartz grains. Some quartz grains exhibit enlargement due to silicious growth at the boundaries. The size of the grains ranges from 0.08 to 0.33 mm.
The rock is a fine-grained sandstone.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-300 | 0.44 | .04 | |
| 0-400 | 0.44 | .04 | (3) |
| 0-500 | 0.45 | .05 | |
| 0-600 | 0.46 | .06 | |




### SPECIFIC GRAVITY / ABSORPTION,%

| Specific gravity avg | Specific gravity range | Absorption,% avg | Absorption,% range | No. spec. |
|---|---|---|---|---|
| 2.10 | - | 9.5 | - | (1) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 6700 | 2200 | (3) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 8.2\ S_3 + 7400$ (18)

Equation of Mohr's envelope

$Y = 1.3\ X + 1300$ (18)

### TENSILE STRENGTH, PSI

avg range

# SANDSTONE

**P-6202**

ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

**Samples are from the Glen Canyon damsite on the Colorado River, 15 miles upstream from Lee's Ferry Junction. The sandstone is massive, and is of the Navajo formation, and is of Triassic age.**

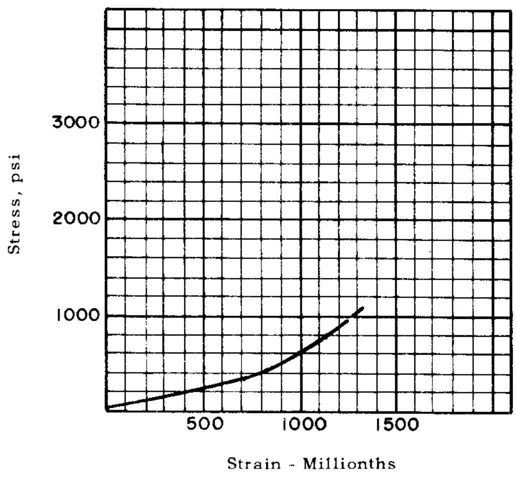
## PETROGRAPHIC DESCRIPTION

**The rock is medium hard, fine- to medium-grained, porous and variably cemented. The samples are primarily composed of subangular to rounded grains of quartz, smaller amounts of microcline, and very minor quantities of hematite and iron oxides, chalcedony, calcite, oligoclase, and sericite. Hematite and other iron oxides occur as coatings on the quartz and feldspar grains, and frequently as filling material in the voids. The average grain size is 0.13 mm and ranges from 0.06 to 0.36 mm in diameter. The grains are poorly to moderately cemented and are in point-to-point contact. The cementing material is primarily secondary quartz, with minor amounts of hematite and chalcedony, and calcite. The rock is a sandstone.**

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-200 | 0.5 | .07 | |
| 0-400 | 0.5 | .10 | (129) |
| 0-600 | 0.6 | .12 | |
| 0-800 | 0.7 | .14 | |




### SPECIFIC GRAVITY / ABSORPTION,%

| Specific gravity avg | Specific gravity range | Absorption, % avg | Absorption, % range | No. spec. |
|---|---|---|---|---|
| 2.02 | 0.30 | 12.0 | 7.4 | (109) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 3550 | 2050 | (100) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$$S_1 = 8.2\ S_3 + 3050 \qquad (150)$$

Equation of Mohr's envelope

$$Y = 1.3\ X + 550 \qquad (150)$$

### TENSILE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 105 | 230 | (32) |

# SANDSTONE
Calcareous
P-4014

ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

**The samples are from Coconino damsite, Coconino Project, Arizona, located on the Little Colorado River, 8 miles downstream from Cameron. The foundation is of Permian age and includes Coconino formation sandstones and Kaibab limestones. At the abutments, the formations appear nearly horizontal and form steep walls.**

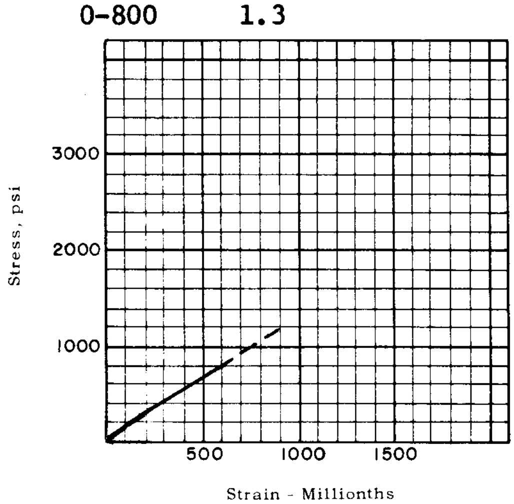
## PETROGRAPHIC DESCRIPTION

**The rock is a hard, light gray, fine-grained, slightly porous sandstone. The greater portion of the sample is composed of quartz and calcite, with smaller amounts of orthoclase, microcline, plagioclase, sericite, biotite, and zircon. The grains average approximately 0.08 mm in diameter. Chemical analysis indicates about 20 percent of the rock is acid soluble (mostly calcite).**
**The rock is a calcareous sandstone.**

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-200 | 1.4 | | |
| 0-400 | 1.3 | — | (2) |
| 0-600 | 1.3 | | |
| 0-800 | 1.3 | | |




### SPECIFIC GRAVITY / ABSORPTION, %

| Specific gravity avg | Specific gravity range | Absorption avg | Absorption range | No. spec. |
|---|---|---|---|---|
| 2.45 | 0.06 | 6.3 | 0.3 | (3) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 10700 | 3600 | (3) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 2.1\ S_3 + 11500$ (10)

Equation of Mohr's envelope

$Y = 0.4\ X + 3900$ (10)

### TENSILE STRENGTH, PSI

| avg | range |
|---|---|
| — | |

ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

The BX samples are from the proposed Bridge Canyon damsite, located on the Colorado River about 2-1/2 miles below Bridge Canyon in Mohave County, Arizona. Foundation rock at the site consists mainly of gneisses, schists, amphibolites, and granites of Precambrian age, and sandstones of the Tapeats formation (Cambrian). Pegmatite dikes cut the abutments at various angles.

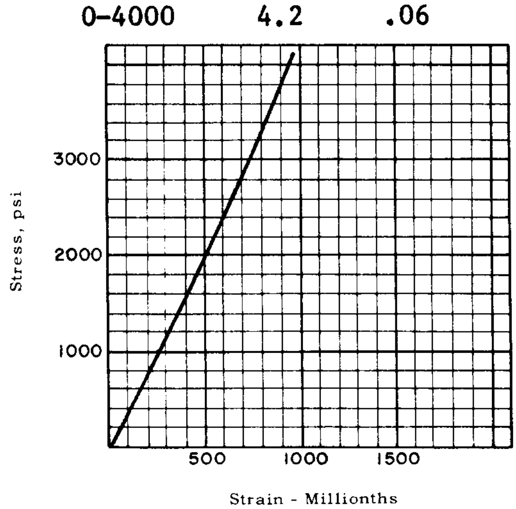
## PETROGRAPHIC DESCRIPTION

The rock is hard, dark red, with a few large white areas, medium-grained, porous, and massive. The samples are composed mainly of subround to subangular quartz grains. Microcline and oligoclase occur in small amounts and are slightly weathered. Apatite occurs in some of the quartz grains as long, prismatic crystals. Some of the grains are in contact with each other, and a thin film of hematite occurs between many of the grains. Very fine-grained quartz appears intermixed with hematite in the matrix. The predominant grain size ranges from 0.23 to 0.46 mm in diameter.
The rock is a ferruginous sandstone.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-1000 | 3.9 | .02 | (2) |
| 0-2000 | 3.8 | .04 | |
| 0-3000 | 4.0 | .04 | |
| 0-4000 | 4.2 | .06 | |




### SPECIFIC GRAVITY / ABSORPTION, %

| Specific gravity avg | Specific gravity range | Absorption, % avg | Absorption, % range | No. spec. |
|---|---|---|---|---|
| 2.39 | 0.27 | 3.0 | 1.4 | (5) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 13100 | 50 | (2) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 10.5\ S_3 + 15200$ (5)

Equation of Mohr's envelope

$Y = 1.5\ X + 2300$ (5)

### TENSILE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 750 | -- | (1) |

# LOCATION & GEOLOGIC OCCURRENCE

The NX rock core samples are from Flaming Gorge damsite, located north of Vernal, Utah, on the Green River, near the Utah-Wyoming border. The geologic occurrence is of the Uinta formation, composed of interbedded quartzites, quartzose sandstones and conglomerates. Beds of shales and siltstone occur intermittently in the abutment.

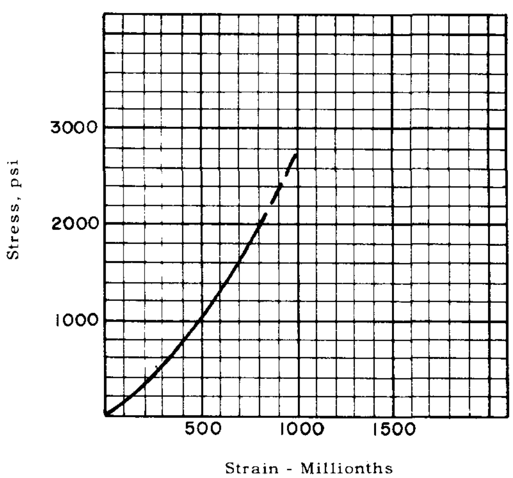
## PETROGRAPHIC DESCRIPTION

The samples are hard, dense, and medium-grained. The rock is primarily composed of well sorted, medium-grained, subround to round quartz grains well cemented with silicious materials. Mica, sericite, and amphibole occur in minor amounts. The quartz grain sizes range from 0.06 to 2.0 mm. Hematite occurs as a cloudy dispersion in the cement and infrequently as filling materials in voids, with thin coatings on the grains. The cementing material is mostly secondary quartz with locally varying amounts of hematite. The rock is similar to the quartzite (P-6318) except that it has slightly less cementing material.
The rock is a quartzitic ferruginous sandstone.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-500 | 1.8 | .03 | |
| 0-1000 | 2.0 | .05 | (25) |
| 0-1500 | 2.3 | .06 | |
| 0-2000 | 2.5 | .08 | |




### SPECIFIC GRAVITY / ABSORPTION, %

| Specific gravity avg | Specific gravity range | Absorption, % avg | Absorption, % range | No. spec. |
|---|---|---|---|---|
| 2.54 | 0.10 | 2.1 | 1.7 | (26) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 16400 | 9200 | (25) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 11.7\ S_3 + 18900$ (86)

Equation of Mohr's envelope

$Y = 1.6\ X + 2800$ (86)

### TENSILE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 470 | 410 | (23) |

# SCHIST

**Hornblende**
**P-5684**

## ROCK DATA SUMMARY

### LOCATION & GEOLOGIC OCCURRENCE

The BX core samples are from Swan Lake damsite, which is located on Falls Creek, 22 miles northeast of Ketchikan, Alaska. The core samples were obtained from Drift No. 1 on the left bank. The site is in a glaciated V-shaped valley bounded mainly by crystalline schists.

### PETROGRAPHIC DESCRIPTION

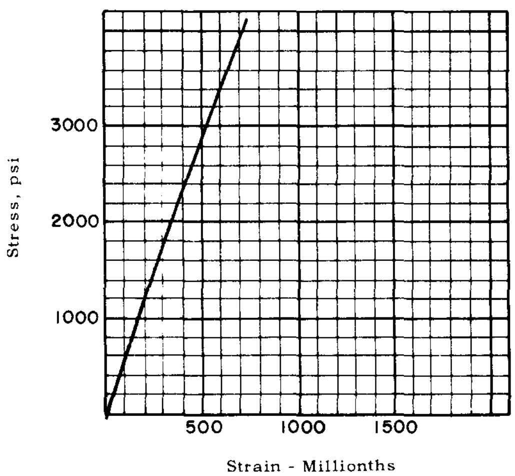
The rock is hard, light to dark gray, medium grained, fractured, and schistose. The samples are composed mainly of anhedral quartz grains, which are moderately well interlocked and present a mosaic fabric. A lesser amount of hornblende crystals and large and small flakes of biotite are embedded within the quartz matrix. The hornblende, and to some extent the biotite crystals, have their long dimensions in the plane of schistosity. Euhedral pyrope crystals 2 to 5 mm in diameter are abundant, and hornblende and biotite surround the pyrope crystals. The quartz grains range from 0.02 to 0.07 mm in size.

The rock is a hornblende garnet biotite schist.

### ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

#### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-1000 | 5.8 | .10 | |
| 0-2000 | 5.6 | .11 | (1) |
| 0-3000 | 5.6 | .12 | |
| 0-4000 | 5.7 | .13 | |




| SPECIFIC GRAVITY avg | SPECIFIC GRAVITY range | ABSORPTION,% avg | ABSORPTION,% range | No. spec. |
|---|---|---|---|---|
| 2.89 | 0.02 | 0.1 | 0.0 | (2) |

#### COMPRESSIVE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 18800 | -- | (1) |

#### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

--

Equation of Mohr's envelope

--

#### TENSILE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 800 | -- | (1) |

# SCHIST
Hornblende
P-5687

## ROCK DATA SUMMARY

### LOCATION & GEOLOGIC OCCURRENCE

The BX core samples are from Swan Lake damsite, which is located on Falls Creek, 22 miles northeast of Ketchikan, Alaska. The core samples were obtained from Drift No. 1 of the left bank. The site is in a glaciated V-shaped valley bounded mainly by crystalline schists.

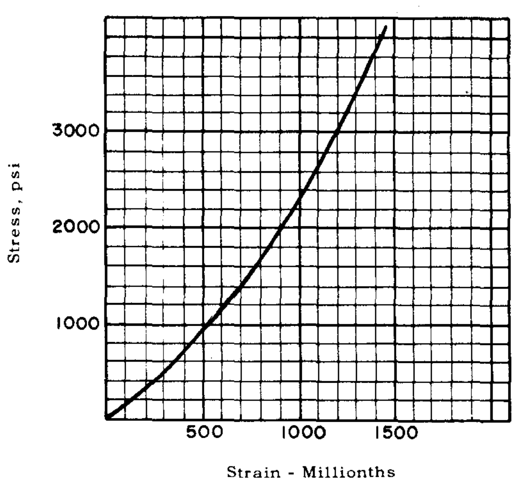
### PETROGRAPHIC DESCRIPTION

The rock is hard, slightly fractured, medium-grained, and schistose. The samples are composed mostly of quartz grains, some of which are slightly elongated in the plane of schistosity. Structurally, the quartz grains are arranged in bands alternating from fine- to medium-grain size. Hornblende crystals and shreds of biotite are embedded in the quartz matrix within the schistosity plane. Garnet, magnetite, and pyrite are present in small amounts. Thin, white stringers of calcite and dolomite parallel the schistosity planes. Anhedral to euhedral calcite crystals occur more abundantly in the coarse-grained laminae. The rock is a hornblende biotite schist.

### ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-1000 | 2.0 | .09 | |
| 0-2000 | 2.2 | .12 | (2) |
| 0-3000 | 2.5 | .15 | |
| 0-4000 | 2.8 | .17 | |




| SPECIFIC GRAVITY avg | SPECIFIC GRAVITY range | ABSORPTION,% avg | ABSORPTION,% range | No. spec. |
|---|---|---|---|---|
| 2.73 | 0.02 | 0.4 | 0.3 | (3) |

COMPRESSIVE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 22800 | - | (1) |

SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 14.8\ S_3 + 24500$ (3)

Equation of Mohr's envelope

$Y = 1.8\ X + 3200$ (3)

TENSILE STRENGTH, PSI

| avg | range |
|---|---|
| — | |

# SHALE
P-5633

ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

These 6-inch-diameter cores are from Marble Canyon damsite, Mile 39.5 on the Colorado River, which is 39.5 miles downstream from Lee's Ferry, Arizona. The rock at the site is of the Mauv formation (Cambrian).

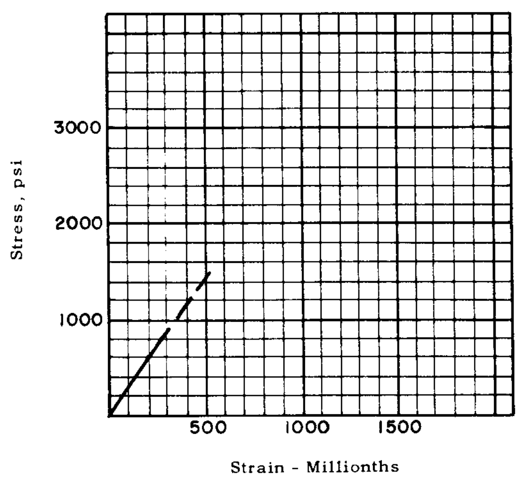
## PETROGRAPHIC DESCRIPTION

The rock is medium hard, greenish gray, fine-grained, and moderately absorptive. Thin sections definitely show the presence of laminated portions which are primarily composed of fine grains of quartz, calcite, dolomite, and illite. Smaller percentages of mica, orthoclase, and carbonaceous matter are present. The grains are angular to platy. The rounded grains vary from point-to-point contact to no contact and are poorly cemented. Upon immersion in water, the rock slakes slightly. It exhibits various degrees of fissility.
The rock is a shale.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES*

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-200 | 3.4 | .09 | |
| 0-400 | 3.2 | .09 | |
| 0-600 | 3.1 | .09 | (5) |
| 0-800 | 3.0 | .09 | |




### SPECIFIC GRAVITY / ABSORPTION,%

| Specific gravity avg | Specific gravity range | Absorption,% avg | Absorption,% range | No. spec. |
|---|---|---|---|---|
| 2.52 | - | 3.05 | - | (1) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 12900 | 5400 | (3) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 6.8\ S_3 + 13400$ (13)

Equation of Mohr's envelope

$Y = 1.1\ X + 2600$ (13)

### TENSILE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 380 | 690 | (3) |

*Tested air dry

# SHALE
P-6316

## ROCK DATA SUMMARY

### LOCATION & GEOLOGIC OCCURRENCE

The NX rock core samples are from Flaming Gorge damsite, located north of Vernal, Utah, on the Green River, near the Utah-Wyoming border. The geologic occurrence is of the Uinta formation, composed of interbedded quartzites, quartzose sandstones, and conglomerates. Beds of shale and siltstone occur intermittently.

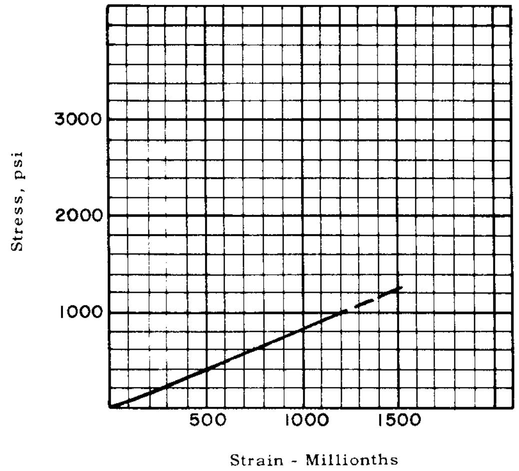
### PETROGRAPHIC DESCRIPTION

The rock is hard, red, dense, moderately absorptive, and slakes upon wetting. The major constituents are quartz with lesser quantities of illite clay, fine mica, and hematite. A laminated structure is caused by streaks of hematite and mica alined in the bedding plane. The material exhibits distinct lamination and bedding. The rock is moderately thistled and cleaves along horizontal planes. Microscopic examination indicates the rock does contain fine- to medium-grained, angular to subrounded quartz and a very fine-grained matrix. The angular grains range from no contact to point-to-point contact and are generally well cemented with silica.
The rock is a sandy, silty shale.

### ENGINEERING PROPERTIES OF ROCK CORE SAMPLES *

STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0 - 400 | 0.79 | .24 | |
| 0 - 600 | 0.80 | .24 | (4) |
| 0 - 800 | 0.80 | .26 | |
| 0 - 1000 | 0.80 | .26 | |




SPECIFIC GRAVITY / ABSORPTION,%

| Specific gravity avg | Specific gravity range | Absorption avg | Absorption range | No. spec. |
|---|---|---|---|---|
| 2.46 | 0.22 | 4.8 | 3.6 | (6) |

COMPRESSIVE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 5100 | 3400 | (5) |

SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

--

Equation of Mohr's envelope

--

TENSILE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 30 | 35 | (2) |

*Tested air dry

SILTSTONE
P-5644

# ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

The NX rock cores are from left abutment spillway site, Sanford Damsite, Canadian River Project, Texas. Geologically, the site is within a subsidence basin in which the Alibates dolomite beds are downwarped. Overlying beds of silty shale and sandstone of the Quartermaster formation have been preserved within the basin.

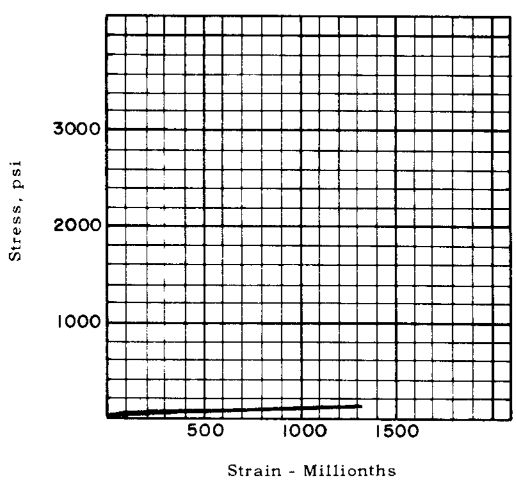
## PETROGRAPHIC DESCRIPTION

The rock is firm to moderately hard, slightly friable, predominantly red-brown, and highly porous. The major portion of the rock samples is composed of subangular to subround, silt-sized quartz particles. These are often arranged in crude laminations embedded in a mixture of exceedingly fine-grained iron oxide compound, with vermiculite and montmorillonite. When wet, the rock slakes slightly. Magnetites present have been altered to iron oxides, including hematite and limonite. The silt particles, such as quartz and feldspar, average 0.05 mm in diameter.
The rock is classed as porous siltstone.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES *

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-50 | 0.11 | .27 | |
| 0-75 | 0.11 | .27 | (3) |
| 0-100 | 0.10 | .28 | |
| 0-125 | 0.10 | .27 | |




### SPECIFIC GRAVITY / ABSORPTION,%

| Specific gravity avg | Specific gravity range | Absorption,% avg | Absorption,% range | No. spec. |
|---|---|---|---|---|
| 2.17 | - | 8.8 | - | (1) |

### COMPRESSIVE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 690 | 100 | (3) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 5.8\ S_3 + 620$ (8)

Equation of Mohr's envelope

$Y = 1.0\ X + 130$ (8)

### TENSILE STRENGTH, PSI

avg range

—

*Tested air dry

SUBGRAYWACKE

# ROCK DATA SUMMARY

Calcareous
P-5668

## LOCATION & GEOLOGIC OCCURRENCE

The samples are from Bhakra damsite, the Bhakra Project, East Punjab, India. The formation includes sediments from the middle Miocene-Dagdsha series.

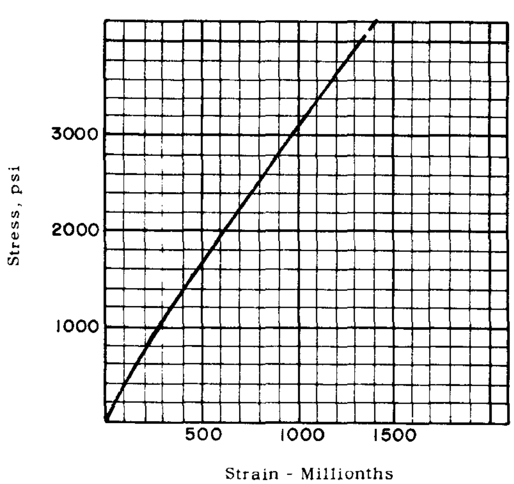
## PETROGRAPHIC DESCRIPTION

The rock is hard, medium gray, medium-grained, dense, and contains shale fragments up to 8 mm in length. The samples are composed primarily of subangular to subround particles of shale, chert, mica, schist, basalt, quartz, with orthoclase, microcline, and plagioclase. In minor amounts calcite, muscovite, biotite, and chlorite are present. The grains are well interlocked and the matrix is visible between grains. The matrix is composed of fine-grained quartz, chlorite, and sericite. The quartz fragments are more abundant than the feldspars, and of course, rock fragments are quite common. Calcite is present in moderate amounts between grains. Most of the grains range from 0.16 to 0.33 mm in diameter.
The rock is a calcareous subgraywacke.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-1000 | 3.5 | .02 | |
| 0-2000 | 3.1 | .03 | (2) |
| 0-3000 | 3.1 | .06 | |
| 0-4000 | 3.0 | .09 | |




| SPECIFIC GRAVITY avg | SPECIFIC GRAVITY range | ABSORPTION,% avg | ABSORPTION,% range | No. spec. |
|---|---|---|---|---|
| 2.67 | 0.02 | 0.8 | 0.5 | (5) |

COMPRESSIVE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 13200 | 3900 | (2) |

SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 8.8\ S_3 + 13300$ (7)

Equation of Mohr's envelope

Y = 1.3 X + 2200 (7)

TENSILE STRENGTH, PSI

| avg | range | |
|---|---|---|
| 700 | 250 | (2) |

ROCK DATA SUMMARY

## LOCATION & GEOLOGIC OCCURRENCE

The rock source is McDowell damsite which is northeast of Phoenix, Arizona, on the Salt River, just below the Verde River. The foundation includes Precambrian granites, and four sedimentary series. These generally consist of a red conglomerate phase, basalt, rhyolite tuff, and gray-brown conglomerate phases.

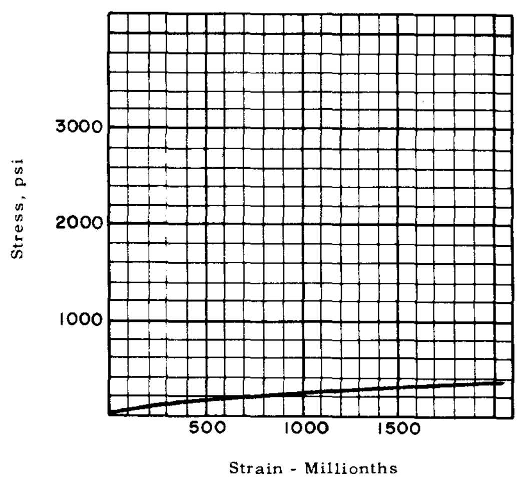
## PETROGRAPHIC DESCRIPTION

The samples are moderately hard, reddish-brown, fine-grained, and laminated. The rock is composed of euhedral quartz, and feldspar crystals altered to montmorillonite and fragments of granite gneiss, microperthite, plagioclase, and rhyolite. These are all embedded in a fine-grained matrix of montmorillonite and silt-size particles of the above minerals. Angular fragments of granite gneiss with other minerals approximately 1 by 2 mm in size, are present. The feldspar phenocrysts have been altered to montmorillonite, and indicate shrinkage between the crystals and the groundmass in which they are embedded. The rock is an altered lithic tuff.

## ENGINEERING PROPERTIES OF ROCK CORE SAMPLES

### STATIC MODULUS OF ELASTICITY

| stress range psi | Secant E $10^6$ psi | $\mu$ | No. spec. |
|---|---|---|---|
| 0-100 | 0.27 | - | |
| 0-200 | 0.21 | - | (3) |
| 0-300 | 0.17 | - | |
| 0-400 | 0.16 | - | |




### SPECIFIC GRAVITY / ABSORPTION,%

| Specific gravity avg | Specific gravity range | Absorption avg | Absorption range | No. spec. |
|---|---|---|---|---|
| — | | — | | |

### COMPRESSIVE STRENGTH, PSI

| avg | range | No. spec. |
|---|---|---|
| 2300 | 1200 | (6) |

### SHEAR STRENGTH, TRIAXIAL, PSI

Principal stress relation

$S_1 = 9.3\ S_3 + 2400$ (9)

Equation of Mohr's envelope

$Y = 1.4\ X + 400$ (9)

### TENSILE STRENGTH, PSI

| avg | range |
|---|---|
| — | |

# APPENDIX

# A MINERALOGIC AND TEXTURAL CLASSIFICATION OF IGNEOUS ROCKS

Modified after J F Kemp and G D Louderback

Compiled by R C Mielenz

| Soda-lime or plagioclase feldspars: Mineral name | Composition: Albite Molecule | Composition: Anorthite Molecule |
|---|---|---|
| Albite | 100 to 90 % | 0 to 10 % |
| Oligoclase | 90 to 70 % | 10 to 30 % |
| Andesine | 70 to 50 % | 30 to 50 % |
| Labradorite | 50 to 30 % | 50 to 70 % |
| Bytownite | 30 to 10 % | 70 to 90 % |
| Anorthite | 10 to 0 % | 90 to 100 % |

Increasing depth of solidification within crust of the earth

The depth at which the intrusives lie influences the rate of cooling and hence of crystallization of igneous masses, greater depths allowing decreased rates of cooling, and hence more coarsely crystalline textures. Textures of the acidic igneous rocks reflect the depth of solidification quite strongly. But the textures of basic and ultrabasic rocks are not so strongly controlled by the rates of cooling, so that plutonic rocks are commonly not distinguishable in terms of texture from hypabyssal types, and hypabyssal rocks may have the same textures as volcanics.

**ESSENTIAL MINERALS** (Minerals essential to classification of rock)

**FELDSPARS** Alkali feldspars include: orthoclase, microcline, albite, anorthoclase, perthite, sanidine (in volcanics). Soda-lime feldspars (plagioclase) are an isomorphous series of minerals $NaAlSi_3O_8$ to $CaAl_2Si_2O_8$

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **CHIEF FELDSPARS IN ROCK** | **ALKALI FELDSPARS PREDOMINATE** | | | **ALKALI AND SODA-LIME FELDSPARS ABOUT EQUAL** | | **SODA-LIME FELDSPARS PREDOMINATE** | | | | | **FELDSPARS ABSENT** (Or nearly so) | | |
| | | Ratio of alkali to soda-lime feldspars | 100/0 to 67/33 If soda-lime feldspars comprise <5% prefix "alkali" used | | Not critical | 67/33 to 33/67 | | 13/87 to 0/100 | | Potash feldspars are rare; but albite is not uncommon in altered basalts, eg spilite | | Small proportions of potash feldspar | Some alkali feldspar may occur | | |
| | | Soda-lime feldspars in normal rock | OLIGOCLASE TO ANDESINE (WHERE ALBITE IS PRESENT, PREFIX "ALKALI" IS USED) | | ALBITE | OLIGOCLASE TO ANDESINE | | OLIGOCLASE AND ANDESINE | | LABRADORITE, BYTOWNITE AND ANORTHITE | | ANDESINE TO BYTOWNITE | SOME SODA-LIME FELDSPAR MAY BE PRESENT | SOME SODA-LIME FELDSPAR MAY CONSTITUTE UP TO 10% OF ROCK. LABRADORITE TO ANORTHITE | |
| | | Other minerals whose presence is necessary or whose virtual absence is characteristic. +Signifies presence in significant amounts. -Signifies virtual absence | + QUARTZ (>5%) | - QUARTZ (or <5%) | NEPHELINE or LEUCITE (-QUARTZ) | + QUARTZ (>5%) | - QUARTZ (or <5%) | + QUARTZ (>5%) | - QUARTZ (or <5%) | - OLIVINE | + OLIVINE | + LEUCITE or + NEPHELINE | + NEPHELINE or + LEUCITE or + ANALCITE | -NEPHELINE -LEUCITE -OLIVINE +PYROXENE or +HORNBLENDE | - NEPHELINE -LEUCITE + OLIVINE +PYROXENE |
| | | **CHARACTERIZING ACCESSORIES** One or more characterizing accessories may be present. If present in significant proportions, mineral is included in rock name | BIOTITE HORNBLENDE Diopside (Alkali pyroxenes and amphiboles characterize "alkali" types) | | ALKALI PYROXENE or AMPHIBOLE, MICA Sodalite, Cancrinite | BIOTITE HORNBLENDE Diopside Hypersthene | | BIOTITE HORNBLENDE DIOPSIDE AUGITE HYPERSTHENE | | PYROXENE Hornblende | | AUGITE, ALKALI PYROXENES and AMPHIBOLES | PYROXENES AMPHIBOLES MICAS OLIVINE | MICA | HORNBLENDE MICA |
| | | Percentages of $SiO_2$ in normal types | 77% to 65% | 68% to 55% | 60% to 50% | 75% to 65% | 65% to 50% | 70% to 62% | 65% to 50% | 60% to 50% | 55% to 45% | 50% to 40% | 50% to 40% | 55% to 43% | 45% to 30% |
| | | Frequency of occurrence of granitic types and lavas | Very common | Common | Rare | Common | Common | Very common | Very common | Very common | Very common | Very rare | Very rare | Rare | Uncommon |
| | **TYPICAL MODES OF OCCURRENCE** | **TYPICAL TEXTURES** | | | | | | | | | | | | | |
| VOLCANIC | Uniform or irregular beds, deposits, or accumulations of volcanic ejectamenta | Fragmental, coarse blocks, or fine ash, cemented or loose, stratified or massive | RHYOLITE ASH, BRECCIA, TUFF, OR AGGLOMERATE | TRACHYTE ASH, BRECCIA, TUFF, OR AGGLOMERATE | PHONOLITE OR LEUCITE PHONOLITE, ASH, BRECCIA, TUFF, AGGLOMERATE | QUARTZ LATITE (DELLENITE) ASH, BRECCIA, TUFF, OR AGGLOMERATE | LATITE (TRACHYANDESITE) ASH, BRECCIA, TUFF, OR AGGLOMERATE | DACITE ASH, BRECCIA, TUFF, OR AGGLOMERATE | ANDESITE ASH, BRECCIA, TUFF, OR AGGLOMERATE | BASALT ASH, BRECCIA, TUFF, OR AGGLOMERATE | OLIVINE BASALT, ASH, BRECCIA, TUFF, OR AGGLOMERATE | TEPHRITE OR BASANITE ASH, BRECCIA, TUFF, OR AGGLOMERATE | | | |
| VOLCANIC | Surface flows; shallow, small intrusives. | Glassy (vitreous or hyaline) crystals absent or nearly so (Identified chemically or by optical properties) | ACIDIC GLASSES AND RARE PHONOLITIC GLASSES: OBSIDIAN — PERLITE — PUMICE — PITCHSTONE | | | | | INTERMEDIATE GLASSES: OBSIDIAN - PUMICE - SCORIA | | BASIC GLASSES: SCORIA, VARIOLITE, TACHYLITE | | | ULTRA BASIC GLASSES | | |
| VOLCANIC | Surface flows, shallow dikes, sills, sheets, marginal zones of hypabyssal intrusives | Porphyritic with aphanitic (felsitic), microcrystalline, or glassy groundmass. Phenocrysts may be sparse or absent (Diabases have diabasic texture) | RHYOLITE | TRACHYTE | PHONOLITE LEUCITE PHONOLITE<br>FELSITE | QUARTZ LATITE (DELLENITE) | LATITE (TRACHYANDESITE) | DACITE | ANDESITE | BASALT If diabasic texture DIABASE | OLIVINE BASALT OLIVINE DIABASE | -Olivine TEPHRITE +Olivine BASANITE | -Olivine NEPHELINITE LEUCITITE +Olivine NEPHELINE BASALT LEUCITE BASALT | AUGITITE | LIMBURGITE +Basic soda-lime feldspar PICRITE PICRITE BASALT +Melilite MELILITE BASALT |
| HYPABYSSAL | Hypabyssal and shallow dikes, sills, laccoliths, interiors of thick surface flows | Porphyritic with abundant phenocrysts held in dense aphanitic, microcrystalline or partly glassy groundmass. Diabases are rarely porphyritic | RHYOLITE PORPHYRY GRANOPHYRE (QUARTZ PORPHYRY) | TRACHYTE PORPHYRY | PHONOLITE PORPHYRY or LEUCITE PHONOLITE PORPHYRY | QUARTZ LATITE PORPHYRY (DELLENITE PORPHYRY) | LATITE PORPHYRY (TRACHYANDESITE PORPHYRY) | DACITE PORPHYRY | ANDESITE PORPHYRY | DIABASE (Rarely porphyritic)<br>DOLERITE | OLIVINE DIABASE | THERALITE ESSEXITE | | | |
| HYPABYSSAL | Deep-seated dikes and laccoliths as well as border zones of larger intrusive masses. Composition same as that of related granitic rock | Porphyritic; phenocrysts constitute over 50% of rock. Groundmass aphanitic or fine-grained. Granophyres may have graphic intergrowth of groundmass quartz and feldspar | GRANITE PORPHYRY GRANOPHYRE | SYENITE PORPHYRY | NEPHELINE SYENITE PORPHYRY or LEUCITE SYENITE PORPHYRY | QUARTZ MONZONITE PORPHYRY (ADAMELLITE PORPHYRY) | MONZONITE PORPHYRY | QUARTZ DIORITE PORPHYRY (TONALITE PORPHYRY) | DIORITE PORPHYRY | DIABASE (Rarely porphyritic)<br>DOLERITE | OLIVINE DIABASE | THERALITE ESSEXITE | -Olivine IJOLITE +Olivine MISSOURITE<br>Rarely porphyritic | PYROXENITE HORNBLENDITE | PERIDOTITE +Basic soda-lime feldspar PICRITE DUNITE |
| HYPABYSSAL | Deep-seated dikes, in part hypabyssal (esp lamprophyres). Acidic and basic differentiates (segregations) from parent magma | Fine-grained, rarely porphyritic. Dark colored minerals less abundant than in related granitic rock. APLITES (Acidic segregations) | APLITE | SYENITE APLITE BOSTONITE | NEPHELINE SYENITE APLITE | QUARTZ MONZONITE APLITE (ADAMELLITE APLITE) | MONZONITE APLITE | MALCHITE | DIORITE APLITE | GABBRO APLITE NORITE APLITE<br>BEERBACHITE | OLIVINE GABBRO APLITE | | | | |
| PLUTONIC | Mainly associated with granites, syenites, monzonites and diorites. | Fine-grained equigranular or porphyritic. May contain some glass. Dark colored minerals abundant. LAMPROPHYRES (Basic segregations) | | MINETTE VOGESITE | | | | QUARTZ KERSANTITE SPESSARTITE | KERSANTITE SPESSARTITE CAMPTONITE | KERSANTITE SPESSARTITE ODINITE | OLIVINE KERSANTITE OLIVINE SPESSARTITE | | -Olivine FOURCHITE +Olivine MONCHIQUITE | | + Melilite ALNOITE |
| PLUTONIC | Deep-seated dikes and irregular masses of all sizes, related to large intrusive bodies, where concentrations of gases and vapors were present during solidification | Very coarse-grained, including spectacular occurrences of giant crystals. Rapid changes in granularity. Rare elements and minerals may be present. | GRANITE PEGMATITE | SYENITE PEGMATITE | NEPHELINE SYENITE PEGMATITE | QUARTZ MONZONITE PEGMATITE (ADAMELLITE PEGMATITE) | MONZONITE PEGMATITE | QUARTZ DIORITE PEGMATITE (TONALITE PEGMATITE) | DIORITE PEGMATITE | GABBRO PEGMATITE NORITE PEGMATITE | OLIVINE GABBRO PEGMATITE | | | | |
| PLUTONIC | Large deep-seated intrusives, such as: batholiths, stocks, laccoliths, and dikes | Fine to coarse-grained, granitic textures. Commonly massive, but some original banding or gneissosity may be present. | GRANITE | SYENITE | NEPHELINE SYENITE (FOYAITE) or SODALITE SYENITE (No plutonic leucite syenite has been found) | QUARTZ MONZONITE (ADAMELLITE) | MONZONITE | + QUARTZ GRANODIORITE (Alkali to soda-lime feldspars: 33/67 to 13/87)<br>QUARTZ DIORITE (TONALITE) | DIORITE | +Augite or Diallage GABBRO +Hypersthene or Enstatite NORITE -Pyroxene ANORTHOSITE | +Augite or Diallage OLIVINE GABBRO +Hypersthene or Enstatite OLIVINE NORITE -Pyroxene TROCTOLITE | THERALITE ESSEXITE | -Olivine IJOLITE +Olivine MISSOURITE | PYROXENITE HORNBLENDITE | PERIDOTITE DUNITE |

← GENERAL INCREASE OF CHEMICAL CONTENT OF $SiO_2$ — GENERAL INCREASINGLY DARK COLOR →

NOTE: The distribution of rocks in the horizontal direction is controlled in this classification by the proportions and kinds of feldspars which may be present. The series granite-syenite-monzonite-granodiorite-diorite-gabbro is characterized by progressively decreasing proportions of alkali feldspars and concomitantly increasing proportions of soda-lime feldspars, which simultaneously become less sodic and more calcic in their isomorphous series. The feldspars are essentially absent from the ultrabasic rocks, classified in the last two columns. These mineralogical changes are characteristically accompanied by increases in the proportions of dark colored minerals. The mineralogic changes are caused by differing chemical composition, so that from left to right in the granite-gabbro series and into the ultrabasic rocks the proportions of silica decrease and the proportions of MgO and, to some extent, of CaO increase. Rocks related in composition to granites, syenites, quartz monzonites, and granodiorites are called "acid" igneous rocks; diorites and chemically related rocks are considered "intermediate". "Basic" igneous rocks include gabbros and family. Feldspar- and feldspathoid-free rocks are called "ultrabasic." Because of normally high contents of $Na_2O$ and/or $K_2O$, rocks containing the feldspathoids (eg nepheline and leucite) are designated as "alkaline" types.



Table 1

## Table 2

**A MINERALOGIC AND TEXTURAL CLASSIFICATION OF SEDIMENTARY ROCKS**

Prepared by R. C. Mielenz

| Texture | Essential constituent | Definitive characteristic | Petrographic type |
|---|---|---|---|
| Clastic (composed predominantly of rock and mineral grains derived by weathering and erosion, and deposited by water, wind, ice, or gravity; showing varying degrees of cementation or consolidation) | Volcanic ejecta | Fragments > 32 mm | Agglomerate or breccia |
| | | Particles > 4 mm < 32 mm | Lapilli tuff |
| | | Particles < 4 mm | Tuff |
| | Gravel | Abraded particles > 4 mm over 50 percent, clay < 25 percent | Conglomerate |
| | Rock and mineral fragments | Angular particles > 4 mm over 50 percent, clay < 25 percent | Breccia |
| | Rock fragments and clay | Fragments are greatly varied, occasionally exhibit faceting, high range of sizes usually unsorted; matrix usually clay, sometimes sand, usually greatly in excess of fragments — Loose | Till |
| | | Compact | Tillite |
| | Sand | Particles < 4 mm > 1/16 mm over 50 percent, clay < 25 percent | Sandstone, quartzite, arkose, graywacke, subgraywacke |
| | Detrital grains of calcite | Calcite more than 50 percent, clay < 25 percent | Limestone |
| | Silt | Particles < 1/16 mm over 50 percent, clay < 25 percent; massive to stratified | Siltstone |
| | | Predominant particles < 1/16 mm, fissile | Shale |
| | | Predominant particles < 1/16 mm, open structure | Loess |
| | Clay minerals | Clay more than 25 percent, massive to stratified | Claystone |
| | | Predominantly clay or silt, fissile | Shale |
| | | Predominantly clays and sericite, incipient recrystallization | Argillite |
| | | Montmorillonite clays more than 75 percent | Bentonite |
| | | Kaolinite clays more than 75 percent | Kaolin |
| | Clay and calcite | Very fine grained; carbonates 25 to 75 percent | Marl, marlstone |
| Crystalline (composed predominantly of coarse to fine or microcrystalline to cryptocrystalline aggregates of crystals precipitated chemically or biochemically from surface or subsurface waters) | Calcite | Carbonate > 50 percent of which calcite is more than 50 percent — Coarse to microcrystalline, compact | Limestone |
| | | Fine to microcrystalline, porous, firm to friable | Chalk |
| | | Spongy, porous, firm to friable, fine to microcrystalline | Tufa |
| | | Compact to porous, banded, fine to microcrystalline | Travertine |
| | Calcite and clay | Very fine-grained; calcite 25 to 75 percent | Marl, marlstone |
| | Carbonates | Carbonates more than 25 percent, compact to earthy; deposited by ground water | Caliche |
| | Dolomite | Carbonate > 50 percent of which dolomite > 50 percent; coarse to fine, compact | Dolomite |
| | Chalcedony | Chalcedony > 25 percent, microcrystalline to cryptocrystalline; conchoidal fracture, compact | Chalcedonic chert |
| | Cryptocrystalline quartz | Cryptocrystalline quartz, > 50 percent | Novaculite |
| | Chalcedony | Chalcedony > 25 percent; friable to firm; earthy to porous | Tripoli |
| | Crystalline phosphates | Crystalline phosphates > 50 percent | Phosphorite |
| | Anhydrite | Anhydrite > 50 percent | Rock anhydrite |
| | Gypsum | Gypsum > 50 percent | Rock gypsum |
| | Halite | Halite > 50 percent | Rock salt |
| | Hematite | Hematite > 50 percent | Hematite rock |
| | Crystalline hydrous aluminum oxides | Hydrous aluminum oxides > 50 percent of which > 50 percent are crystalline | Bauxite |
| Amorphous (composed predominantly of noncrystalline substances precipitated or produced by chemical or biochemical action in surface or ground water or within sediments by geologic processes) | Opal | Opal > 50 percent; massive to banded; compact | Opal, opaline chert |
| | | Opal > 50 percent; porous, massive to laminated | Siliceous sinter |
| | | Deposited by geysers | Geyserite |
| | Collophane | Accumulated bird excrement | Guano |
| | | Amorphous phosphates > 50 percent | Phosphorite |
| | Limonite | Limonite > 50 percent | Limonite, bog iron ore |
| | Amorphous hydrous aluminum oxides | Hydrous aluminum oxides > 50 percent, of which > 50 percent are amorphous | Bauxite |
| | Hydrocarbons | Solid | Asphalt, mineral tar, gilsonite, grahamite |
| | Amorphous carbon | Fibrous to spongy to compact; carbonized plant remains < 50 percent; black to brown | Coal (see below) |
| | Oxygenated hydrocarbons | Resinous, various light colors | Amber |
| Biofragmental (composed of whole or fragmental remains of plants or animals) | Calcareous shells and fragments | Whole or fragmental shells > 50 percent | Coquina |
| | Diatom tests | Diatom tests > 50 percent | Diatomite, diatomaceous earth |
| | Radiolarian tests | Radiolarian tests > 50 percent | Radiolarite, radiolarian earth |
| | Foraminifera tests | Foraminifera tests > 50 percent | Foraminiferal limestone |
| | Algal structures | Algal structures > 50 percent | Algal limestone |
| | Coral structures | Coral structures > 50 percent | Coral limestone |
| | Phosphatic shells teeth, bones | Phosphatic fossils > 50 percent | Phosphorite |
| | Partially or completely carbonized plant remains | Brown to black, spongy to compact, plant remains readily visible | Peat |
| | | Brown to black, fibrous to compact, slakes readily | Lignite |
| | | Black, massive to banded, compact, slakes slowly | Bituminous coal |
| | | Black, massive to banded, submetallic, conchoidal fracture | Anthracite coal |

## A MINERALOGIC AND TEXTURAL CLASSIFICATION OF METAMORPHIC ROCKS

Prepared by R. C. Mielenz

| Structure | Essential constituent | | Definitive characteristic | Petrographic type |
|---|---|---|---|---|
| Cataclastic (composed of crushed, sheared, broken, and strained, angular fragments of rocks and minerals, usually with some recrystallization) | Crushed, sheared, and granulated fragments of rocks and minerals | | Angular particles $>$ 4 mm over 50 percent, in granulated or recrystallized matrix | Breccia |
| | | | Fractured and sheared, with partial recrystallization and development of new minerals, but original texture, structure and mineralogy largely preserved | Original rock name with prefix "meta" as metasandstone, metarhyolite, metatuff, etc. |
| | | | Fragments of original rock sheared into lenses and streaks surrounded by finely granulated and recrystallized material: Planar structure poorly developed | Original rock name with prefix "flaser" as flaser-granite, flaser-conglomerate, etc. |
| | | | Planar structure well developed | Flaser-gneiss<br>Augen-gneiss |
| | | | Fragments of original rock pulverized to microscopical or submicroscopical dimensions, or locally fused; partially recrystallized; massive to laminated | Mylonite |
| | | | Fissile; cryptocrystalline to microcrystalline; partially recrystallized; closely spaced, well developed fractures cut across bedding | Slate |
| Foliated (marked lamellar, plicated, or planar structure developed by tabular or prismatic minerals in parallel orientation; completely or largely recrystallized) | Tabular and/or prismatic minerals | | Microcrystalline to fine grained | Phyllite |
| | | | Fine to coarse grained | Schist |
| | Antigorite | | Fine to coarse grained; antigorite $>$ 50 percent | Serpentine, serpentinite |
| Banded (composed of alternating foliated and granular lenses, the latter being conspicuous or dominant; completely recrystallized) | Tabular or prismatic and granular minerals abundant | | Fine to coarse grained | Gneiss |
| Granular (composed predominantly of equidimensional grains, largely or completely recrystallized) | Calcite | Coarse to fine grained | Total carbonates $>$ 90 percent, of which calcite $>$ 50 percent | Marble |
| | Dolomite | Coarse to fine grained | Total carbonates $>$ 90 percent, of which dolomite $>$ 50 percent | Dolomite marble |
| | Calcic and magnesian silicates | Coarse to fine grained | Calcite and/or dolomite usually abundant, calcic and magnesian silicates conspicuous or predominant | Calc-silcate rock<br>Calc-silicate hornfels<br>Calc-flinta |
| | Quartz | Coarse to fine grained | Quartz $>$ 90 percent | Quartzite |
| | Tabular and prismatic minerals predominant | Coarse to fine grained | Decussate texture, normally tabular and prismatic minerals abundant and almost equidimensional | Hornfels |
| | Granular minerals | Coarse to fine grained | Equidimensional minerals predominant; normally tabular and prismatic minerals inconspicuous | Granulite |
| | Amphibole | Coarse to fine grained | Amphibole conspicuous or predominant | Amphibolite |
| | Tabular and prismatic minerals predominant | Micro- to cryptocrystalline | Decussate texture, normally tabular and prismatic minerals abundant and almost equidimensional | Hornfels |
| | Granular minerals | Micro- to cryptocrystalline | Equidimensional minerals predominant, normally tabular and prismatic minerals inconspicuous | Granulite |
| | Quartz and/or chalcedony and iron oxides | Micro- to cryptocrystalline | Banded, with alternating layers of quartz and chalcedony and of iron oxides | Jaspilite |
| | Quartz | Micro- to cryptocrystalline | Banded to massive, micro- to cryptocrystalline quartz predominant | Novaculite |
| | Micaceous minerals | Micro- to cryptocrystalline | Banded, laminated, or massive, mixed granular and micaceous minerals without conspicuous foliation; incomplete recrystallization | Argillite |
| Felted (composed predominantly of tabular or prismatic minerals, in random, decussate, or subradiate arrangement, without foliation, completely or largely recrystallized) | Tabular and/or prismatic minerals | | Decussate texture, tabular minerals thick and prismatic minerals stumpy | Hornfels |
| | | | Random or subradiate arrangement; amphibole conspicuous or predominant | Amphibolite |
| | | | Random or subradiate arrangement; antigorite predominant | Serpentine, serpentinite |
| | | | Random or subradiate arrangement; one, two, or three minerals predominant | Use mineral names as prefix, as cummingtonite-garnet rock |

Interior - Reclamation - Denver, Colo.

# CONVERSION FACTORS–BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, E 380-68) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given in the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg, that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values.

Table I

QUANTITIES AND UNITS OF SPACE

| Multiply | By | To obtain |
|---|---|---|
| | LENGTH | |
| Mil | 25.4 (exactly) | Micron |
| Inches | 25.4 (exactly) | Millimeters |
| Inches | 2.54 (exactly)* | Centimeters |
| Feet | 30.48 (exactly) | Centimeters |
| Feet | 0.3048 (exactly)* | Meters |
| Feet | 0.0003048 (exactly)* | Kilometers |
| Yards | 0.9144 (exactly) | Meters |
| Miles (statute) | 1,609.344 (exactly)* | Meters |
| Miles | 1.609344 (exactly) | Kilometers |
| | AREA | |
| Square inches | 6.4516 (exactly) | Square centimeters |
| Square feet | *929.03 | Square centimeters |
| Square feet | 0.092903 | Square meters |
| Square yards | 0.836127 | Square meters |
| Acres | *0.40469 | Hectares |
| Acres | *4,046.9 | Square meters |
| Acres | *0.0040469 | Square kilometers |
| Square miles | 2.58999 | Square kilometers |
| | VOLUME | |
| Cubic inches | 16.3871 | Cubic centimeters |
| Cubic feet | 0.0283168 | Cubic meters |
| Cubic yards | 0.764555 | Cubic meters |
| | CAPACITY | |
| Fluid ounces (U.S.) | 29.5737 | Cubic centimeters |
| Fluid ounces (U.S.) | 29.5729 | Milliliters |
| Liquid pints (U.S.) | 0.473179 | Cubic decimeters |
| Liquid pints (U.S.) | 0.473166 | Liters |
| Quarts (U.S.) | *946.358 | Cubic centimeters |
| Quarts (U.S.) | *0.946331 | Liters |
| Gallons (U.S.) | *3,785.43 | Cubic centimeters |
| Gallons (U.S.) | 3.78543 | Cubic decimeters |
| Gallons (U.S.) | 3.78533 | Liters |
| Gallons (U.S.) | *0.00378543 | Cubic meters |
| Gallons (U.K.) | 4.54609 | Cubic decimeters |
| Gallons (U.K.) | 4.54596 | Liters |
| Cubic feet | 28.3160 | Liters |
| Cubic yards | *764.55 | Liters |
| Acre-feet | *1,233.5 | Cubic meters |
| Acre-feet | *1,233,500 | Liters |

## Table II

### QUANTITIES AND UNITS OF MECHANICS

| Multiply | By | To obtain |
|---|---|---|
| **MASS** | | |
| Grains (1/7,000 lb) | 64.79891 (exactly) | Milligrams |
| Troy ounces (480 grains) | 31.1035 | Grams |
| Ounces (avdp) | 28.3495 | Grams |
| Pounds (avdp) | 0.45359237 (exactly) | Kilograms |
| Short tons (2,000 lb) | 907.185 | Kilograms |
| Short tons (2,000 lb) | 0.907185 | Metric tons |
| Long tons (2,240 lb) | 1,016.05 | Kilograms |
| **FORCE/AREA** | | |
| Pounds per square inch | 0.070307 | Kilograms per square centimeter |
| Pounds per square inch | 0.689476 | Newtons per square centimeter |
| Pounds per square foot | 4.88243 | Kilograms per square meter |
| Pounds per square foot | 47.8803 | Newtons per square meter |
| **MASS/VOLUME (DENSITY)** | | |
| Ounces per cubic inch | 1.72999 | Grams per cubic centimeter |
| Pounds per cubic foot | 16.0185 | Kilograms per cubic meter |
| Pounds per cubic foot | 0.0160185 | Grams per cubic centimeter |
| Tons (long) per cubic yard | 1.32894 | Grams per cubic centimeter |
| **MASS/CAPACITY** | | |
| Ounces per gallon (U.S.) | 7.4893 | Grams per liter |
| Ounces per gallon (U.K.) | 6.2362 | Grams per liter |
| Pounds per gallon (U.S.) | 119.829 | Grams per liter |
| Pounds per gallon (U.K.) | 99.779 | Grams per liter |
| **BENDING MOMENT OR TORQUE** | | |
| Inch-pounds | 0.011521 | Meter-kilograms |
| Inch-pounds | 1.12985 x $10^6$ | Centimeter-dynes |
| Foot-pounds | 0.138255 | Meter-kilograms |
| Foot-pounds | 1.35582 x $10^7$ | Centimeter-dynes |
| Foot-pounds per inch | 5.4431 | Centimeter-kilograms per centimeter |
| Ounce-inches | 72.008 | Gram-centimeters |
| **VELOCITY** | | |
| Feet per second | 30.48 (exactly) | Centimeters per second |
| Feet per second | 0.3048 (exactly)* | Meters per second |
| Feet per year | *0.965873 x $10^{-6}$ | Centimeters per second |
| Miles per hour | 1.609344 (exactly) | Kilometers per hour |
| Miles per hour | 0.44704 (exactly) | Meters per second |
| **ACCELERATION*** | | |
| Feet per second$^2$ | *0.3048 | Meters per second$^2$ |
| **FLOW** | | |
| Cubic feet per second (second-feet) | *0.028317 | Cubic meters per second |
| Cubic feet per minute | 0.4719 | Liters per second |
| Gallons (U.S.) per minute | 0.06309 | Liters per second |
| **FORCE*** | | |
| Pounds | *0.453592 | Kilograms |
| Pounds | *4.4482 | Newtons |
| Pounds | *4.4482 x $10^5$ | Dynes |

### Table II--Continued

| Multiply | By | To obtain |
|---|---|---|
| **WORK AND ENERGY*** | | |
| British thermal units (Btu) | *0.252 | Kilogram calories |
| British thermal units (Btu) | 1,055.06 | Joules |
| Btu per pound | 2.326 (exactly) | Joules per gram |
| Foot-pounds | *1.35582 | Joules |
| **POWER** | | |
| Horsepower | 745.700 | Watts |
| Btu per hour | 0.293071 | Watts |
| Foot-pounds per second | 1.35582 | Watts |
| **HEAT TRANSFER** | | |
| Btu in./hr ft$^2$ degree F (k, thermal conductivity) | 1.442 | Milliwatts/cm degree C |
| Btu in./hr ft$^2$ degree F (k, thermal conductivity) | 0.1240 | Kg cal/hr m degree C |
| Btu ft/hr ft$^2$ degree F | *1.4880 | Kg cal m/hr m$^2$ degree C |
| Btu/hr ft$^2$ degree F (C, thermal conductance) | 0.568 | Milliwatts/cm$^2$ degree C |
| Btu/hr ft$^2$ degree F (C, thermal conductance) | 4.882 | Kg cal/hr m$^2$ degree C |
| Degree F hr ft$^2$/Btu (R, thermal resistance) | 1.761 | Degree C cm$^2$/milliwatt |
| Btu/lb degree F (c, heat capacity) | 4.1868 | J/g degree C |
| Btu/lb degree F | *1.000 | Cal/gram degree C |
| Ft$^2$/hr (thermal diffusivity) | 0.2581 | Cm$^2$/sec |
| Ft$^2$/hr (thermal diffusivity) | *0.09290 | M$^2$/hr |
| **WATER VAPOR TRANSMISSION** | | |
| Grains/hr ft$^2$ (water vapor) transmission) | 16.7 | Grams/24 hr m$^2$ |
| Perms (permeance) | 0.659 | Metric perms |
| Perm-inches (permeability) | 1.67 | Metric perm-centimeters |

## Table III

### OTHER QUANTITIES AND UNITS

| Multiply | By | To obtain |
|---|---|---|
| Cubic feet per square foot per day (seepage) | *304.8 | Liters per square meter per day |
| Pound-seconds per square foot (viscosity) | *4.8824 | Kilogram second per square meter |
| Square feet per second (viscosity) | *0.092903 | Square meters per second |
| Fahrenheit degrees (change)* | 5/9 exactly | Celsius or Kelvin degrees (change)* |
| Volts per mil | 0.03937 | Kilovolts per millimeter |
| Lumens per square foot (foot-candles) | 10.764 | Lumens per square meter |
| Ohm-circular mils per foot | 0.001662 | Ohm-square millimeters per meter |
| Millicuries per cubic foot | *35.3147 | Millicuries per cubic meter |
| Milliamps per square foot | *10.7639 | Milliamps per square meter |
| Gallons per square yard | *4.527219 | Liters per square meter |
| Pounds per inch | *0.17858 | Kilograms per centimeter |

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