TEI-841

GEOLOGY OF THE PLUTO SITE, AREA 401, NEVADA TEST SITE, NYE COUNTY, NEVADA

By Ross B. Johnson and John R. Ege

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

TEI-841

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGY OF THE PLUTO SITE, AREA 401, NEVADA TEST SITE, NYE COUNTY, NEVADA*

By

Ross B. Johnson and John R. Ege

April 1964

Report TEI-841

This report is preliminary
and has not been edited for
conformity with Geological
Survey format and nomenclature.

*Prepared partly on behalf of the U.S. Atomic Energy Commission.

UNITED STATES
DEPARTMENT OF THE INTERIOR
Geological Survey

Washington 25, D . C.

April 17, 1964

Mr. James E. Reeves, Manager
Nevada Operations Office
U.S. Atomic Energy Commission
P. O. Box 1676
Las Vegas, Nevada

Dear Mr. Reeves:

Transmitted herewith, are two copies of TEI-841, "Geology of the Pluto Site, Area 401, Nevada Test Site, Nye County, Nevada," by Ross B. Johnson and John R. Ege, April, 1964.

We plan to release this report to the public in the open files.

Sincerely yours,

V. R. Wilmarth, by E. B. Eckel

V. R. Wilmarth
Assistant Chief Geologist
Office of Engineering Geology

Enclosures

Distribution - AEC	No. of copies
Nevada Operations Office (J. E. Reeves)	2
Nevada Operations Office (Technical Library)	4
Director of Military Application, Washington	1
Division of Military Application, Washington	2
San Francisco Operations Office (J. F. Philip)	1
Division of Peaceful Nuclear Explosion (R. Hamburger)	1
Division of Research, Washington (D. R. Miller)	1
Division of Technical Information Extension	1
Engineer Research and Development Lab., Ft. Belvoir, Va. (Chief, Special Projects Branch)	1
Health Physics Div., Oak Ridge Natl. Lab. (F. L. Parker)	1
Lawrence Radiation Lab., Livermore (R. E. Batzel)	2
Lawrence Radiation Lab., Livermore (D. E. Rawson/N. M. Short)	1
Lawrence Radiation Lab., Livermore (A. V. Shelton)	1
Lawrence Radiation Lab., Mercury (W. D. Richards)	5
Lawrence Radiation Lab., Mercury (D. T. Schueler/N. M. Fillip)	1
Lawrence Radiation Lab., Mercury (J. L. Olsen)	1
Los Alamos Scientific Laboratory (J. H. Hall)	1
Los Alamos Scientific Laboratory (R. W. Newman)	1
Marquardt Corp., Van Nuys, Calif. (S. S. Berman)	3
Sandia Corp., Albuquerque, (D. B. Shuster)	2
Stanford Research Institute, Menlo Park (R. B. Hoy)	1
Roland F. Beers, Inc	14
Hazleton-Nuclear Science Corp	3
Headquarters, USAF/AFTAC, Washington (Wayne Helterbran)	1
U.S. Coast and Geodetic Survey, Mercury	1
Field Command, Defense Atomic Support Agency, Albuquerque	3
Advanced Research Projects Agency, Washington (C. C. Bates)	2
Lincoln Laboratories, Lexington, Mass	1
United Earth Sciences, Alexandria, Va	1
University of Michigan, Ann Arbor, Mich	1
U.S. Coast & Geodetic Survey, Washington	1
Texas Instruments, Inc., Dallas (R. Arnett)	1
Fenix & Scisson, Inc., Las Vegas	1
	64

Distribution - USGS	No. of copies
Director	1
Conservation Division, Mineral Classification Branch	1
Water Resources Division	
Radiohydrology Section, Washington	10
Radiohydrology Section, Denver (W. E. Hale)	2
Publications Section, Washington	2
Ground Water Branch, Washington	1
Quality of Water Branch, Washington	1
Surface Water Branch, Washington	1
Branch Area Chief, GW	
Denver, Colo	1
Menlo Park, Calif	1
District Geologist, Albuquerque	1
District Hydrologist, Carson City	1
A. M. Piper, Menlo Park, Calif	1
W. A. Beetem, Denver, Colo	1
Ground Water Office, Las Vegas, Nev	14
Geologic Division	
Office of Engineering Geology	1
Library, Washington	1
Denver	2
Menlo Park	1
Alaskan Geology Branch	1
Astrogeology Branch	1
Crustal Studies Branch	1
DAPU (provision for future open-filing)	10
Field Geochemistry & Petrology Branch	1
Military Geology Branch	2
New England Branch	1
Regional Geophysics Branch	2
Geologic Data Center, Mercury	5
Southwestern Geology Branch	1
Special Projects Branch, Denver	20
WAPU (Wenonah Bergquist)	2
	91

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS--Continued

ILLUSTRATIONS--Continued

TABLES

TABLES--Continued

GEOLOGY OF THE PLUTO SITE

AREA 401, NEVADA TEST SITE, NYE COUNTY, NEVADA

By Ross B. Johnson and John R. Ege

INTRODUCTION

Geologic studies by the U.S. Geological Survey in support of the U.S. Air Force's Project Pluto in Area 401 of the Nevada Test Site were made on behalf of the U.S. Atomic Energy Commission. The Survey was requested to make a detailed geologic investigation of the area and to provide basic geologic data for the use of the Marquardt Corporation, contractor to the Air Force, in the design, construction, and testing of a pilot underground air-storage chamber for the Pluto nuclear-powered ram-jet.

Area 401 is in the south-central part of the U.S. Atomic Energy Commission's Nevada Test Site and consists of about 9.6 square miles including Wahmonie Flat (fig. 1). The area is approximately 12 miles northwest of Mercury, Nev., and is easily reached from Mercury by either the Cane Spring Road or the Jackass Flats Highway. Area 401 does not have officially delimited boundaries, but it is largely included between Nevada State coordinates N. 747,000, N. 759,000, E. 645,000, and E. 666,000. Geographically, the area generally is bounded on the southwest by the low drainage divide between Wahmonie Flat and Jackass Flats, on the northwest by the southeastern slopes of Lookout Peak, on the north and northeast by small rugged hills that are unnamed, and on the south by the northern slopes of Skull Mountain.

The area of principal interest consists of about 3 square miles in the northeast corner of Area 401 (fig. 2) and is bounded by Nevada State coordinates N. 753,000.00, N. 759,000.00, E. 651,000.00, and E. 666,000.00.

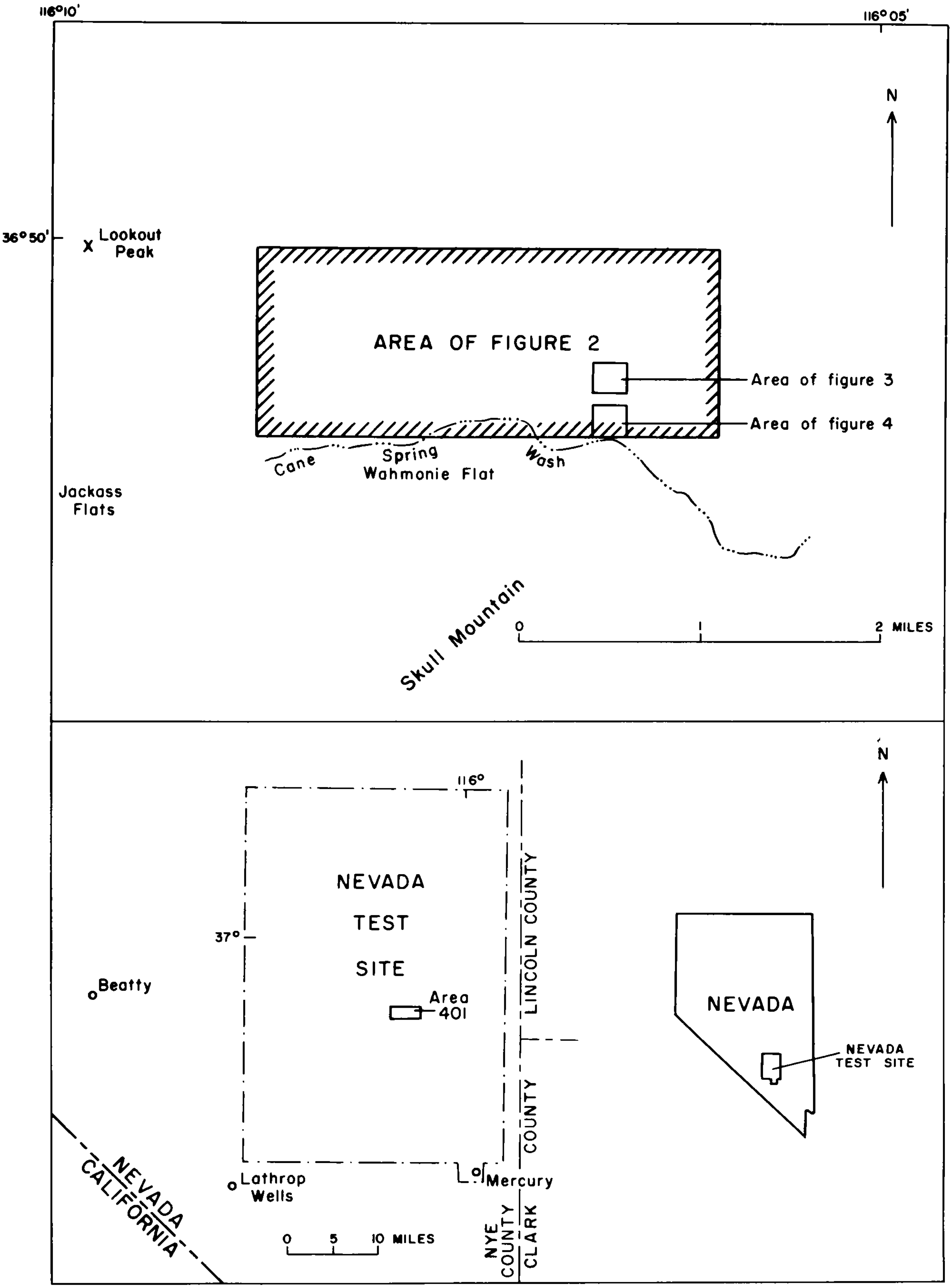


Figure 1.-- Index map of geologic map (figure 2) in Area 401, Nevada Test Site

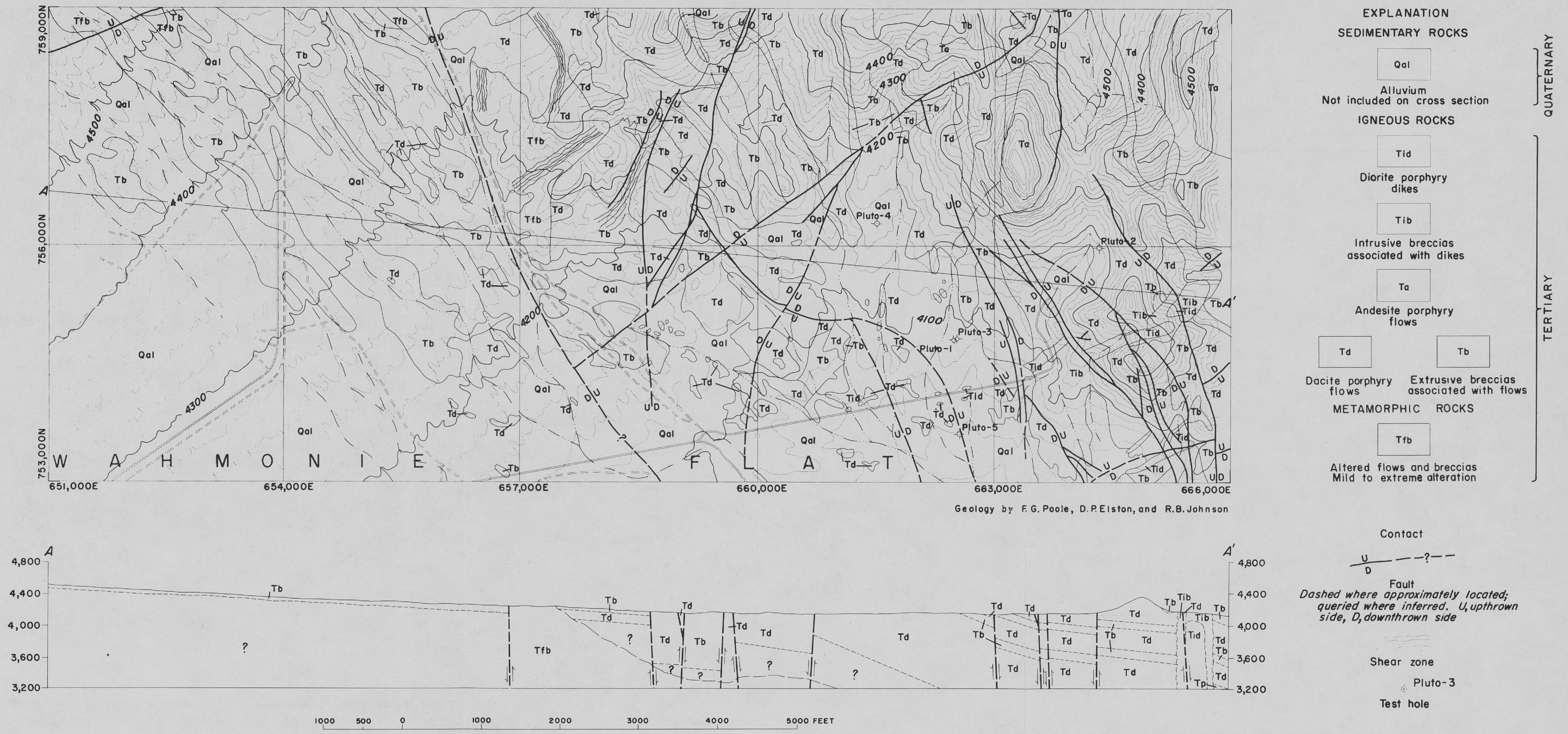


Figure 2.--Generalized geologic map and cross section of Area 401, Nevada Test Site, Nye County, Nevada

In order to provide an adequate geologic background, particularly in structure, petrography, and geologic history, Area 401 was mapped in detail at a scale of 1:12,000 (fig. 2). Two prospective chamber sites were mapped by planetable and telescopic alidade to delineate smaller structural features (figs. 3, 4). These were compiled on topographic base maps, scale of 1:600, prepared by Pafford and Associates of Los Angeles, Calif. The maps were reduced photographically to a scale of 1:1,200 for publication. To obtain a more accurate 3-dimensional picture of the geology and to investigate ground-water conditions, five exploratory test holes were cored to depths ranging from 111 to 778 feet (p. 96-126).

Gravity, seismic, and resistivity surveys were made of the area (figs. 5, 6) to supplement geologic studies by providing subsurface information on the bulk physical properties of the rock, changes in rock types, variation in water content, and major structural features.

The authors thank Dr. John C. Manning, Geologic Consultant to the Marquardt Corp., for his cooperation in the field. We also thank Mr. Howard D. MacDonald, Engineer with the Marquardt Corp., for his explanation of the engineering design, construction, and function of the pilot chamber.

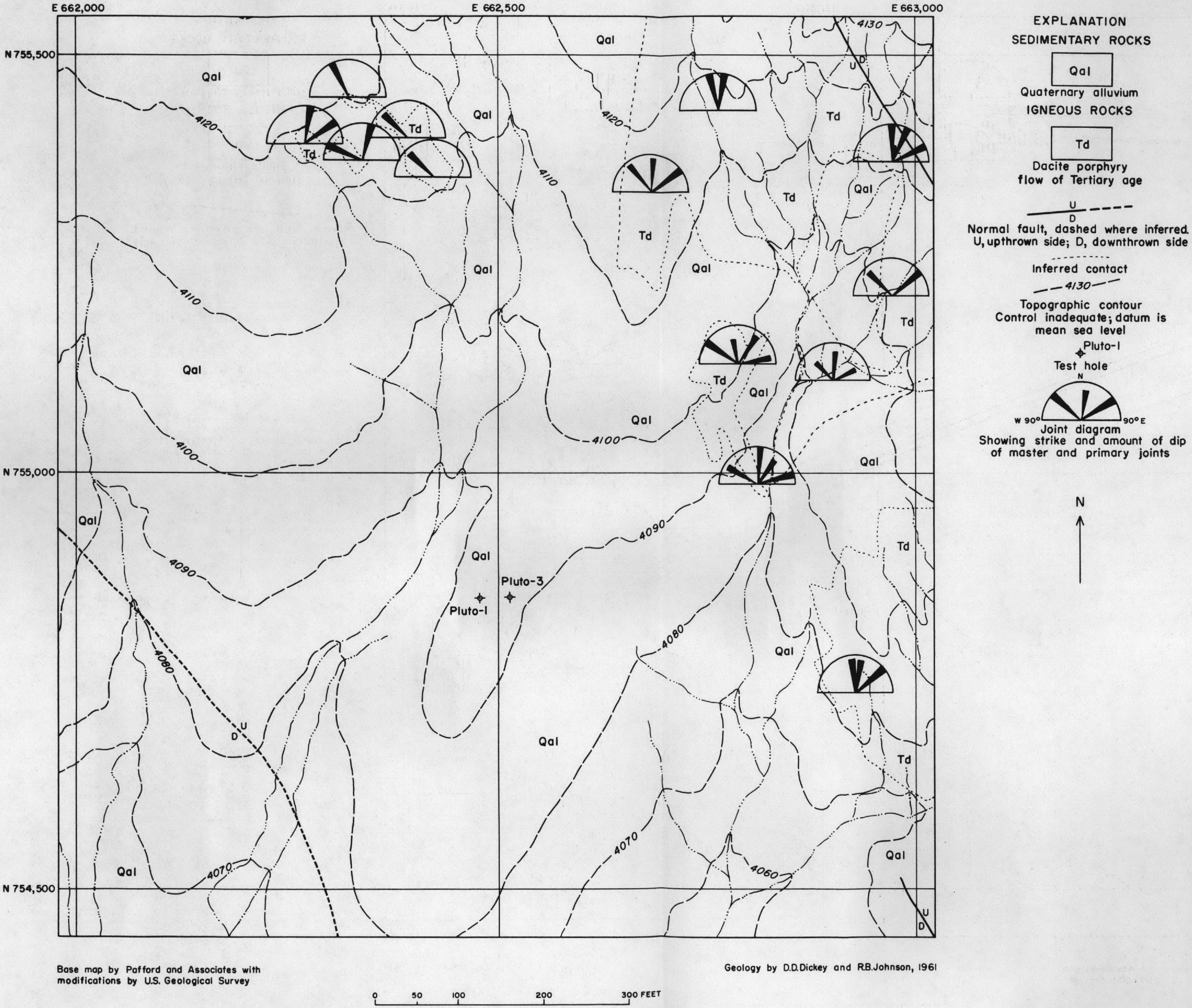


Figure 3.-- Geologic map of area adjacent to test holes Pluto-1 and Pluto-3, Area 401, Nevada Test Site

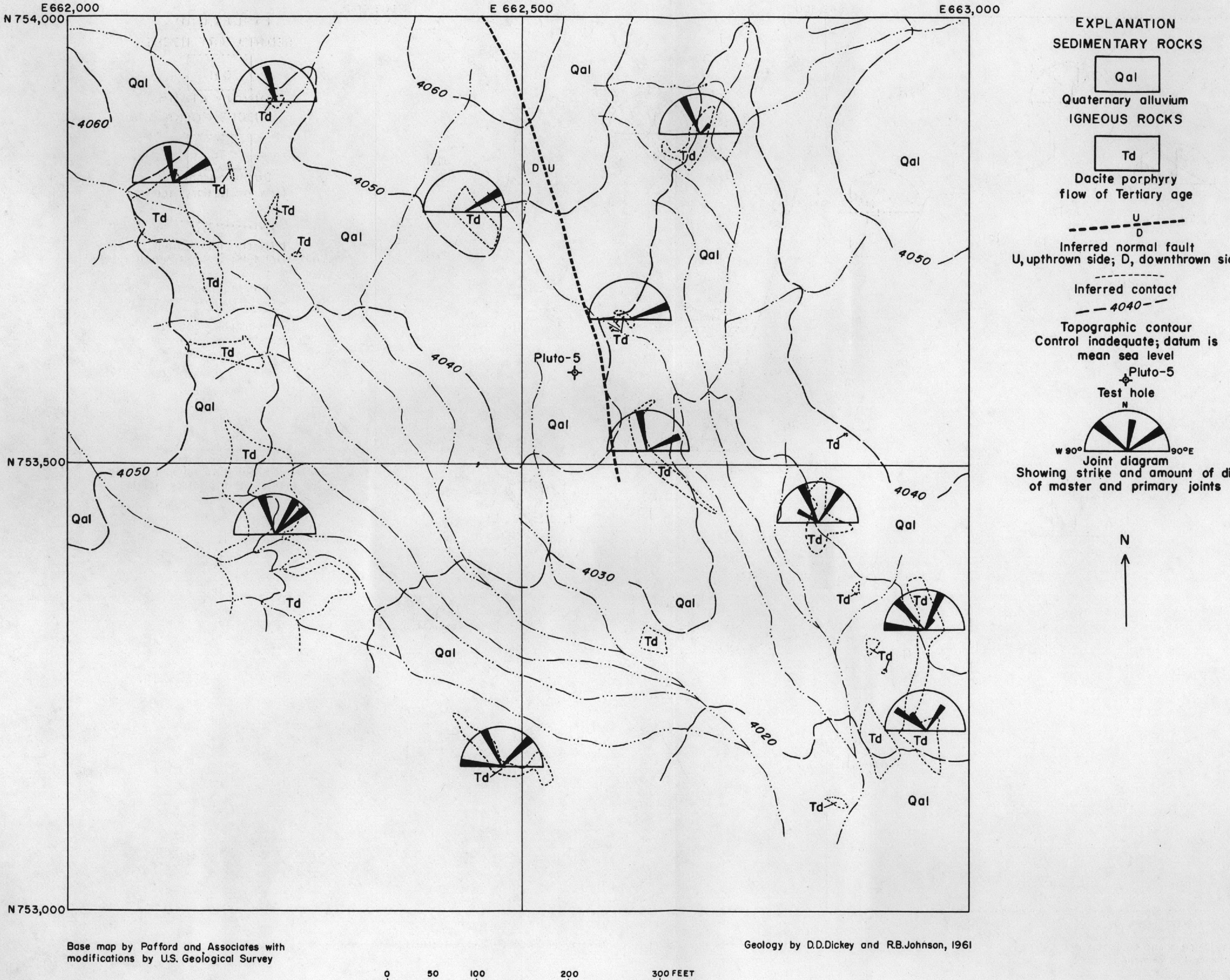
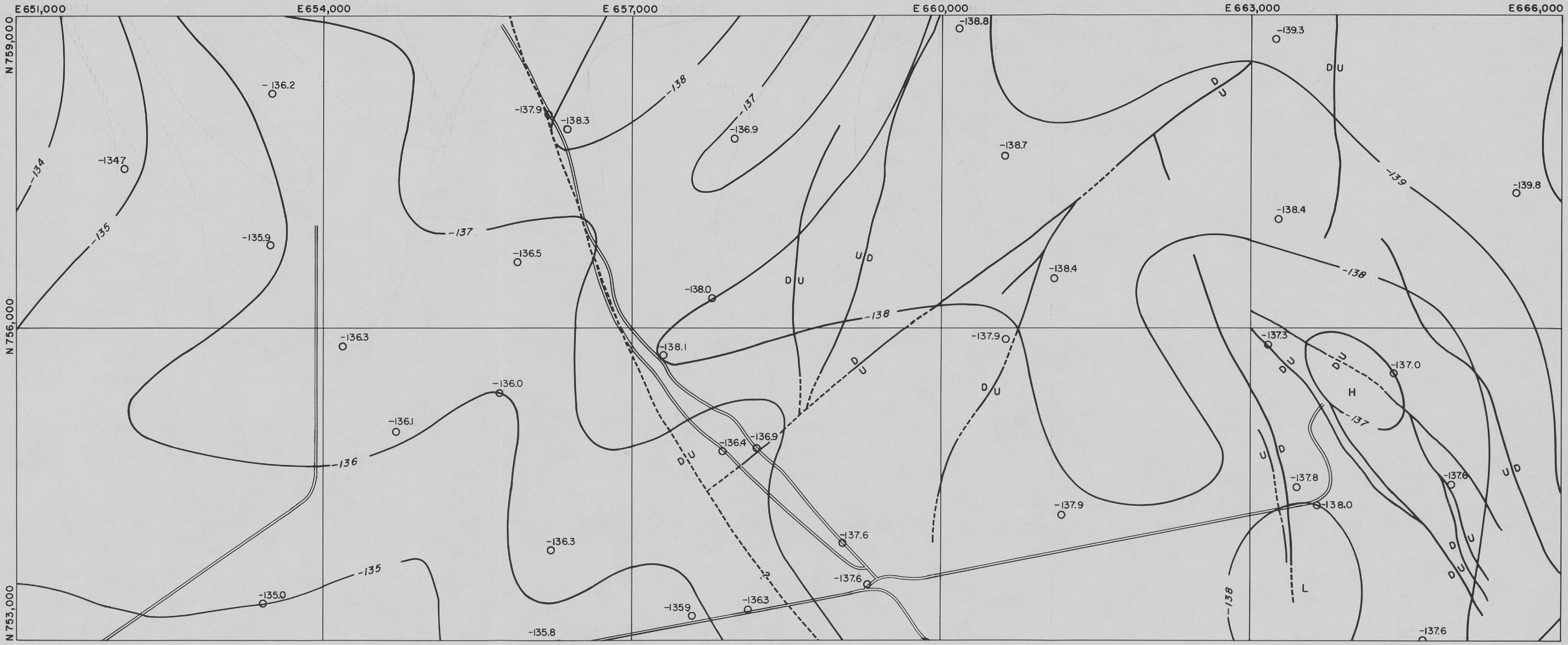


Figure 4.-- Geologic map of area adjacent to test hole Pluto-5, Area 401, Nevada Test Site



Gravity data by D.L. Healey and C.H. Miller, May 1961

Figure 5.--Gravity map of Area 401, Nevada Test Site

Faults generalized from figure 2

EXPLANATION

—— -139 ——
Gravity contour, interval = 1 milligal
H, area of gravity high
L, area of gravity low

○ -137.8
Gravity station, measurement in milligals

U/D ——— ? ——
Fault
Dashed where inferred; queried where doubtful. U, upthrown side; D, downthrown side

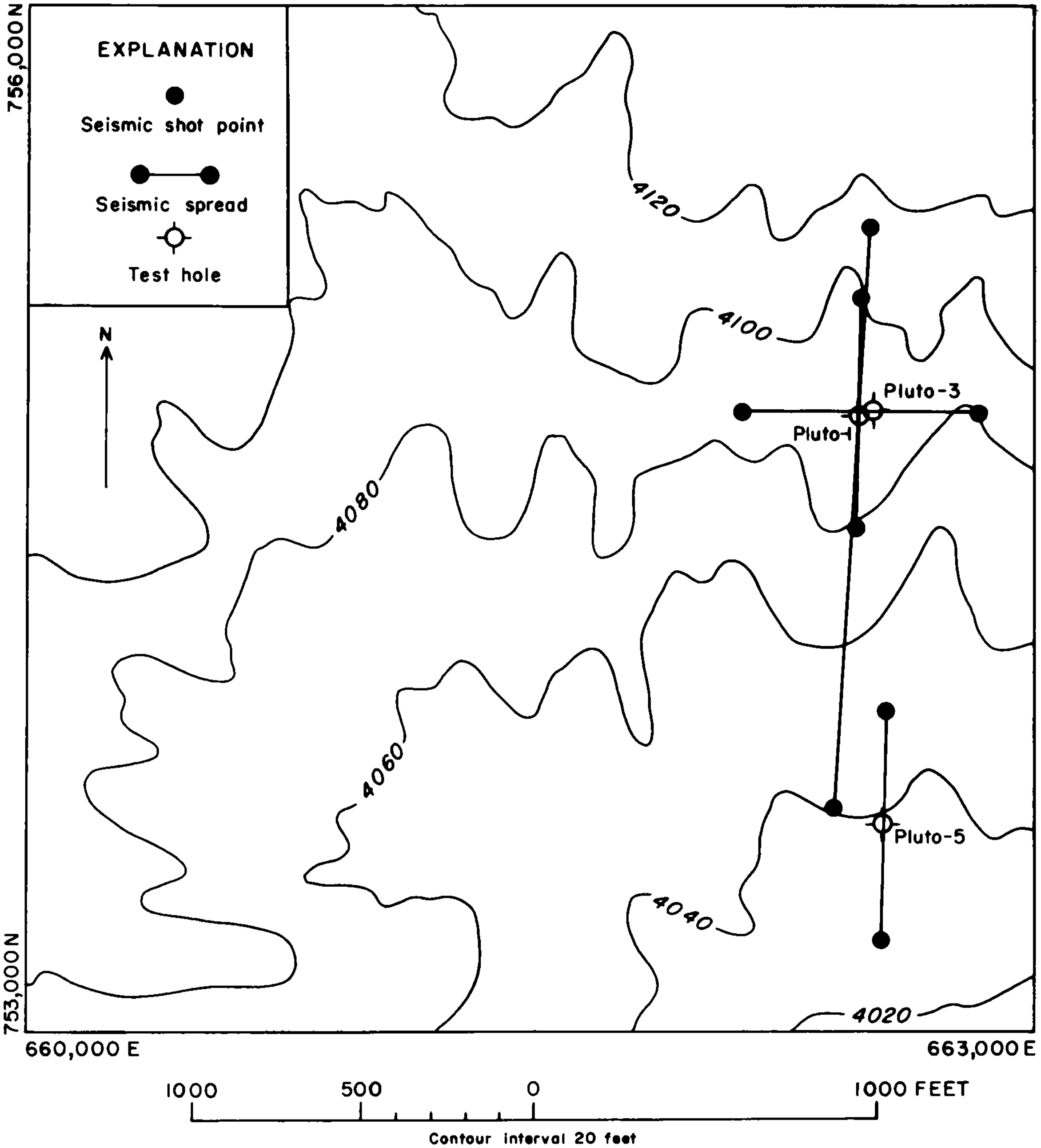


Figure 6.-- Index map of part of Area 401, Nevada Test Site, showing spacing of seismic shot points around test holes Pluto-1,-3, and-5.

GENERAL GEOLOGY

Area 401 is largely covered by thin gravels capping a pediment that dips 3°-6° SE.; the pediment gravels merge with the valley alluvium along Cane Spring Wash to the south. Where exposed, mainly on the steeper slopes in the northern and eastern parts of the area (fig. 2), the bedrock consists mostly of extrusive igneous rocks with some associated breccias of limited areal extent. A few thin beds of consolidated sedimentary rocks occur between some of the extrusive rocks. The extrusive rocks dip gently to the east, are highly faulted and jointed, and are locally sheared. These rocks commonly are highly weathered and intensely altered in the shear zones and along some of the faults. A few small dikes crop out in the southeast corner of the map area.

Igneous rocks

Extrusive rocks

Extrusive rocks in Area 401 consist entirely of lava flows and their associated breccias. All these rocks are very similar chemically although the oldest flows are somewhat more silicic than the youngest flows. Petrographically, the lower flow rocks are dacites, whereas the younger rocks are most commonly andesites. The dacite is porphyritic with phenocrysts of plagioclase, biotite, andesine, hypersthene, hornblende, and rare quartz in a glassy or stony groundmass. Fine grains of magnetite are disseminated throughout the rock. The andesite is also porphyritic, but the phenocrysts differ from those of the dacite in that biotite is uncommon, andesine is absent, hornblende is common, and a few crystals of diopside and hypersthene are present. The youngest andesite flows in the northeast corner of the mapped area (fig. 2) are nearly basaltic, the plagioclase being somewhat more calcic and diopside and hypersthene more abundant than in the older andesite flows.

In general, the rocks of individual flows are banded and have stony interiors surrounded by a zone of porphyritic glass, which, in turn, has a rind of dense black or gray glass. The glass zones vary in thickness within the individual flows and, locally, are absent.

The mapped units in the extrusive rocks are lenticular and limited in areal extent. The lenticularity of these units is apparently due to the flows having followed the low areas of the land surface that existed at the time of volcanic eruption. Many of the flows and breccias are less than several thousand feet in extent.

The breccias associated with the dacite and andesite flows consist mainly of small to large fragments of flow rock in a fine matrix of rock fragments, glass, and cinders. The percentage and size of the fragments vary locally in the individual and separate breccias. The breccias are less dense than the flow rocks and are more easily weathered.

Several zones of highly altered dacite and associated breccias occur in the north-central part of the mapped area (fig. 2). Abundant crypto-crystalline quartz was deposited in these zones by hydrothermal solutions which permeated the country rock. Locally, alteration of the dacite has obliterated the character of the original rock. Hydrothermal alteration has been most extensive along shear zones. Locally in the eastern part of the area, small irregular veins of cryptocrystalline quartz occur in the less altered rocks.

The highly weathered rocks are near the surface, but weathering is also apparent at depth. The most intensely weathered rocks contain the greatest pore space, in the form of connected or nonconnected cavities and fractures.

Intrusive rocks

Several narrow diorite porphyry dikes cut dacite and andesite flow rocks in the southeastern part of the area (fig. 2). Their chemical and mineralogical compositions are similar to those of the andesitic rocks and suggest that the dikes may have been magma conduits for some of the younger andesite flows. The dikes appear to be vertical, or nearly so, and may increase in width at depth. Intrusive breccias are associated with the dikes at many localities.

Three well-defined zones are apparent in each dike: an interior crystalline zone, a transition zone, and an outer glassy zone. The interior zone consists of medium to coarse phenocrysts of calcic plagioclase, hornblende, some pyroxene, and rare biotite in a groundmass of microscopic crystals of the same minerals. The groundmass constitutes 70 percent of the rock and contains disseminated fine grains of magnetite. The interior zone is bounded on both sides by a transition zone of fine to medium phenocrysts of calcic plagioclase, hornblende, pyroxene, and, rarely, biotite in a groundmass of microscopic crystals of the same minerals. The groundmass constitutes nearly 70 percent of the rock. Fine grains of magnetite also occur in the groundmass of the transition zone, and the pyroxene phenocrysts are locally altered to iron oxides.

The border zones of the dikes are composed of medium to coarse phenocrysts of calcic plagioclase and fine to medium phenocrysts of hornblende, pyroxene, and biotite in a groundmass of dense black glass. Phenocrysts of hornblende are abundant; those of biotite are rare. The glassy groundmass constitutes 50 to 60 percent of the rock and contains clusters of finely disseminated crystals of pyrite and magnetite.

The interior zones of the dikes are most easily weathered; so, topographically, each dike is expressed as two linear ridges. The ridges are formed by the transition and outer zones and are separated by a gentle swale covered by a thin mantle of alluvium that represents the interior zone.

Structural geology

Geologic structures in Area 401 (fig. 2) include normal faults, shear zones, and joints that are primarily the results of regional uplift and major block faulting that occurred throughout Nevada and much of the southwestern United States in late Tertiary time. The normal faults trend northwest to northeast and dip steeply. The predominant movement along the faults has been vertical; the maximum vertical displacement probably does not exceed 100 feet. Nearby, however, there are large faults that commonly have 500 feet of vertical displacement and locally may exceed 1,000 feet. Many faults are arcuate, some are sinuous, and a few are straight. Most are forked. Locally, the rocks adjoining the fault planes are distorted, and many faults are filled by gouge and marked by slickensides. Many more faults undoubtedly are hidden by alluvial deposits and pediment gravels that cover large parts of Area 401.

Shear zones occur in altered and unaltered dacite porphyry and dacite breccia in the central part of the area; locally the rock in these zones has been crushed into fragments less than an inch across. The shear zones trend north and northeast, dip from about 45° to nearly vertical, and they may be as much as 1,300 feet long and 200 feet wide. Hydrothermal alteration is greatest in these shear zones.

The rocks in Area 401 are intricately jointed throughout, having wide variations in the magnitude, attitude, and spacing of the joints. The diversely oriented joints extend from a few inches to more than several hundred feet along their strikes. Most of the prominent joints are straight, but many are wavy or arcuate. Most of the smaller joints are irregular along strike; locally they are wavy, curved, and for short distances straight. Dips of the joints range from about 10° to vertical, but most dips are 40°-60° and 70°-90°.

Ground-water conditions

A perched water table occurs throughout most of Area 401 with recorded depths to its static water level ranging from 81.0 to 167.0 feet below the land surface. The perched water occurs in a zone of highly fractured rock with many open joints and may extend to depths exceeding 261 feet (p. 96-126) before rocks having low-fracture permeability are penetrated.

Table 1 shows the depth to water level measurements taken in core holes for a 1-month period during excavation of the pilot chamber. Fluctuations in the water level in the Pluto-6 and -7 holes, which are located very close to the underground chamber, may reflect the drawdown effect caused by mine pumping operation during excavation.

Electrical resistivity vertical profiles in Area 401 indicate zones of saturation at depths between 24 and 136 feet, 460 and 900 feet, and 1,050 and 1,800 feet (table 2). Therefore, other layers of perched water may be in permeable zones between the regional water table, which is assumed to be at a depth of about 1,700 feet, and the known perched water table.

Table 1.--Water levels at the Pluto Site, Area 401, Nevada Test Site

Drill hole	Location (Nevada coordinates)	Drill-collar elevation (feet above sea level)	Date Logged (1962)	Depth to water level (feet)	water level (feet above sea leval)
Pluto-4	N. 756,261.85 E. 661,491.41	4,152	June 29 July 21-26	109 1/ 109.59 max 109.61 min 109.57	4,043 1/ 4,042
Pluto-5	N. 753,602.00 E. 662,558.45	4,041	June 23 June 29 July 21-26	80 77 2/ 80.93 max 80.95 min 80.91	3,961 3,964 2/ 3,960
Pluto-6	N. 754,696.75 E. 662,440.83	4,091	June 24 June 29 July 21-26	160 182 1/ 167.00 max 168.60 min 166.38	3,931 3,909 1/ 3,924
Pluto-7	N. 754,708.20 E. 662,540.16	4,091	June 29 July 21-26	181 2/ 159.19 max 159.29 min 159.03	3,910 2/ 3,932
Pluto-10	N. 754,228.79 E. 662,801.60	4,060	June 24 June 29 July 21-26	130 125 2/ 129.03 max 129.21 min 128.82	3,930 3,935 2/ 3,931
Pluto-11	N. 754,128.95 E. 662,796.37	4,060	June 24 June 29 July 21-26	125 127 2/ 125.85 max 125.98 min 125.65	3,935 3,933 2/ 3,934
Pluto-12	N. 754,328.63 E. 662,806.83	4,060	June 24 June 29 July 21-26	125 125 2/ 128.49 max 128.63 min 128.30	3,935 3,935 2/ 3,932

1/ Average of 5 measurements taken over a 6-day period.

2/ Average of 4 measurements taken over a 6-day period.

Table 2.--Interpretation of electrical resistivity vertical profile obtained at test hole Pluto-1, Area 401, Nevada Test Site

[Interpretation by R. A. Black and R. M. Hazlewood]

Resistivity layer	Depth interval (feet)	Resistivity (ohm-meter)	Remarks
1	0-0.85	42	Soil.
2	0.85-3.4	420	Dry weathered dacite.
3	3.4-24	88	Layers 3 to 6 are dacite. Layers 3 and 5 appear to be partially saturated with the difference in resistivity a function of porosity differences between the two layers. Layer 4 has a relatively high porosity averaging about 17.5 percent and appears to be completely saturated. Layer 6 is saturated dacite.
4	24-136	13	
5	136-460	33	
6	460-approx. 900-----	10-20	
7	Approx. 900-1,050---	Greater than layers 6 and 8.	This layer may represent a decrease in porosity in dacite or a welded tuff layer.
8	Approx. 1,050-1,800-	21	Possibly saturated dacite with increased porosity, or may be bedded tuff.

GEOLOGY OF THE AIR CHAMBER SITE

Lithologic description

The dacite porphyry is exposed in small scattered and isolated outcrops northeast and southeast of test holes Pluto-1 and -3 (figs. 3, 4). At these outcrops the dacite varies in color from light gray to buff, reddish brown, and dark greenish gray. The fresh rock is light gray. Weathered dacite is buff or reddish brown, the most highly weathered being buff. The hydrothermally altered rocks are generally greenish gray although, locally, alteration has not changed the gross color of the rocks (fig. 7).

Texturally, the rock is porphyritic and is composed of more or less isolated medium-grained phenocrysts (1/2 to 1 mm) set in a groundmass of glass. The phenocrysts are plagioclase, biotite, and, rarely, hornblende and hypersthene. The groundmass consists mainly of devitrified to partly devitrified glass and constitutes from 50 to 75 percent of the rock. It contains rare lithic fragments of lava and metamorphic rock. Structurally, the porphyry is lenticular in cross section, flow banded, massive, and locally vuggy.

Structure

Faults

Several faults were mapped in the areas of two prospective sites (figs. 3, 4). A north-northwest trending fault, downthrown on the east, extends across the northeast corner of site 1 near test holes Pluto-1 and -3 (fig. 3). The amount of displacement could not be measured, and there is no apparent distortion of the rock adjoining the fault. Another northwest-trending fault, downthrown to the west, cuts across the southwest corner of site 1 (fig. 3) and extends into the area of site 2 (fig. 4) near

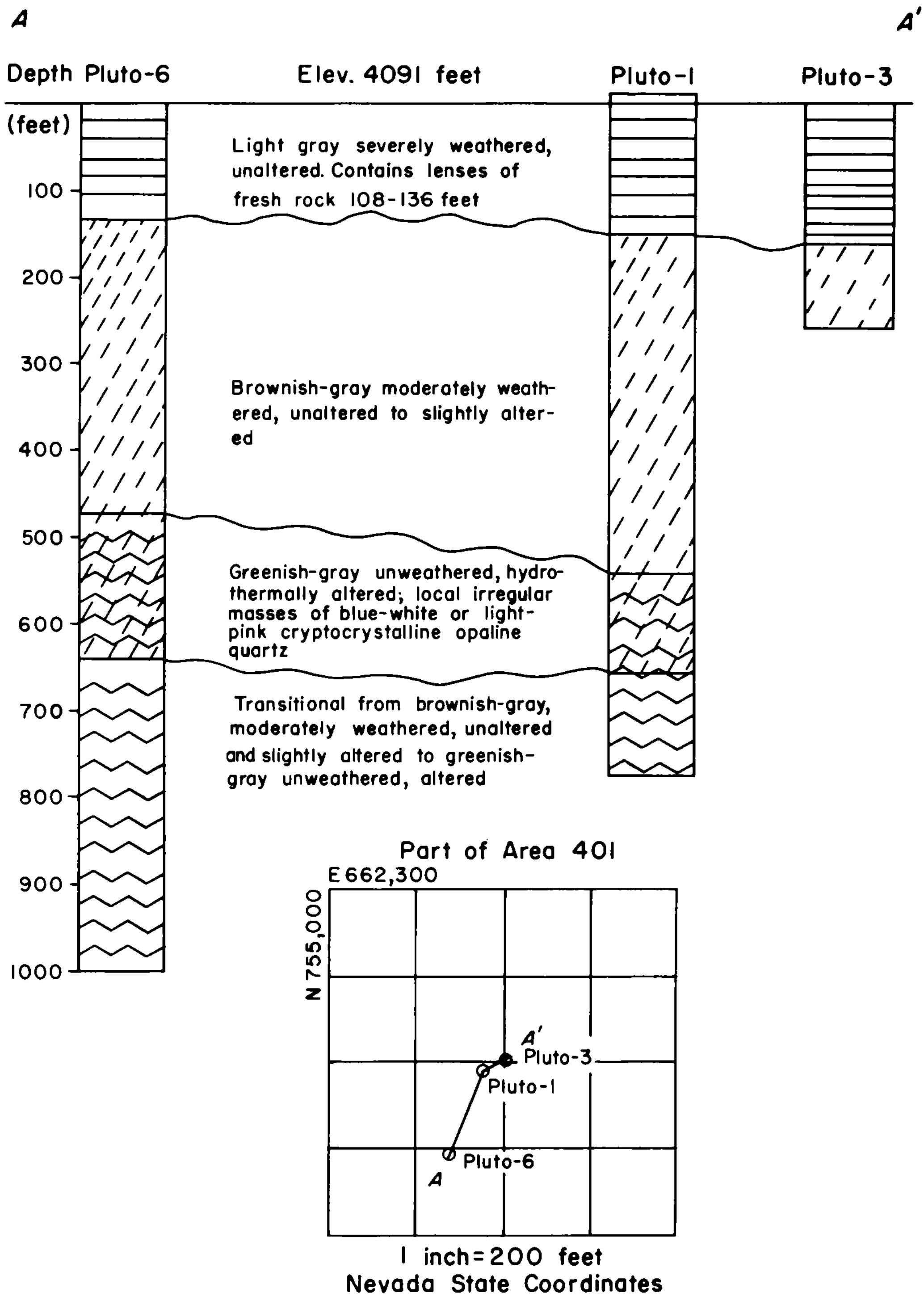


Figure 7.--Alteration zones from cores within dacite porphyry, Area 401, Nevada Test Site

test hole Pluto-5. This fault trends northwest, apparently passing within a few feet of test hole Pluto-5, and is exposed about 200 feet north of the hole. It may extend south along strike for almost a mile. Several small faults cut the diorite porphyry dike that crops out between these two sites. The faults probably extend for short distances into these sites; however, they could be mapped with certainty only in the vicinity of the dike.

Cores recovered from the drill holes indicate that faulting occurred at only a few places. At 463.5 feet below the surface, the drill hole at Pluto-1 penetrated a nearly vertical 1/2-inch wide fracture having slickensided walls and filled with material that may be fault gouge. Another piece of rock recovered from a depth of 660 feet in Pluto-1 has been broken and crushed; it contains 1/2-inch-thick bands of slickensided clay gouge. For 11 feet above and below the gouge zone, the core consists of broken rock intersected by many fractures that have numerous slickensided surfaces. This evidence suggests that at this depth the drill hole intersected, or nearly intersected, a high-angle normal fault.

Cores recovered from test hole Pluto-5 at 153 feet, 270 feet, and 281 feet below the surface show that the rock was crushed into many small fragments and that most of the fracture surfaces display slickensides. The highly broken rock was cemented later by fine-grained calcite; locally, isolated fragments are surrounded by calcite. The rocks were probably torn and crushed by movement along high-angle normal faults.

Joints

The joints were mapped in great detail in the areas of the prospective sites. They are grouped according to magnitude as master, primary, secondary, and tertiary. Master joints are those that are the longest, widest, most persistent, most parallel, and most regular. Primary joints are persistent and strike nearly normal to the master joints; secondary joints extend for 10 to 20 feet along strike, are irregular, and have variable dips; and tertiary joints are minute irregular fractures that are observed only on fresh clean surfaces of outcrops.

The attitudes of the master and primary joints at the two sites have been diagrammed and shown on the geologic maps (figs. 3, 4) near the individual outcrops that were examined. The general strike of the joints is shown by the direction of the wedge-shaped bars, and the dip by the length of the bars. The center of the semicircle represents 0° of dip (horizontal joints) and the circumference of the semicircle represents 90° of dip (vertical joints). A more precise method of graphically representing joints has been used to prepare figure 8, which not only shows the strike and dip, but also the direction of the dip of the joints. This joint diagram (fig. 8) is a compilation of the attitudes of 163 joints measured at rock exposures near the prospective chamber sites and represents an upper hemispheric equal-area plot of the joint poles. By use of the upper hemisphere, the plotted poles fall in the same quadrant as the dip directions. The strike directions are read normal to the dip directions.

The attitudes of all the joints measured in the areas of sites 1 and 2 show a strong northeast trend and a vertical to nearly vertical dip. There are six strong joint trends. The joints of the dominant set strike N. 40° E. and dip 60° SW. The five other major joint sets have average attitudes of N. 80° W., 80° SW.; N. 50° W., 60° SW.; N. 65° W., vertical; N. 80° E., vertical; and N.-S., 30° E. The last may follow the flow banding.

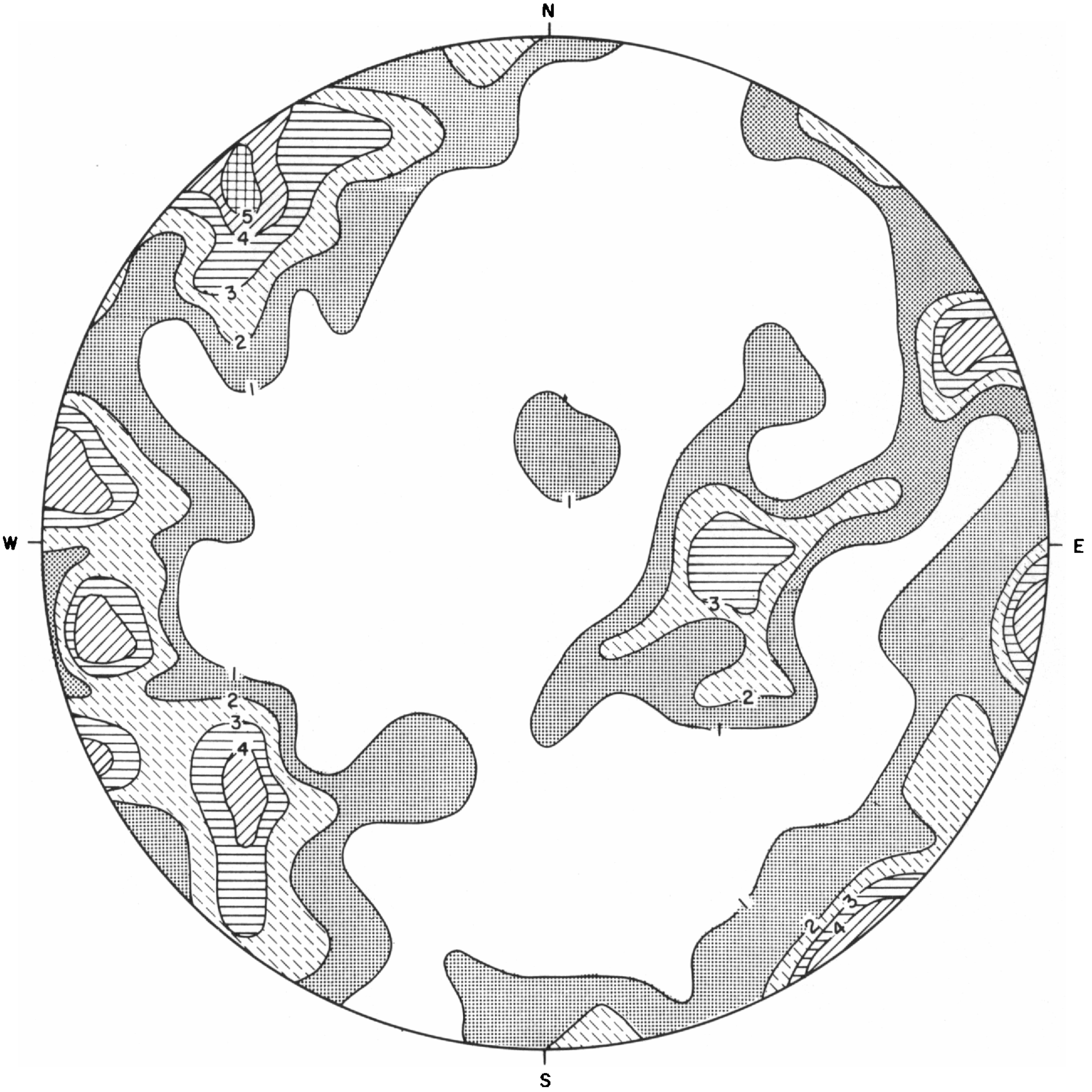


Figure 8.-- Joint diagram of 163 poles of surface joints in area adjacent to test holes Pluto-1 and Pluto-5, Area 401, Nevada Test Site. Plotted on upper hemisphere, contour interval 1 percent

The strikes of the joints observed in the core of the test holes could not be determined, but most of the joints dip 40 to 60° or are nearly vertical. The joints in individual sets are from less than 1 inch to as much as 5 feet apart, averaging 6 inches apart. The most highly fractured rock occurs at joint intersections where fractures reach their highest density. A maximum average fracture density of 3.5 fractures per foot of core was recorded in the interval 84.0-135.0 feet in test hole Pluto-1. In test hole Pluto-3, maximum fracture density of slightly more than 2.0 fractures per foot of core was recorded for the interval 81.3-163.8 feet, and a fracture density of slightly less than 2.0 was recorded for the interval 187.4-210.0 feet. For test hole Pluto-5 the maximum fracture density is 2.3 in the interval 72.6-99.4 feet. The values given for fracture density in the cores are not the maximum except for those nearly horizontal fractures that cut the drill hole at right angles. The higher the angle of the fractures, the lower the fracture-density values shown by the core. Fractures that are nearly vertical or vertical and are almost parallel to the drill hole would intersect the core at only a few places, regardless of how closely they are spaced. Thus, an inadequate picture is shown of the density of high-angle and vertical joints, which are commonly master and primary joints.

At exposures of fresh rock and in the cores most of the joint surfaces are slightly rough, but some are slickensided with polished and striated surfaces. Most of the joints are closed, but a few are open and show evidence of having been channels for the downward or lateral movement of ground water. Examination of the core from the test holes shows that many open joints, especially at greater depths, have been sealed by deposits of calcite, montmorillonite, iron oxide, and manganese oxide.

Petrography

Petrographic studies of the cores from the five test holes in Area 401 were made to determine the mineralogic, textural, and structural characteristics of the rock, as well as to determine the effects of weathering and alteration. Thin sections were cut from 21 samples of fresh, weathered, and altered rock from depths of 65.5, 83.3, 109.8, 130.0, 158.0, 217.5, 260.0, 400.0, 450.0, and 550.0 feet in test hole Pluto-1, from a depth of 221.0 feet in test hole Pluto-3, and from depths of 13.0, 35.5, 75.5, 102.0, 120.0, 167.0, 224.5, 276.0, 298.0, and 311.0 feet in test hole Pluto-5. These samples are considered to be representative of the host rock for the underground chamber. Study of the thin sections has shown that this rock may be mineralogically classed as a dacite porphyry because of the amounts of quartz, sanidine, plagioclase, biotite, hornblende, and hypersthene phenocrysts (table 2-A).

Texture and fabric

The dacite is a hypocrystalline porphyry having fine- to medium-grained hypidiomorphic phenocrysts in a groundmass of slightly devitrified perlite to completely devitrified glass with abundant microlites. Locally, the microlites are arranged subparallel to each other and to the flow banding to give the rock a slightly trachytic texture. The phenocrysts are largely scattered and isolated in the groundmass and are not well packed or interlocked. The vuggy or vesicular character of the rock, noted at several places, may be the result of weathering or of expanding gas in the lavas. In the fresh rock the cavities are mostly nonconnected and locally they may be amygdules. Variations in porosity appear to be largely a function of weathering and alteration; weathering tends to increase the porosity, whereas hydrothermal alteration tends to decrease the porosity.

Table 2a.-- Petrographic modal analyses of test-hole dacite porphyry core thin sections from Area 401, Nevada Test Site

[Analyses are given in percentage of total volume of rock]

Sample No. Pluto-	Depth (feet)	Quartz	Glass	Plagioclase	Biotite	Hornblende	Hypersthene	Iron oxides	Calcite
1A	65.5	Trace	58.5	35.4	2.9	1.6	0.2	1.5	-------
1B	83.3	Trace	79.2	13.4	4.4	0.9	-----------	1.7	0.9
1D	109.8	0.2	71.0	21.0	4.2	1.9	0.6	1.3	-------
1F	130.0	Trace	70.8	12.3	0.9	----------	-----------	2.8	13.2
1G	158.0	0.1	73.5	16.4	8.0	----------	-----------	1.9	-------
1K	217.5	Trace	77.1	17.7	4.2	----------	-----------	1.0	-------
1M	260.0	Trace	71.1	24.3	2.7	----------	-----------	1.9	Trace
1S	400.0	0.1	71.0	17.8	2.4	----------	-----------	2.8	5.8
1U	450.0	Trace	77.1	17.2	2.9	----------	-----------	2.4	Trace
1X	550.0	Trace	75.0	19.2	4.4	----------	-----------	1.4	Trace
Average----	-------	Trace	72.0	19.5	3.7	0.4	0.1	1.9	1.9
3H	221.0	Trace	67.4	25.8	3.6	----------	-----------	2.0	1.2
5A	13.0	------	72.5	22.1	2.3	----------	-----------	3.0	0.2
5B	35.5	0.5	75.2	18.4	3.9	----------	-----------	1.5	0.7
5D	75.5	Trace	73.5	16.4	6.3	----------	-----------	3.6	-------
5E	102.0	------	71.1	23.5	2.5	----------	-----------	2.9	-------
5F	120.0	0.1	46.6	27.9	2.3	----------	-----------	3.3	20.0
5H	167.0	Trace	70.5	25.9	1.7	----------	-----------	1.9	-------
5L	224.5	Trace	49.5	10.5	1.2	----------	-----------	1.8	37.2
5P	276.0	0.5	70.5	20.5	5.4	----------	-----------	2.9	-------
5Q	298.0	0.2	63.1	28.7	2.3	----------	-----------	2.3	3.3
5R	311.0	0.2	78.1	17.6	1.5	----------	-----------	2.5	0.4
Average----	-------	0.2	67.1	21.2	2.9	----------	-----------	2.6	6.2

Mineralogy

Fresh, unweathered, and unaltered dacite porphyry occurs only locally and consists mainly of plagioclase, biotite, and magnetite in a groundmass of perlitic glass. Such rocks occur locally at depths less than 100 feet in the site areas. Perlite is the major constituent and comprises an average of 72.0 percent, by volume, of the dacite. The perlitic cracks commonly form complete spheroids in the glass, which is colorless or light gray. The glass is slightly devitrified, most commonly along adjoining perlitic cracks and along the edges of phenocrysts. Small felsitic aggregates of quartz and feldspar occur in scattered patches. Deuteric action has left reaction rims on most of the hornblende and hypersthene phenocrysts and on some of the biotite phenocrysts.

Crystals of sanidine, which are generally rare although common locally, occur as unaltered euhedral to subhedral crystals as much as 2 mm across. A few quartz microlites are scattered in the groundmass. The largest phenocrysts in the rock are zoned plagioclase crystals as much as 6 mm in diameter. The outer zones are oligoclase and andesine, ranging from An_{25} to An_{40} in composition. Numerous andesine microlites in the groundmass glass are An_{35-50}. Plagioclase crystals comprise an average of 20.0 percent, by volume, of the rock. Biotite phenocrysts as much as 1.5 mm in diameter compose 3.7 percent of the rock. They are unaltered except for reaction rims and contain a few scattered inclusions of sanidine and magnetite. The biotite is reddish brown and mainly euhedral although some crystals have battlemented ends. Locally, small euhedral crystals of olive-green hornblende and pleochroic hypersthene, less than 1 mm in diameter, compose less than 0.5 percent of the rock. Euhedral to anhedral crystals of magnetite are disseminated throughout the rock and constitute almost 2.0 percent of the rock by volume.

Alteration and weathering

The dacite porphyry is commonly altered hydrothermally and weathered at various depth intervals. Hydrothermal alteration is most intense in the areas penetrated by test holes Pluto-4 and -5 and below 300 feet in Pluto-1 (p. 96-126). The effect of weathering is apparent in both the fresh and hydrothermally altered rocks, which occur randomly throughout the rock drilled. In general, the most weathered rock is near the surface at depths less than 160 feet, but moderate weathering has occured along fractures as deep as 650 feet.

Locally, opal, deposited from silica-bearing hydrothermal solutions, constitutes a large percentage of the rock. The hydrothermal solutions also reacted with the rock constituents to form montmorillonite, dolomite, calcite, epidote, chlorite, and gypsum. The montmorillonite and other clay minerals were derived, in large part, by hydrothermal action on the groundmass glass and, to a lesser extent, from plagioclase. Dolomite formed from magnesium- and calcium-bearing minerals such as hornblende and hypersthene in close association with plagioclase. Epidote is closely associated with chlorite, and both are formed from alteration of plagioclase, biotite, hornblende, and hypersthene. Gypsum has been formed locally as blebs and stringers by the introduction of calcium- and sulfur- bearing hydrothermal solutions.

Weathering, accelerated mainly by the action of downward-moving meteroric waters, has caused mild to severe changes in the mineralogic, textural, and structural form of the fresh and hydrothermally altered rock. The groundmass has been most susceptible to attack. It has been oxidized to a reddish brown and changed to a mixture of clay minerals. Generally, the perlitic cracks are no longer discernable. The phenocrysts remain relatively unaffected, but the edges of most of the magnetite grains are oxidized. Pore space is greatest in the most intensely weathered rocks and occurs either as connected or as nonconnected cavities that commonly are partly or entirely filled with clay minerals, calcite, iron oxides, and rarely with an unidentified zeolite.

X-ray analyses of 14 samples (table 3) were made of representative rock specimens from depths of 83.3, 130.0, 450.0, and 550.0 feet in test hole Pluto-1, from depths of 83.5 and 108.0 feet in test hole Pluto-2, from a depth of 221.0 feet in test hole Pluto-3, from depths of 99.0 and 252.5 feet from test hole Pluto-4, and from depths of 13.0, 35.5, 75.5, 224.5, and 311.0 feet in test hole Pluto-5. The minerals identified are cristobalite, clay (montmorillonite and illite), mica, feldspar, dolomite, and calcite; the results of the analyses are given in a numerical code that represents the percentage-range of the minerals found (table 3).

Chemical composition

Rapid rock chemical analyses and semiquantitative spectrographic analyses were run for 23 samples. The results of the rapid rock analyses are given by the percentages of oxides present (table 4); the samples were analyzed by methods similar to those described by Shapiro and Brannock (1956, p. 19-56). The results of spectrographic analyses of these rock samples are given by percentages of elements present, and only the elements detected are reported (table 5).

Table 3.--X-ray analyses of core samples from Area 401, Nevada Test Site

Analyst: Theodore Botinelly

[Analyses code: 1 = > 75 percent; 2 = 50 to 75 percent; 3 = 25 to 50 percent; 4 = 10 to 25 percent; 5 = < 10 percent]

Sample No. Pluto-	Depth (feet)	Cristobalite	Clay	Mica	Feldspar	Dolomite	Calcite
1B	83.3	4	3	4	4	--------	-------
1F	130.0	4	3	4	2-3	--------	-------
1U	450.0	2-3	3	5	4	--------	-------
1X	550.0	2-3	3	----	3	--------	-------
2D	83.5	3	3	----	2-3	--------	-------
2F	108.0	3	3	----	3	--------	-------
3H	221.0	3	4	5	4	--------	-------
4F	99.0	3	4	----	3	--------	-------
4T	252.5	3	4	----	2-3	--------	-------
5A	13.0	3	4	----	4	--------	-------
5B	35.5	3	3	----	4	--------	5
5D	75.5	2-3	4	----	4	--------	-------
5L	244.5	5	4	5	3	5	5
5R	311.0	3	3	----	4	--------	-------

Table 4.--Chemical analyses (in percent) of core samples from Area 401, Nevada Test Site

Sample Pluto-	Depth (feet)	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O_3	K_2O	H_2O	TiO_2	P_2O_5	MnO	CO_2
Unweathered to slightly weathered unaltered dacite														
1A	65.5	64.0	15.9	2.4	1.1	1.8	3.8	2.3	3.1	4.8	0.50	0.28	0.09	<0.05
1D	109.8	64.5	16.2	2.4	1.1	1.4	3.7	2.6	3.7	3.6	.48	.24	.08	<.05
1F	130.0	62.6	16.2	3.1	.27	1.8	4.4	2.2	1.2	6.7	.50	.27	.02	.15
1X	550.0	63.8	16.2	4.3	.18	1.2	3.0	2.6	3.6	3.8	.58	.24	.03	.10
2D	83.5	61.7	16.7	5.2	.09	1.6	4.1	2.8	2.8	3.7	.68	.30	.05	<.05
2F	108.0	61.4	17.2	5.3	.13	1.4	4.6	3.0	2.6	3.2	.70	.32	.05	<.05
5D	75.5	60.6	17.4	4.7	.37	1.4	4.1	2.9	2.8	4.4	.73	.32	.04	.06
Average-----------------------		62.7	16.5	3.9	.46	1.5	4.0	2.6	2.8	4.3	.60	.28	.05	.06
Moderately to severely weathered unaltered dacite														
1B	83.3	64.9	13.8	3.0	0.16	1.9	4.7	1.6	1.1	6.9	0.47	0.20	0.05	1.20
1K	217.5	63.5	16.6	3.3	.30	1.2	4.2	2.7	3.4	3.1	.52	.26	.05	.62
1S	400.0	63.4	15.4	3.8	.11	1.6	3.9	2.6	3.6	3.3	.54	.23	.09	1.60
1U	450.0	64.4	15.7	4.1	.06	1.3	3.2	2.6	3.6	3.5	.57	.24	.05	.51
3H	221.0	62.2	15.7	4.7	.10	1.4	3.8	2.3	3.8	4.0	.52	.24	.08	.88
4F	99.0	59.5	16.2	4.9	.06	2.2	5.9	2.6	2.2	4.4	.66	.28	.14	1.20
4T	252.5	60.1	16.4	4.3	.05	2.2	3.2	2.0	2.6	7.8	.60	.27	.06	.32
5A	13.0	58.6	15.4	6.1	.05	1.3	5.4	2.2	2.6	5.4	.70	.28	.16	1.90
Average-----------------------		62.1	15.7	4.3	.11	1.6	4.3	2.3	2.9	4.8	.57	.25	.08	1.03
Unweathered to slightly weathered altered dacite														
5F	120.0	60.2	17.2	3.7	1.40	1.8	4.9	2.7	2.8	3.5	0.76	0.30	0.06	0.60
5H	167.0	47.7	12.5	3.1	2.20	3.4	12.8	2.2	2.2	2.8	.58	.24	.40	10.10
5P	276.0	59.5	16.1	4.1	1.30	2.5	4.8	3.0	3.1	3.8	.73	.30	.10	.90
5Q	298.0	60.4	16.2	3.5	1.80	2.3	5.2	3.0	2.8	2.8	.70	.29	.08	1.00
5R	311.0	58.7	15.6	5.1	.68	2.9	3.7	2.1	3.4	5.4	.71	.28	.06	1.50
Average-----------------------		57.3	15.5	3.9	1.48	2.6	6.3	2.6	2.9	3.7	.70	.28	.14	2.82
Moderately to severely weathered altered rock														
5B	35.5	46.5	12.1	5.3	.14	1.0	15.0	1.6	2.5	5.5	0.58	0.24	0.12	9.80
5E	102.0	59.8	16.5	5.0	.20	1.4	5.0	2.4	2.8	4.6	.71	.29	.08	1.30
5L	224.5	41.5	11.1	2.6	3.60	6.4	12.6	1.6	1.9	4.2	.48	.21	.54	13.50
Average-----------------------		49.3	13.2	4.3	1.31	2.9	10.9	1.9	2.4	4.8	.59	.25	.25	8.20

Table 5.--Semiquantitative spectrographic analyses of core samples from Area 401, Nevada Test Site

[M, >10 percent]

Sample No. Pluto-	1A	1B	1D	1F	1K	1S	1U	1X	2D	2F	3H	4F	4T	5A	5B	5D	5E	5F	5H	5L	5P	5Q	5R
Depth (feet)	65.5	83.3	109.8	130.0	217.5	400.0	450.0	550.0	83.5	108.0	221.0	99.0	252.5	13.0	35.5	75.5	102.0	120.0	167.0	224.5	275.0	298.0	311.0
Si	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
Al	M	7	M	7	M	M	M	M	M	M	M	M	M	M	7	M	7	7	7	7	7	7	7
Fe	3	3	3	3	3	3	3	3	5	5	3	3	3	3	3	3	3	3	3	2	3	3	3
Mg	1.5	1.5	1	1	1	1	1	1	1	1	.7	1	1.5	1	1	1	1	1	2	3	1	1	1.5
Ca	5	5	3	3	3	5	3	2	3	3	2	5	3	3	M	3	3	3	M	M	3	3	2
Na	2	1.5	2	1.5	2	2	2	1.5	2	2	2	1.5	1.5	1.5	1.5	2	1.5	1.5	2	1.5	1.5	1.5	1.5
K	3	1.5	3	1	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	3	3	3
Ti	.3	.2	.3	.2	.3	.3	.3	.3	.3	.3	.2	.2	.2	.2	.2	.3	.3	.3	.2	.15	.3	.3	.3
Mn	.07	.05	.07	.02	.05	.07	.05	.02	.05	.03	.03	.15	.05	.1	.07	.02	.03	.03	.2	.3	.05	.03	.05
Ba	.15	.1	.15	.15	.2	.2	.2	.15	.15	.15	.15	.15	.15	.15	.1	.15	.15	.1	.07	.07	.15	.15	.15
Be	.0002	0	.00015	0	.00015	.00015	0	.00015	0	.00015	.00015	0	0	0	0	.00015	0	0	0	0	0	0	0
Ce	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02
Co	.001	.0007	.0007	.0007	.0007	.001	.0007	.0007	.0015	.0015	.001	.0015	.0015	.0015	.001	.0015	.0015	.0015	.0007	.001	.0007	.001	.001
Cr	.0015	.0015	.0015	.0015	.0015	.002	.002	.0015	.002	.003	.001	.002	.003	.003	.003	.003	.002	.002	.002	.001	.002	.002	.002
Cu	.001	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.002	.002	.0015	.002	.002	.0015	.003	.0015	.0015
Ga	.002	.002	.003	.002	.002	.002	.002	.002	.002	.003	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002
La	.007	.007	.007	.007	.007	.007	.007	.007	.007	.007	.007	.007	.007	.007	.007	.007	.007	.007	.007	.007	.007	.007	.005
Nb	0	0	0	0	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.0015	0	0	0	.0015	.0015
Ni	0	.0005	.002	.0007	.0007	.0007	.001	.0007	.002	.002	.0007	.0015	.001	.002	.001	.0015	.0015	.0015	.001	.0007	.001	.0015	.0015
Pb	.003	.002	.005	.002	.003	.003	.002	.002	.002	.002	.002	.002	.003	.002	.002	.002	.002	.002	.0015	.0015	.002	.002	.0015
Sc	.001	.001	.001	.001	.001	.002	.001	.001	.002	.002	.001	.0015	.0015	.0015	.0015	.002	.0015	.002	.0015	.001	.0015	.002	.0015
Sr	.07	.05	.07	.05	.07	.05	.05	.07	.07	.1	.07	.07	.07	.07	.07	.05	.07	.07	.07	.05	.07	.1	.05
Th	.03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
V	.007	.005	.007	.007	.007	.007	.007	.005	.01	.02	.005	.01	.01	.01	.01	.02	.01	.015	.01	.007	.01	.01	.01
Y	.003	.002	.003	.003	.003	.003	.003	.002	.003	.003	.002	.003	.002	.003	.003	.003	.003	.003	.003	.002	.002	.002	.002
Yb	.0003	.0002	.0003	.0003	.0003	.0003	.0003	.0002	.0003	.0005	.0003	.0003	.0003	.0003	.0003	.0003	.0005	.0003	.0003	.0002	.0003	.0003	.0003
Zr	.02	.015	.02	.015	.02	.015	.015	.015	.01	.02	.015	.015	.01	.015	.01	.02	.02	.02	.007	.007	.01	.01	.02
Nd	<.01	0	0	0	<.01	<.01	0	0	<.01	<.01	0	0	0	0	0	<.01	0	0	0	0	0	0	0

Major chemical constituents

The large amount of glass in the groundmass prohibited an estimation of the chemical composition of the host rock by petrographic methods. Samples from rocks showing varying degrees of hydrothermal alteration and weathering, as well as from unaltered rock, were selected for chemical and spectrographic analyses (tables 4 and 5, respectively). The classification by alteration and weathering shown in table 4 was based on petrographic examination. Analyses of the dacite porphyry have shown that it may be classified chemically as rhyodacite due to the high percentage of silica in the groundmass glass.

Hydrothermal alteration and weathering change the composition of the dacite porphyry. The large amounts of CaO and CO_2 in certain specimens is a good indicator of the amount of alteration and weathering and is represented by secondary calcite. The ratio of ferrous oxide (FeO) to ferric oxide (Fe_2O_3) is also an indicator of hydrothermal alteration and weathering. The percentage of FeO was increased greatly by alteration and decreased moderately by weathering. Fe_2O_3 was not affected by alteration but was increased slightly by weathering. In unweathered and unaltered dacite the amount of FeO is much less than Fe_2O_3, but in rocks subjected to hydrothermal alteration the percentage of FeO may approach or exceed the percentage of Fe_2O_3. The amount of MgO and MnO may be 4 or 5 times greater in the altered rock than in unaltered rock. MgO was increased slightly in percentage by weathering and was increased moderately by alteration, whereas MnO was increased moderately by weathering and was increased greatly by alteration.

The remaining oxides also demonstrate a tendency to increase or decrease as the result of hydrothermal alteration and weathering but do not change so strikingly as those oxides mentioned above. SiO_2 and Al_2O_3 was decreased moderately by alteration and slightly in percentage by weathering. The percentage of H_2O was decreased slightly in the dacites subjected to alteration, but was increased slightly in weathered rocks. Alteration tended to increase slightly the amount of Ti^O2, whereas weathering appears to have reduced slightly the amount of Ti^O2.

Minor chemical constituents

Spectrographic chemical analyses (table 5) were made for the same samples used in the rapid rock chemical analyses (table 4) to determine the minor elements in the dacite porphyry and to ascertain the effect of weathering and hydrothermal alteration on the amount, distribution, and occurrence of the minor elements. There are no noticeable deviations in the percentages of most of the minor elements found as the result of hydrothermal alteration or weathering. The percentages of barium, copper, and lead are not affected by weathering, but the barium and lead tend to decrease slightly and copper tends to increase moderately upon alteration. The percentages of nickel and vanadium are not changed by alteration and are only slightly decreased by weathering. Beryllium is increased by weathering but appears to have been eliminated by alteration. Zirconium is decreased slightly by weathering and alteration.

Physical properties

Porosity and density

Porosity, grain density, and dry bulk density measurements were determined on core samples from the 5 test holes (tables 6 and 7). These measurements were determined by saturation in either water or

Table 6.--Density and porosity measurements of core samples from Area 401, Nevada Test Site

Sample No. Pluto-	Depth (feet)	Porosity (percent)	Grain density (g/cc)	Dry bulk density (g/cc)
1A	65.5	11.5	2.46	2.28
1B	83.3	45.5	2.47	1/ 1.35
1C	101.0	16.3	2.52	2.11
1D	109.8	9.3	2.52	2.29
1E	127.5	13.7	2.42	1/ 2.09
1F	130.0	19.7	2.50	1/ 2.01
1Fa	144.0	17.2	2.56	1/ 2.12
1G	158.0	14.8	2.55	2.17
1H	173.0	5.5	2.42	2.29
1J	190.0	10.6	2.17	1.94
1K	217.5	10.9	2.61	2.32
1L	240.0	7.1	2.58	2.39
1M	271.0	11.2	2.54	2.25
1N	298.0	10.8	2.54	2.26
1P	326.0	12.6	2.54	2.22
1Q	354.0	8.9	2.52	2.30
1R	378.0	10.0	2.50	2.25
1S	400.0	8.1	2.52	2.31
1T	421.0	8.3	2.43	2.23
1U	450.0	8.1	2.51	2.31
1V	478.0	5.9	2.51	2.36
1W	520.0	8.3	2.50	2.29
1X	550.0	16.4	2.58	2.15
1Y	580.0	11.8	2.57	2.26
1Z	625.0	12.4	2.56	2.24
1AA	643.0	11.6	2.54	2.24
1BB	673.0	11.3	2.53	2.24
1CC	686.0	10.1	2.56	2.30
1DD	721.0	5.3	2.55	2.42
1EE	758.0	4.1	2.56	2.46
1FF	776.0	9.3	2.63	2.39
2A	12.5	19.8	2.61	2.09
2B	45.0	6.7	2.61	2.43
2C	65.0	12.6	2.61	2.28
2D	83.5	9.3	2.59	2.35
2E	102.0	10.4	2.60	2.33
2F	108.0	5.1	2.62	2.48

Table 6.--Density and porosity measurements of core samples from Area 401, Nevada Test Site--Continued

Sample No. Pluto-	Depth (feet)	Porosity (percent)	Grain density (g/cc)	Dry-bulk density (g/cc)
3A	62.0	29.9	2.51	1/ 1.76
3B	100.0	25.7	2.48	1/ 1.84
3C	130.0	2.0	2.48	1/ 2.43
3D	161.5	13.4	2.59	2.24
3E	164.0	13.0	2.49	1/ 2.17
3F	190.5	8.0	2.50	2.30
3G	207.5	12.2	2.60	2.28
3H	221.0	7.8	2.52	2.32
3J	232.5	11.6	2.56	2.26
3K	258.5	5.6	2.50	2.36
4A	57.0	14.9	2.57	1/ 2.18
4B	64.0	23.4	2.57	1/ 1.97
4C	80.0	13.8	2.56	1/ 2.21
4D	83.5	11.3	2.61	1/ 2.31
4E	92.5	9.7	2.59	1/ 2.34
4F	99.0	9.8	2.59	1/ 2.34
4G	106.5	8.5	2.58	1/ 2.37
4H	117.5	6.1	2.59	1/ 2.43
4J	130.0	16.1	2.60	1/ 2.18
4K	148.0	6.0	2.61	2.46
4L	153.5	9.2	2.62	1/ 2.38
4M	178.0	3.3	2.56	1/ 2.48
4N	189.0	4.8	2.55	1/ 2.43
4P	204.5	2.3	2.58	1/ 2.52
4Q	214.5	4.7	2.58	1/ 2.46
4R	223.0	4.2	2.60	2.49
4S	237.0	3.7	2.55	1/ 2.45
4T	252.5	5.5	2.54	1/ 2.40
5A	13.0	15.7	2.60	1/ 2.19
5B	35.5	15.9	2.56	1/ 2.15
5C	59.0	13.4	2.61	1/ 2.26
5D	75.5	9.0	2.58	1/ 2.35
5E	102.0	14.6	2.57	1/ 2.19
5F	120.0	9.9	2.61	1/ 2.35
5G	148.0	5.3	2.59	1/ 2.45
5H	167.0	4.4	2.57	1/ 2.46
5J	193.5	3.0	2.63	2.55
5L	224.5	7.0	2.56	1/ 2.39

Table 6.--Density and porosity measurements of core samples from Area 401, Nevada Test Site--Continued

Sample No. Pluto-	Depth (feet)	Porosity (percent)	Grain density (g/cc)	Dry-bulk density (g/cc)
5M	238.0	9.0	2.61	2.37
5N	257.0	7.7	2.58	1/ 2.38
5P	276.0	3.2	2.56	1/ 2.48
5Q	298.0	9.2	2.57	1/ 2.33
5R	311.0	12.8	2.55	1/ 2.23
5S	318.0	4.5	2.57	1/ 2.42

1/ Density determined by kerosene-saturation method; all other measurements by water-saturation method.

Table 7.--Porosity and density measurements of core samples from test hole Pluto-1, Area 401, Nevada Test Site, taken at approximately 10-foot intervals

[Method used: Kerosene saturation]

Depth (feet)	Porosity (percent)	Grain density (g/cc)	Dry bulk density (g/cc)	Depth (feet)	Porosity (percent)	Grain density (g/cc)	Dry bulk density (g/cc)
37.6	29.2	2.55	1.81	430.0	10.1	2.57	2.31
49.7	23.7	2.49	1.90	440.0	10.0	2.58	2.32
60.2	14.2	2.45	2.10	450.0	7.5	2.53	2.34
71.4	3.7	2.45	2.35	460.0	11.5	2.55	2.26
80.0	24.5	2.45	1.85	470.0	15.0	2.56	2.17
88.7	11.9	2.45	2.16	480.0	8.7	2.54	2.32
100.0	21.7	2.45	1.92	490.0	11.3	2.56	2.27
109.7	1.8	2.47	2.43	499.3	7.0	2.54	2.36
120.0	20.2	2.49	1.98	509.4	13.6	2.56	2.21
130.0	21.9	2.55	1.99	520.6	8.0	2.55	2.35
140.0	19.9	2.57	2.06	530.0	15.3	2.56	2.17
150.0	14.7	2.56	2.18	540.0	10.1	2.55	2.29
160.0	14.0	2.56	2.21	550.0	8.5	2.55	2.33
171.5	11.5	2.54	2.25	559.0	8.3	2.55	2.33
180.0	11.9	2.55	2.24	570.0	7.0	2.53	2.35
190.0	8.4	2.54	2.32	579.4	8.4	2.55	2.33
200.0	7.1	2.54	2.36	590.0	9.5	2.56	2.31
210.0	11.7	2.55	2.25	600.0	7.2	2.53	2.35
220.0	7.6	2.53	2.34	610.0	5.6	2.55	2.40
230.0	7.0	2.52	2.34	620.0	6.4	2.55	2.39
239.5	9.9	2.54	2.29	630.0	8.0	2.54	2.34
250.0	9.9	2.54	2.29	640.0	6.2	2.55	2.39
260.0	10.5	2.56	2.29	652.0	9.9	2.54	2.29
270.0	9.4	2.55	2.31	657.3	10.1	2.54	2.28
280.0	7.1	2.53	2.35	670.0	14.1	2.53	2.17
289.6	13.3	2.56	2.22	680.0	11.6	2.55	2.26
300.0	13.8	2.56	2.20	689.5	10.0	2.56	2.30
310.0	8.9	2.55	2.32	700.0	5.2	2.56	2.42
320.0	8.4	2.55	2.33	710.0	9.4	2.56	2.32
330.0	9.6	2.55	2.30	720.0	10.4	2.57	2.30
340.0	10.8	2.55	2.28	730.0	9.0	2.57	2.34
350.0	8.0	2.56	2.35	740.0	8.7	2.56	2.34
360.0	6.4	2.53	2.37	750.0	5.7	2.55	2.40
370.0	11.8	2.56	2.26	760.0	6.9	2.56	2.39
380.0	10.6	2.57	2.30	770.0	7.1	2.55	2.37
390.0	10.0	2.55	2.29	775.0	6.4	2.59	2.42
400.0	11.1	2.57	2.28				
410.0	9.1	2.56	2.33				
420.0	8.8	2.55	2.33				

kerosene. Kerosene saturation was used for rock samples that disintegrated when water saturation was attempted. The two methods are identical except that the calculations on kerosene-saturated samples are corrected to take into account the different specific gravities of the two liquids.

The grain densities of four core samples were determined by the powder-density method (table 8). This procedure is much slower than the water-saturation method, but more accurate for those samples which have some nonconnected pore space. The results of the two methods are within 0.03 g/cc in all samples measured. This indicates, first, that the water saturation method is generally reliable for these rocks and, second, that these rocks do not have a large percentage of nonconnected pore space.

The porosity, grain density, and dry bulk density analyses (tables 6 and 7) show great variability in the rock. Because the elasticity and strength of the rocks appear to be closely related to porosity and density, the wide range in the porosity and density values suggests that the elasticity and strength of the rocks also are variable. Porosity of these rocks ranges from 1.8 to 45.5 percent with an average porosity of 10.7 percent. The grain density of the dacite porphyry ranges from 2.17 to 2.63 g/cc and averages 2.5 g/cc. The dry bulk density of the dacite porphyry ranges from 1.35 g/cc to 2.55 g/cc and averages 2.27 g/cc.

The porosity and density are affected by the kind and extent of weathering and hydrothermal alteration to which the rocks have been subjected. Porosity is a particularly good indicator of whether the rocks are weathered or altered. The average porosities of the unweathered to slightly weathered fresh dacite porphyry and altered dacite porphyry are 11.5 and 7.9 percent, respectively. The porosities average 14.9 and 12.5 percent, respectively, in moderately to severely weathered unaltered dacite porphyry

Table 8.--Comparison of grain density of four samples determined by water-saturation and powder-density methods

Sample No. Pluto-	Grain density (g/cc) (water-saturation method)	Grain density (g/cc) (powder-density method)
2C	2.61	2.59
2E	2.60	2.62
4A	2.57	2.60
5F	2.61	2.59

and altered dacite porphyry (table 8-A).

Gas permeability

Laboratory tests to determine gas permeability values were made for core samples representative of the dacite porphyry. The results of the permeability tests (table 9) indicate that there is no direct relation between permeability and depth. With the exception of the core sample from 670 feet, the table shows that the free paths of the nitrogen molecules are greatly reduced as the pressures on the samples are increased. A barely discernible fracture parrallel to the long direction of the core accounts for the fact that the sample from 670 feet has the highest porosity and permeability of any tested.

Magnetic susceptibility

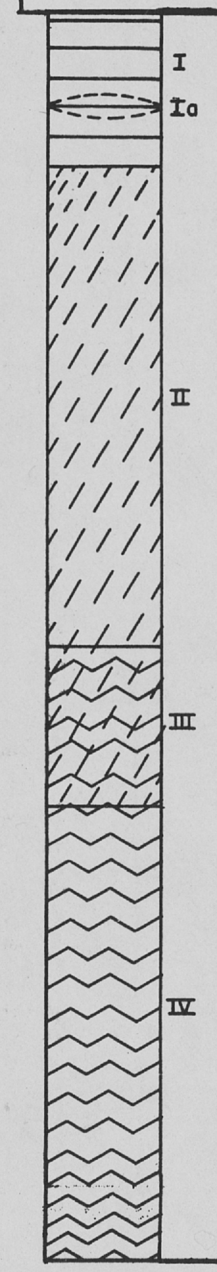
Magnetic susceptibility measurements of cores from all of the test holes in Area 401 were made in the laboratory. The magnetic susceptibility of the dacite porphyry (table 10) ranges widely from $3{,}394.8 \times 10^{-6}$ units (c.g.s. system) in an unweathered sample that was highly altered hydrothermally to 19.5×10^{-6} units in a very severely weathered rock sample that was unaltered. The magnetic susceptibility of all the samples tested averaged 837.0×10^{-6} units.

The magnetic susceptibility of these rocks appears to be a good indication of weathering and hydrothermal alteration. Although there are some notable exceptions, weathering tends to decrease the susceptibility and alteration tends to increase it. In unweathered to slightly weathered unaltered samples the magnetic susceptibility averages 986.2×10^{-6} units, whereas in moderately to severely weathered unaltered rock the average magnetic susceptibility is 481.0×10^{-6} units, or less than half. Unweathered to slightly weathered hydrothermally altered dacite

Table 8A.--Averages for physical properties of dacite porphyry, Area 401, Nevada Test Site

[N, number of samples analyzed]

Explanation of alteration zones



Not to scale

Description	Physical properties	Pluto-1 Zone Ia 108-136 ft	(N)	Pluto-1 Zone I 0-164 ft	(N)	Pluto-1 Zone II 164-550 ft	(N)	Pluto-1 Zone III 550-670 ft	(N)	Pluto-1 Zone IV 670-778 ft	(N)
Light-gray, severely weathered and unaltered.	Porosity (percent)------------	5.5	2	17.1	22	9.9	58	9.1	15	8.2	16
Lenses of light-gray fresh rock.	Grain density (g/cc)----------	2.50	2	2.50	22	2.54	58	2.54	15	2.56	16
	Dry bulk density (g/cc)-------	2.36	2	2.07	22	2.28	58	2.31	15	2.35	16
Brownish-gray, moderately weathered, unaltered to slightly altered.	Saturated bulk density (g/cc)-	---	---	2.37	1	2.37	4	---	---	---	---
	Natural-state bulk density (g/cc)---------------------	---	---	---	---	---	---	---	---	---	---
	Dynamic:										
	Young's modulus (10^6 psi)---	8.13	1	2.90	3	3.84	16	4.37	2	4.78	2
	Poisson's ratio-------------	.2940	1	.0976	3	.1395	16	.1761	2	.1020	2
	Modulus of rigidity (10^6 psi)----------------------	3.14	1	1.31	3	1.69	16	1.86	2	2.16	2
Transitional between zones II and IV, banded brownish gray and greenish gray.	Longitudinal velocity (ft/sec)------------------	18,205	1	10,016	3	11,431	16	12,189	2	11,505	2
	Transverse velocity (ft/sec)	9,824	1	6,963	3	7,391	16	7,635	2	8,133	2
Greenish-gray, unweathered and altered.	Static:										
	Young's modulus (10^6 psi)---	---	---	1.74	3	3.47	11	2.11	5	4.82	4
	Poisson's ratio (10^6 psi)---	---	---	.22	2	.16	11	.15	2	.28	3
	Unconfined compressive strength (psi)------------	---	---	9,200	3	14,900	11	13,833	3	15,533	3
	Magnetic susceptibility (-10^6 cgs)----------------	1,597.3	1	1,353.6	7	657.8	17	659.6	4	1,381.7	3

Physical properties	Pluto-3 Zone Ia 110(?)-156 ft	(N)	Pluto-3 Zone I 0-160 ft	(N)	Pluto-3 Zone II 160-263 ft	(N)	Pluto-6 Zone II 160-475 ft	(N)	Pluto-6 Zone III 475-640 ft	(N)	Pluto-6 Zone IV 640-1,000 ft	(N)
Porosity (percent)------------	5.1	2	24.3	2	11.2	11	13.0	3	12.7	2	---	---
Grain density (g/cc)----------	2.48	2	2.50	2	2.54	11	2.60	3	2.61	2	---	---
Dry bulk density (g/cc)-------	2.35	2	1.80	2	2.25	11	2.26	3	2.28	2	---	---
Saturated bulk density (g/cc)-	2.36	1	---	---	2.34	4	---	---	---	---	---	---
Natural-state bulk density (g/cc)---------------------	---	---	---	---	---	---	---	---	---	---	---	---
Dynamic:												
Young's modulus (10^6 psi)---	9.19	1	---	---	4.25	9	---	---	---	---	---	---
Poisson's ratio-------------	.1692	1	---	---	.1227	9	---	---	---	---	---	---
Modulus of rigidity (10^6 psi)----------------------	3.93	1	---	---	1.88	9	---	---	---	---	---	---
Longitudinal velocity (ft/sec)------------------	---	---	---	---	11,726	9	---	---	---	---	---	---
Transverse velocity (ft/sec)	---	---	---	---	7,582	9	---	---	---	---	---	---
Static:												
Young's modulus (10^6 psi)---	---	---	---	---	3.56	5	---	---	---	---	---	---
Poisson's ratio (10^6 psi)---	---	---	---	---	.18	4	---	---	---	---	---	---
Unconfined compressive strength (psi)------------	---	---	---	---	14,360	5	---	---	---	---	---	---
Magnetic susceptibility (-10^6 cgs)----------------	1,755.7	2	1,039.6	2	550.7	11	168.2	10	394.3	9	1,635.2	3

Physical properties	Shaft, anchor, and chamber Zone Ia 110-135 ft	(N)	Shaft, anchor, and chamber Zone I 0-165 ft	(N)	Shaft, anchor, and chamber Zone II 165-180 ft	(N)	Grand averages Zone Ia	(N)	Grand averages Zone I	(N)	Grand averages Zone II	(N)	Grand averages Zone III	(N)	Grand averages Zone IV	(N)
Porosity (percent)------------	7.9	2	22.0	6	14.4	11	6.2	6	18.6	30	10.8	83	9.5	17	8.2	16
Grain density (g/cc)----------	2.56	2	2.61	6	2.59	11	2.51	6	2.52	30	2.54	83	2.55	17	2.56	16
Dry bulk density (g/cc)-------	2.36	2	1.95	11	2.44	10	2.36	6	2.02	35	2.27	82	2.30	17	2.35	16
Saturated bulk density (g/cc)-	2.44	2	2.26	6	2.37	11	2.41	3	2.27	7	2.36	19	---	---	---	---
Natural-state bulk density (g/cc)---------------------	2.43	2	2.23	6	2.32	11	2.43	2	2.23	6	2.32	11	---	---	---	---
Dynamic:																
Young's modulus (10^6 psi)---	4.76	2	1.64	5	4.16	7	6.71	4	2.36	8	4.03	32	4.37	2	4.78	2
Poisson's ratio-------------	.2226	2	.2050	5	.1923	7	.2273	4	.1647	8	.1464	32	.1761	2	.1020	2
Modulus of rigidity (10^6 psi)----------------------	1.95	2	.67	5	1.74	7	2.74	4	.94	8	1.75	32	1.86	2	2.16	2
Longitudinal velocity (ft/sec)------------------	13,561	2	8,276	5	12,475	7	15,109	3	8,929	8	11,742	32	12,189	2	11,505	2
Transverse velocity (ft/sec)	7,933	2	4,931	5	7,569	7	8,563	3	5,693	8	6,595	32	7,635	2	8,133	2
Static:																
Young's modulus (10^6 psi)---	---	---	---	---	---	---	---	---	1.74	3	3.44	16	2.11	5	4.82	4
Poisson's ratio (10^6 psi)---	---	---	---	---	---	---	---	---	.22	2	.16	15	.15	2	.28	2
Unconfined compressive strength (psi)------------	---	---	---	---	---	---	---	---	9,200	3	14,731	16	13,833	3	15,533	3
Magnetic susceptibility (-10^6 cgs)----------------	1,865.3	2	1,353.3	13	956.8	9	1,767.8	5	1,324.9	22	256.1	47	475.8	13	1,508.5	6

Table 9.--Permeability to nitrogen of five samples from test hole Pluto-1, Area 401, Nevada Test Site

[Analyses by D. D. Dickey and E. F. Monk]

Depth (feet)	Porosity (percent)	Permeability (millidarcys) measured at different pressures						
		14.7 (psi)	100 (psi)	250 (psi)	500 (psi)	1,000 (psi)	1,500 (psi)	2,000 (psi)
320	8.4	<0.1	<0.005	<0.005	0.0005	0.0005	0.00067	0.0017
450	7.5	<.1	<.005	<.005	<.0001	<.0001	<.0001	<.0001
579	8.4	<.1	<.005	<.005	.00017	.00013	.00014	.00014
670 1/	14.1	1.7	1.4	1.1	.8	1.1	2/	2/
750	5.7	<.1	<.005	<.005	.0006	.0005	.0015	.0017

1/ Very small fracture present.

2/ Flow too rapid for accurate measurement with equipment used.

Table 10.--Magnetic susceptibility of core samples from Area 401, Nevada Test Site

Sample No. Pluto-	Depth (feet)	Magnetic susceptibility (10^{-6} cgs)	Alteration zone
1A	65.5	2,040.6	Light-gray, severely weathered, unaltered with lenses of fresh rock.
1B	83.3	1,115.1	
1D	109.8	1,597.3	
1E	127.5	1,004.8	
1F	130.0	944.1	
1Fa	144.0	990.1	
1Fd	156.0	1,679.3	
1G	158.0	1,700.9	
1Gb	167.0	1,773.3	Brownish-gray, moderately weathered, unaltered to slightly altered.
1Gd	172.8	985.0	
1H	173.0	920.5	
1Ha	175.0	1,373.6	
1Hc	183.0	1,440.7	
1J	190.0	903.8	
1K	217.5	695.2	
1L	240.0	1,032.0	
1M	271.0	393.9	
1N	298.0	176.2	
1P	326.0	113.9	
1R	378.0	158.2	
1S	400.0	193.2	
1T	421.0	195.4	
1U	450.0	326.5	
1W	520.0	223.7	
1X	550.0	277.6	
1Y	580.0	634.1	Transitional brownish- and greenish-gray.
1Z	625.0	1,002.1	
1AA	643.0	300.9	
1BB	673.0	964.9	Greenish-gray, unweathered, altered.
1CC	686.0	370.4	
1DD	721.0	986.5	
1EE	758.0	1,579.8	
1FF	776.0	1,578.8	
2A	12.5	324.8	
2B	45.0	545.9	
2C	65.0	374.8	
2D	83.5	406.3	

Table 10.--Magnetic susceptibility of core samples from Area 401, Nevada Test Site--Continued

Sample No. Pluto-	Depth (feet)	Magnetic susceptibility (10^{-6} cgs)	Alteration zone
2E	102.0	329.1	
2F	108.0	488.4	
3A	62.0	1,077.6	Light-gray, severely weathered, unaltered with lenses of fresh rock.
3B	100.0	1,001.6	
3C	130.0	1,903.9	
3Ca	156.0	1,607.4	
3D	161.5	1,430.0	Brownish-gray, moderately weathered, unaltered to slightly altered.
3E	164.0	474.7	
3Ea	167.2	409.0	
3Eb	172.2	605.3	
3Ec	175.0	712.2	
3Ed	180.0	462.9	
3F	190.5	344.5	
3G	207.5	757.1	
3H	221.0	274.7	
3J	232.5	274.5	
3K	258.5	313.2	
4A	57.0	19.5	
4B	64.0	22.7	
4C	80.0	35.0	
4D	83.5	102.1	
4E	92.5	127.5	
4F	99.0	281.0	
4G	106.5	565.4	
4H	117.5	613.7	
4J	130.0	734.8	
4L	153.5	897.3	
4M	178.0	670.1	
4N	189.0	444.5	
4P	204.5	558.6	
4Q	214.5	220.5	
4R	223.0	475.9	
4S	237.0	436.4	

Table 10.--Magnetic susceptibility of core samples from Area 401, Nevada Test Site--Continued

Sample No. Pluto-	Depth (feet)	Magnetic susceptibility (10^{-6} cgs)	Alteration zone
5A	13.0	481.1	
5B	35.5	601.3	
5C	59.0	969.0	
5D	75.5	1,149.2	
5E	102.0	662.1	
5F	120.0	768.2	
5G	148.0	2,475.2	
5H	167.0	3,257.8	
5J	193.5	3,394.8	
5K	208.0	2,768.8	
5L	224.5	2,053.2	
5M	238.0	460.3	
5N	257.0	516.6	
5P	276.0	1,797.9	
5Q	298.0	667.4	
5R	311.0	175.7	
5S	318.0	626.9	

porphyry has an average magnetic susceptibility of $1,333.4\times10^{-6}$ units, and moderately to severely weathered altered dacite porphyry has an average susceptibility of $1,105.5\times10^{-6}$ units.

Elasticity and strength

Dynamic elastic properties were determined for samples taken from the cores of test holes Pluto-1, -3, -4, and -5 (table 11). Young's modulus, Poisson's ratio, transverse velocity, longitudinal velocity, and the modulus of rigidity were calculated from measurements of the resonant frequencies of rock cores.

Static tests were run in the laboratory to determine Young's modulus, Poisson's ratio, and unconfined compressive strength on rock cores from test holes Pluto-1, -2, -3, and -5 (table 12).

Elasticity

Elastic moduli determined on air-dried samples in the laboratory by dynamic tests are Young's modulus, modulus of rigidity, Poisson's ratio, longitudinal velocity, and transverse velocity (table 11). Young's modulus and Poisson's ratio were also determined by static tests (table 12).

Dynamic Young's moduli for the dacite porphyry in Area 401 range from 1.04×10^{6} to 8.13×10^{6} psi, averaging 3.91×10^{6} psi, whereas static Young's moduli range from 0.76×10^{6} to 7.81×10^{6} psi, averaging 3.90×10^{6} psi overall. The range in Poisson's ratio, as determined by dynamic tests, is from 0.0277 to 0.3305, averaging 0.135 overall. Static measurements of Poisson's ratio range from 0.08 to 0.39, averaging 0.20 in all the samples tested. Table 13 compares the strain analyses between the first and last cycles of compressive tests. In the 28 rock samples for which Young's modulus and Poisson's ration were determined by

Table 11.--Elastic moduli determined by measurement of resonant frequency of core samples from Area 401, Nevada Test Site

[Air-dried specimens]

Sample No. Pluto-	Depth (feet)	Young's modulus (10^6 psi)	Modulus of rigidity (10^6 psi)	Poisson's ratio	Longitudinal velocity (ft/sec)	Transverse velocity (ft/sec)
1D	109.8	8.13	3.14	0.2946	18,205	9,824
1Fa	144.0	2.37	1.14	.0395	9,141	6,330
1Fd	156.0	3.65	1.54	.1851	11,428	7,104
1G	158.0	2.69	1.26	.0675	9,478	6,455
1Gb	167.0	4.70	2.06	.1408	11,999	8,223
1Gd	172.8	5.14	2.29	.1223	13,294	8,721
1H	173.0	4.02	1.68	.1964	12,051	7,407
1Ha	175.0	3.80	1.65	.1515	11,456	7,342
1Hc	183.0	3.71	1.70	.0912	11,024	7,353
1J	190.0	3.59	1.63	.1012	11,876	7,517
1K	217.5	5.13	2.34	.0962	12,828	8,575
1L	240.0	4.59	1.87	.2111	12,577	7,611
1M	271.0	3.39	1.52	.1151	9,679	6,956
1N	298.0	3.25	1.41	.1525	10,741	6,763
1P	326.0	2.44	1.17	.0427	8,937	6,177
1R	378.0	3.36	1.42	.1831	10,920	6,802
1S	400.0	3.39	1.41	.2021	11,190	6,837
1U	450.0	4.23	2.00	.0575	11,488	8,319
1W	520.0	4.05	1.56	.2981	13,320	7,145
1X	550.0	2.70	1.26	.0714	9,671	6,571
1Y	580.0	4.44	1.86	.1935	12,461	7,681
1Z	625.0	4.31	1.86	.1586	11,916	7,590
1DD	721.0	4.37	2.04	.0659	11,494	7,836
1FF	776.0	5.19	2.28	.1381	11,515	8,430
2	No results.					
3D	161.5	2.48	1.09	.1429	9,139	5,899
3E	164.0	2.05	.94	.0894	8,244	5,513
3Ea	167.2	2.93	1.33	.1015	10,069	6,706
3Eb	172.2	5.92	2.54	.1654	13,960	8,851
3Ec	175.0	7.08	2.86	.2378	15,999	9,384
3Ed	180.0	4.66	2.03	.1479	12,629	8,119
3F	190.5	4.45	2.10	.0595	11,886	7,910
3G	207.5	3.83	1.81	.0580	11,432	7,813
3K	258.5	3.52	1.61	.0932	10,623	7,115
4B	64.0	1.35	.61	.1065	6,858	4,494
4C	80.0	3.14	1.18	.3305	13,811	6,170
4D	83.5	1.04	.51	.0327	5,718	3,974
4E	92.5	1.77	.88	1/	7,355	5,185
4F	99.0	2.22	1.08	.0277	8,228	5,734
4K	148.0	5.79	2.24	.2924	14,871	8,057
4R	223.0	6.93	3.16	.0965	14,537	9,714
5A	13.0	4.32	2.08	.0385	12,070	8,362
5B	35.5	1.56	.74	.0541	7,051	4,841
5C	59.0	2.95	1.30	.1346	10,051	6,532
5J	193.5	4.39	2.07	.0604	11,111	7,599
5M	238.0	4.56	1.98	.1515	12,272	7,864
5N	257.0	6.07	2.93	.0358	13,893	9,640
5P	276.0	3.41	1.34	.2724	11,563	6,467
5Q	298.0	4.44	2.01	.1049	11,989	7,965
5R	311.0	2.70	1.06	.2617	10,256	5,826
5S	318.0	5.25	2.29	.1463	12,848	8,271

1/ Not representative.

Table 12.--Unconfined compressive strength and strain analyses by static methods of core samples from Area 401, Nevada Test Site

Sample No. 1/ Pluto-	Depth (feet)	End parallelism (inches)	Core condition	Unconfined compressive strength (psi)	Young's modulus (10⁶ psi)	Secant range (psi)	Poissan's ratio (U)	Remarks X = No. of loading cycles OD = oven dried
1E	127.5	0.0010	Poor. Solution-filled fracture. Perpendicular and parallel to platens. Ends chipped.	7,300	0.76	1,100-3,900	0.30	X = 1. Failure by shear. Only one failure was along preexisting fracture plane. OD.
1Fa	144.0	.0012	Good. Slightly chipped on ends. Sides slightly pitted.	9,100	1.68	600-4,500	.17	X = 3. OD.
1G	158.0	.0004	Good. Small vugs------------------	11,200	2.78	600-5,600	.19	X = 4. OD.
1H	173.0	.0006	Good. Many small vugs. Slight chip on one end.	14,600	4.51	600-6,600	.20	X = 3. OD.
1J	190.0	.0006	Good. No fractures----------------	16,300	3.45	600-6,600	.26	X = 1. OD.
1L	240.0	.0004	Good. One solution-filled fracture diagonal from top to bottom.	18,200	4.36	600-6,700	2/	Do.
1M	271.0	----------	Good. One very small solution-filled fracture.	14,300	3.49	600-5,000	.16	X = 3. OD.
1N	298.0	.0007	Good. Many vugs. No fractures-----	12,600	2.74	1,800-6,500	.17	X = 1. OD.
1P	326.0	.0008	Good. One fracture diagonal from top to right side.	12,000	2.56	600-5,100	.16	X = 3. OD.
1R	378.0	.0004	Good. No fractures----------------	15,000	3.27	600-5,700	.15	X = 1. OD.
1S	400.0	.0003	----------do-----------------------	16,700	4.00	600-5,600	.26	X = 4. OD.
1U	450.0	.0002	----------do-----------------------	16,000	3.49	600-5,000	.12	X = 3. OD.
1W	520.0	.0003	----------do-----------------------	17,000	3.55	700-8,600	.10	Do.
1X	550.0	.0004	Good. Small vugs------------------	11,200	2.78	600-5,600	.19	Do.
1Y	580.0	.0005	Good. No fractures. Chip on one end.	16,000	2.74	560-6,200	.18	X = 1. Chip on one end probably caused unequal longitudinal deformation. OD.
1Z	625.0	.0010	Good. Small fractures-------------	12,900	2.40	600-5,500	2/	X = 2. Failed along fracture. OD.
1AA	643.0	.0010	Good. No fractures----------------	12,600	2.72	600-6,700	.11	X = 1. OD.
1BB	673.0	.0003	Poor. Fracture and many small vugs-	5,900	2.69	600-2,800	2/	X = 3. Failed along fracture. OD.
1CC	686.0	.0003	Fair. Core badly pitted. Fractures 75° to platens.	5,300	5.82	660-4,500	2/	X = 2. Failure occurred along pre-existing fractures. OD.
1DD	721.0	----------	Good. No fractures----------------	12,000	3.70	600-5,000	.31	X = 3. OD.
1EE	758.0	.0008	----------do-----------------------	13,200	4.58	600-5,500	.36	X = 1. OD.
1FF	776.0	----------	Good. Few pits, no fractures. Slight chip on one end.	21,400	4.10	500-550	.16	X = 1.
2A	12.5	.0006	Good. No fractures----------------	13,400	3.54	600-7,400	.23	X = 3. OD.
3D	161.5	.0004	----------do-----------------------	16,900	2.91	600-6,300	.14	X = 1. OD.
3E	164.0	.0004	----------do-----------------------	10,700	2.15	600-5,100	.25	X = 3. OD.
3F	190.5	----------	Good. Few pits, one solution-filled fracture on each end.	15,300	E = 4.81 (max); E = 4.54 (avg); E = 4.27 (min).	3/600-5,600 and 4/1,100-5,600	.18	X = 6.
3G	207.5	.0006	Good. A solution-filled fracture extending across both ends. Many small and medium vugs.	14,400	2.46	600-5,700	.13	X = 2.
3J	232.5	.0005	Good. One small fracture----------	14,800	5.21	600-8,000	.30	X = 1. OD.
4C	80.0	.0009	Good. Two medium fractures. Small and medium vugs and chips on both ends.	13,800	3.03	600-3,300	.08	X = 4.
4H	117.5	.0006	Fair. Two fractures extending length of core.	15,300	6.80	600-7,400	.18	X = 3. Unequal longitudinal deformation due to movement along hidden internal fracture. OD.
4K	148.0	.0008	Poor. Large and small fractures through core. One end chipped. Vugs.	17,900	E = 7.58 (max); E = 6.96 (avg); E = 6.33 (min).	3/600-5,600 and 4/1,100-5,600	.27	X = 1. Failure occurred along fracture plane.
4P	204.5	.0008	Good. Small fractures parallel to platens.	20,600	7.81	600-6,300	.25	X = 3. Did not break along fractures. OD.
4Q	214.5	.0035	Fair. Several filled fractures about 70° to platens.	5,000	3.86	600-4,200	2/	X = 3. Failed on fracture at angle of 70° to platen. OD.
4R	223.0	----------	Good. Lineation approximately 60° from platens.	21,500	E = 7.08 (max); E = 6.80 (avg); E = 6.54 (min).	600-5,700	.21	X = 4.
5C	59.0	.0004	Poor. Three major solution-filled fractures.	8,800	2.50	600-2,800	.18	X = 5. Some failure along pre-existing fractures. OD.
5G	148.0	.0031	Fair. Many solution-filled fractures.	5,300	3.42	600-4,500	.16	X = 2. Failed along fractures. OD.
5J	193.5	.0012	Good. Many small solution-filled fractures. Both ends slightly chipped.	22,100	6.94	3/600-5,600 4/1,100-5,600	.39	X = 1.
5M	238.0	.0010	Good. Small solution-filled fractures normal to platens.	13,900	5.38	600-5,600	.19	X = 6.
5S	318.0	.0004	Good. No fractures----------------	16,500	5.48	600-5,700	.31	X = 1. Compressive strength value approximate.

1/ Sample number refers also to hole number.

2/ Not representative.

3/ Young's modulus used to determine range.

4/ Poisson's ratio used to determine range.

Table 13.--Comparison of strain analyses between first (A) and last (B) cycles of compression tests on core from Area 401, Nevada Test Site

[Analysts: R. A. Speirer and J. C. Thomas]

Sample No. Pluto-	Static Young's modulus (10^6 psi)		Poisson's ratio		Stress range (psi)
	A	B	A	B	
1G	2.45	2.45	-------	0.15	600-3300
4Q	3.27	3.86	-------	--------	600-4200
5G	2.81	3.51	0.20	.21	600-3300
4P	7.61	8.18	.30	.21	600-6000
1DD	3.55	2.62	.42	.31	600-3300
1Z	2.42	2.40	-------	--------	600-5500
1W	3.81	3.59	-------	--------	712-5700
1X	2.22	2.44	-------	--------	600-2800
1U	3.67	3.49	.09	.14	1/ 1100-5000 2/ 600-5000
1BB	2.35	2.39	-------	--------	600-2200
1Fa	1.27	1.68	.14	.17	600-4500
1H	4.48	4.51	.22	.20	600-6600
1M	3.33	3.49	.14	.16	600-5000
1P	2.39	2.56	.18	.16	600-5100
3E	1.79	2.15	.23	.23	600-2300
2A	2.96	3.37	.21	.24	600-4000
4H	6.60	6.80	.17	.18	600-7400
5C	2.62	2.50	.18	.18	600-2800

1/ Poisson's ratio.

2/ Static Young's modulus.

both dynamic and static methods, there is only a slight correlation between the numerical values for the two moduli on the same core sample. The average of these 28 samples is rather close for Young's modulus, 3.87×10^{6} psi by dynamic methods as compared to 3.74×10^{6} psi by static methods. However, the Poisson's ratio averages 0.14 by dynamic methods as compared to 0.19 by static methods. No correlation was found between the values for Young's modulus or Poisson's ratio and the degree of weathering or alteration in these rocks.

The laboratory values for Young's modulus are probably considerably lower than they would be if the tests had been made in place because the many incipient joints in the dacite porphyry, which are tightly sealed at depth, would have had no appreciable effect. Variations in the measurements of the elastic moduli of a particular rock sample by the two methods are due mainly to inhomogeneities in the rock, such as differences in number of fractures, in porosity, and in grain size. Closer agreement between the measurements by dynamic and by static methods may be attained on harder materials, and perfect agreement between the methods may be approached in testing completely isotropic substances.

Values of the modulus of rigidity, as determined by dynamic tests, range from 0.51×10^{6} to 3.16×10^{6} psi (table 11) in the samples tested, with an overall average modulus of 1.72×10^{6} psi. The longitudinal velocity ranges from 5,718 to 18,205 ft/sec, and the transverse velocity ranges from 3,974 to 9,824 ft/sec on these samples. The overall average for longitudinal velocity is 11,343 ft/sec and that for transverse velocity is 7,271 ft/sec.

Strength

The unconfined compressive strengths of the samples of dacite porphyry tested range from 5,000 psi to 22,100 psi (table 12) averaging 13,800 psi overall. Stress-strain curves of 26 of these samples are illustrated on figures 9 through 34. Unconfined compressive-strength tests on 80-percent-saturated specimens show a substantial reduction in the strength of the rock (table 14). The strength of the partly saturated samples ranges from 6,400 psi to 13,100 psi, averaging 10,200 psi overall.

Sampling tends to select the strongest, as well as the most elastic, rocks. Some of the rock is so friable that drilling reduces it to mud or sand. Furthermore, at many places the rock is so fractured that cores of sufficient length for testing are not obtained. Incipient and healed joints tend to lower the strength of the rocks; figure 35 shows a comparison of Young's modulus with the unconfined compressive strength of rocks having variously oriented fractures. It may be generally assumed that the rocks from Area 401 with an unconfined compressive strength of less than 5,000 psi failed before testing procedures were completed.

Correlation of various physical properties

Method of study

An attempt was made to compare values for compressive strength, Young's modulus, dry bulk density, magnetic susceptibility, and porosity of the rocks in order to understand the relations of these properties. Physical properties were paired as follows: unconfined compressive strength versus Young's modulus, porosity versus unconfined compressive strength, porosity versus Young's modulus, dry bulk density versus Young's modulus, dynamic Young's modulus versus static Young's modulus, and magnetic susceptibility versus Young's modulus. The

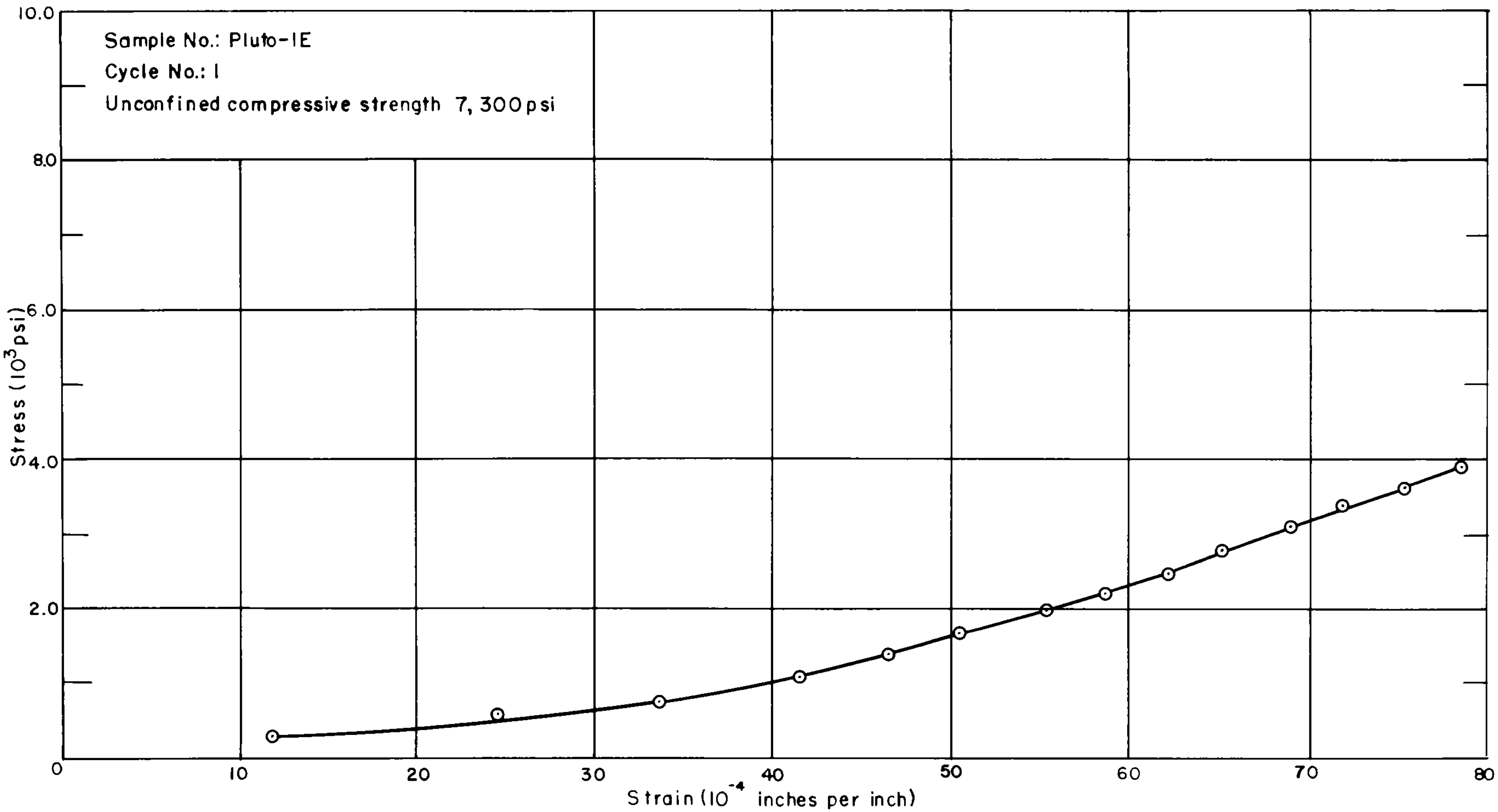


Figure 9.—Stress–strain curve of rock core from Area 401, Nevada Test Site, Nye County, Nevada

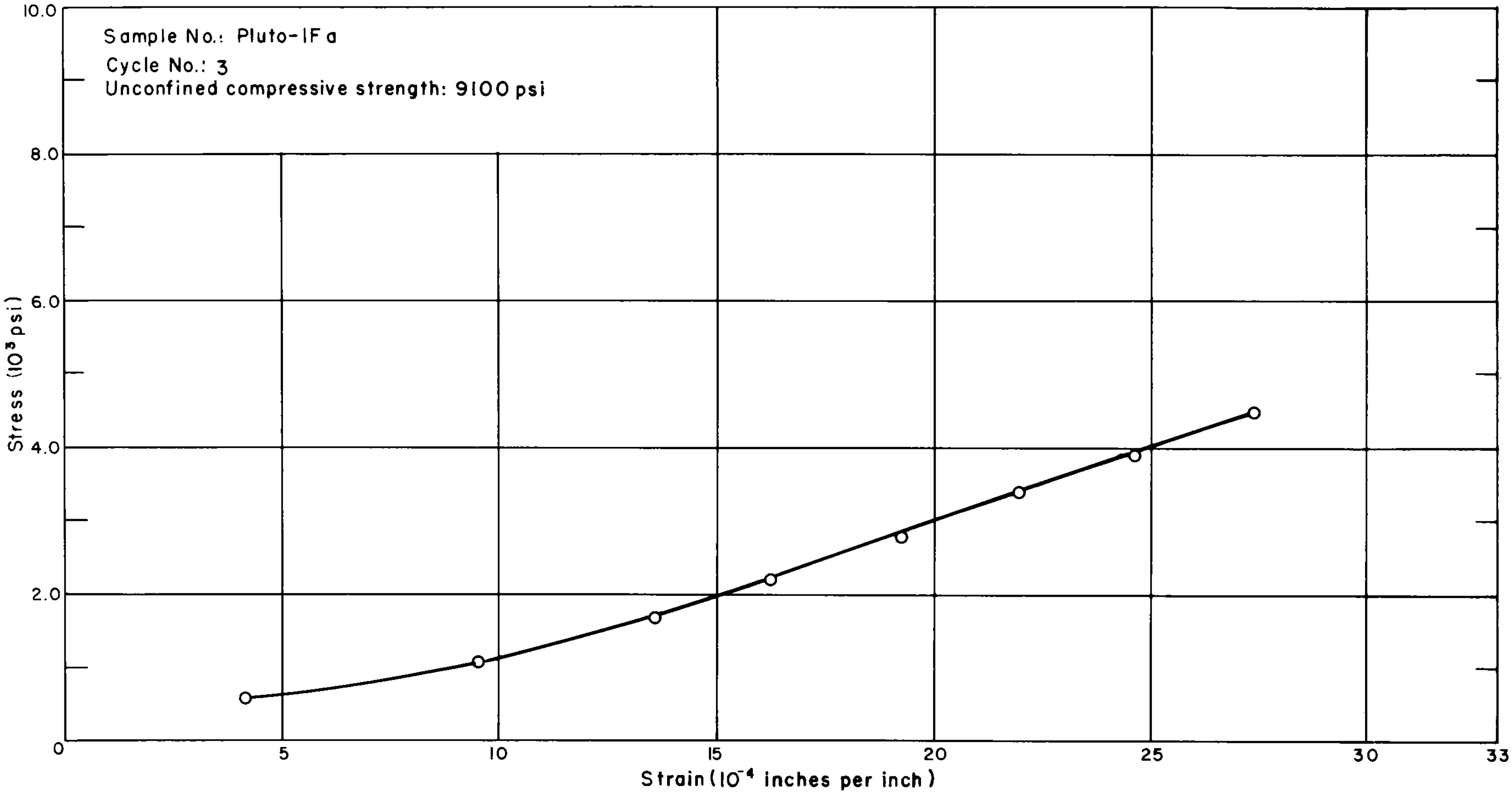


Figure 10.—Stress-strain curve of rock core from Area 401, Nevada Test Site, Nye County, Nevada

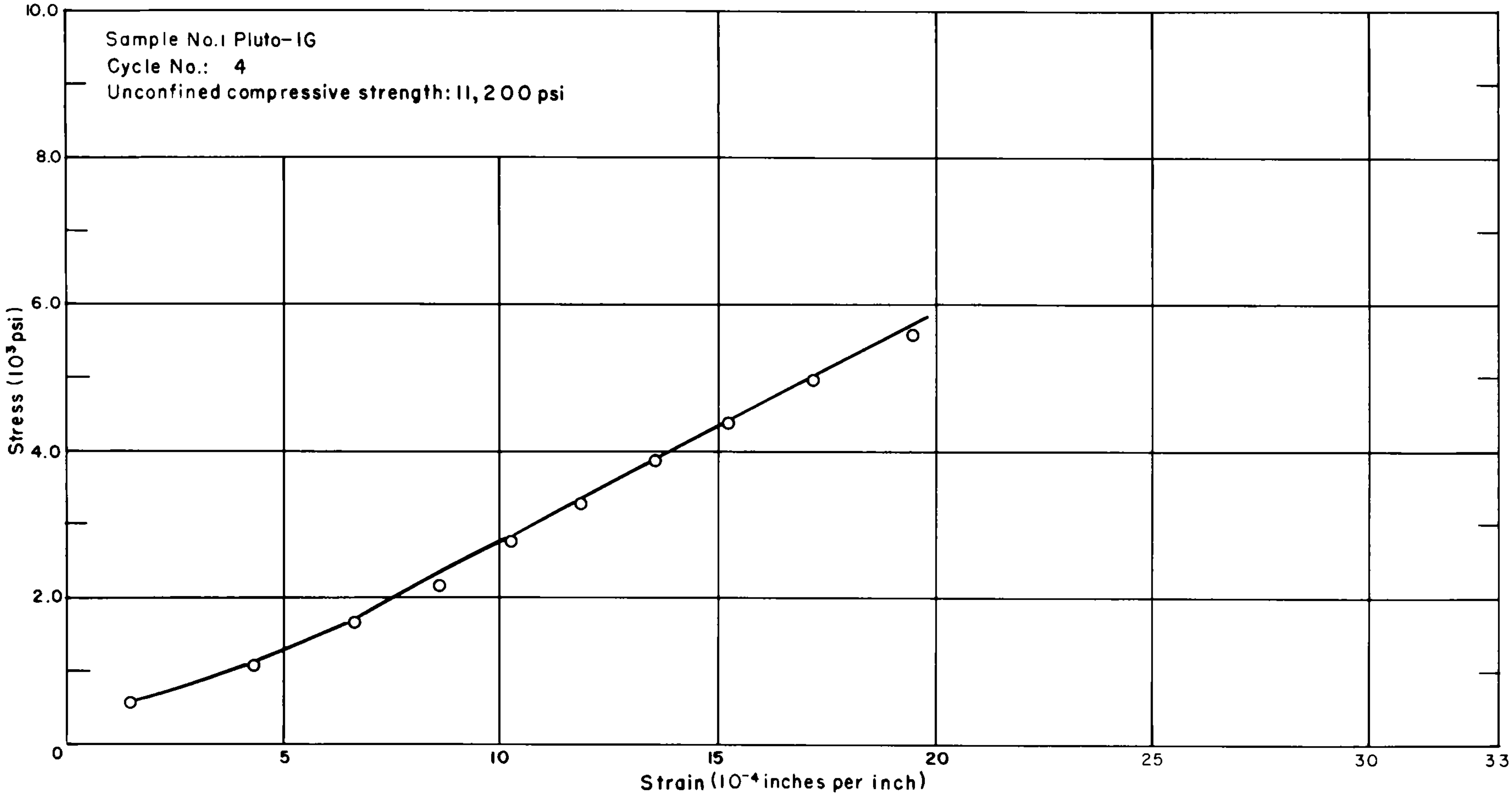


Figure 11.- Stress-strain curve of rock core from Area 401, Nevada Test Site, Nye County, Nevada

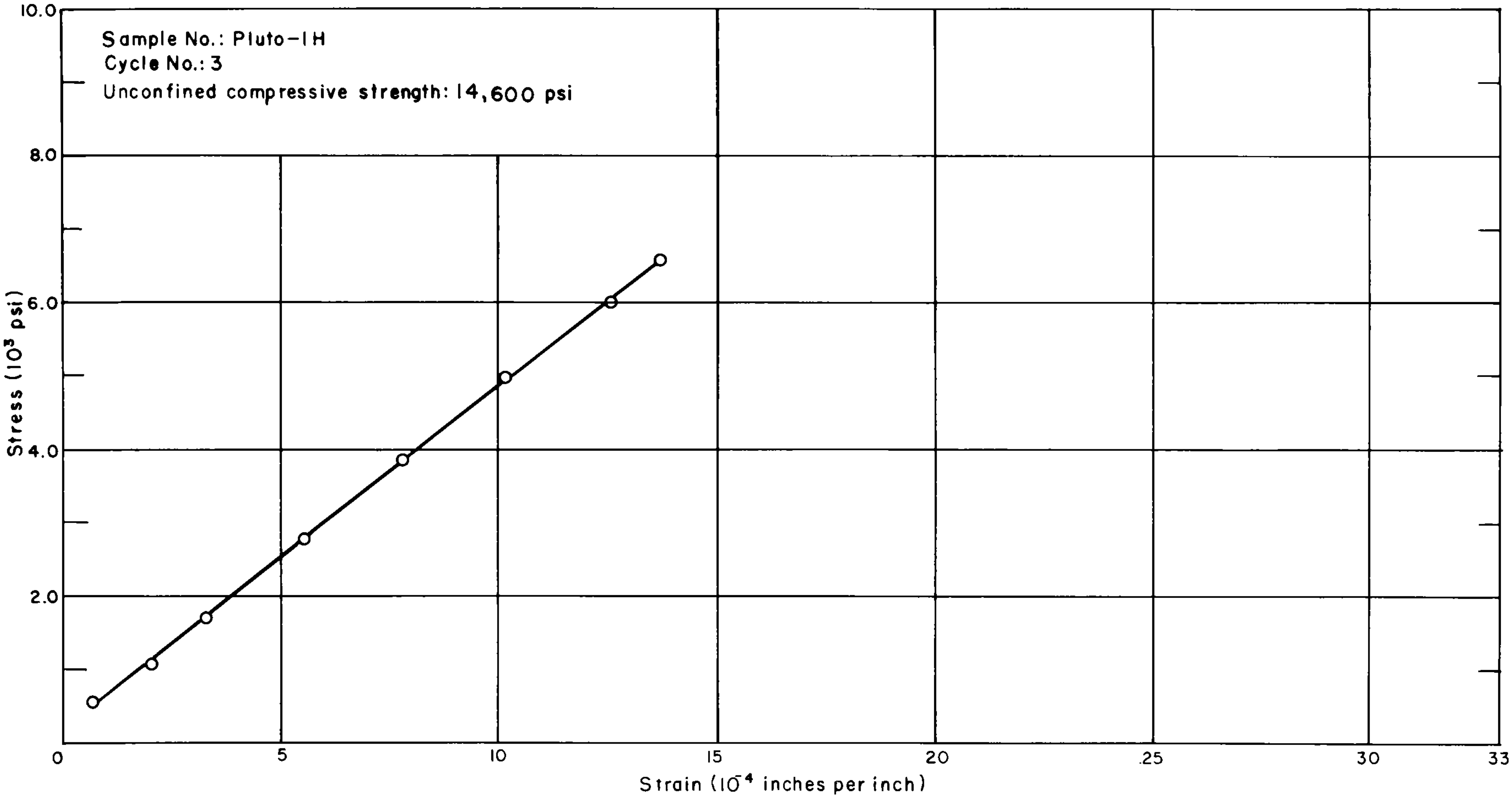


Figure 12.–Stress-strain curve of rock core from Area 401, Nevada Test Site, Nye County, Nevada

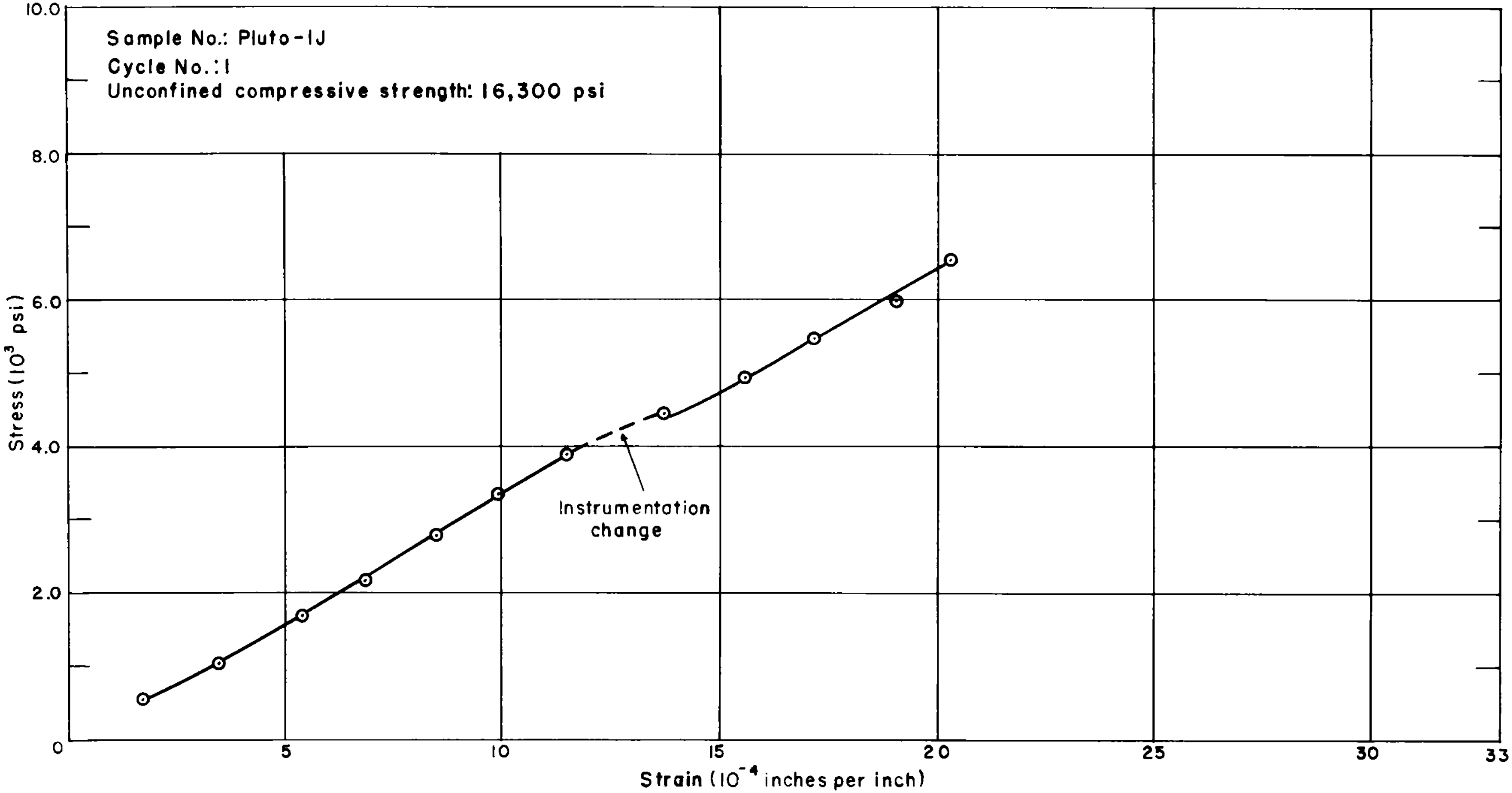


Figure 13.–Stress–strain curve of rock core from Area 401, Nevada Test Site, Nye County, Nevada

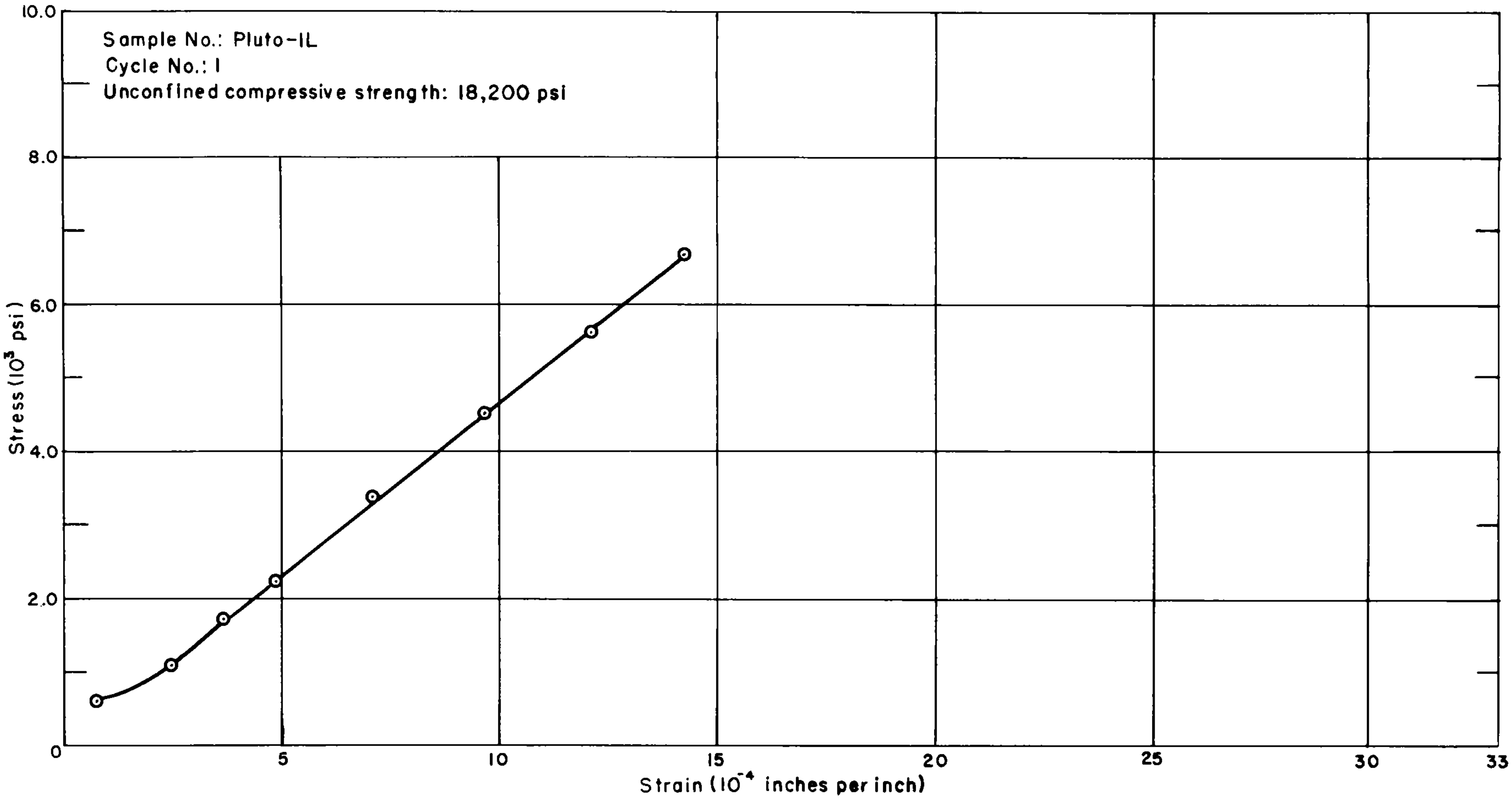


Figure 14.—Stress-strain curve of rock core from Area 401, Nevada Test, Nye County, Nevada

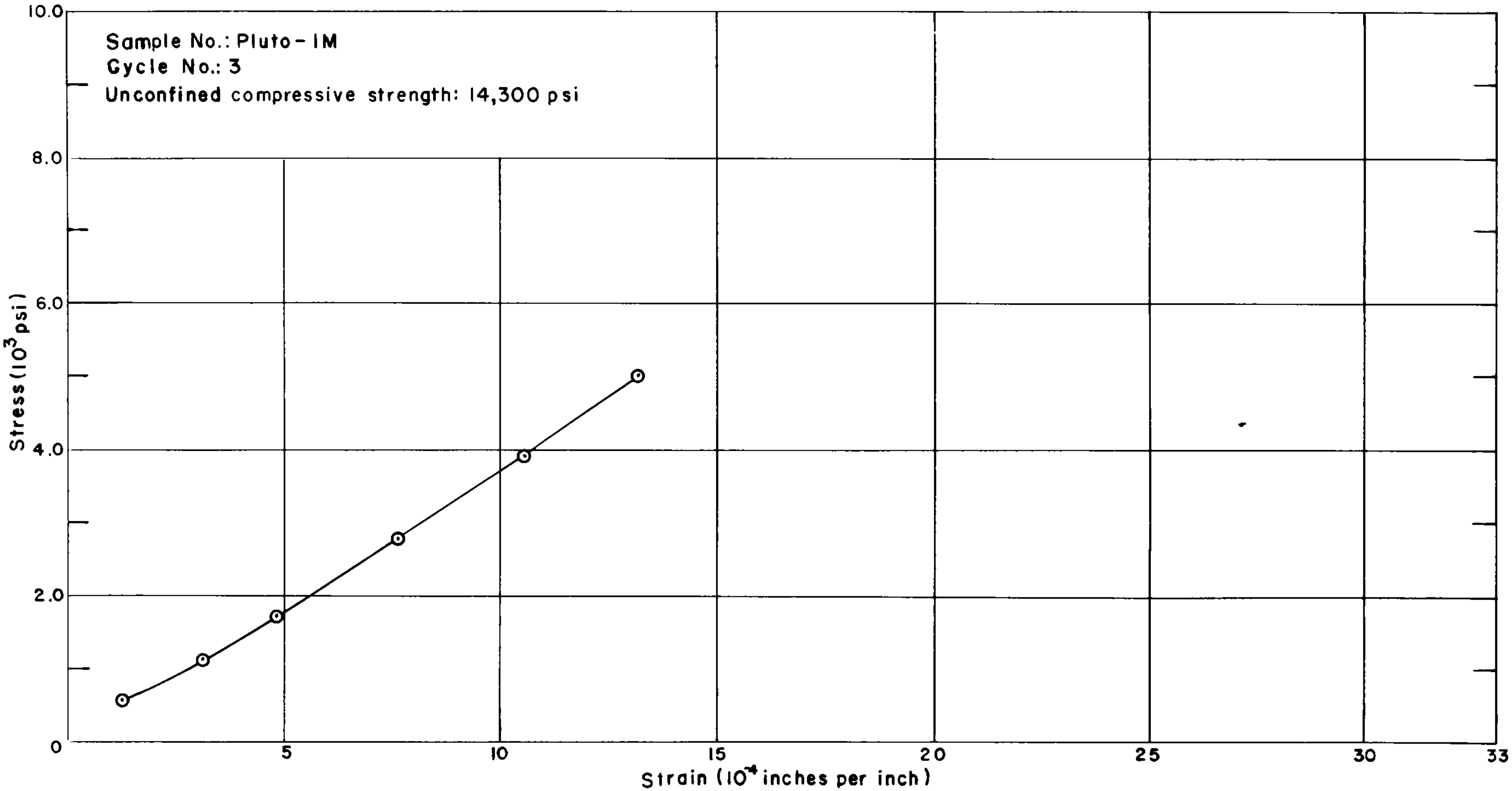


Figure 15.– Stress–strain curve of rock core from Area 401, Nevada Test Site, Nye County, Nevada

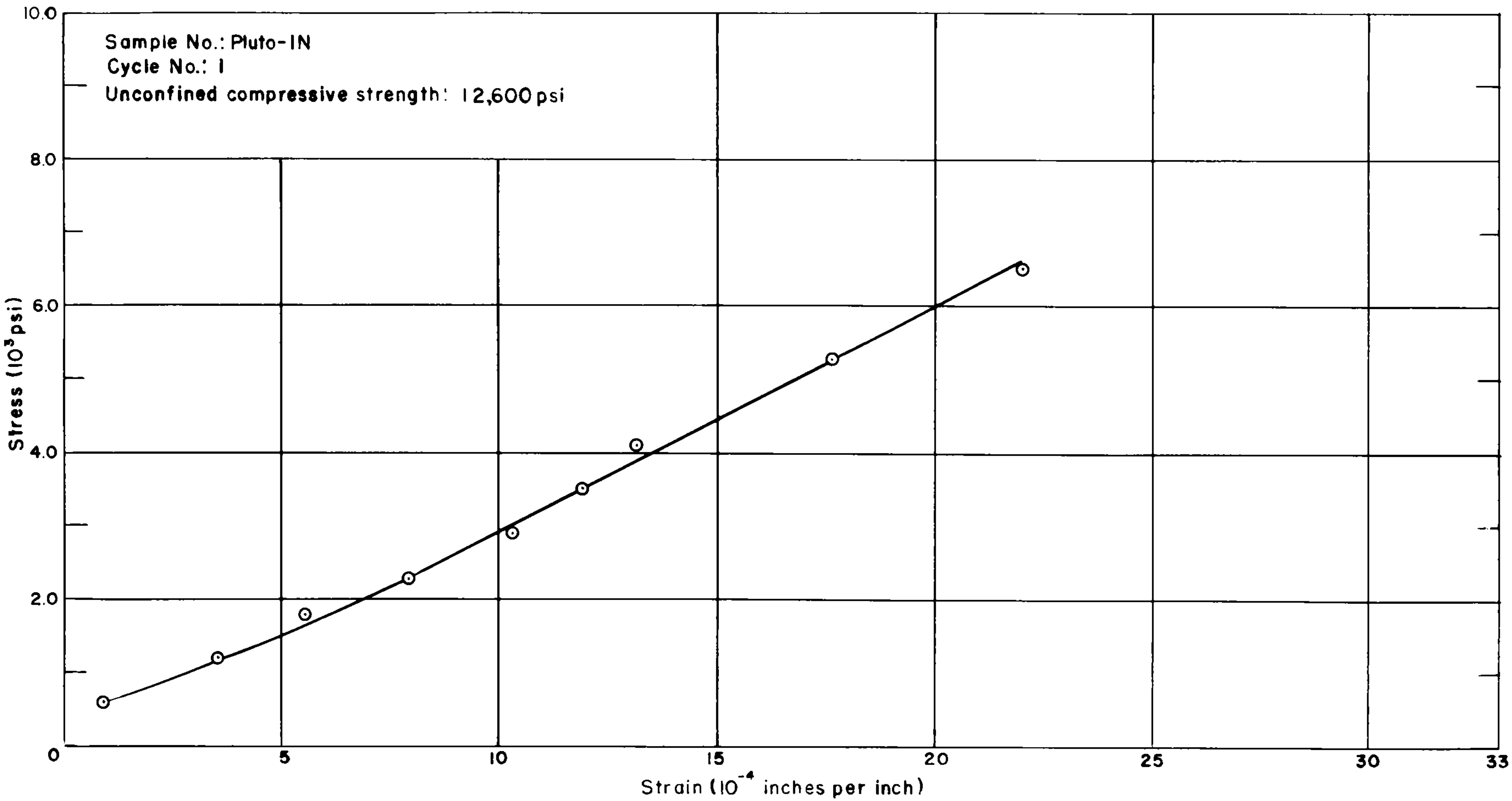


Figure 16.—Stress–strain curve of rock core from Area 401, Nevada Test Site, Nye County, Nevada

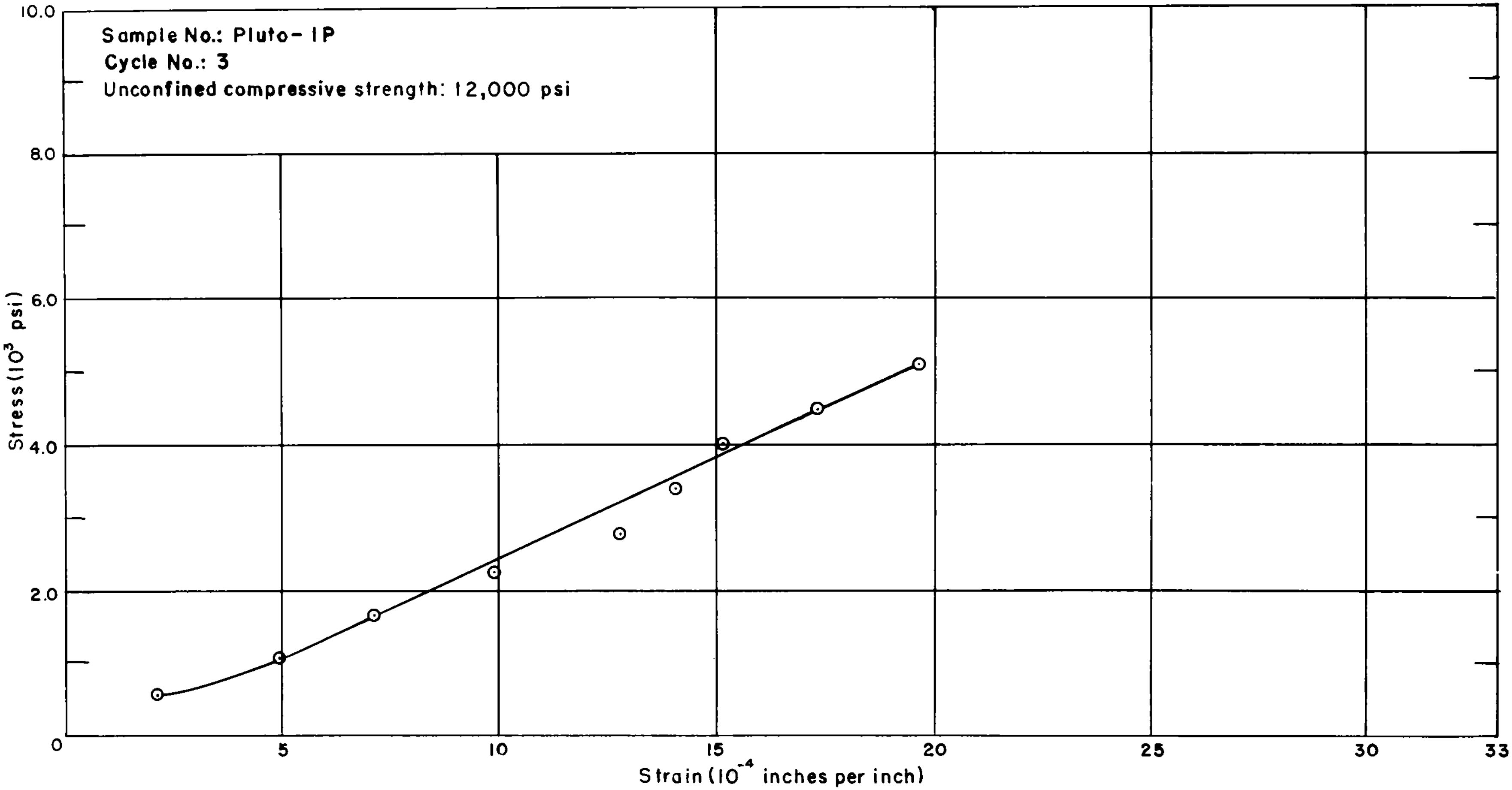


Figure 17.– Stress–strain curve of rock core from Area 401, Nevada Test Site, Nye County, Nevada

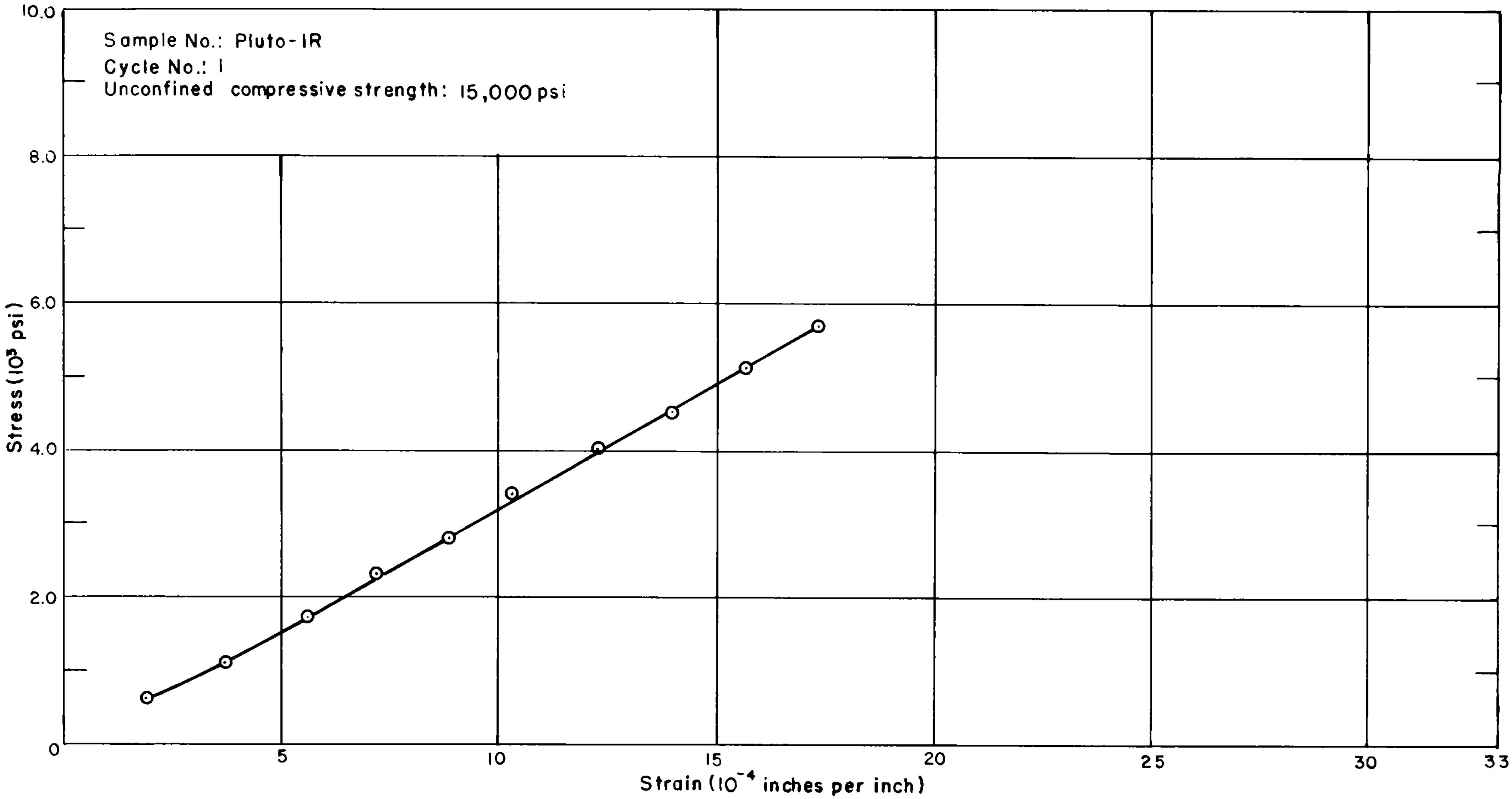


Figure 18.– Stress–strain curve of rock core from Area 401, Nevada Test Site, Nye County, Nevada

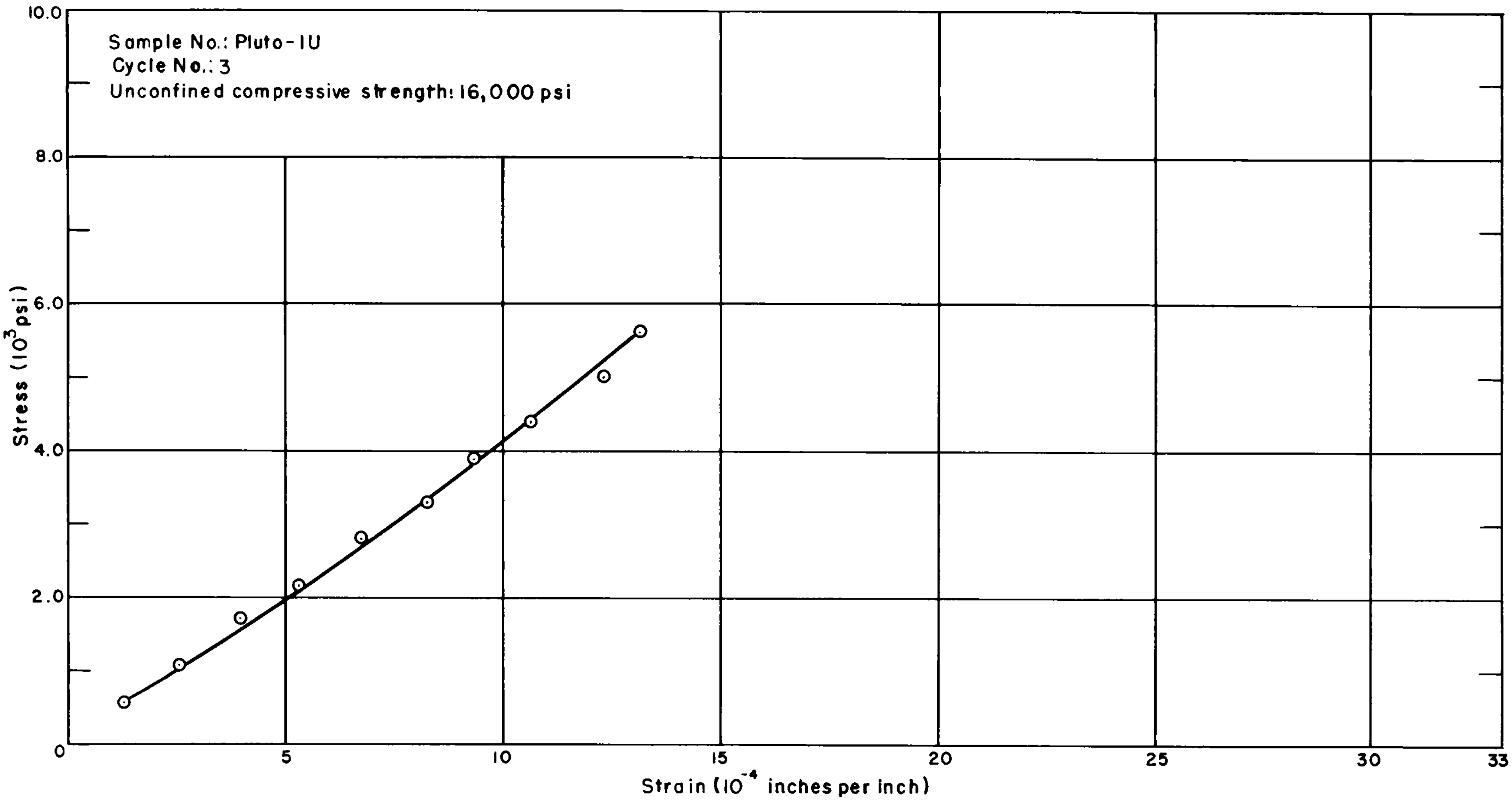


Figure 19. —Stress-strain curve of rock core from Area 401, Nevada Test Site, Nye County, Nevada

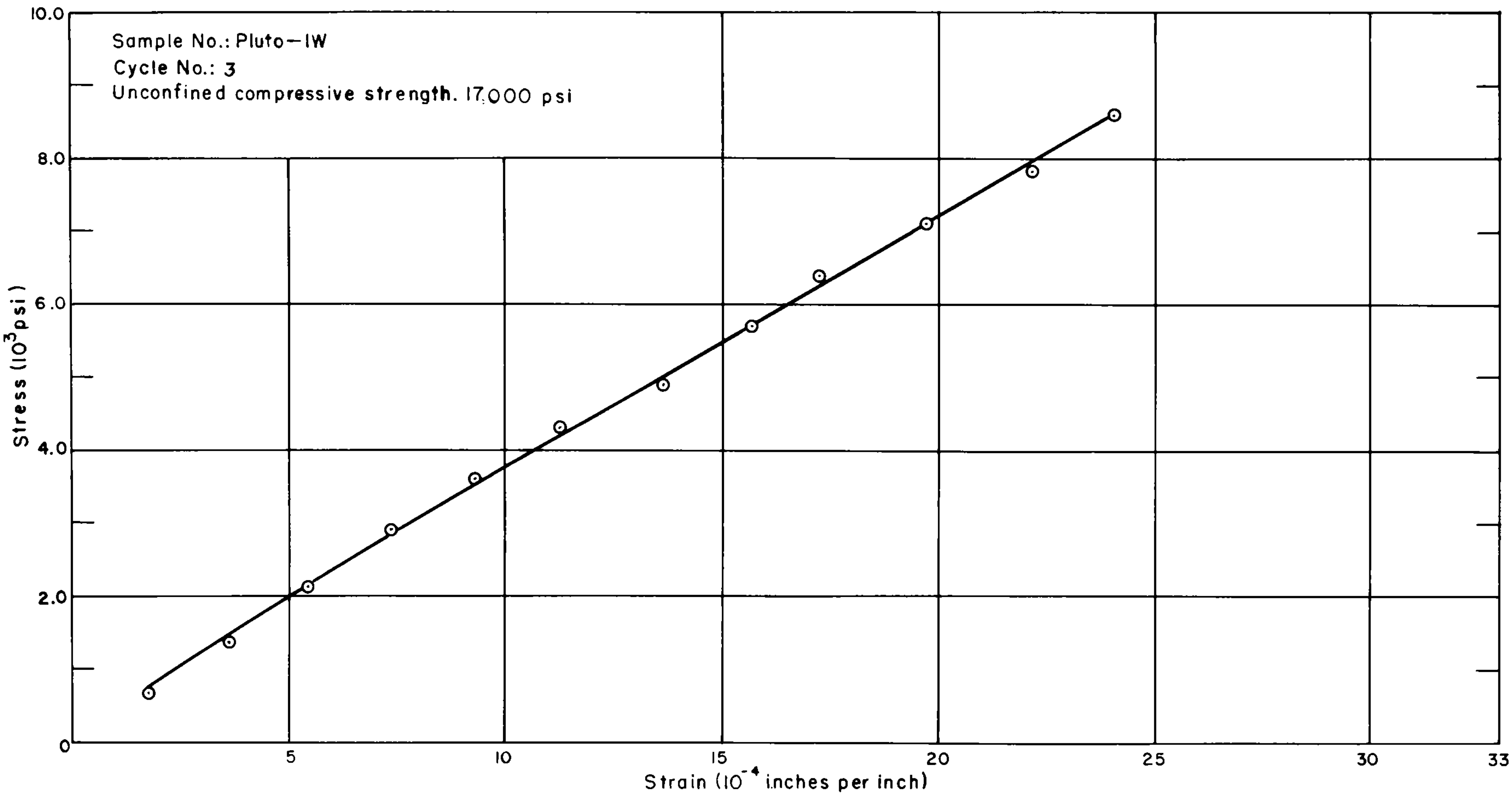


Figure 20.: Stress-strain curve of rock core from Area 401, Nevada Test Site, Nye County, Nevada

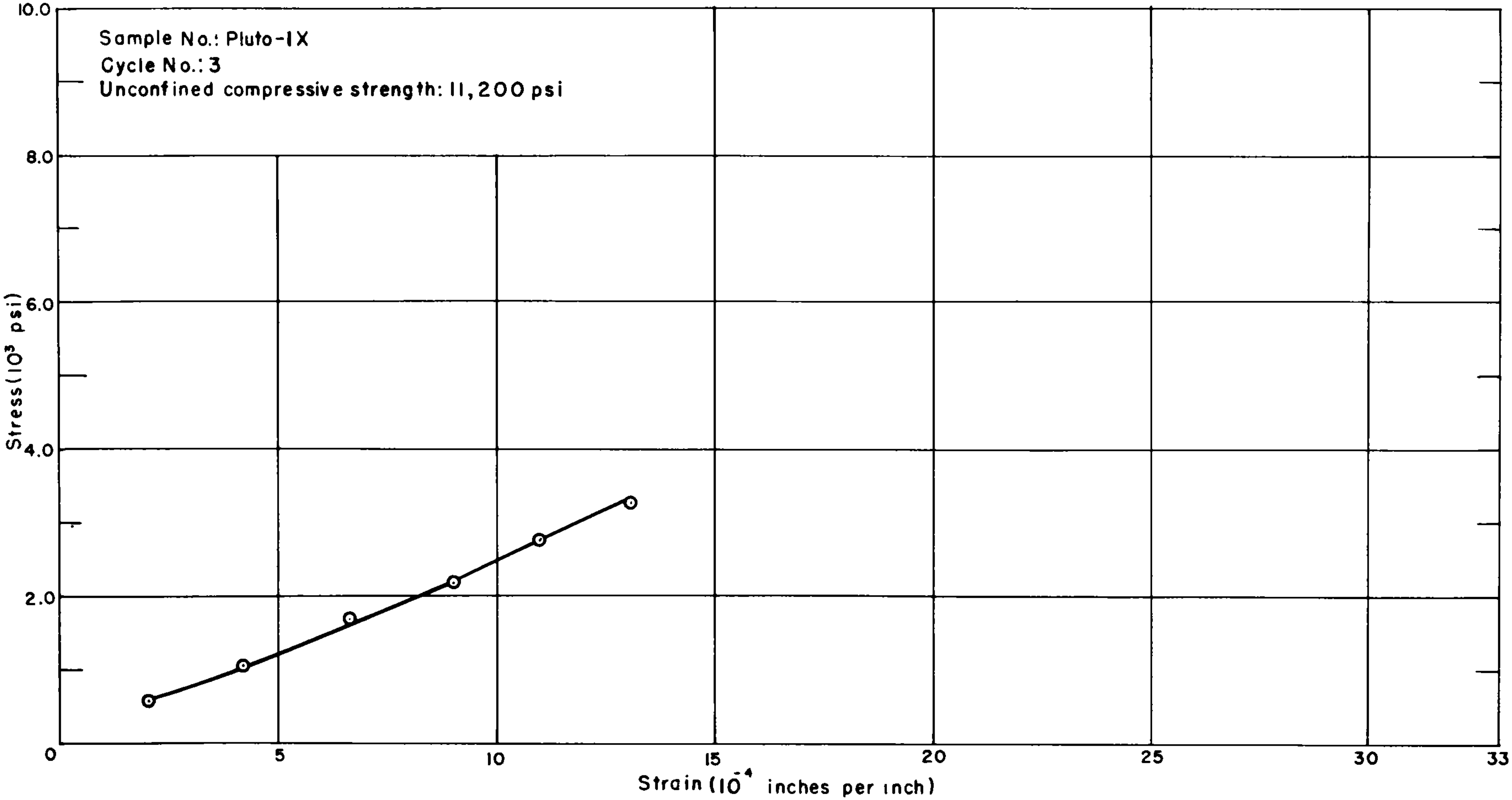


Figure 21.– Stress-strain curve of rock core from Area 401, Nevada Test Site, Nye County, Nevada

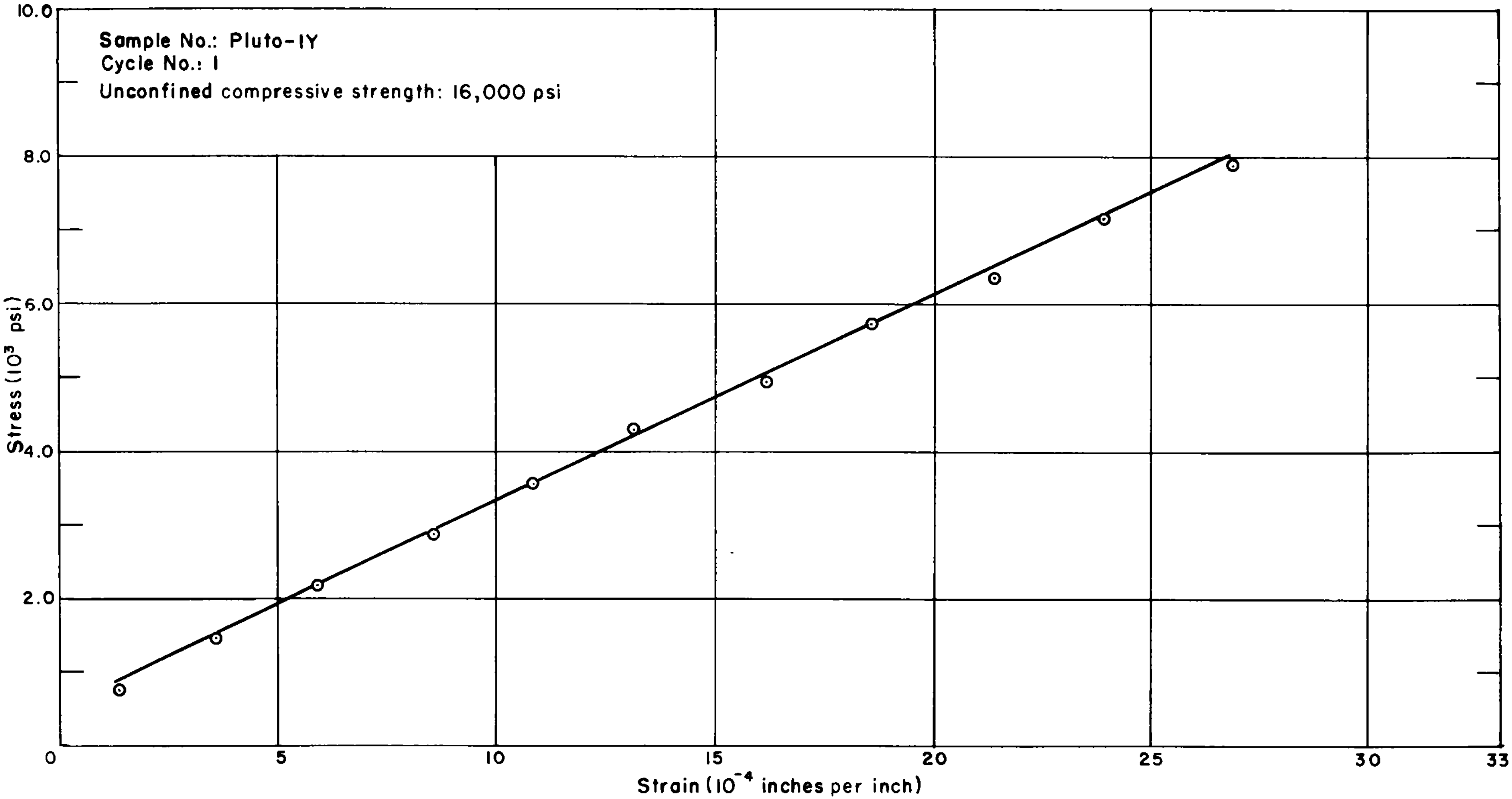


Figure 22.–Stress-strain curve of rock core from Area 401, Nevada Test Site, Nye County, Nevada

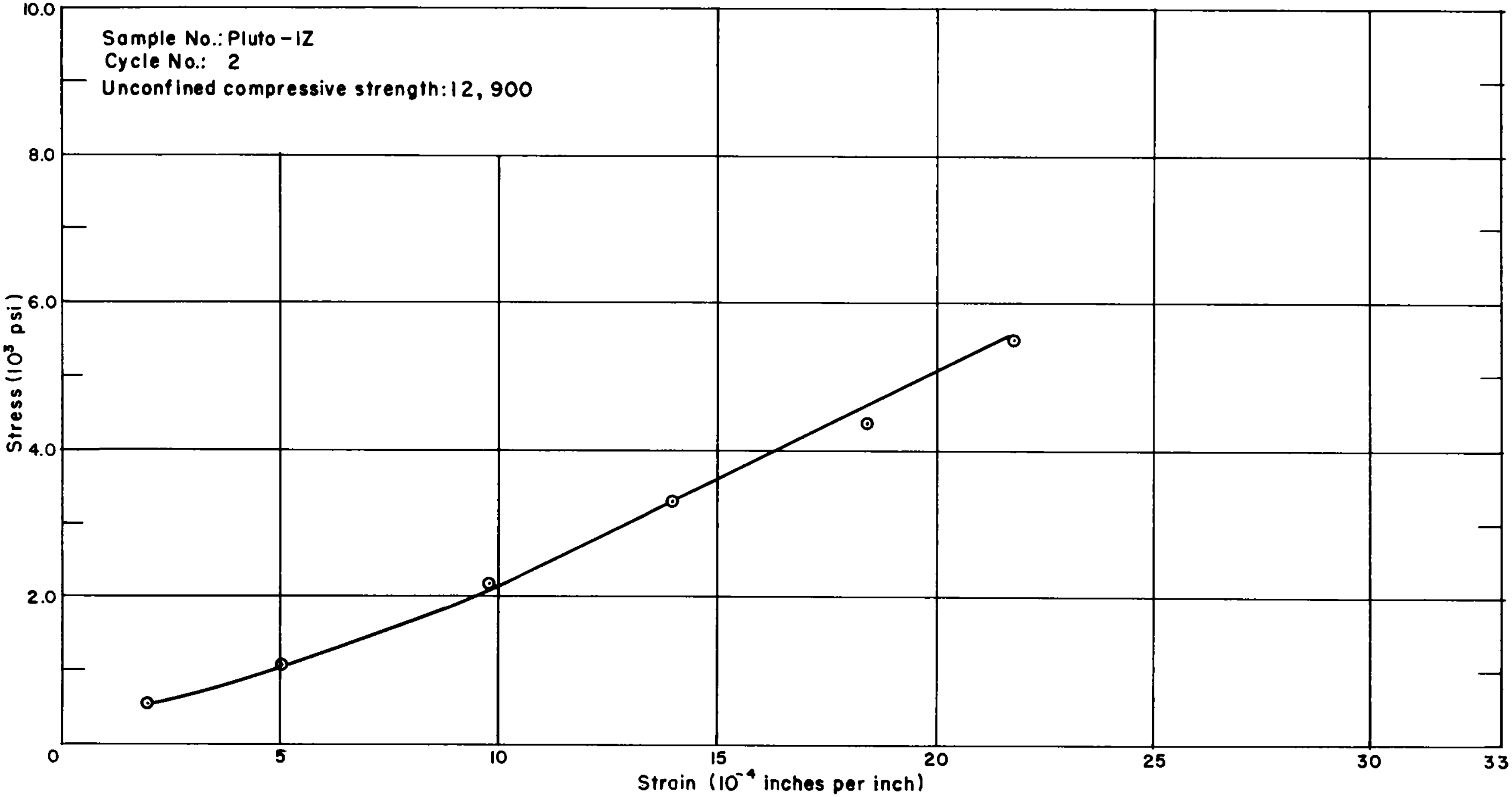


Figure 23.-Stress-strain curve of rock core from Area 401, Nevada Test Site, Nye County, Nevada

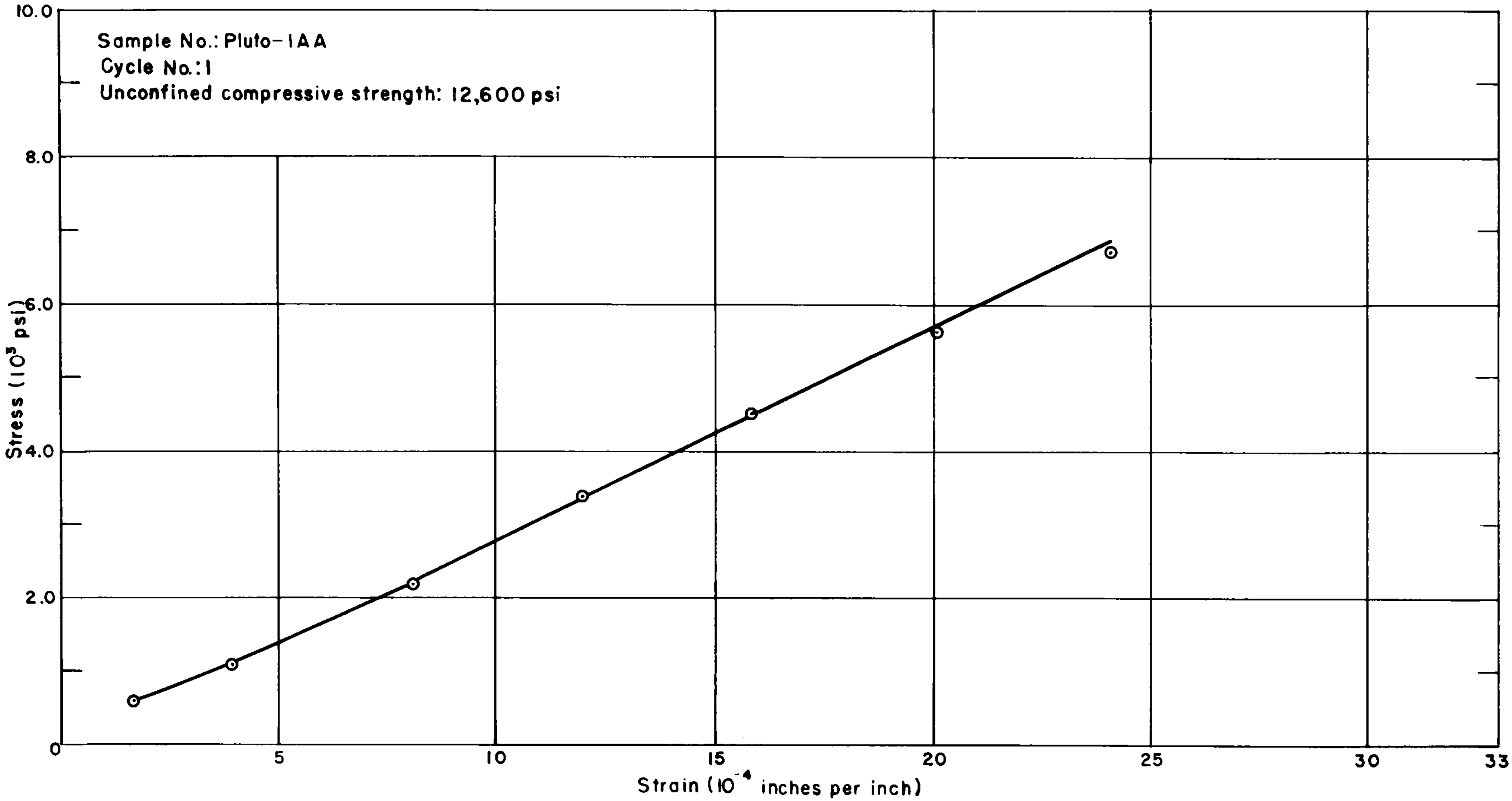


Figure 24.- Stress-strain curve of rock core from Area 401, Nevada Test Site, Nye County, Nevada

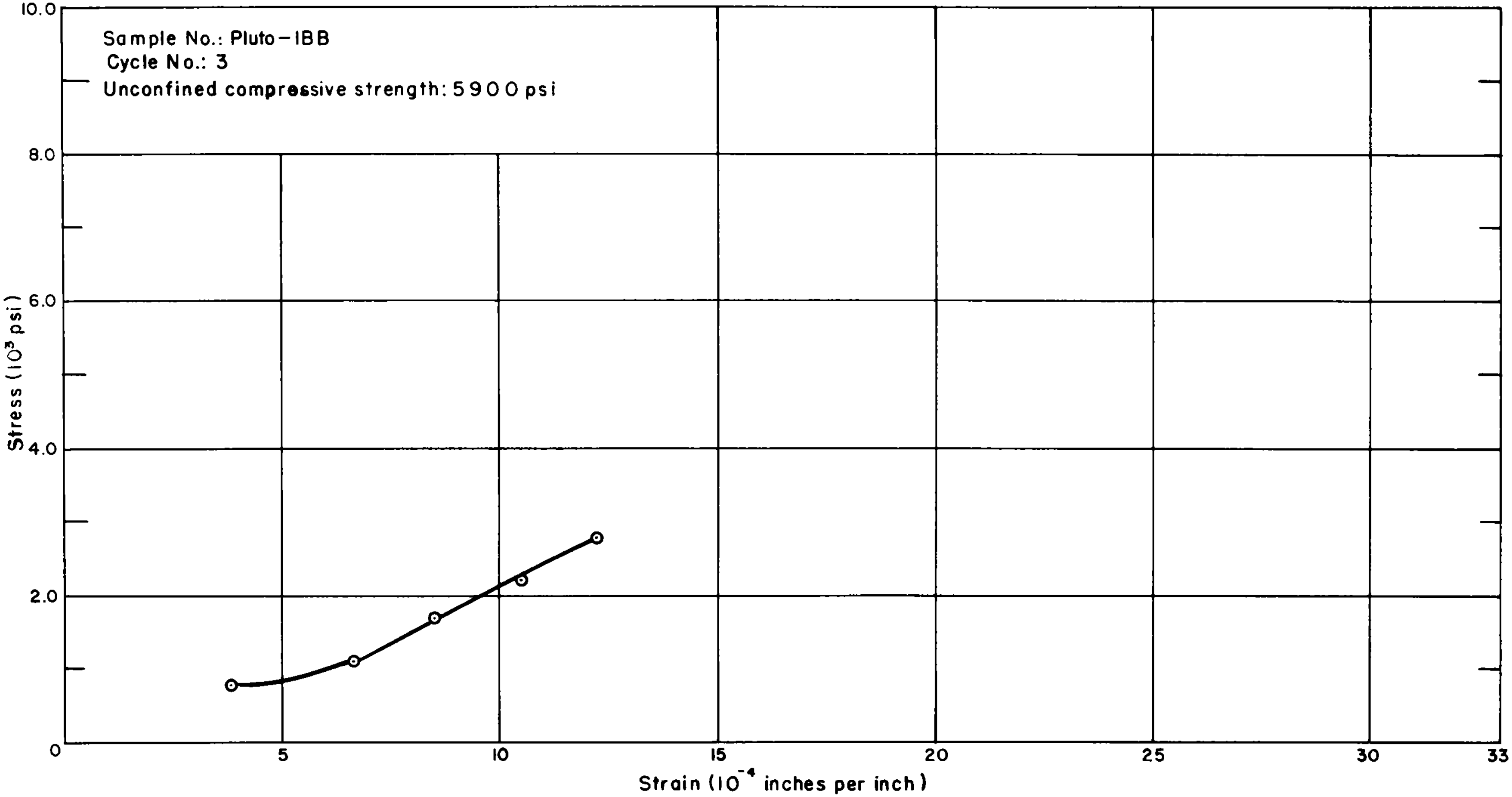


Figure 25.-Stress-strain curve of rock core from Area 401, Nevada Test Site, Nye County, Nevada

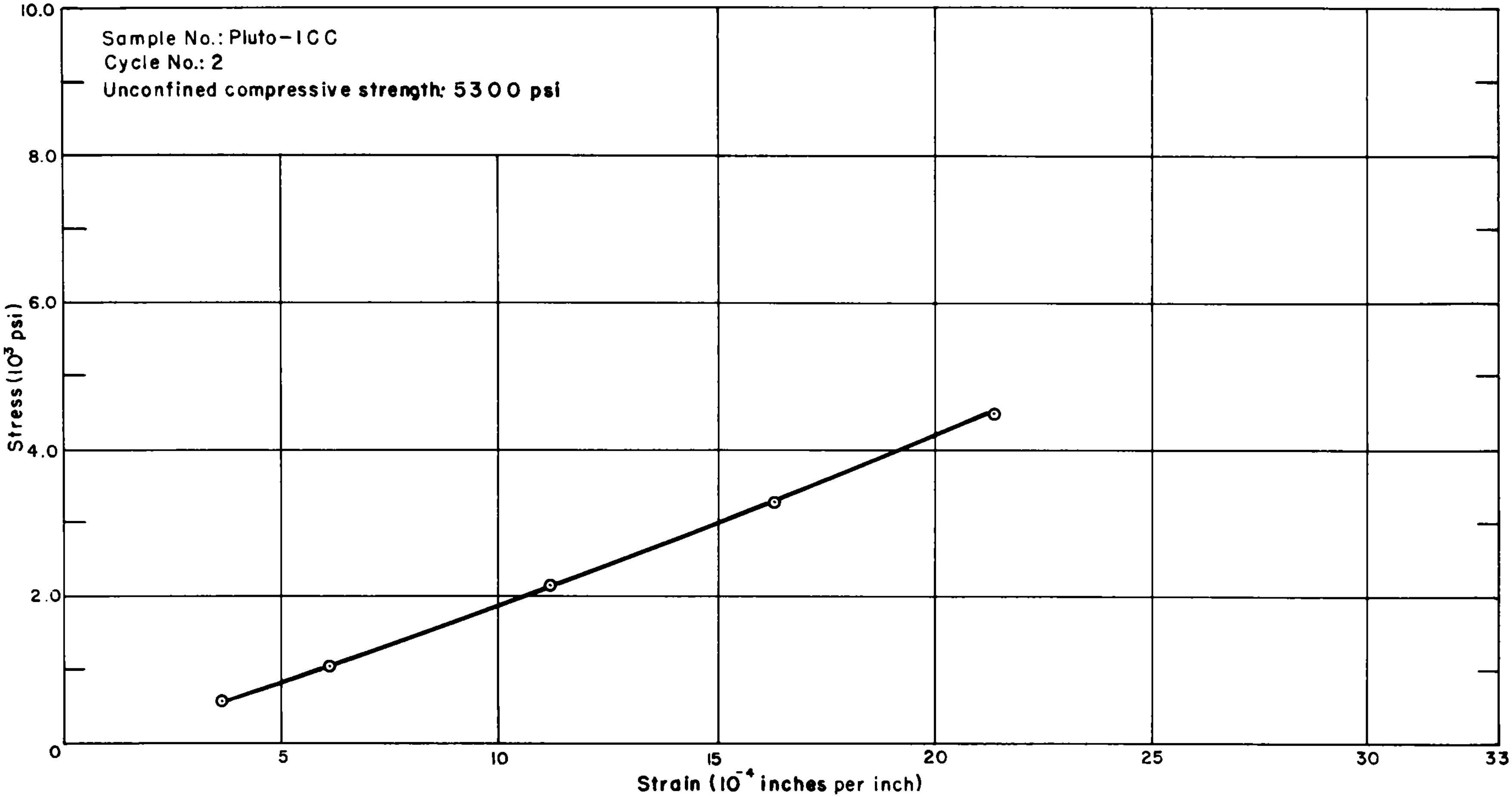


Figure 26.-Stress-strain curve of rock core from Area 401, Nevada Test Site, Nye County, Nevada

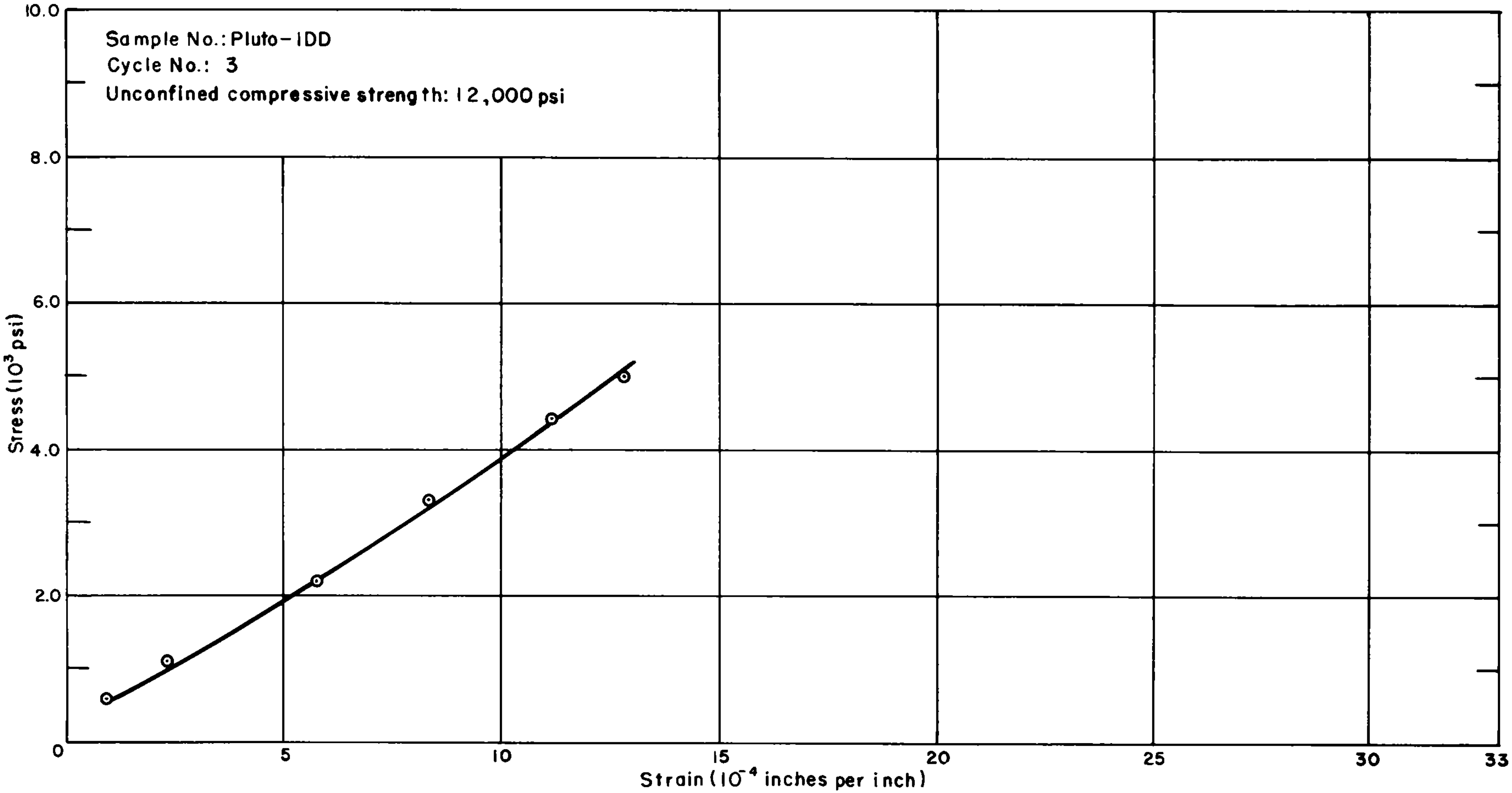


Figure 27.-Stress-strain curve of rock core from Area 401, Nevada Test Site, Nye County, Nevada

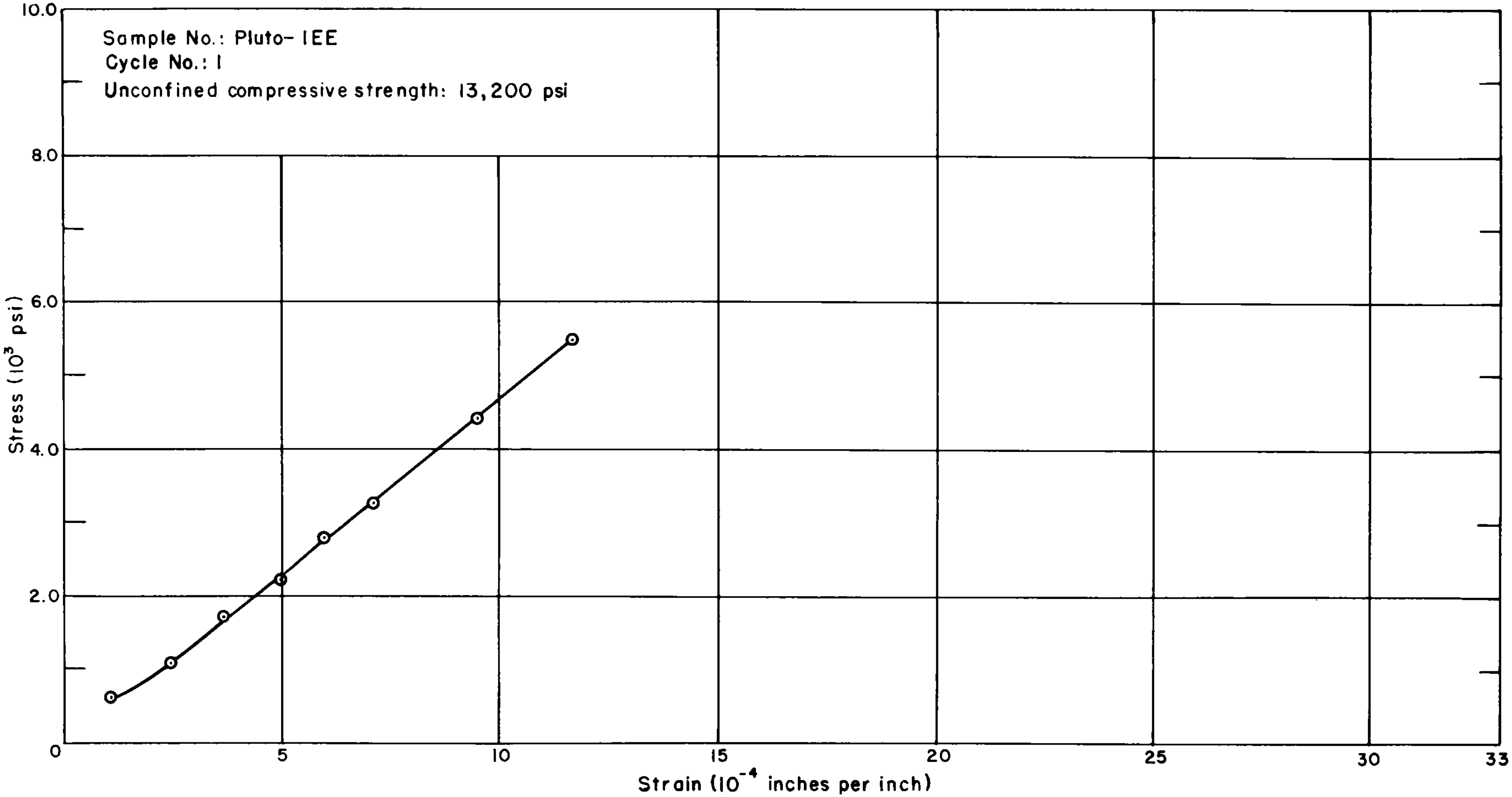


Figure 28.–Stress–strain curve of rock core from Area 401, Nevada Test Site, Nye County, Nevada

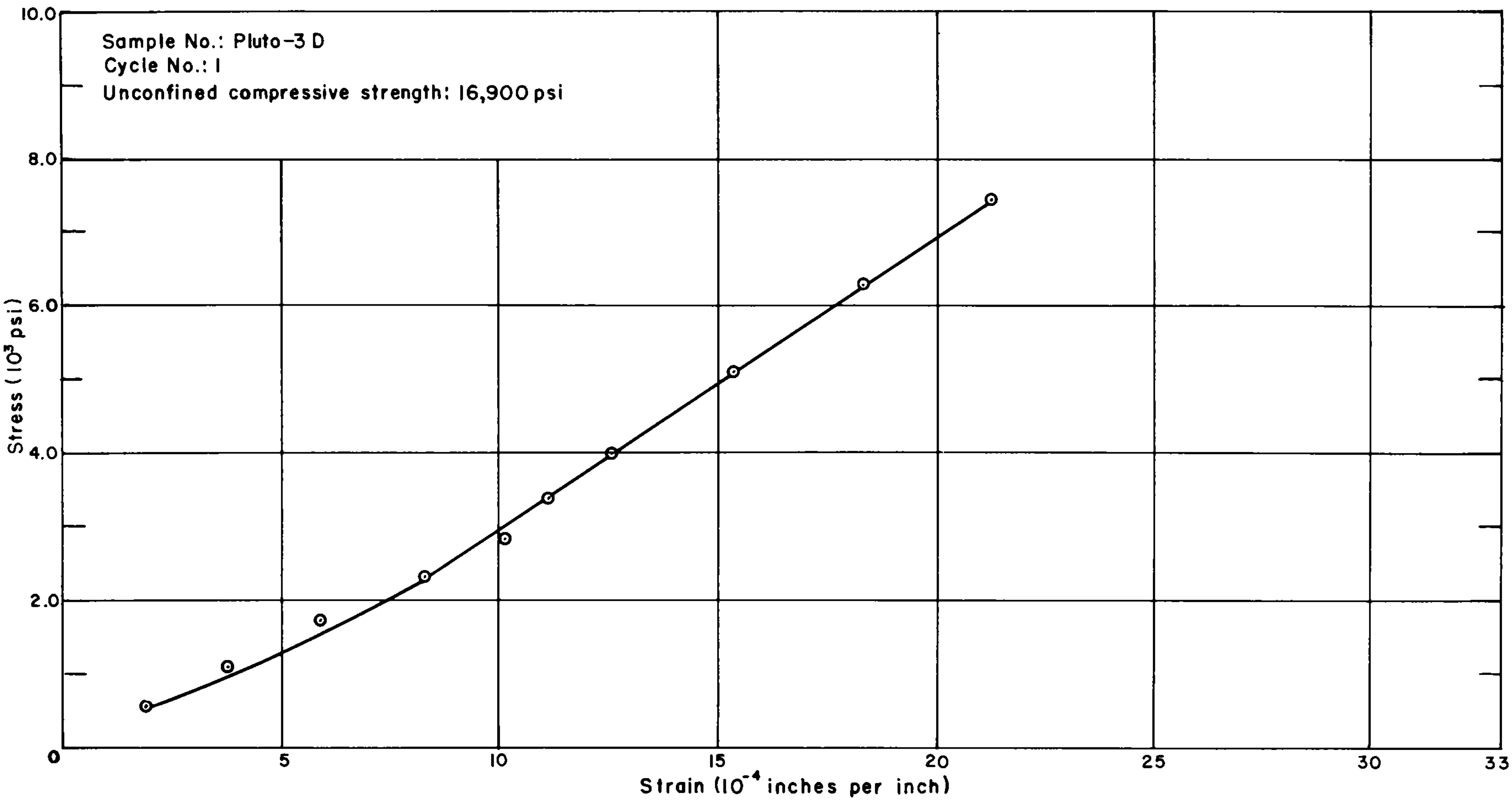


Figure 29.– Stress-strain curve of rock core from Area 401, Nevada Test Site, Nye County, Nevada

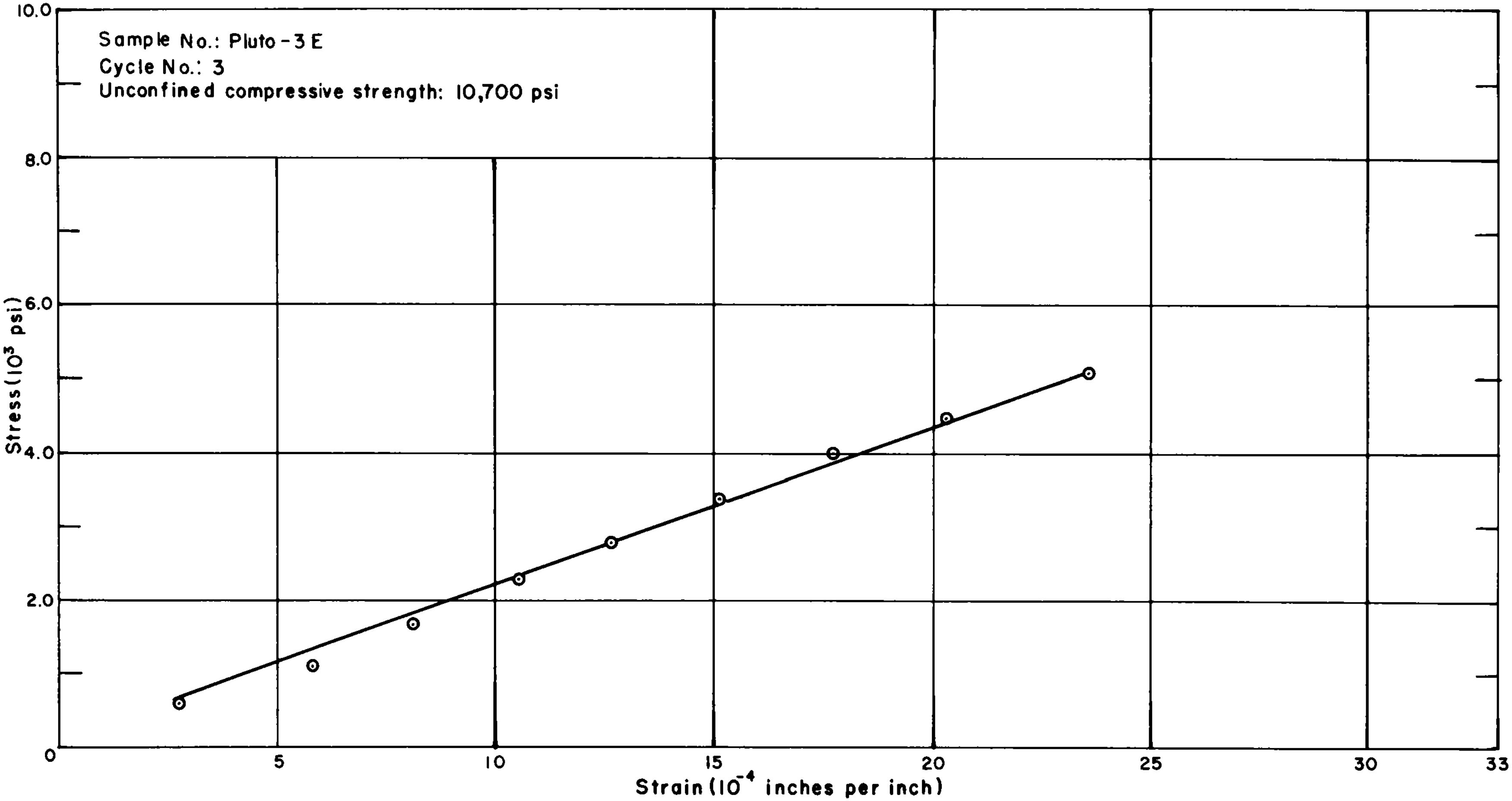


Figure 30-Stress-strain curve of rock core from Area 401, Nevada Test Site, Nye County, Nevada

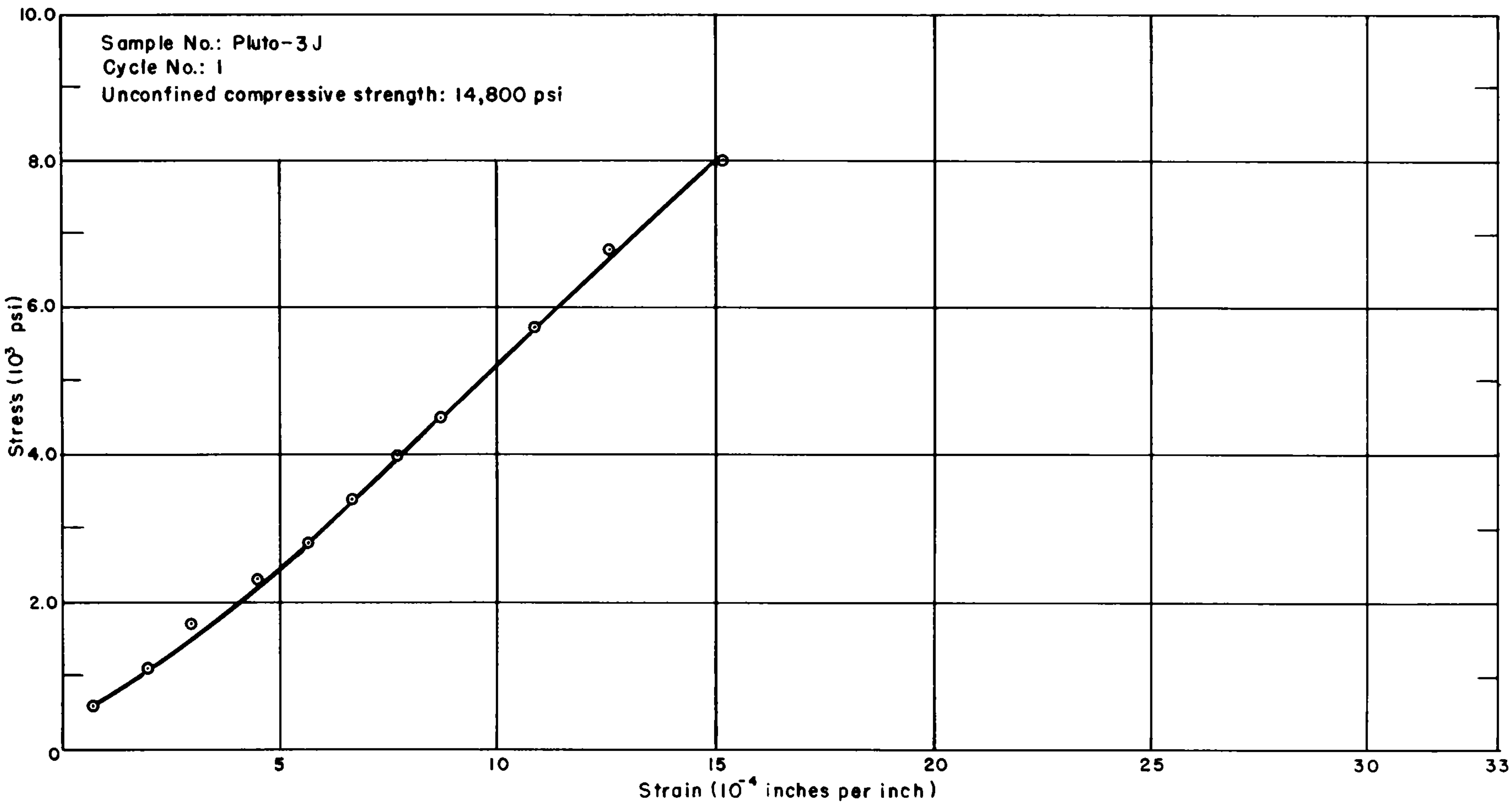


Figure 31.—Stress-strain curve of rock core TMC 3. from Area 401, Nevada Test Site, Nye County, Nevada

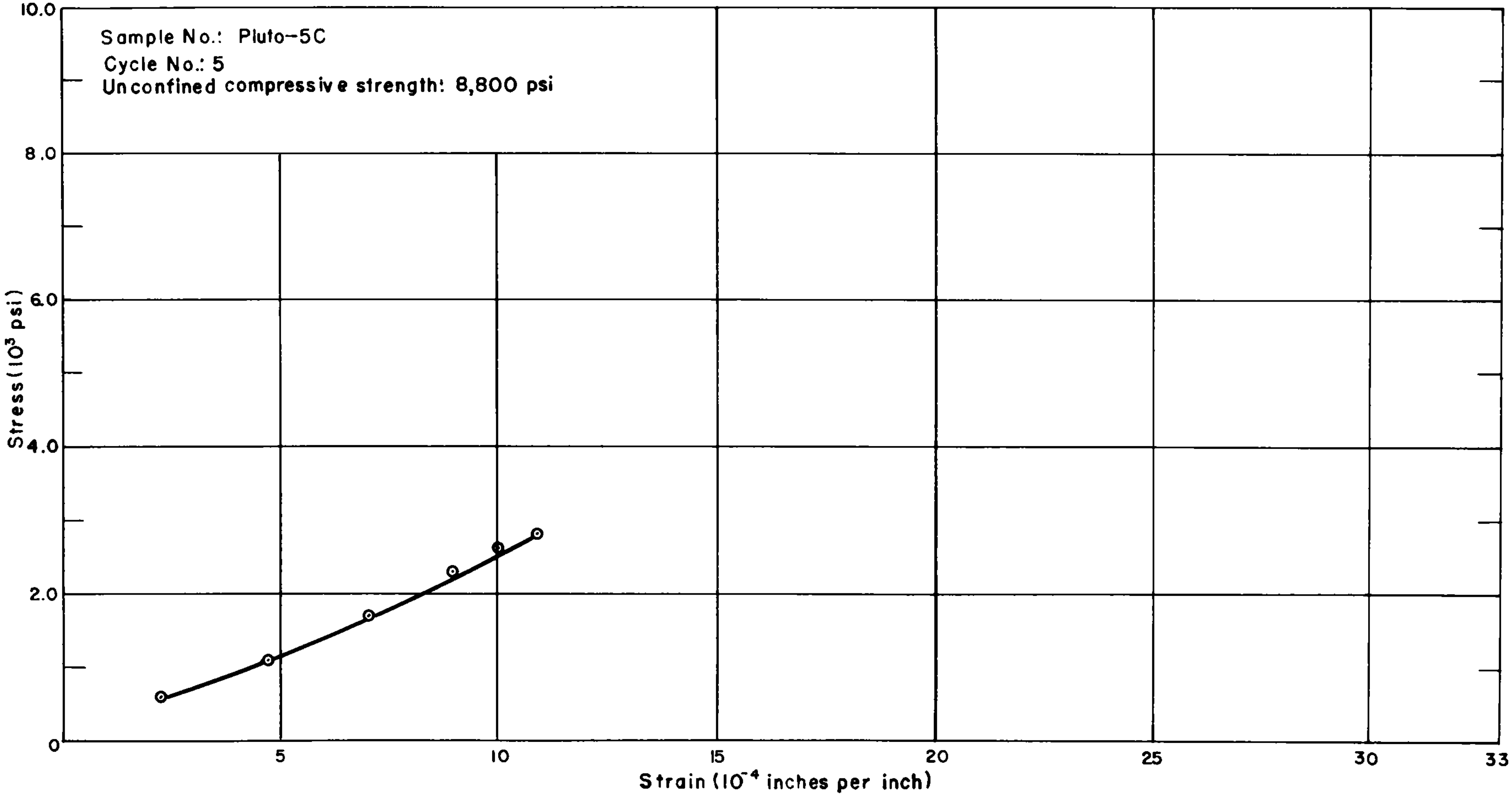


Figure 32.— Stress-strain curve of rock core from Area 401, Nevada Test Site, Nye County, Nevada

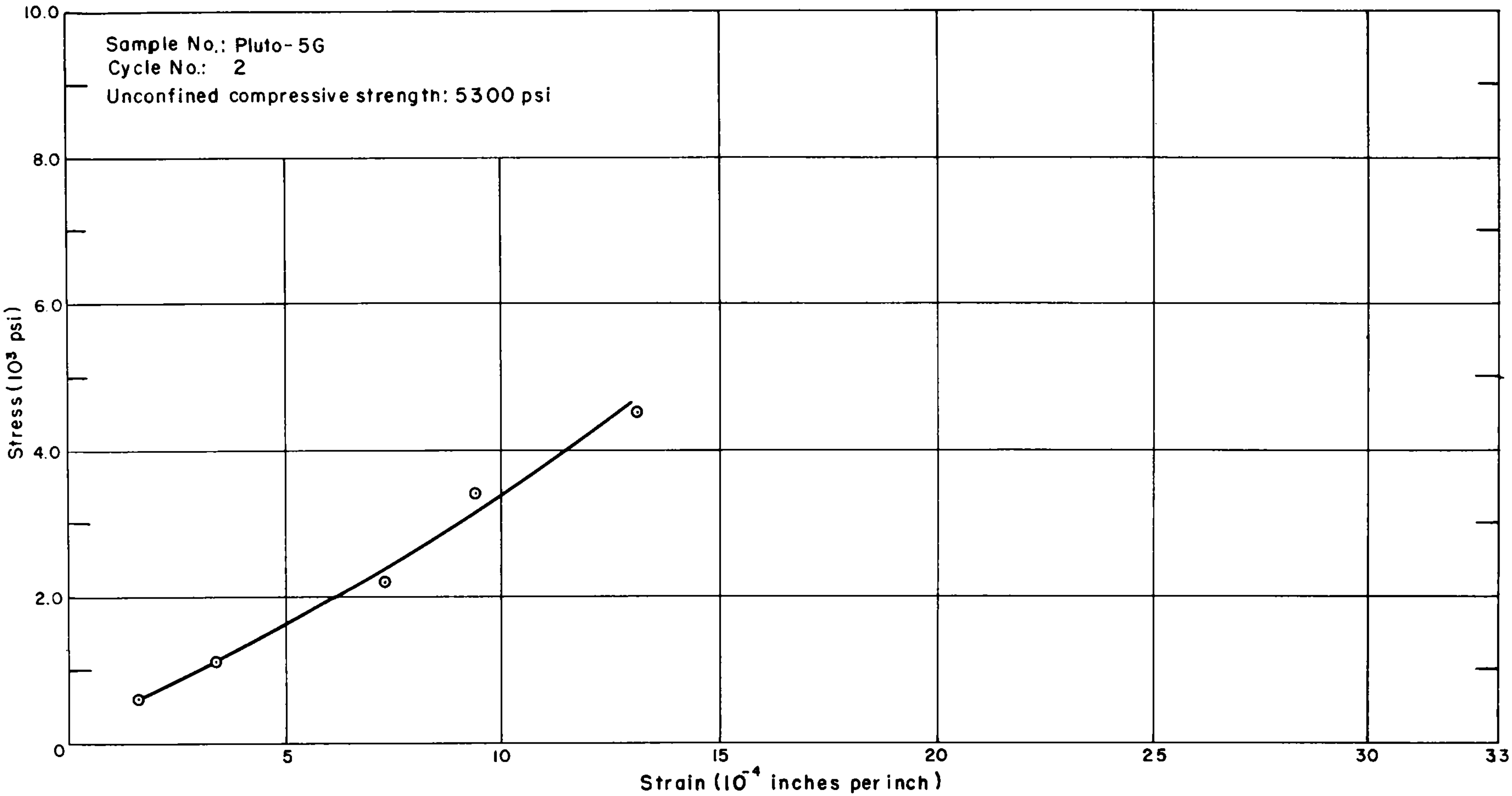


Figure 33.–Stress-strain curve of rock core from Area 401, Nevada Test Site, Nye County, Nevada

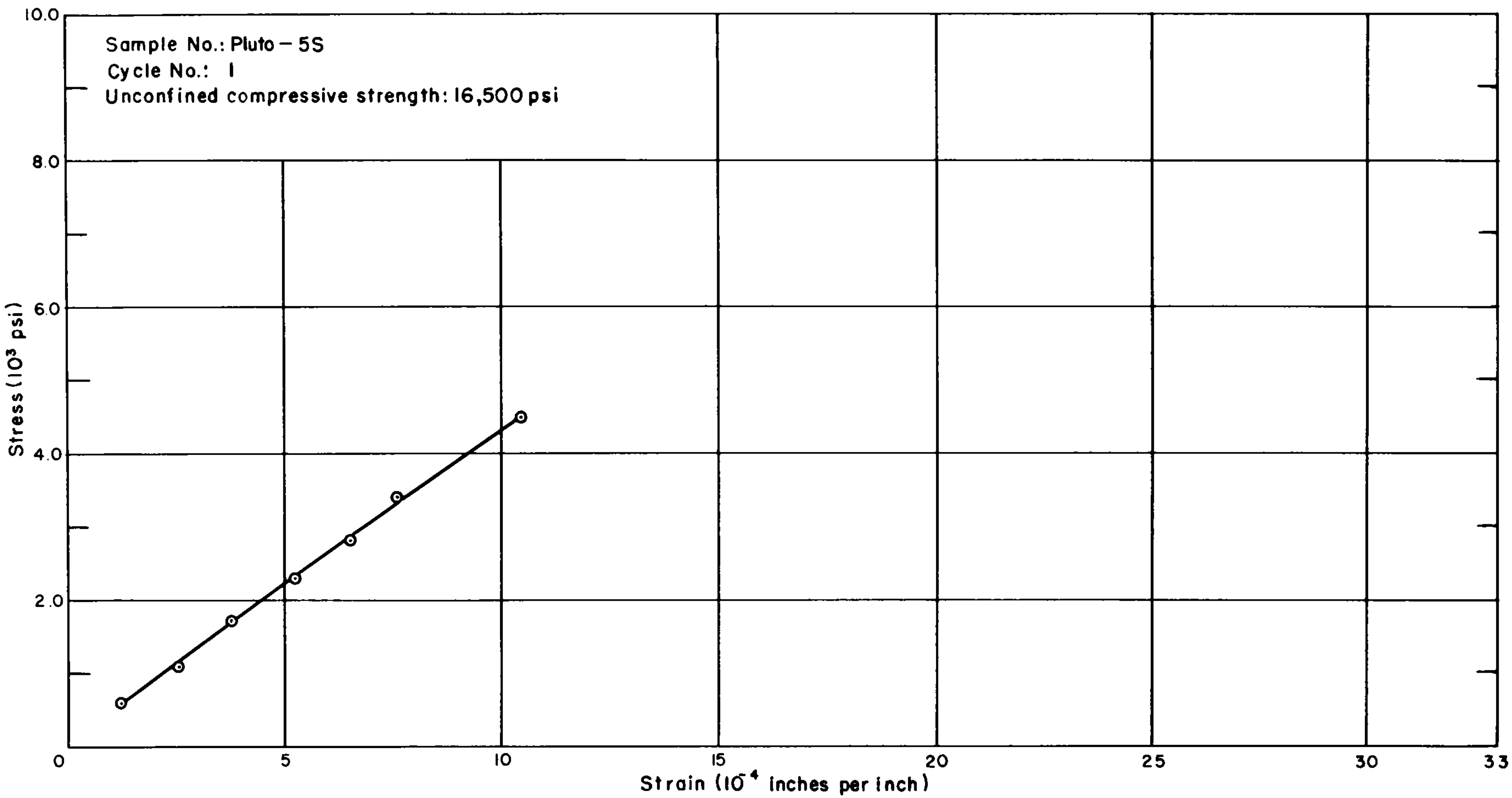


Figure 34.– Stress-strain curve of rock core from Area 401, Nevada Test Site, Nye County, Nevada

Table 14.--Unconfined compressive strength, Young's modulus, and Poisson's ratio for partly saturated core samples from test hole Pluto-1, Area 401, Nevada Test Site

[Analysts: T. C. Nichols, R. A. Speirer, and J. C. Thomas]

Depth (feet)	Core size (inches)	End parallelism (inches)	Core condition[1/]	Unconfined compressive strength (psi)	Secant Young's modulus psiX10^6(E)	Poisson's ratio range (u)	Secant range (psi)	Remarks[2/]
325.3-326.0	4-3/8 x 2-1/8	0.0020	Good. No fractures. Slightly chipped one end.	10,400	2.63	0.29	300-5,700	Predominant failure was along a shear fracture. Unaltered moderately weathered rock.
325.3-326.0	2 x 1	.0008	No fractures. Large chip one end.	6,400	2.55	not obtained	1,300-6,400	Predominant failure was along a shear fracture. Unaltered moderately weathered rock.
256.1	4-3/8 x 2-1/8	.0020	Good. Two preexisting fractures.	11,000	4.21	.22	600-5,100	Predominant failure was along a shear fracture, but not along preexisting fracture. Unaltered moderately weathered rock.
505.8-506.4	2-15/16 x 1-1/2	.0010	Good. No fractures-------	8,500	7.05	.27	600-6,800	Predominant failure was along a shear fracture. Slightly altered unweathered rock.
680.0-680.80	2 x 1	.0006	-------------do-----------	8,300	3.41	.30	1,300-7,600	Predominant failure was along a shear fracture. Moderately altered unweathered rock.
770.8-771.4	3 x 1-1/2	.0010	-------------do-----------	12,500	3.28	.06	600-6,800	Predominant failure was along a shear fracture. Moderately altered unweathered rock.
722.2-723.3	3-1/16 x 1-1/2	.0004	Good. One small chip----	13,100	4.66	.10	600-7,400	Predominant failure was along a shear fracture. Moderately altered unweathered rock.

1/ Samples were brought to constant moisture content in 80 percent relative humidity chamber.

2/ Cores were cycled until no more permanent set was observed.

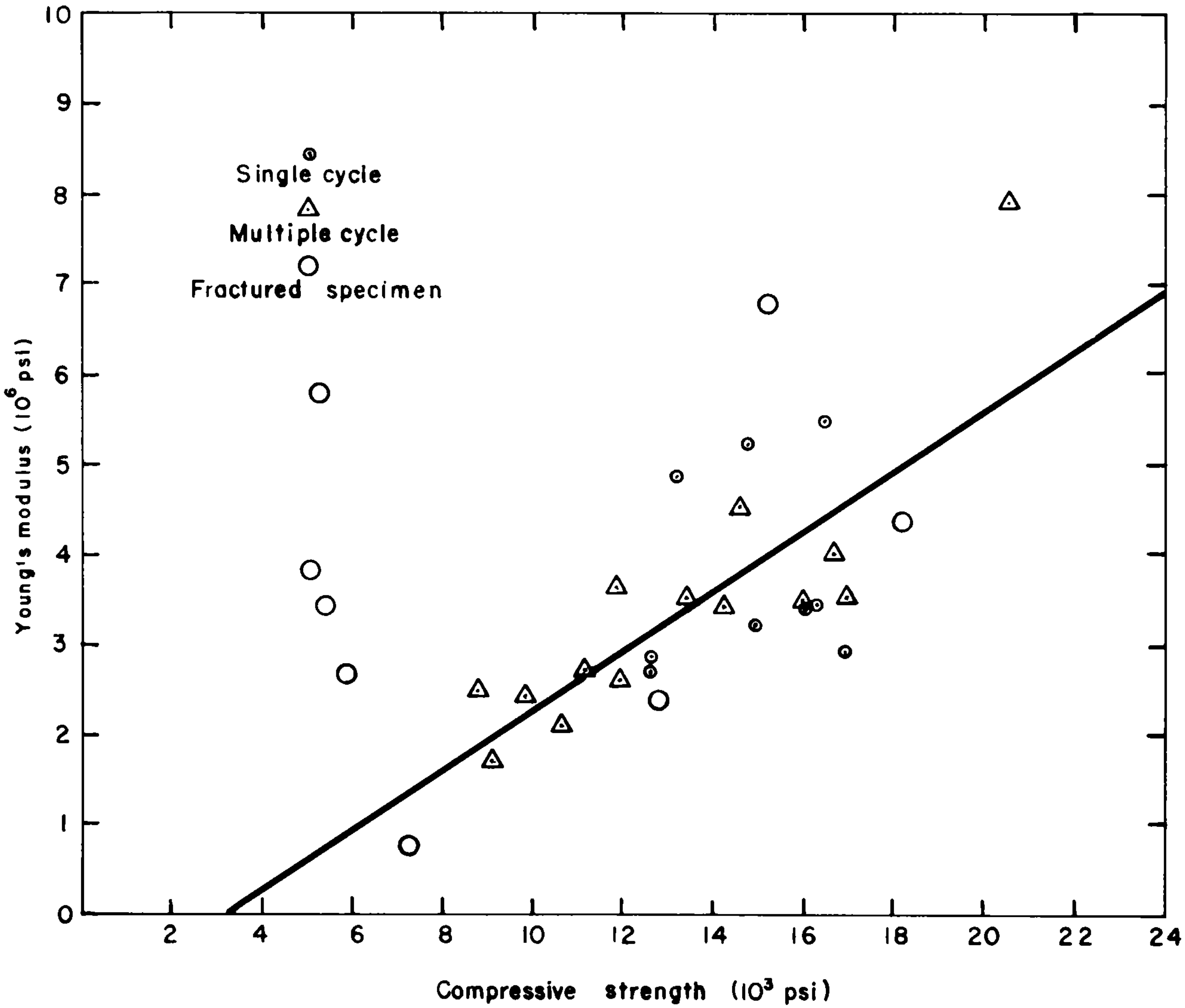


FIGURE 35.—COMPARISON OF STATICALLY DETERMINED YOUNG'S MODULUS WITH THE UNCONFINED COMPRESSIVE STRENGTH OF DACITE PORPHYRY SAMPLES FROM AREA 401, NEVADA TEST SITE, NYE COUNTY, NEVADA

results are plotted on figures 36 to 41.

Correlation of physical property parameters

Compressive strength versus dynamic Young's modulus.--A scatter diagram was drawn by plotting Young's modulus values (E) on the Y axis against compressive strength values (C) on the X axis (fig. 36). A total of 13 points was used. The plotted values show a linear relation. A linear regression was established, and the standard error was calculated. Constants were derived for this particular core, and they were substituted in the standard straight-line equation as shown below:

Equation 1. $E = 0.4X10^6+219C$, E = Young's modulus;

Equation 2. $C = \frac{E-0.4X10^6}{219}$, C = compressive strength.

The standard errors (S), or the limits within which 68 percent of all cases will fall, are respectively:

Equation 3. $1\ S_e = 0.4X10^6$ psi from the theoretical value (Young's modulus);

Equation 4. $1\ S_c = \pm 1800$ psi from the theoretical value (compressive strength).

Porosity versus compressive strength.--Porosity values plotted against compressive strength values suggest that a good inverse correlation exists between these properties (fig. 37). A total of 14 points was used. The compressive strength decreases with increasing porosity. A linear equation was fitted to the data.

Equation 5. $C = 23{,}380-824\ P$, C = compressive strength, psi

P = porosity, in percent.

The standard error is:

Equation 6. $1\ S_c = \pm\ 1{,}018.8$ psi.

This equation may be valid only between certain porosity limits.

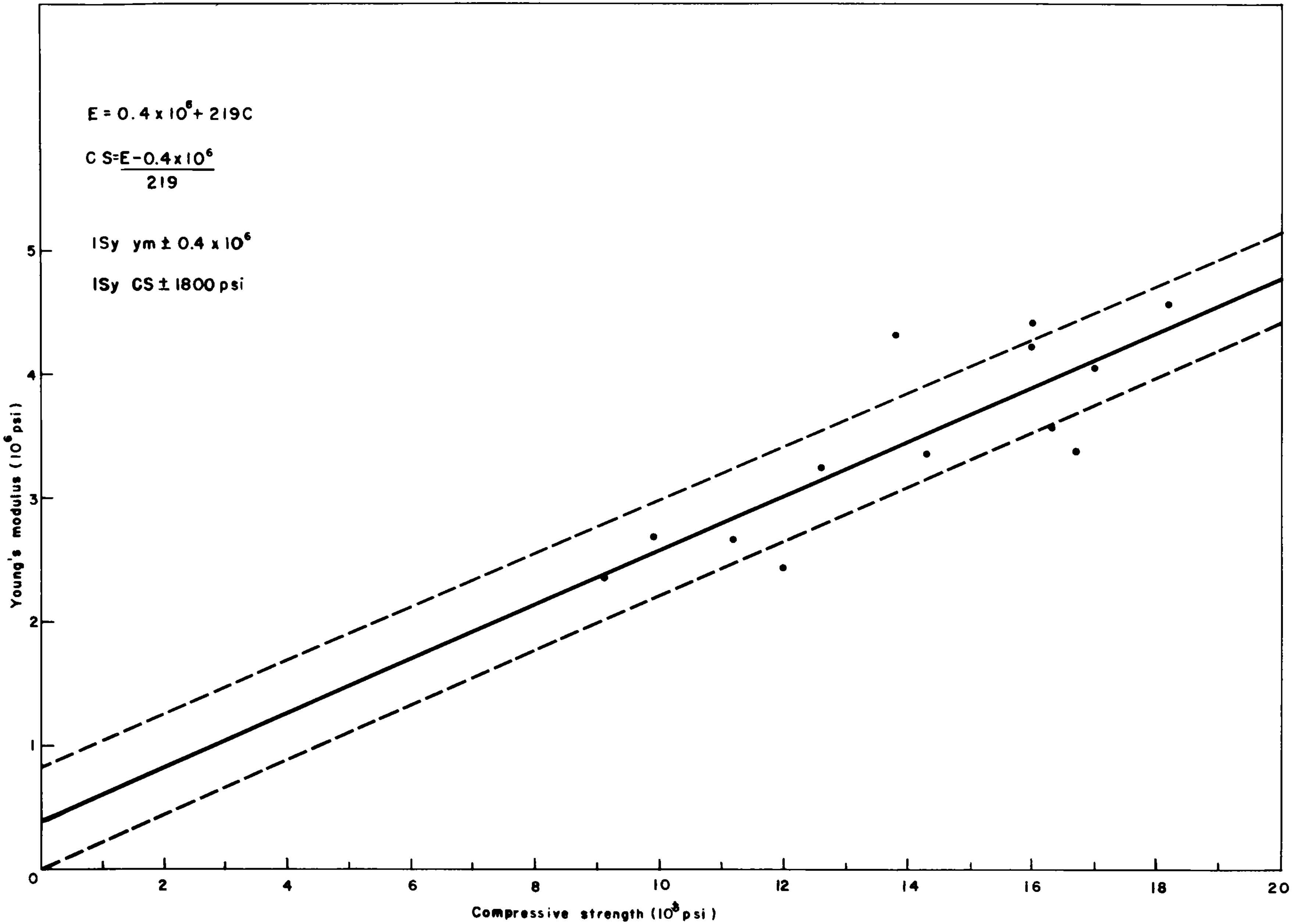


FIGURE 36.- COMPARISON OF DYNAMICALLY DETERMINED YOUNG'S MODULUS WITH THE UNCONFINED COMPRESSIVE STRENGTH OF ROCK SAMPLES FROM TEST HOLE PLUTO-1, AREA 401, NEVADA TEST SITE

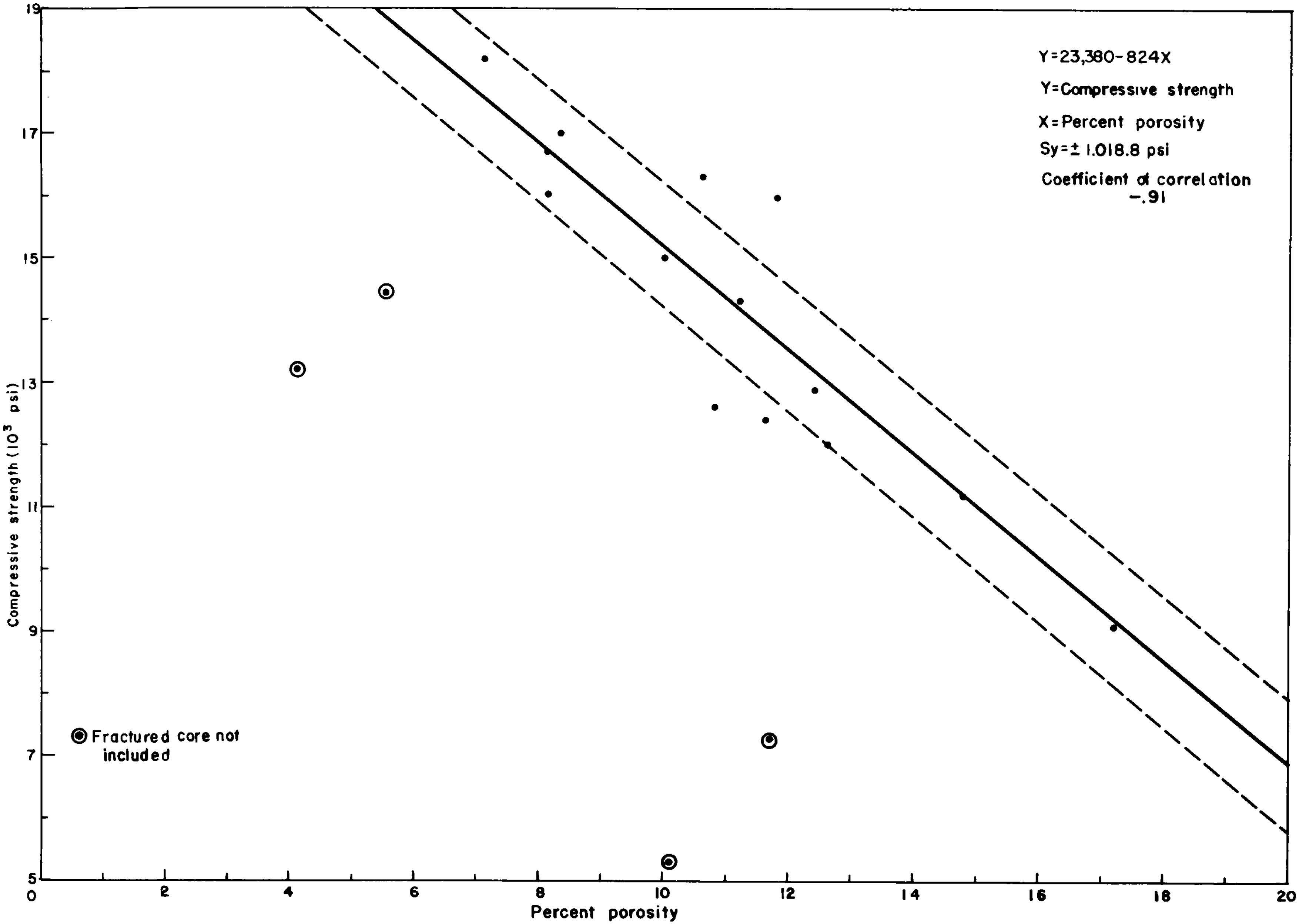


FIGURE 37.– COMPARISON OF POROSITY WITH UNCONFINED COMPRESSIVE STRENGTH OF ROCK SAMPLES FROM TEST HOLE ~~PLUTO~~-1, AREA 401, NEVADA TEST SITE

Beyond these limits the linear relation may not be valid.

Dynamic Young's modulus versus dry bulk density.--Scatter diagrams were made by plotting Young's modulus against porosity and dry bulk density (figs. 38 and 39). A direct relation seems to exist between dynamic Young's modulus and the dry bulk density, as both values increase in respect to each other. An inverse correlation appears to exist between Young's modulus and porosity. The trend between these parameters, however, is not linear, but slightly curvilinear. The dry bulk density versus Young's modulus values were taken because, on inspection, they appeared to have a better trend. The value obtained for the curve is:

Equation 7. $E = 13.04X10^6 D + 3.33X10^6 D^2$,

E = Young's modulus,

D = dry bulk density.

The standard error is:

Equation 8. $S_y = \pm\ 0.6X10^6$ psi (approximate) Young's modulus.

Magnetic susceptibility versus dynamic Young's modulus and compressive strength.-- Values for magnetic susceptibility were plotted against dynamic Young's modulus (fig. 40).

In this case there is no apparent correlation between these two properties. Negative results were also obtained when magnetic susceptibility was compared to compressive strength.

Static Young's modulus versus dynamic Young's modulus.--There is a direct correlation between the two Young's moduli obtained by static and dynamic methods (fig. 41). The equation of the line is:

Equation 9. $Y_d = 0.8X10^6 + 0.88X10^6 Y_s$ psi, Y_d = dynamic Young's modulus,

Y_s = static Young's modulus.

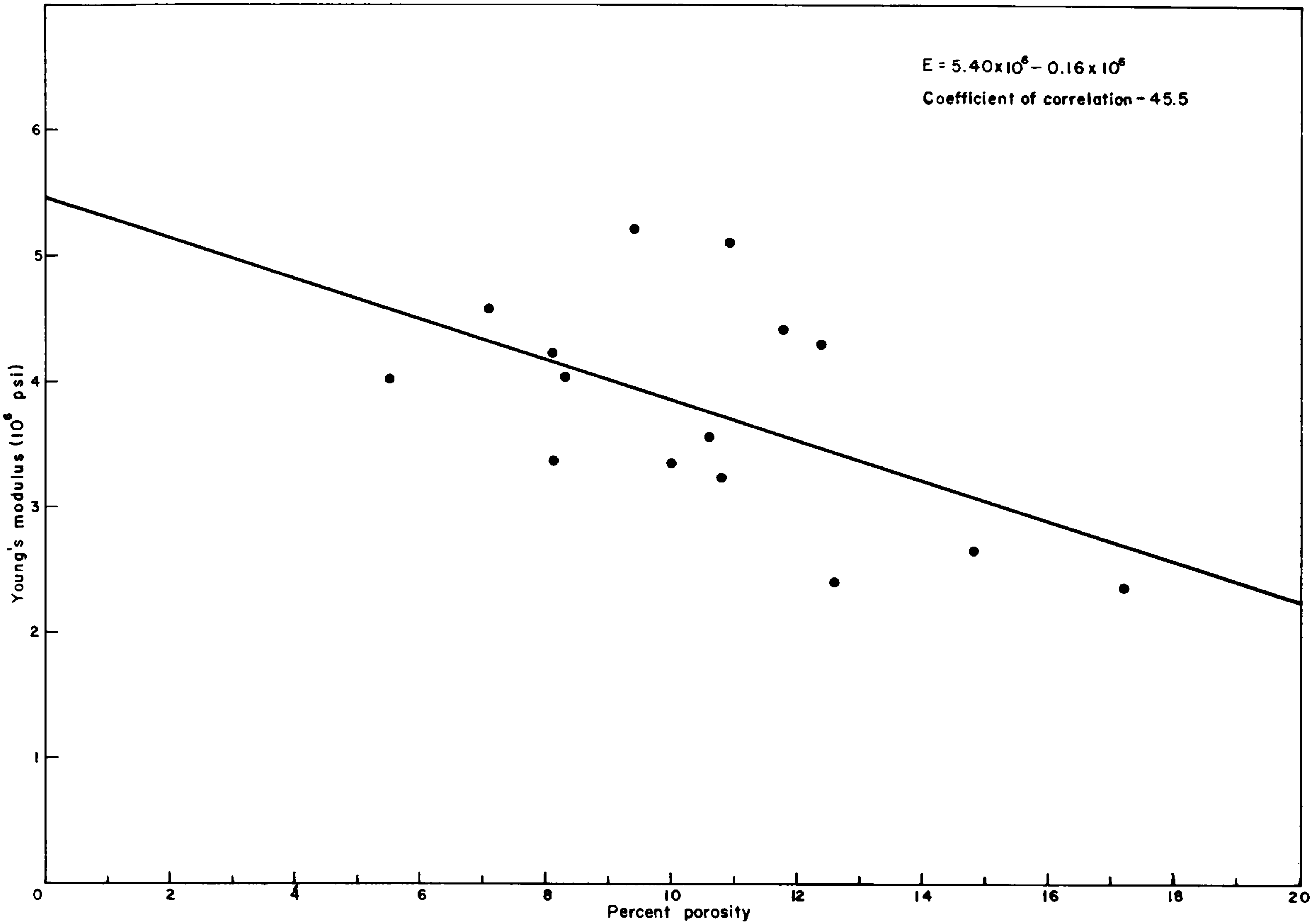


FIGURE 38.— COMPARISON OF DYNAMICALLY DETERMINED YOUNG'S MODULUS WITH POROSITY SAMPLES FROM TEST HOLE PLUTO-1, AREA 401, NEVADA TEST SITE

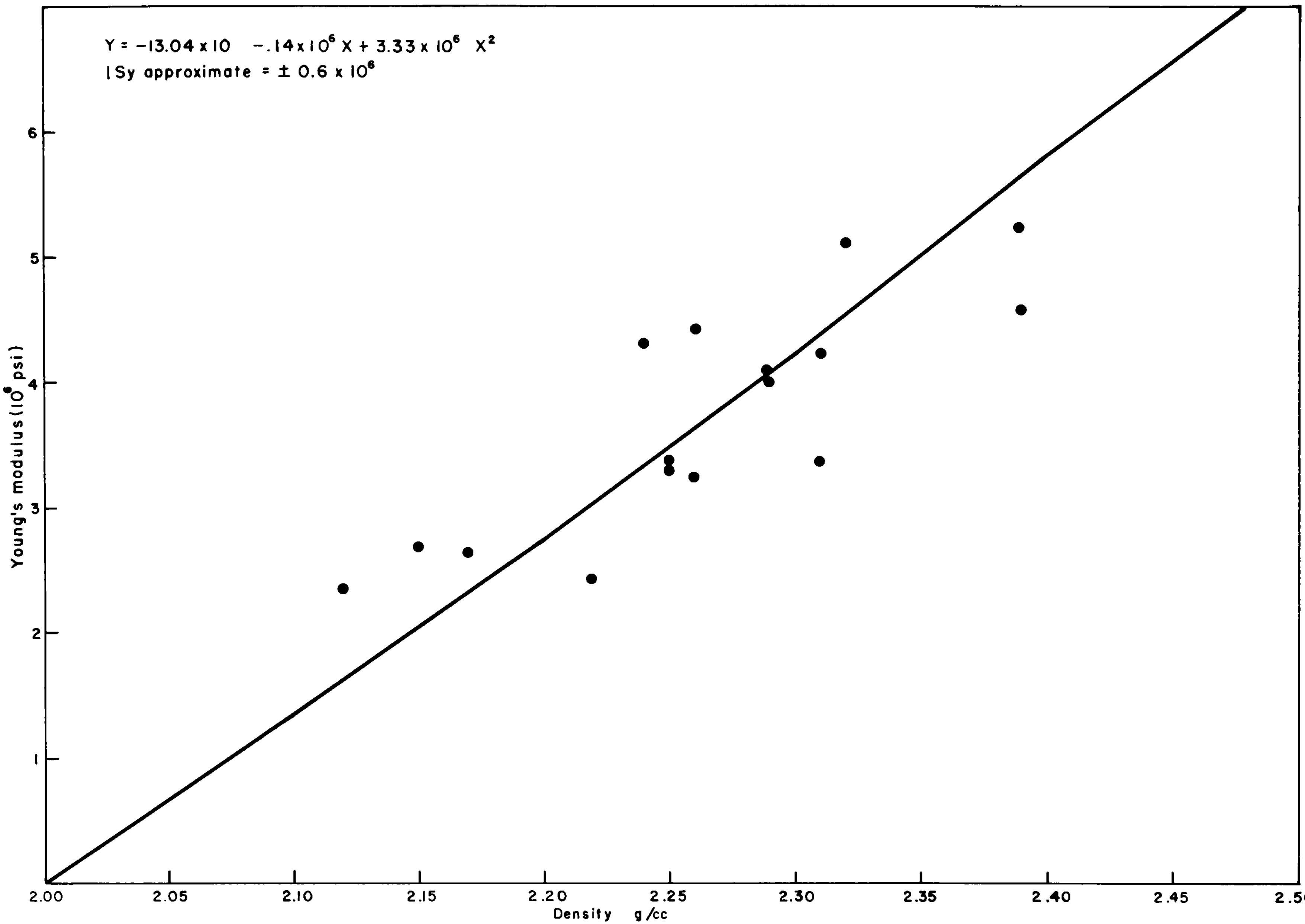


FIGURE 39.— COMPARISON OF DYNAMICALLY DETERMINED YOUNG'S MODULUS WITH DRY BULK DENSITY OF ROCK SAMPLES FROM TEST HOLE PLUTO-1, AREA 401, NEVADA TEST SITE

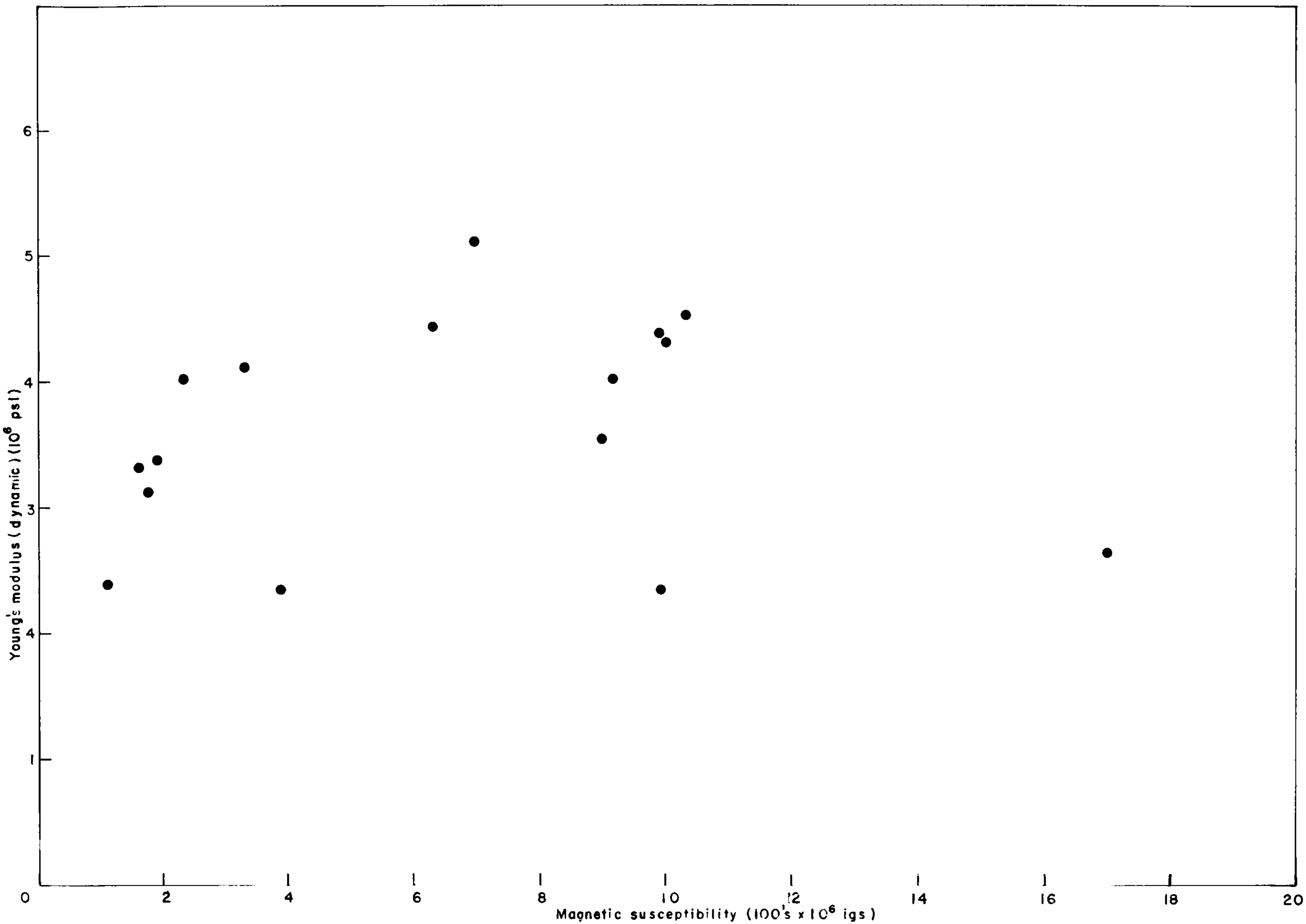


FIGURE 40.-- COMPARISON OF DYNAMICALLY DETERMINED YOUNG'S MODULUS WITH MAGNETIC SUSCEPTIBILITY OF ROCK SAMPLES FROM TEST HOLE PLUTO-1, AREA 401, NEVADA TEST SITE

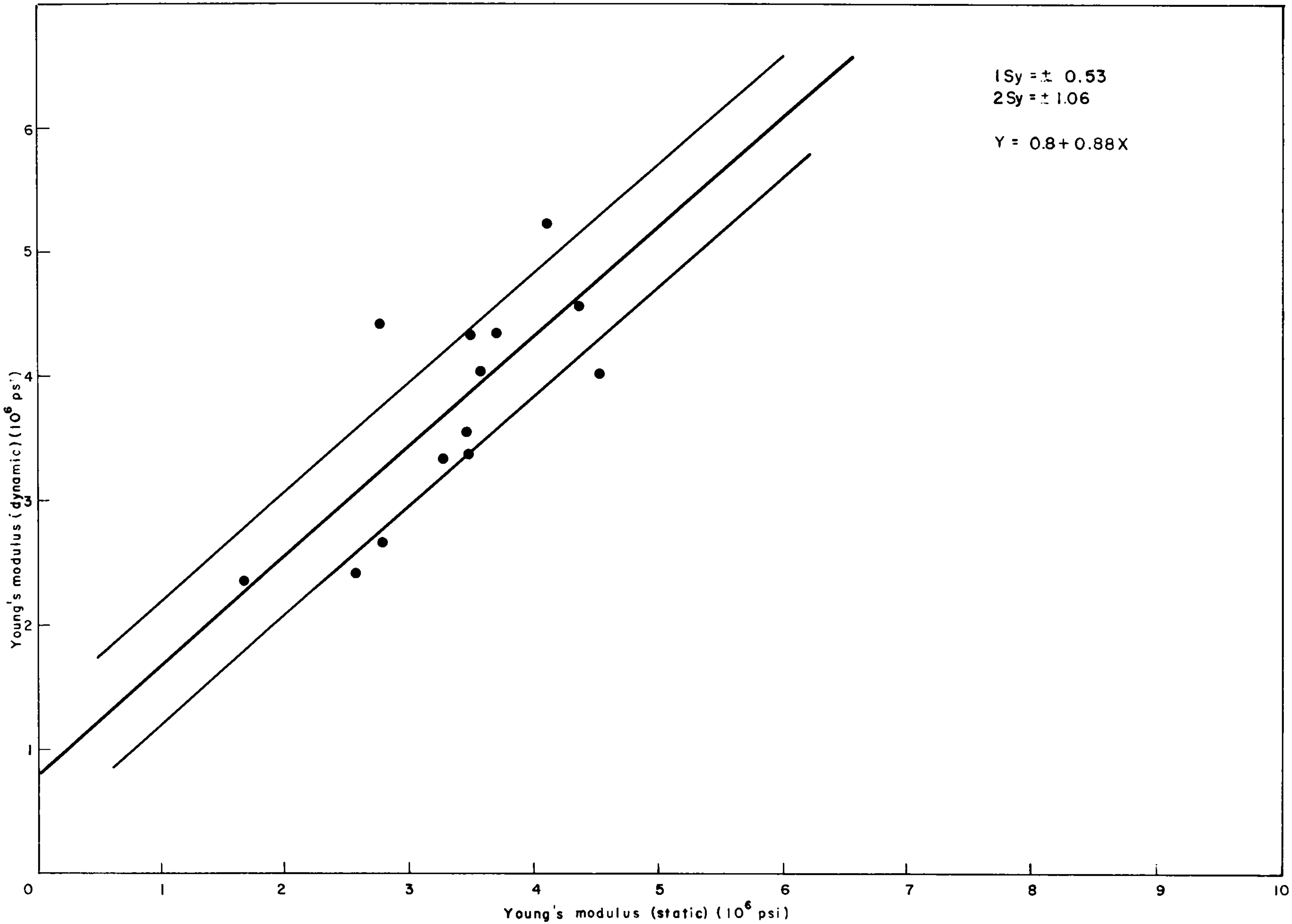


FIGURE 41.- COMPARISON OF STATICALLY DETERMINED YOUNG'S MODULUS WITH DYNAMICALLY DETERMINED YOUNG'S MODULUS OF ROCK SAMPLES FROM TEST HOLE PLUTO-1, AREA 401, NEVADA TEST SITE

The standard error is:

<u>Equation 10.</u> 1 $S_{yd} = \pm 0.53X10^6$ psi.

At a point below $Y_d = 3.50X10^6$, the majority of plots fall under the line of best fit, and above this point the majority of plots lie over it. This may indicate a characteristic of the rock or be an indication of the different methods of obtaining the two Young's moduli values.

The results of this study of the rocks in Area 401 indicate an inverse relation between porosity versus unconfined compressive strength and Young's modulus, and a direct relation between dynamic and static Young's moduli. There is no apparent relation between compressive strength and magnetic susceptibility, nor between Young's modulus and magnetic susceptibility.

SUMMARY

The location of the Pluto nuclear reactor made it necessary to construct the proposed underground air-storage chamber in Area 401. Large parts of Area 401 are underlain by weathered, hydrothermally altered, locally mineralized, and structurally complex rocks unsuitable for construction of the underground air chamber. Nevertheless, geologic and geophysical studies did show that in several areas underlain by dacite porphyry there are potentially suitable sites for the air chamber. Two of these sites (figs. 3 and 4) were mapped and studied in greater detail for purposes of further predicting and evaluating the characteristics of the subsurface rocks, the excavation hazards, and occurrence of ground water. Five exploratory test holes, core to depths ranging from 111 to 778 feet, were drilled in the two sites to obtain data on the subsurface structure, petrography, chemistry, and physical properties of the dacite porphyry.

Partings along flow banding, joints, inactive faults, and shear zones have broken the rocks extensively in Area 401. In the areas (figs. 3 and 4) of potentially favorable sites, joints with highly variable orientations and partings along flow banding are present at all depths tested by drilling. Shear zones and wide persistent faults, however, are not found in these areas. The partings along the flow bands decrease in number with depth, the dominant joints strike rather consistently northeast and northwest, and all fractures at depth are tighter because of the weight of the overburden and the effective sealing of many joints by calcite. A few joints are open and show evidence of having been channels for the downward or lateral movement of ground water.

Defined on the basis of petrography and chemistry the rocks in the two potential sites are divided into three lithologic zones: (1) light-gray intensely weathered unaltered dacite porphyry having local lenses of fresh rock that extends into the vicinity of Pluto holes 1 and 3 from the surface to a depth of 160 feet, (2) brownish-gray moderately weathered unaltered dacite porphyry that extends from 160 to 560 feet, and (3) greenish-gray hydrothermally altered dacite porphyry that extends from 560 to 1,000 feet. Figure 7 and table 8a show that the properties of the dacite porphyry vary in each of these three zones.

The fresh rock tends to be strong because it is largely amorphous to medium grained. The crystals in the rock, however, are not well interlocked or packed due to the large amount of groundmass glass; therefore, the dacite porphyry is weaker and more inelastic than an otherwise similar rock with an interlocking groundmass. The average unconfined compressive strength of the fresh dacite is 11,200 psi, and the average dynamic Young's modulus is 6.71 psi X 10^6. The porosity of the fresh dacite porphyry averages 6.2 percent. The intensely weathered unaltered dacite, which comprises the bulk of the upper zone, has an average unconfined compressive strength of 9,200 psi, an average static Young's modulus of 1.74 psi X 10^6, and an average porosity of 18.6 percent. The comparatively high porosity within 160 feet of the surface is due to the effect of weathering on the groundmass glass of the dacite porphyry.

In the moderately weathered unaltered zone between 160 and 560 feet in depth the unconfined compressive strength averages 14,731 psi, the average static Young's modulus is 3.44 psi X 10^{-6}, and the average porosity is 10.8 percent. Some values for the unconfined compressive strength in this intermediate zone are as much as 21,400 psi.

In the hydrothermally altered zone between 560 and 1,000 feet the unconfined compressive strength averages 15,533 psi, the average static Young's modulus is 4.82 psi X 10^{-6}, and the average porosity is 8.2 percent.

Descriptions of cores from test holes

Test hole Pluto-1

Nevada State Coordinates: N. 754,788.50; E. 662,480.56

Logged by John C. Manning and Ross B. Johnson

Description	Interval (feet)	Core recovery (percent)
Cased. Ditch shows same as below---------------------	0 - 35	
Dacite porphyry, weathered, white to light-gray;		
predominantly devitrified glass; medium-grained		
crystals; 15 percent phenocrysts of biotite with		
accessory magnetite and rare hornblende. Appears		
to be impervious except along joints. Normal		
joints indistinct, highly weathered. Several	35 - 36.5	50
nearly vertical shear joints show slickensides	36.5- 45	70
and small movement. Driller reports small water	45 - 48.6	90
loss. Core recovery good, but few core segments	48.6- 53	80
longer than 4 in. Much of core comes out of	53 - 58	95
barrel fragmented, but not ground up------------	58 - 64	85
Dacite porphyry, same as above, but harder, and much		
less weathered. Glassy groundmass partly		
devitrified, but much stronger than unit above.		
Jointing: prominent sets dip 30° to 40°, 60°,		
and nearly vertical (from horizontal plane)		
spacing 4 to 6 in.; some joint surfaces are		
coated with claylike material, and some joints		
have been sealed. Sample Pluto-1A at 65.5 ft		

Test hole Pluto-1--Continued

Description	Interval (feet)	Core recovery (percent)
(footage at top of sample)	64 - 68.6	95
Dacite porphyry, same as above, but grades within 2 ft to more deeply weathered rock with a color change from gray to buff. Lower 18 ft much softer than gray dacite above; jointing not nearly so prominent, a few joints show minor shearing, and a few have been sealed by clay. Spacing indefinite, but more widely spaced than in unit above. Rare lithic fragments of dark basic lava and highly disturbed carbonate rock. Calcite vein (1/2 in) at 85 ft. Rock more porous than unit 2 above. Sample Pluto-1B at 83.3 ft	68.6- 91.2	90
Dacite porphyry, similar to above but firmer, less porous, and less weathered groundmass. Gray to buff with many closely spaced dark joint planes. Dark material coating joints appears to be manganese stained clay. Few thin calcite veins. Scattered lithic fragments as in unit above. Groundmass appears to be strong, but massive rock is cut by numerous clay partings. Lower 10 ft is harder and has fewer clay partings and more pronounced jointing. Orientation of joints same as in units above.		

Test hole Pluto-1--Continued

Description	Interval (feet)	Core recovery (percent)
Sample Pluto-1C at 101.0 ft; sample Pluto-1D at 109.8 ft------------------------------------	91.2-118	90
Dacite porphyry, similar to above. Color white to buff, glassy groundmass firm, but a little more weathered than unit above. Few widely scattered noncalcareous lithic fragments of dark lava. Scattered thin calcite veins. Few sealed fractures and jointing similar to above with 1- to 2-foot spacing. Most joints tight. Sample Pluto-1E at 127.5 ft------------------	118 -129.1	95
Dacite porphyry, same as above. Joints dip 60°. Lost circulation at 143 ft--core shows broken fragments and short interval of poor recovery. Scattered small crystals of pyrite. Sample Pluto-1F at 130 ft; sample Pluto-Fa at 144 ft--------------------	129.1-146	95
Dacite porphyry; same as above. Joints dip 45° to 60°. Joints not sealed as well as in unit above. Lost circulation at 154 ft where core shows open vertical crack and a horizontal fracture. At 154 ft rock shows slight banding that becomes more apparent downward. Sample Pluto-1G at 158 ft-------------------	146 -160	90

Test hole Pluto-1--Continued

Description	Interval (feet)	Core recovery (percent)
Missing core (not recovered). Lost water------------	160.6-162	0
Dacite porphyry, similar to above, but with a gradual change in character of the rock from 162 to 163.5 ft. At 163.5 ft and below rock is hard, somewhat porous. Vuggy, from 163.5 to 173 ft--rock is much jointed and some vertical cracks lined with iron oxide. In spite of fractures, rock cores well with good recovery. From 173 to 213 ft rock has several jointed blocky zones with open fractures. Below 213 ft rock is firmer and joints appear to be sealed tighter. Core from 213.5 to 221 ft in single piece. Joints dip 60° (2 sets), 45°, 75°. Banding at 15° from horizontal. Lost water 165 ft------------	162 -221	95
Dacite porphyry, coarse-grained, reddish color due to partly devitrified glass. Phenocrysts are mainly biotite and feldspar with rare quartz. Phenocrysts make up 20 percent of rock; glass, 75 percent. Sample Pluto-1H at 173 ft; sample Pluto-1J at 190 ft; sample Pluto-1K at 217.5 ft.		

Test hole Pluto-1--Continued

Description	Interval (feet)	Core recovery (percent)
Same as above, firm and hard with joints well sealed, except for vertical cracks at 251-252 ft and 253-257 ft. Sample Pluto-1L at 240 ft; sample Pluto-1M at 271 ft------------------------------	221 -273	95
Same as above, firm and hard except for friable zone from 293-297 ft where core recovery was poor. Vertical jointing prominent, most joints are tight and coated with iron oxide. At 291 and 300-301 ft joints are partly filled with thick (1/4- to 1-in.) coating of chalcedony and	273 -293	95
crystalline quartz. Sample Pluto-1N at 298	293 -297	65
ft; sample Pluto-1P at 326 ft------------------	297 -330	95
Same as above, firm and hard with sealed joints. Some joints in this interval show thin seam of clay which may be due to hydrothermal alteration of glassy groundmass. Rare lithic fragments of dark lava (1/4 to 2 in.) in lower part of this interval. Sample Pluto-1Q at	330 -367	97
354 ft--	367 -371	95
Same as above, firm and hard; some cores come out of core barrel in 4- and 5-foot lengths of solid rock. Joints tight and well sealed except for a few vertical joints that separate		

Test hole Pluto-1--Continued

Description	Interval (feet)	Core recovery (percent)
during coring. Sample Pluto-1R at 378 ft;	371 -379	95
sample Pluto-1S at 400 ft; sample Pluto-1T	379 -383	90
at 421 ft------------------------------------	383 -424	95
Same as above, firm, hard rock with joints tightly sealed. Rock comes out of core barrel in 5- to 7-foot lengths. Rare lithic fragments of dark lava (1/8 to 1/2 in.). Sample Pluto-1U at 450 ft--------------------------------------	424 -454	98
Same as above; firm, hard rock---------------------	454 -463.5	98
Same as above, but rock is softer, somewhat friable, and shows moderate amount of weathering. Nearly vertical joint at 463.5 ft with 1/2 in. of iron oxide and calcite, and showing slickensides (may be small fault with thin gouge zone). Joints below 463.5 ft show effects of hydrothermal alteration, but no slickensides. Rock in this interval generally softer and more friable than rock above-------------------------------------	463.5-474	80
Same as above, vertical joint sealed with calcite, and vugs filled with crystalline (2 to 4 mm) calcite. One piece of core 9 in. long, and rest of core broken and crumbled--------------	474 -477	90
Same as above, but much firmer with 8- to 18-in. pieces of core; joints sealed. Rock somewhat weathered and more porous than rock above		

Test hole Pluto-1--Continued

Description	Interval (feet)	Core recovery (percent)
463 ft. Sample Pluto-1V at 478 ft--------------	477 -491	97
Dacite porphyry, rock is weathered almost beyond recognition to a soft porous dark-brown material that looks like dried mud (but is definitely not caused by drilling operations)-------------	491 -491.5	85 (?)
Dacite porphyry, soft, porous, white to gray iron-stained, much weathered. Joints coated with soft iron oxide. Manganese dendrites along joint surfaces indicate weathering, but intense degree of alteration in the massive rock suggests hydrothermal alteration in this zone. Core is not ground up, but is broken into small (1- to 4-in.) sections with rounded outlines---	491.5-496	90
Same as above, but less altered---------------------	496 -499	95
Same as above, becoming firmer and less altered. Vertical joints still show effects of alteration, but rock away from joints is harder and fresher than rock in interval just above--	499 -504	95
Dacite porphyry, firm, hard rock with joints tightly sealed. In interval from 514 to 524 ft there		

Test hole Pluto-1--Continued

Description	Interval (feet)	Core recovery (percent)
was a single piece of core that broke coming out of core barrel into two pieces, one 9 1/2 in. long and the other 9 ft 2 1/2 in. long. Sample Pluto-1W at 520 ft----------------------	504 -534	98
Same as above, firm, hard rock with tight joints (vertical, 60° and 25°). Color, buff to reddish. Sample Pluto-1X at 550 ft-----------	534 -553	98
Same as above, firm, hard rock, but with zones of bluish-green color interspersed with the normal buff to reddish color. The patches of green are composed of altered glass, and this material is softer than the surrounding reddish glass. There are clots (1 to 2 mm) of magnetite crystals and considerable calcareous material throughout the rock matrix as well as along the joints. The joints (especially the vertical joints) have been sealed with calcite and a mixture of iron oxide and clay. There are open vugs along a joint at 580 ft with calcite crystals (1 mm) lining the cavities. Most joints are tight and well sealed. Core comes from the core barrel in long lengths. Where the joints come apart in the core, there are no		

Test hole Pluto-1--Continued

Description	Interval (feet)	Core recovery (percent)
slickensides or evidence of movement along the joints. There has been a moderate amount of hydrothermal alteration, but the massive strength of the rock does not seem to have been significantly affected. There are rare elongate lithic fragments of dark rock (1/4 to 3/4 in.) in this interval. The interval from 574 to 576 ft has been more strongly altered and the joints are not so tightly sealed. Small calcite-lined vugs throughout this interval. Sample Pluto-1Y at 580 ft-------------------	553 -583	98
Same as above. Core broken into small fragments in 2 zones at 600 to 601 ft and at 605.5 to 606.5 ft. Broken zones have been much more deeply altered than surrounding rock, but there is no evidence of extensive movement in these zones. Except for the two broken zones, the core is firm and hard with all joints tightly sealed. Sample Pluto-1Z at 625 ft------------	583 -625	98
Same as above, but with 4- to 5-foot zones of coarser grained rock (crystals make up 40 percent of rock) with horizontal banding of alternating dark-green and light-green bands of		

Test hole Pluto-1--Continued

Description	Interval (feet)	Core recovery (percent)
color. Zone of friable and fragmented core at 633 ft. Joints tight. Rare dark lithic fragments of lava or metamorphic rock. Sample Pluto-1AA at 643 ft-------------------------	625 -645	98
Similar to above, but rock is reddish to white and is more weathered than interval above. Joints are filled with soft material (iron oxide and clay) that washes out during coring. Vertical joint from 646 to 647 ft had about 1/2 in. of soft filling that was not recovered with two halves of core which came out of core barrel in two long pieces. Massive rock softer and more weathered than reddish dacite porphyry above. Some slickensides along fractures in core. Joints: vertical and 2 sets at 60° with	645 -649	75
horizontal-----------------------------------	649 -653	95
Rock same as above, but much altered and broken. Rock is friable and is intersected with many fractures; some zones in core come out of core barrel as sand; many core fragments show slickensides. Core has 1/2 in. of slickensided clay gouge at 660 ft. This whole zone (653-664 ft) has been broken and		

Test hole Pluto-1--Continued

Description	Interval (feet)	Core recovery (percent)
crushed, probably by faulting, and core comes	653 -659	70
from or is very near a fault zone. Evidence,	659 -661	80
from core, indicates a high-angle fault------	661 -664	70
Same as above, but firmer rock in lower 1 ft of interval. Calcite crystals (1 to 2 mm) in open vugs (1/16 to 1/4 in.) at 669 ft--------	664 -670	60
Dacite porphyry as in interval above 645 ft, firm, hard rock, grades from reddish to greenish-gray color at about 672 ft. Prominent vertical joints tightly sealed with calcite and clay. Rock comes from core barrel in long solid lengths except for broken interval at 679 ft. Rock is hard in broken zone and fragmentation of core is probably due to drill hole penetrating an intersection of joint planes. Sample Pluto-1BB at 673 ft; sample Pluto-1CC at 686 ft------------------------------------	670 -690	98
Same as above, firm, hard greenish-gray rock. Core blocky with small fragments in several zones in interval from 717 to 737 ft. Where core is broken rock is hard, and broken zones are probably due to drill hole penetrating joint		

Test hole Pluto-1--Continued

Description	Interval (feet)	Core recovery (percent)
intersections. Few 1/2-inch light-gray	690 -717	95
streaks at 25° with horizontal (flow banding).	717 -727	80
Tight joints widely spaced. Sample Pluto-1DD	727 -737	85
at 721 ft; sample Pluto-1EE at 758 ft---------	737 -774	98
Same as above, but finer grained and smaller proportion of crystals (20 percent crystals in rock); greenish-gray to gray partly devitrified glass matrix. Lower 2 ft broken with some shearing (slickensides) along 60° joints and vertical joints, with minor claylike alteration along joints. Sample Pluto-1FF at 776 ft-------------------------------------	774 -778	85
Total depth 778 ft.		
4 1/2 in. O. D. casing cemented at 24 ft with screw cap (hand tight) on top.		
Acid bottle run to 778 ft showed hole deviation from vertical less than 1°.		

Test hole Pluto-2

Nevada State Coordinates: N. 755,967.40; E. 664,320.80

Logged by John C. Manning and Ross B. Johnson

Description	Interval (feet)	Core recovery (percent)
Overburden cased. Six ft of 4 1/2-in. casing cemented into bedrock. Cored with large casing bit to seat casing, and core not saved (diameter too large to put in core box--	0 - 6	
lithology same as below)----------------------	6 - 11	95
Dacite porphyry, gray to red color. Coarse-grained, firm hard rock with about 30 percent crystals in dense groundmass of partly devitrified reddish glass. Crystals are mainly feldspar (2 to 4 mm) and biotite (2 to 6 mm) with accessory magnetite and rare fine-grained pyrite. This core is from weathered zone, and rock is slightly porous with a moderate amount of weathering. Joints: vertical and 25° with horizontal, but most prominent set at 45°. Joints closely spaced and some are open at this depth, but rock cores well. Sample Pluto-2A at 12.5 ft--------------------------------------	11 - 38	95
Same as above, rock firm and hard, but core breaks into short lengths (2 to 6 in.) coming out of core barrel. Core from 45.5 ft to 47 ft came		

Test hole Pluto-2--Continued

Description	Interval (feet)	Core recovery (percent)
out of barrel in small fragments, but total recovery was still very good. Prominent joints at 60° with horizontal. Sample Pluto-2B at 45 ft--------------------------	38 - 48	95
Same as above, rock firm and most joints sealed. Joint at 66 ft shows slickensides. Rock somewhat altered in lower part of this interval with rare dark grains of sulfide(?) mineral. A few open vugs up to 1/4 in. in diameter. From 70 to 82 ft core is broken into fragments. In this interval crystals make up 40-50 percent of rock volume. Sample	48 - 68	95
Pluto-2C at 65 ft--------------------------	68 - 82	90
Same as above, rock fairly hard with moderate amount of weathering. Joints appear fairly tight, but core is broken up into fragments and short pieces (2 to 6 in.) as it comes from core barrel; some fractures in core follow joint pattern, but many are random; Sample Pluto-2D at 83.5 ft-------------------	82 -89	90
Same as above, rock moderately hard but altered; slickensides on several fracture planes.		

Test hole Pluto-2--Continued

Description	Interval (feet)	Core recovery (percent)
Occasional open vugs as above. Crystals make up 50 to 60 percent of rock volume. Many dark grains and films of blue-black mineral, malleable and nonmagnetic. Rock is intersected by many random fractures although vertical	89 - 92	98
fractures are most common. Some prominent	92 - 97	98
70° joints and fractures. Rock is moderately	97 - 99	80
strong, but is broken into small blocks by	99 -101	90
closely-spaced fractures. Massive strength	101 -105	90
of rock is low as compared with strength of solid	105 -107	75
pieces. Sample Pluto-2E at 102 ft; sample Pluto-	107 -109	95
2F at 108 ft-----------------------------------	109 -111	95

Hole was abandoned at 111 ft 10 in. Intensive and repeated fracturing at this locality has apparently produced a zone of jointed and broken rock with many closely spaced and random fractures. This does not look like a fault zone, although the slickensides on a few fracture surfaces show some movement in the broken rock.

Six ft of 4 1/2-in. O. D. casing with a screw cap (hand tight) is cemented into bedrock and sticks up about 8 in. above the ground surface. The hole is dry and empty.

Test hole Pluto-3

Nevada State Coordinates: N. 754,807.80; E. 662,506.58

Logged by John C. Manning and Ross B. Johnson

Description	Interval (feet)	Core recovery (percent)
Overburden--	0- 31	0
Dacite porphyry, white to buff, medium-grained (1 to 2 mm). Almost completely weathered to clay. Rare quartz with abundant feldspar and biotite crystals (1 to 2 mm) in claylike matrix of completely devitrified volcanic glass. Crystals make up approximately 25 percent of rock. Matrix and feldspar crystals are so weathered as to obscure the original texture of the rock. Rock is very soft and is plastic when it comes from core	31 - 33	30
barrel wet. Joints: 2 sets at 45°, 25°.	33 - 43	1
Joints are not prominent in this interval	43 - 53	50
due to plastic nature of rock. Poor core	53 - 58	80
recovery in upper part of interval was due	58 - 64	80
to rock washing away during drilling.	64 - 73	0 (lost)
Hornblende crystals are visible in lower	73 - 83	80
part of this interval. Sample Pluto-3A	83 - 93	90
at 62 ft; sample Pluto-3B at 100 ft-----------	93 -100	90

Test hole Pluto-3--Continued

Description	Interval (feet)	Core recovery (percent)
Same as above, but very much harder and less weathered; gray to green in color, medium grained with crystals making up about 40 percent of rock; crystals of feldspar, biotite, and hornblende (1 to 4 mm). Rock somewhat porous with joints filled with iron oxide, clay, and calcite. Joints: vertical and 2 sets at 45°. Sample	100-119	0 (lost)
Pluto-3C at 130 ft---------------------------	119-136	95
Same as above, but with hard and soft zones, depending on intensity of weathering, from 136 to 164 ft. From 164 to 210 ft rock is firm and hard with red streaks in upper part grading to mottled reddish color for most of lower part of this interval. Crystals of biotite, feldspar, and relict hornblende make up about 40 to 50 percent of rock. Weathering has affected glassy matrix and crystals, producing a somewhat porous, moderately hard rock. Some lithic fragments of dark lava or metamorphic rock. Joints: vertical, 2 sets at 60°, 25°. Scattered open vugs (1/16 to 3/16 in.) in core.		

Test hole Pluto-3--Continued

Description	Interval (feet)	Core recovery (percent)
This interval matches rock of same depth in test hole Pluto-1, and in this core rock grades from greenish-gray altered dacite above to reddish-gray dacite below without any apparent contact. Sample Pluto-3D at 161.5 ft; sample Pluto-3E at 164 ft; sample Pluto-3F at 190.5 ft; and sample Pluto-3G at 207.5 ft----------------------------------	136-162 162-171 171-210	90 95 98
Same as above, firm hard rock, red to gray in color; joints as above; most joints tight and sealed with thin seams of iron oxide, clay, and calcite. Some joints separate during coring, but most core in this interval came from core barrel in long (2 to 6 ft) solid lengths. Where core is broken, as in zone from 218 to 219 ft, rock is hard, and broken zone is probably due to drill hole penetrating an intersection of 2 or more joint planes. Most joints in this interval are vertical and are tightly sealed. Sample Pluto-3H at 221 ft; sample Pluto-3J at 232.5 ft; and sample Pluto-3K at 258.5 ft---	210-218 218-219 219-227 227-235 235-245 245-263	90 60 0 (lost) 98 95 98

Test hole Pluto-3--Continued

Description	Interval (feet)	Core recovery (percent)
Hole abandoned at 263 ft.		
24 ft of 4 1/2-in. O. D. casing set on bedrock; cemented at surface for 1 1/2 ft. Hole is dry and empty.		

Test hole Pluto-4

Nevada State Coordinates: N. 756,261.85; E. 661,491.41

Logged by John C. Manning and Ross B. Johnson

Description	Interval (feet)	Core recovery (percent)
Overburden--	0 - 39	0
Dacite porphyry, coarse-grained with crystals of hornblende, biotite, feldspar (>2 mm) making up 50 percent of rock volume. Groundmass is partly devitrified red to gray glass. Both groundmass and crystals are weathered. At 39-55 ft rock is soft; at 51-55 ft rock is intensively weathered and has consistency of stiff clay; at 55-72 ft same as above but much firmer, although somewhat weathered; at 72-113 ft rock similar to above, but with mottling consisting of irregular blocks of coarse-grained rock in finer matrix. Blocks vary from 1 to 8 in. in diam. Rock is mainly firm and hard with tight joints sealed with calcite at 60° from horizontal in interval from 76 to 100 ft. Between 100 to 113 ft joints are tight but not well sealed and core joints along joint surfaces. Joints: 2 sets at 60° (dominant), 1 vertical set, one 45° set (local). Sample Pluto-4A at 57 ft; sample Pluto-4B at 64 ft; sample Pluto-4C at 80 ft; sample Pluto-4D at 83.5 ft, sample Pluto-4E at	39 - 41	25
	41 - 48	30
	48 - 51	50
	51 - 55	20
	55 - 61	95
	61 - 71	98
	71 - 76	96
	76 - 86	98
	86 - 95	98

Test hole Pluto-4--Continued

Description	Interval (feet)	Core recovery (percent)
at 92.5 ft; sample Pluto-4F at 99 ft; and sample	95 -104	98
Pluto-4G at 106.5 ft---------------------------	104 -113	98
Same as above, firm rock with most joints well sealed from 113 to 130 ft. From 130 to 175 ft joints are tight, but not well sealed. Core is blocky and comes out of barrel in short pieces and small fragments. Intensity of fracturing throughout massive rock is about the same between 130 to 175 ft as in interval above, but with joints not tightly sealed and numerous fractures resulting in broken core. The rock is mostly firm; however, it seems softer in lower part, but this may be due to lack of cementing material along joints and other fractures. In lower part of	113 -118	98
interval rock shows banding (1/2 in.) at 45°	118 -128	98
and rock tends to break along banding. Dominant	128 -134	90
joints: 2 sets at 60°, 1 at 90°, and 1 at 45°	134 -137	80
(local). Few small vugs (1/16 to 3/16 in.).	137 -143	98
Few lithic fragments of altered lava. Joints	143 -146	98
below 130 ft are coated with iron oxide and	146 -152	90
clay, while those above 130 ft are cemented	152 -160	90
with calcite, with some clay and iron oxide.	160 -164	98
Sample Pluto-4H at 117.5 ft; sample Pluto 4 J	164 -166	80

Test hole Pluto-4--Continued

Description	Interval (feet)	Core recovery (percent)
at 130 ft; sample Pluto-4K at 148 ft; and	166 -170	85
sample Pluto-4L at 153.5 ft----------------------	170 -175	95
Same as above, core in short lengths and fragments (as above) to 188 ft. From 188 to 224 ft, core is in longer lengths with few fragmented zones. Rock is hard with prominent red and gray flow banding. Dark-gray zone at 202-209 ft with calcite and bright-green clay filling joints; joints are well sealed in this interval and core is in 1- to 3-foot lengths. From 209 to 222 ft, rock is slightly weathered and joints are not as well sealed as in interval above; rock is softer and more porous in this interval. Rock is hard with tight joints from 222 to 224 ft. Flow banding at various inclinations throughout interval (25° to 45° horizontal). Joints: 2 sets at 60° with horizontal (prominent), 45° (local), vertical (well sealed), filled with calcite and iron oxide with clay. Many joints are cemented with thin calcite filling, and core tends to break across rather than along these joints. Sample Pluto-4M at 178 ft; sample Pluto-4N at 189 ft; sample Pluto-4P at 204.5 ft; sample Pluto-4Q at 214.5 ft and sample		

Test hole Pluto-4--Continued

Description	Interval (feet)	Core recovery (percent)
Pluto-4R at 223 ft------------------------------	175 -224	95
Same as above. From 225 to 230.5 ft, rock is weathered and soft, and core breaks into small fragments. From 230.5 to 241 ft, rock is much harder with tight joints and with red and gray flow banding at 45° to 60°; joints are sealed by calcite, and the hard rock tends to break across rather than along the joints. Two dominant joint sets of 60° with horizontal. From 241 to 253 ft rock is intensively weathered and is very soft. In this interval (240-253 ft) there is one 6-inch piece of core, one 3-inch piece, and a few 1-inch fragments; the rest of the recovered core is like coarse sand and gravel. Core has not been ground up during coring; pieces of soft core several inches long come out of core barrel, and air-slack to a coarse sandy aggregate within a few hours. The whole pieces of core do not show slickensides, and there is no visible evidence of faulting or	224 -230	80
shearing in this zone. This is an intensively	230 -240	98
weathered zone, and the massive rock has very	240 -244	65

Test hole Pluto-4--Continued

Description	Interval (feet)	Core recovery (percent)
little strength. Sample Pluto-4S at 237 ft;	244 -249	60
sample Pluto-4T at 252.5 ft--------------------	249 -253	60
Same as above; friable, weathered rock that comes out of core barrel as sand with a few rounded fragments of rock-----------------------------	253 -261	30
Total depth 261 ft		
4 1/2-in. O. D. casing cemented in rock at 51 ft with screw cap (hand tight) on top.		

Test hole Pluto-5

Nevada State Coordinates: N. 753,602.00; E. 662,558.45

Logged by John C. Manning and Ross B. Johnson

Description	Interval (feet)	Core recovery (percent)
Drilled weathered rock with rock bit. Cored with 3 5/8-in. casing bit; core described but not saved--	0 - 6	0
Dacite porphyry, firm, hard, coarse-grained rock with 30 to 40 percent crystals of feldspar, biotite, and hornblende (1 to 4 mm) in a partly devitrified groundmass of reddish-gray glass. Vertical joints and seams filled with calcite and with clay and iron oxide. Rock is "case hardened" near surface due to weathering while other weathering processes have produced a much softer rock a few feet below the surface---	6 - 11	50
Same as above, but with soft friable zones where weathering has penetrated deeply into rock mass, mostly along vertical joints. Massive rock away from weathered joint planes is firm and hard. Joints: vertical joints are dominant and are filled with up to 1/2 in. of	11 - 15	90
calcite-iron oxide-clay cement, and most	15 - 24	85
joints are tight. Weathered rock breaks across	24 - 31	75

Test hole Pluto-5--Continued

Description	Interval (feet)	Core recovery (percent)
rather than along joints. Sample Pluto-5A at		
13 ft; sample Pluto-5B at 35.5 ft------------	31 - 36	95
Same as above, from 50.5 to 75 feet rock is firmer		
with longer core segments, and varies in color		
from reddish gray to greenish gray. Joints, up		
to 1 1/3 in. wide, are filled with calcite and		
clay with some iron oxide; rock breaks across		
joints in this interval. From 75 to 89 ft		
rock is softer with friable zones and zones	36 - 46	90
where core is broken into small fragments.	46 - 54	90
Joints less well cemented than in interval	54 - 62	98
above and rock breaks along joints. Joints:	62 - 72	98
2 sets dominant at 60° with horizontal.	72 - 79	98
Occasional vertical joints and many small	79 - 83	90
random calcite-filled joints. Occasional	83 - 87	85
lithic fragments of altered lava------------	87 - 89	85
Same as above, but rock firmer and core segments		
are larger (2 to 6 in.) from 89 to 94.5 ft.		
From 94.5 to 104.5 ft rock is firm with tight		
well-sealed joints and core segments are longer		
(6 to 18 in.); color varies from reddish gray		
to greenish gray, joints sealed by calcite		

Test hole Pluto-5--Continued

Description	Interval (feet)	Core recovery (percent)
and iron oxide with clay; a few lithic fragments of greenish altered lava. A few calcite-lined vugs. From 104.5 to 113 ft rock is firm, but more altered than in interval above, and core is in short segments and small fragments; joints tight, but coated with iron oxide and clay and not well sealed; core breaks along joints; color red to gray. From 113 to 138 ft rock is firm and hard with most joints well sealed with calcite and a green claylike material; core segments are 6 in. to 2 ft; rock is greenish gray and reddish gray in alternating zones that are several feet thick; this is evident during drilling, as drilling water changes color in ditch from greenish to reddish. Green zones may represent more intensive hydrothermal alteration; rock is generally firmer, and joints are better sealed in green zones. From 138 to 145 ft rock is softer and more weathered; core breaks in short segments along joints. From 145 to 153 ft rock is firm, greenish-gray in color, and with tight well-sealed joints. At 153 ft there is a	89 - 93	90

Test hole Pluto-5--Continued

Description	Interval (feet)	Core recovery (percent)
brecciated zone 1 1/2 in. thick that has been	93 - 99	95
completely sealed by fine-grained calcite	99 -105	80
cement. In general, the reddish zones are	105 -108	90
softer than the greenish zones. Joints:	108 -112	90
vertical and 2 sets at 60° with horizontal;	112 -116	90
45° joints locally; many random hair-line	116 -126	95
fractures cemented with calcite. Sample	126 -135	98
Pluto-5E at 102 ft; sample Pluto-5F at 120 ft;	135 -143	90
sample Pluto-5G at 148 ft---------------------	143 -153	98
Same as above; firm greenish-gray rock with all joints tight and most joints well sealed; prominent vertical joint from 164 to 170 ft with filling of calcite (1/8 to 1/4 in.) that cements joint so that core breaks across rather than along joint. Core segments are 3 to 18 in. Occasional lithic fragments of dark lava. Reddish-gray interval from 190 to 195 ft where rock is firm and joints are well sealed to 218 ft. Rock breaks along some joints, because calcite and clay cement is weaker than massive rock on low-angle joints. Joints: vertical and prominent set at 45°. Many random fractures, tightly		

Test hole Pluto-5--Continued

Description	Interval (feet)	Core recovery (percent)
sealed. Rock has been subjected to extensive	153 -161	98
hydrothermal alteration with the introduction	161 -171	98
of calcite, sulfides, and perhaps chlorite as	171 -181	98
the greenish alteration product of the glassy	181 -191	98
matrix. Sample Pluto-5H at 167 ft; sample	191 -198	98
Pluto-5J at 193.5 ft; sample Pluto-5K at	198 -208	98
217 ft------------------------------------	208 -218	98
Same as above; purplish and reddish zones interspersed with predominant greenish-gray color; rock is firm with many joints and fractures that are sealed with white calcite. Rock was intensively fractured at some time, and subsequent alteration by hydrothermal processes has filled and sealed the fractures. In places, as at 270 to 271 ft, wide veins (1 in.) of calcite contain fragments of the rock broken from the walls of the fractures and now frozen in the white calcite vein material. Minor slickensides are also present as evidence of brecciation and shearing in the massive rock prior to the period of alteration. Few lithic fragments of dark lava or metamorphic rock. Joints: rock core tends to break along		

Test hole Pluto-5--Continued

Description	Interval (feet)	Core recovery (percent)
predominant 60° and 45° joints. Vertical joints and random fractures are well sealed, and core does not break along these. Core segments are mostly 6 to 18 in. There is a soft slickensided, shattered zone at 226.5-227.5 ft. In addition to the calcite veins and fracture fillings, the groundmass of the green rock is filled with tiny veinlets and selvages of a green claylike alteration product. Sample Pluto-5L at 224.5 ft; sample Pluto-5M at 238 ft; sample Pluto-5N at 257 ft; sample Pluto-5P at 276 ft---------------	218 -227 227 -237 237 -247 247 -257 257 -267 267 -277	95 95 98 98 98 98
Same as above, firm, coarse-grained greenish-gray rock. Sealed joints and fractures as above. Slickensides along sealed fractures at 281 and 284 ft. Porous, vuggy core at 310-311 ft. Joints, as above; joints, spaced from 6 to 18 in. In lower part of hole, white veinlets that seal fractures contain clay as well as calcite; where clay predominates over calcite as fracture-sealing material, the joints and fractures are tight but not well sealed. Core breaks along clay-filled joints. Sample Pluto-5Q at 298 ft; sample Pluto-5R	277 -287 287 -296 296 -303 303 -309 309 -313	98 98 94 94 98

Test hole Pluto-5--Continued

Description	Interval (feet)	Core recovery (percent)
at 311 ft; sample Pluto-5S at 318 ft-------------	313 -322	98

Total depth 322 ft

4 1/2-in. O. D. casing cemented in rock at 6 ft with screw cap on top.

REFERENCE CITED

Shapiro, Leonard, and Brannock, W. W., 1956, Rapid analysis of silicate rocks: U.S. Geol. Survey Bull. 1036-C, p. 19-56.