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PROJECT
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Preshot Geologic Investigation

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NUCLEAR EXPLOSIONS—PEACEFUL APPLICATIONS
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PROJECT SULKY

PNE-719P

PRESHOT GEOLOGIC INVESTIGATIONS

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ABSTRACT

A comprehensive geologic and engineering investigation was undertaken at the site on Buckboard Mesa selected for the SULKY event, a nuclear cratering experiment, conducted in dry basalt.

Foundation conditions were determined by six borings: one centrally located, 6-inch-diameter boring to a depth of 80 feet and five NX-size holes ranging in depth from 59 to 212 feet. The site is blanketed by a thin soil cover of rather uniform thickness, ranging from 1.4 to 2.5 feet, overlying a basalt cap at least 192 feet thick. The uppermost portion of this basalt cap is comprised of vesicular basalt 47 to 72 feet thick (average 58 feet), which grades into an underlying dense basalt about 128 feet thick. The basalt is immediately underlain by approximately 14 feet of ash or cinder beds. *level*

From the existing subsurface data, it is not possible either to confirm the existence of faults or to ascribe any differences in stratigraphy or lithology to faulting at the SULKY site. A survey of the joint patterns at the SULKY site disclosed four predominant high-angle strike sets, each set showing an extremely variable dip, and a fifth generally low-angle bedding or flow-layer joint set. The high-angle joint sets have the following average strikes: Set 1, $N75^{\circ}W$; Set 2, $N17^{\circ}W$; Set 3, $N17^{\circ}E$; and Set 4, $N41^{\circ}E$.

Contrary to borehole photography analysis, observations of the mesa walls disclosed that the high-angle joints are the most conspicuous. This discrepancy is due to the magnitude of the area observed, i.e. there is a lesser probability of encountering high-angle joints when utilizing data

obtained from vertical boreholes, thereby exaggerating the importance of low-angle joints. The nearly vertical high-angle joints were the most open fractures found on the mesa and also the most continuous.

A joint frequency curve derived for the SULKY site indicates that although local fluctuations are present, no significant change in the frequency of joints occurs with depth. In several instances the joints were spaced over 10 feet apart; however, about 54 percent of the joints were spaced less than 1 foot apart, and about 97 percent were spaced less than 5 feet apart. The superimposed cumulative joint frequency curve for Pre-SCHOONER sites 3, 4, 7, and 11 indicated both curves to be quite similar, having the same median value (approximately 0.88 foot) and a closely paralleling relation. Based on investigations of DANNY BOY and Pre-SCHOONER, it is expected that the ejecta sizes will be closely related to the block size produced by jointing.

The average physical property values of the foundation materials as determined from geophysical logging are in close agreement with those determined in laboratory tests, and appear related to the vesicularity of the basalt. The maximum average unconfined compressive strengths of sound specimens with no joints ranged from approximately 20,000 psi for dense basalt to 10,000 psi for the most vesicular basalt. The bulk specific gravity ranged from 2.74 for dense basalt to 2.40 for vesicular basalt. The modulus of elasticity varied from 4.48×10^6 to 7.66×10^6 psi, with the values showing no particular relation to the degree of vesicularity. The values of physical properties as determined on the limited number of samples of basalt types from the SULKY site were all within the range of similar data scatter of an earlier study

(Reference 2) of Buckboard Mesa basalt.

The results of water pressure tests in drill holes NCG 10.4 and NCG 10.5 showed no evidence of any relation between the computed water-loss coefficient and the bulk porosity value of the rock as determined by gamma-gamma density logging. The average bulk porosity at the SULKY site was approximately 8 percent. The computed water-loss coefficient appears to be related to the effective porosity calculated on the basis of observed joint openings as indicated by the borehole camera.

PREFACE

The geologic studies, and field and laboratory investigations reported herein were conducted by personnel of the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, under the sponsorship of the U. S. Army Engineer Nuclear Cratering Group (NCG), Livermore, California. Site selection investigations, general geologic observations, and the logging of the initial drill cores were performed in the summer of 1963 by Messrs. R. W. Hunt and D. E. Andrews, and logging of supplementary borings drilled in February 1964 was performed by Dr. R. J. Lutton and Mr. Hunt, all of the Geology Branch, Soils Division, WES. The drilling program, except for the calyx hole, was under the direction of Mr. T. B. Goode, Embankment and Foundation Branch, Soils Division. Physical tests of cores and petrographic examinations were performed by personnel of the Engineering Materials Branch and Engineering Sciences Branch, Concrete Division, WES, under the supervision of Messrs. J. M. Polatty and B. Mather, respectively. Project Officer was Mr. W. C. Sherman, Jr., Embankment and Foundation Branch.

Chapters 1, 2, and 3 of this report were written by 1st Lt. R. C. Nugent, Geology Branch, and Chapters 4 and 5 were written by Mr. D. C. Banks, Embankment and Foundation Branch. The report was prepared under the direction of Messrs. W. J. Turnbull, A. A. Maxwell, J. R. Compton, W. B. Steinriede, Jr., and W. C. Sherman, Jr., Soils Division, WES.

Directors of the NCG during the conduct of this study and preparation of this report were Lt. Col. E. C. Graves, CE, and Lt. Col. W. J. Slazak, CE. Director of the WES was Col. Alex G. Sutton, Jr., CE; Technical Director of the WES was Mr. J. B. Tiffany.

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CHAPTER I

1. INTRODUCTION

1.1 DESCRIPTION OF PROJECT SULKY

Project SULKY was a nuclear cratering experiment in hard rock executed as part of the Plowshare Program for development of nuclear excavation. The purposes of the SULKY experiment were: (1) to determine the distribution of radioactivity produced at a greater scaled depth than DANNY BOY, which would provide basic input for the design of follow-on larger yield experiments in a similar medium; (2) to determine the concentrations of certain radionuclides airborne at various distances; and (3) to produce crater mechanics information at a greater scaled depth than DANNY BOY.

Project SULKY was fired 18 December 1964 at approximately 1135 Pacific Standard time (1935 Greenwich Mean Time) on Buckboard Mesa, Area 18, Nevada Test Site (see Figure 1.1). The depth of burial was 27.4 meters (90 feet) and the resultant yield was 85 ± 15 tons. The emplacement hole, U18d, was located at geodetic coordinates

Lat N $37^{\circ} 4' 57''$
Long W $116^{\circ} 20' 33''$

1.2 SCOPE

This report presents the results of the preshot geologic and engineering investigations conducted for Project SULKY by the U.S. Army Engineer Waterways Station (WES) under the sponsorship of the U. S. Army Engineer Nuclear Cratering Group (NCG).

The site selection investigations were conducted in the summer of 1963 as an extension of the Project Pre-SCHOONER site investigations

Figure 1.1 General location map.

on Buckboard Mesa (Reference 1). Site 10 (see Figure 1.2) was selected for the ground zero location since it lay in an area of low relief with minimal soil cover and met additional requirements that ground zero be at least 800 feet from the mesa edge and at least 500 feet from existing craters.

Initial drilling at the site included a central 6-inch hole (NCG 10.0) and three NX-size satellite holes (NCG 10.1, NCG 10.2, and NCG 10.3) drilled at the ends of 35-foot radials that were spaced 120 degrees apart (see Figure 1.2). Two additional NX borings (NCG 10.4 and NCG 10.5) were drilled during February 1964. The NX holes varied in depth from 59 to 212 feet (see Table 1.1). The central 6-inch-diameter hole had a total depth of 80 feet. Lithologic logs of the NX and 6-inch-diameter holes, all vertical borings, are shown in Appendix A of this report.

A borehole camera survey was made of each of the NX satellite holes at the selected site (see Table 1.1). The survey provided 476.9 feet of photography coverage and permitted an accurate determination of the nature and orientation of the numerous joints encountered in the basalt. In addition to the joint data, the camera survey provided supplementary lithologic information that was especially useful in interpreting intervals of low core recovery. The borehole camera logs were integrated into the lithologic logs of the NX holes shown in Appendix A.

The NX holes were pressure-tested and then flooded with a dye solution for subsequent ease in distinguishing natural joints. Notched tapes were grouted in place in each hole in preparation for a missile study that will be conducted during the postshot investigations.

A 36-inch-diameter emplacement hole was drilled and utilized as

Figure 1.2 Locations of borings and sections.

TABLE 1.1 SUMMARY OF SUBSURFACE INVESTIGATIONS OF THE SULKY SITE

Boring	Coordinates*	Elevation	Total Depth	Angle of Boring	Type of Boring	Core Recovery	Borehole Camera Log	Nuclear Density Log	Three-Dimensional Log	Neutron Moisture Log	Natural Gamma Log
		feet, msl	feet			percent	interval feet	interval feet	interval feet	interval feet	interval feet
NCG 10.0	N 849,239.36 E 594,540.77	5328.8	80.0	Vertical	6-inch	99.8	None	0.0 to 75.0	0.0 to 67.0	None	None
NCG 10.1	N 849,207.05 E 594,553.52	5328.4	212.0	Vertical	NX	93.3	1.3 to 210.0	None	None	None	None
NCG 10.2	N 849,244.86 E 594,505.91	5328.4	59.3	Vertical	NX	97.9	1.0 to 40.0	None	None	None	None
NCG 10.3	N 849,267.71 E 594,562.33	5328.5	60.0	Vertical	NX	93.3	1.3 to 53.0	None	None	None	None
NCG 10.4	N 849,251.47 E 594,466.79	5328.2	100.0	Vertical	NX	98.1	1.0 to 90.4	5.0 to 100.0	None	3.0 to 91.0	3.0 to 91.0
NCG 10.5	N 849,303.16 E 594,551.48	5329.0	100.0	Vertical	NX	98.5	2.3 to 90.4	10.0 to 100.0	None	10.0 to 100.0	10.0 to 100.0
U 18 D	N 849,239.36 E 594,540.77	5328.8	110.0	Vertical	36-inch	--	None	None	None	None	None
U 18 D-2	N 849,162.63 E 594,496.59	5327.4	116.9	45N 30E	8-inch	--	None	None	None	None	None
U 18 D-3	N 849,128.97 E 594,541.06	5327.0	90.0	Vertical	8-inch	--	None	None	None	None	None

* Nevada State Coordinate System.

part of the preshot investigations. This calyx hole, centered on NCG 10.0, was logged by WES geologists with respect to lithology and fractures; the resulting log is presented in Appendix B of this report.

Two 8-inch-diameter instrumentation holes (U 18 D-2 and U 18 D-3) were drilled by the Atomic Energy Commission (AEC) near ground zero (see Figure 3.2). One was a 116.9-foot-deep boring drilled at a 45-degree angle, and the other was a 90-foot-deep vertical boring. Neither of these borings was cored, nor were the borings logged; and since the diameters of the holes exceeded the capabilities of the camera, no borehole photographs were taken.

Representative core samples were taken for testing in the laboratory at WES to obtain data on the physical properties of the basalt (e. g. compressive strength, specific gravity, and bulk density). These data are presented and evaluated in Chapter 4.

A nuclear (density)log and three-dimensional velocity logs were obtained from the 6-inch-diameter hole to a depth of about 75 feet (Table 1.1) by the Birdwell Company. Operational difficulties restricted the amount of useful data obtained from the three-dimensional logs (see Chapter 5). Geophysical logs (neutron-neutron moisture logs, natural gamma logs, and nuclear density logs) were also obtained from Borings NCG 10.4 and NCG 10.5 by the U. S. Atomic Energy Commission (AEC) office at Grand Junction, Colorado.

1.3 PREVIOUS INVESTIGATIONS

The preliminary geologic investigations of Buckboard Mesa in connection with cratering experiments were conducted as part of Project

BUCKBOARD (Reference 17), a series of 13 high-explosive events detonated in the summer of 1960. In June 1960, 37 exploratory NX core holes, ranging from 13 to 120 feet in depth, were drilled in various areas on Buckboard Mesa south of coordinate N 860,000.¹ The U. S. Geological Survey (USGS) used the data from the cores and from the emplacement holes to evaluate the effect of geologic factors (e.g. jointing) on crater shapes and sizes and on the distribution of ejecta (Reference 3).

In early 1961, resistivity measurements were made and a series of 12 core holes were drilled in the immediate vicinity of the Project DANNY BOY site (Figure 1.2). The results of the resistivity survey and the logs of the core holes are contained in reports by the USGS (References 4, 8, and 9). Postshot geologic investigations conducted at the DANNY BOY site by Lawrence Radiation Laboratory (IRL) have recently been published (References 14 and 18). Additional geologic investigations and postshot drilling have been conducted at the DANNY BOY site by WES; the results will be presented in a forthcoming report.

The most extensive geologic and engineering investigations on Buckboard Mesa were conducted by the WES during Projects Pre-SCHOONER and SULKY (Reference 2). A comprehensive analysis of the results of the preshot Pre-SCHOONER investigations is currently being published (Reference 1).

¹All coordinates in this report are Nevada State Coordinates.

CHAPTER 2

REGIONAL SETTING

2.1 LOCATION

Buckboard Mesa is located in Area 18 of the NTS between $37^{\circ}04'$ and $37^{\circ}09'$ north latitude and $116^{\circ}20'$ and $116^{\circ}24'$ west longitude (see Figure 1.1). The center of the mesa is approximately 38 miles north-northwest of Mercury, Nev., and about 33 miles north of Lathrop Wells, Nev. Buckboard Mesa lies near the head of Fortymile Canyon between Timber Mountain to the southwest and Pahute and Rainier Mesas to the north and northeast. The mesa is accessible by way of the improved Tippipah Spring Road which leads westward for about 20 miles from the paved Mercury Highway on Yucca Flat (Figure 1.1).

2.2 GENERAL GEOLOGY

The NTS lies within the Basin and Range province, a structural-physiographic province that is characterized by north-south trending fault-block mountains (ranges) and deep intermontane basins (Reference 11). Being representative of the Basin and Range province, the NTS and adjacent areas have a similar physiography and are underlain by structurally complex, thick deposits of Precambrian and Paleozoic sedimentary rocks that are overlain in places by faulted volcanic and sedimentary rocks of Cenozoic age.

The pre-Cenozoic deposits, with a maximum aggregate thickness of 37,000 feet (Reference 3), consist of limestone, dolomite, argillite, quartzite, and siltstone and are intruded in places by granitic stocks and dikes of Mesozoic age. These Precambrian and Paleozoic rocks have a

complex structure; they were intricately folded and cut by thrust faults during several different periods of deformation (Reference 11). The occurrence of the many high ranges that have pre-Cenozoic cores and rise abruptly along steep scarplike faces is not generally controlled by this complex structure, but largely by later superimposed block faulting. At least four stages of block faulting have been identified within the Basin and Range province, starting from before late Miocene time (Reference 11). The ranges are separated by deep basins filled to various degrees with Cenozoic deposits.

Tertiary deposits within the NTS are mostly volcanic, although minor amounts of sedimentary rocks appear in the lower part of the section. The volcanic rocks have a maximum aggregate thickness of 3,500 feet and, except for a few minor unassigned stratigraphic units, are subdivided into two formations (Reference 3) with a total of seven members. These Tertiary rocks (mostly of Miocene-Pliocene age) consist predominantly of welded and nonwelded ashflow tuffs with minor bedded ashfall tuffs. Some rhyolite and basalt are also present. These volcanics were deposited before the ranges were uplifted to their present full elevations, although the relief was still considerable. It has been estimated that the lower member of the Indian Trail formation was deposited over a surface that had a maximum relief of 2,000 feet (Reference 3). As successively younger Tertiary rocks were deposited, the relief on the pre-Cenozoic erosion surface became progressively less. Consequently, many of the lower subunits are highly lenticular and pinch out against buried hills of older rock. Massive welded and nonwelded ashflow tuffs and lakebeds (tuffaceous siltstones and sandstones) occupy the lows on this erosion surface. The younger units are

generally more continuous and uniform in thickness. A large caldera that was located at Timber Mountain (Figure 1.1) is believed (Reference 3) to be the source of most of these volcanic materials.

In late Pliocene-Pleistocene time, the ranges were elevated to their present position. Large coalescing alluvial fans formed at the base of the ranges and masked the controlling fault scarps, while playa lakes formed in the deeper parts of some basins. Quaternary alluvial and colluvial deposits generally overlies the Tertiary volcanic rocks, although locally they overlies the pre-Cenozoic rocks. In Yucca Flat, these alluvial deposits exceed 1,000 feet in thickness.

The basalt cap of Buckboard Mesa is considered the most recent expression of volcanic activity in the area (Quaternary) and lies above the Quaternary alluvium and Tertiary volcanics. The rocks within a radius of several miles of Buckboard Mesa are either the previously mentioned Tertiary volcanics or the Quaternary alluvium (Reference 12). The Cenozoic rocks are relatively simple in structure, most commonly being cut by high-angle normal faults with a predominantly north-south trend. However, a broadly arcuate pattern of high-angle to vertical faults, downthrown to the west and believed to be structurally related to the collapse of the Timber Mountain caldera in late Tertiary times (Reference 12), is found 2 to 10 miles east and northeast of Buckboard Mesa and north of Shoshone Mountain.

- CHAPTER 3

LOCAL GEOLOGY

3.1 PHYSIOGRAPHY

Buckboard Mesa has a gentle southerly dip, and is capped by a relatively undissected sheet of basalt that varies irregularly in thickness from less than 50 feet to more than 200 feet. Along its long axis (trending roughly northwest-southeast), the mesa is approximately 5.5 miles long. From a maximum width of about 2.5 miles at its northwest end, the mesa gradually narrows to a point at its southern tip, at the intersection of the two branches of Fortymile Canyon. The northern one-third of the mesa is dominated by Scrugham Peak, a slightly asymmetrical cinder cone that rises about 600 feet above the average elevation of the mesa (about elevation 5400).² This is in marked contrast to the southern two-thirds of Buckboard Mesa which is relatively flat. Sloping outward from a central sinuous ridge to the mesa edges, the surface of the southern part of the mesa has a maximum relief of 100 feet. The basalt cap crops out intermittently along the mesa rim, forming slopes that dip at an average of approximately 72 degrees through an average slope distance of approximately 49 feet down to the upper limit of the talus slopes. The talus deposits slope down to the valley floor in a vertical distance of 100 to 400 feet, with an upper slope averaging 27 degrees (varying from 18 to 43 degrees) and a flatter lower slope (Reference 1).

Low annual rainfall and the high permeability of the basalt (as a

² All elevations are in feet above mean sea level.

result of jointing) account for the absence of a good drainage network. The small amount of runoff that does occur is channeled into the joint-controlled erosional reentrants. According to a USGS estimate (Reference 5), the groundwater table is 775 feet below the average elevation of the mesa.

3.2 STRATIGRAPHY

3.2.1 Stratigraphy of Buckboard Mesa. Buckboard Mesa was formed by the differential erosion of a moderately fractured thick basalt, capping older tuff and alluvium deposits (Reference 1). This basalt cap is bi-convex in shape when viewed in an east-west cross section (Figure 3.1), being thickest along its northwest-southeast trending axis and thinning rapidly toward the edges of the mesa. The maximum thickness of basalt, 197 feet, was found near the center of the mesa in Boring NCG 17.1. A thin soil cover has formed over the basalt, which averages about 3 feet in thickness but may exceed 10 feet in thickness.

As shown in Sections A-A', B-B', and C-C' (Figure 3.1), the basalt cap on Buckboard Mesa consists of a complex succession of alternating layers of vesicular and nonvesicular (dense) basalt. In the southern part of the mesa (south of Boring NCG 9.1), the lithologic sequence consists of an upper vesicular zone 25 to 50 feet thick, a central zone of dense basalt 100 to 150 feet thick, and a thin lower vesicular zone 0 to 20 feet thick that extends to the base of the basalt cap. Generally, the most vesicular basalt within the upper vesicular zone occurs near the surface, with the percentage of vesicles gradually decreasing with depth. In the central part of the mesa, between Boring NCG 9.1 and Boring WD-11

Figure 3.1 Generalized geologic sections through Buckboard Mesa.

(Figure 3.1), the stratigraphic succession is more complex. Here three or four distinct layers of vesicular basalt are intercalated with layers of dense basalt. The several repetitions of the vesicular-nonvesicular sequences are thought to represent the presence of more than one basalt flow or several lobes of the same flow. Irregularly shaped and discontinuous masses or pockets of cindery or scoriaceous material are also present, particularly near the contacts of assumed flow units (Reference 1). Zones of this type frequently are characterized by little or no core recovery. These cinder zones were most common in Borings NCG 17.1, 18.1, and 19.1, and are believed to become more numerous and continuous when traced in a northerly direction toward the apparent source of these volcanic rocks.

The transition between the vesicular and the underlying dense basalt zones is characterized by an alternation of vesicular and nonvesicular (or less vesicular) basalt layers. The thickness of these individual layers may range from several feet to several inches, depending on the scale of observation (Reference 1). Alternating zones may be horizontal, inclined at angles up to 90 degrees, or occur in undulatory layers. Individual zones may disappear and reappear suddenly with no easily explainable pattern.

3.2.2 Detailed Stratigraphy of Site 10. As shown in Figure 3.2, sections A-A' and B-B' were developed through the boring locations; these sections are shown in Figures 3.3 and 3.4. The basalt underlying the SULKY site is blanketed by a thin soil layer consisting of a tan to light reddish brown heterogeneous mixture of silt and sand, with large quantities of gravel- to boulder-size fragments of vesicular basalt. The thickness of the soil cover is rather uniform, varying from 1.4 to 2.5 feet

Figure 3.2 Plan of borings drilled at the SULKY site and location of Sections A-A' and B-B'. (Coordinates shown are Nevada State Coordinates.)

Figure 3.3 Stratigraphy at Section A-A'.

LEGEND

Figure 3.4 Stratigraphy at Section B-B'.

and averaging approximately 2.1 feet.

The basalt cap at the SULKY site is at least 192.2 feet thick and can be subdivided into three major units (see Figures 3.3 and 3.4): an upper vesicular basalt, a middle dense basalt, and a lower, thin layer of vesicular basalt. The upper vesicular zone, which has an average thickness of approximately 58 feet, can be further subdivided into three tabular subunits. These subunits, based on the percentage of vesicles present, are arranged in order of decreasing vesicularity from top to bottom. The middle dense basalt zone is gradational with the overlying vesicular basalt. Boring NCG 10.1 (see Figure 3.3) penetrated the basalt cap and showed that this dense basalt is at least 127.9 feet thick. Beneath the dense basalt is a thin (0.6 foot) layer of vesicular basalt.

A 14.4-foot core-loss zone separates the basalt from the underlying tuff beds and is believed to indicate the presence of either ash beds or a cinder zone. A similar cinder zone occurs at the base of the basalt in several outcrops along the south end of the mesa near the SULKY site (Reference 1).

3.3 PETROGRAPHY OF THE BASALT

A petrographic study, conducted at WES, of selected core samples from the Project DANNY BOY site (Reference 21) revealed that the vesicular basalt is an olivine basalt of normal composition, and the dense basalt is a subandesite.

In thin section, the vesicular olivine basalt is a medium dark gray, dense, fine-grained mass of subhedral plagioclase laths (labradorite), with minor amounts of scattered subhedral to euhedral phenocrysts averaging

about 0.5 mm in longest dimension. All of the sections examined, whether they showed any megascopic flow structure or not, showed a striking microscopic flow structure.

This general class of vesicular basalt can be further described according to the amount and distribution of vesicles, size and shape of vesicles, and presence or absence of flow layers or flow lines.³ The fact that vesicles may constitute as much as 40 percent of the mass permits a subdivision of the basalt according to the vesicle content (< 10 percent, 10-20 percent, > 20 percent). Individual vesicles range from almost microscopic size to several inches in maximum dimension, although the average vesicles range from 1/4 to 1/2 inch. Gas cavities of a larger size, several feet in diameter, have been found in calyx holes and in outcrop. Vesicle shapes may be either globular and randomly oriented or elongated and flattened showing a preferred orientation in dip. Examples of such aligned vesicles are found in the flow layers that commonly occur in the transition zone between vesicular and dense basalt. These flow layers are strongly oriented, thin layers of vesicles, aligned parallel to the layer, and dip from 0 to 90 degrees. These layers are generally of a single thickness of vesicles and spaced 1 or 2 inches apart.

³ In portions of this report, the terms flow layer and foliation are used synonymously to indicate a planar structural element resulting from the preferred orientation of the vesicles and/or the concentration of vesicles in layers. The term flow line has been used to refer to the trace of the foliation as it is observed on a two-dimensional surface such as the surface of a core or on the walls of a calyx hole.

Although most of the vesicles are open or unfilled, some tend to be coated with materials of one of three types: (1) white mixtures of hair-like crystals and colloform surfaces, (2) cream to light brown clayey powders, and (3) hard, clear to translucent opaline substances. The first type is a mixture of calcite and devitrified glass; the second type is apparently decomposed basalt (Reference 21).

Dense basalt is a most useful field term for describing the non-vesicular, medium-light gray basalts. Petrographic examination of selected core samples revealed that these rocks would be classified as subandesite, a transition between basalt and andesite that has the chemical composition of a basalt and the color and plagioclase of an andesite. The plagioclase laths are more sodic, being oligoclase-andesine in composition rather than labradorite, and tend to be larger and show less flow orientation than the olivine basalts.

3.4 STRUCTURE

3.4.1 Faults. Knowledge of the structural pattern of Buckboard Mesa and its immediate vicinity is severely limited by the lack of detailed field work. However, studies by the USGS (References 5 and 13) indicate that at least two faults affect Buckboard Mesa. The first is a normal fault of small vertical displacement near the north edge of the mesa (exact position unavailable). The second fault trends northwest-southeast along the western side of the mesa. Subsurface evidence indicates that the fault is nearly vertical, with approximately 100 feet of vertical displacement, and downthrown on the eastern side. The western flank of the mesa is believed to be the physiographic expression of this fault. Disturbed

exposures of tuff, lying in grid square N 844,000-N 845,000 and E 592,000-E 593,000 at the junction of Cat Canyon and the west branch of Fortymile Canyon, provide further evidence of the presence of this northwest-trending fault. A small, N80°W-trending, normal fault, with a maximum displacement of 8 feet, was noted by WES personnel in exposures located at coordinates N 849,150 and E 590,400. Attempts to trace the extent of this fault have been unsuccessful.

An examination of aerial photographs revealed certain subtle differences in the tone of the soil on the mesa and certain alignments of minor drainageways that could be interpreted as indications of faults. Two of these possible faults lie near the north end of the mesa in the vicinity of the cinder cone (Scrugham Peak). Two other possible faults trend northwest-southeast along the western side of the mesa. One of these appears to trend from the vicinity of Boring DB-5 through a point about 500 feet east of Boring NCG 18.1 (see Figure 1.2). The other fault begins in the vicinity of Site 7 and continues to the northwest, parallel to the first one. However, with existing subsurface data it is not possible either to confirm the existence of faults in these areas or to ascribe any differences in stratigraphy or lithology to faulting.

3.4.2 Joints. The moderately to well-developed joint pattern of the basalt of Buckboard Mesa has been the subject of intensive research. Such interest is warranted by the control that jointing may have on both the physical dimensions and the slope stability of craters resulting from nuclear and high-explosive events. To evaluate the extent of this control, joint data were obtained by several methods, including analysis of bore-hole photographs from NX core holes, detailed logging of cores

and emplacement calyx holes, and field observations of the joints developed in outcrops along the edge of the mesa. Difficulty was experienced both in obtaining oriented cores and in distinguishing between natural joints and fractures caused by the drilling operations. Consequently, the borehole photographs provided practically the sole source of information on the orientation, frequency, and spacing of joints. The photographic determinations of joint orientations are believed to be accurate within 5 degrees. The midpoints of joints are believed to be located within several inches of their true elevations.

The pattern of jointing in any medium is best studied by plotting the data on an equal-area (Schmidt projection, Reference 19) net, a three-dimensional technique of data presentation that permits the simultaneous examination of the variation in strike and dip of the joints. Equal-area projections are constructed by taking the spherical projections of lines and planes and projecting them onto the geographically oriented, horizontal, equatorial plane of the reference sphere.

In theory, this is accomplished by first orienting the planes and lines within a reference sphere. These planes and lines pass through the center and intersect the surface of the sphere as great circles and points, respectively. The resultant spherical projections (great circles and points) are then projected downward onto the horizontal equatorial plane of the reference sphere (see Figure 3.5). This is accomplished by drawing connecting lines between the spherical projections on the upper hemisphere and the lower vertical zenith (Z) of the sphere. It is convenient to plot the orientation of a joint plane as a "pole" (projection of the impingement point, i.e. the point at which the normal to the plane

Note: A plane with N-S strike and 40° E dip intercepts surface of reference sphere as great circle BSCN. Pole, or normal to plane, through center of sphere projects spherically as point P. Tie lines drawn from spherical projections on the upper hemisphere to the lower zenith Z of the sphere intercept the horizontal equatorial plane to form equal-area projections of plane either as a "trace" SDN, or as a pole P'.

Figure 3.5 Construction of equal-area projections of joint planes.

intersects the reference hemisphere). Using upper hemisphere projections, the poles plot in the dip direction of their respective joint planes, but at the complementary dip angle.

In practice, the equal-area plotting of structural data is facilitated by a three-dimensional protractor, called an equal-area net, that is made from an equal-area projection of a hemisphere inscribed with parallels of latitude and meridians of longitude, generally at 2-degree intervals (see Figure 3.6). Points are plotted on a clear overlay which revolves about the tine of a thumbtack piercing the net (Reference 19). The up dip direction of each pole, equal to the true dip direction of its respective joint plane, is located on the overlay by placing a tick mark at the appropriate bearing along the net perimeter and revolving the overlay until the tick mark on the overlay lies along the E-W axis of the net. The dip angle of each pole is marked off by starting at the perimeter, the 0-degree great circle, and counting in the appropriate number of degrees. This procedure is repeated until the pole of each measured joint plane has been plotted. The pole of a horizontal plane plots as a point at the center of the net, while the pole of a vertical joint plots on the perimeter of the net at right angles to the strike.

When the plotting has been completed, the point diagrams are contoured according to point density to emphasize any patterns of preferred orientation. A counting circle, 1 percent of the total area of the net, is passed over the net in systematic fashion and the percentage of total points lying within each 1-percent area is determined. Contours are then drawn delineating areas within which the point density exceeds some minimum value, e.g. 5 percent of the total points per 1-percent area. Significant

Note: The pole dips in the same direction as the plane, but at the complementary dip angle (50°E). A vertical plane would plot as a horizontal pole on the net perimeter, while a horizontal plane would plot as a vertical pole at the center of the net.

Figure 3.6 Equal-area net showing plotted position of a pole P' to a joint plane striking N-S and dipping 40°E projected from the upper hemisphere.

patterns are represented by either maximum, single areas of high concentration with well-defined centers of gravity, or girdles, arcuate concentrations that coincide with either great or small circle projections. Most girdles have one maximum or more.

Utilizing these three-dimensional techniques, point density diagrams (contoured point diagrams of joint poles) were constructed to analyze the combined joint pattern for the Pre-SCHOONER and SULKY sites (Figure 3.7) and the joint pattern at the SULKY site (Figure 3.8). A series of concentric circles spaced at 10-degree intervals and representing the complementary angles to the dip angles of the poles, was superimposed on the pole diagrams (see Figures 3.7 and 3.8). These circles permit the reader to examine a plotted concentration of poles and make a direct reading of the average dip angle of the corresponding joint planes.

An examination of these point density diagrams reveals the extreme variability of the joints of Buckboard Mesa. Areas devoid of any points (areas bounded by the $1/n$ contour line, where n equals the total number of plotted points) are very restricted on both the composite diagram and the SULKY site diagram. The tendency for the zero areas to disappear as the number of data points increases attests to the highly variable orientation of the joints and suggests that a joint of almost any possible orientation may be encountered.

In spite of this extreme variability, a definite pattern can be readily discerned. The composite diagram (Figure 3.7) shows a pronounced concentration of poles at its center (10-40 percent of the total points per 1-percent area) that reflects the high percentage of near-horizontal joints encountered in the drilling.

LEGEND

CONCENTRIC CIRCLES INDICATE
AMOUNT OF DIP OF JOINT PLANES

DIP DIRECTION OF JOINT PLANES
EQUAL TO BEARING OF RADIAL
LINES DRAWN THROUGH A GIVEN
POLE CONCENTRATION

(E.G., PLOT OF POLES AT (1) COR-
RESPONDS TO JOINT PLANES THAT
DIP 60° TO 575°E)

POINT DENSITY SYMBOLS (PERCENT OF TOTAL POINTS PER 1% UNIT AREA)

	<1/823%
	1/823 TO 1%
	1 TO 3%
	3 TO 5%
	5 TO 10%
	10 TO 40%

Note: Contoured point diagram of 823 joint poles, plotted on the upper hemisphere of an equal-area net, superimposed upon concentric circles to allow direct reading of joint-plane orientations.

Figure 3.7 Joint density diagram for Project SULKY and Project Pre-SCHOONER.

LEGEND

CONCENTRIC CIRCLES INDICATE
AMOUNT OF DIP OF JOINT PLANES
DIP DIRECTION OF JOINT PLANES
EQUAL TO BEARING OF RADIAL
LINES DRAWN THROUGH A GIVEN
POLE CONCENTRATION

(E.G., PLOT OF POLES AT (1) COR-
RESPONDS TO JOINT PLANES THAT
DIP 60° TO 575°E)

POINT DENSITY SYMBOLS (PERCENT OF TOTAL POINTS PER 1% UNIT AREA)

	< 1/351%
	1/351 TO 1%
	1 TO 3%
	3 TO 5%
	5 TO 10%
	10 TO 40%

Note: Contoured point diagram of 351 joint poles, plotted on the upper hemisphere of an equal-area net, superimposed upon concentric circles to allow direct reading of joint-plane orientations.

Figure 3.8 Joint density diagram for Project SULKY Site 10.

The second major trend revealed is the presence of a very pronounced great-circle girdle that represents joints that have an average strike of $N17^{\circ}E$ (see Figure 3.7, Set 3). Although the dips of this strike set are extremely variable, with joints dipping from 0 to 90 degrees to both the northwest and the southeast, the majority of the joints dip to the southeast and cluster about a dip angle of 65 degrees.

Additional trends are represented by numerous maxima of smaller point concentrations arranged in two definite patterns. The more-or-less isolated maxima tend to outline two imperfectly formed small-circle girdles concentrically arranged about the center of the net. Small-circle girdles of this type represent a set of joints that have a constant angle of dip but an extremely variable dip direction, varying from 0 to 360 degrees. The first girdle is formed by joints that dip from 35 to 70 degrees from the horizontal, with an average dip of 45 degrees. The second girdle is formed by near-vertical joints that vary up to 15 degrees to either side of the vertical.

The maxima forming the small-circle girdles are also arranged in such a way that they lie along four great circles (that project as straight lines), all intersecting at the center of the net. These great-circle girdles, numbered 1 through 4 (see Figure 3.7), represent four predominant strike sets of joints, each set showing an extremely variable dip. As previously mentioned, the dips for each set tend to be vertical or horizontal, or to dip 45 degrees to either side of strike. The average strikes of these joint sets are as follows: Set 1, $N76^{\circ}W$; Set 2, $N27^{\circ}W$; Set 3, $N17^{\circ}E$; and Set 4, $N60^{\circ}E$. Of the four strike sets, which are spaced approximately 45 degrees apart, Set 3 is by far the most dominant, as shown in Figure 3.7.

An examination of the contour diagram for the SULKY site (Figure 3.8) shows a pattern that lacks the strong development of Set 3 (N17°E strike). The pattern is similar to the composite, however, in demonstrating both a preponderance of near-horizontal joints and a strong development of two concentric small-circle girdles, centered at dip angles of 45 and 90 degrees. Considering the large number of joints used to construct Figure 3.8 (351 joint poles), this difference from the composite pattern is believed to be statistically valid.

Although the joint pattern is indeed a complex one, supplementary field data offer a possible interpretation. Preliminary field investigations indicate that although the jointing is extremely variable (see Figure 3.9), the joints may be grouped into five major joint sets: four high-angle strike sets, and one generally low-angle, bedding or flow-layer joint set. The four strike sets have essentially the same average strike directions as those revealed by the borehole photographs. The strike of each set varies 15 to 25 degrees to either side of the mean value, while the dip generally varies up to 20 degrees to either side of the vertical. Set 3 is the most dominant set, although other fractures may be locally of greater importance. Contrary to borehole photography analysis, field observations revealed (Figure 3.9) that these high-angle joints are the most conspicuous. This discrepancy may be explained by the lesser probability of encountering high-angle joints when utilizing data obtained from vertical core holes, thereby exaggerating the importance of low-angle joints. The fracturing produces surfaces that are curved to a large extent and highly irregular, with numerous local changes or reversals in dip and/or strike on any fracture surface. The near-vertical joints are the

a. Pronounced vertical jointing.

b. Typical, distorted, "swirl" pattern.

Figure 3.9 Views of the major joint sets exposed in basalt outcrops along the edge of Buckboard Mesa.

most open fractures found on the mesa and also the most continuous. A large percentage of all the major high-angle joints extends from the surface of the basalt to the lowest observable points (35 to 50 feet below the surface) and probably continues to the base of the basalt. The spacing between two adjacent joints of the same strike ranges from about 3 to 14 feet, although it averages 7 to 8 feet. However, the average spacing, in a lateral direction, between adjacent joints with any orientation is closer to 2 or 3 feet. These high-angle joints are assumed to result from regional tectonic stresses because of the constancy of the general trends and the presence of similarly oriented joints and faults in adjoining areas within the NTS (References 3, 7, and 12).

The fifth predominant joint set is considered to be a bedding or flow layer set because of the parallelism of these fractures to the flow layers. With the generally horizontal orientation and close spacing (usually less than 1 foot) of the fractures, the pronounced lithologic control of these fractures is best displayed in the vicinity of the previously discussed "swirls." The fractures are in both dense and vesicular basalt and parallel the flow layers, even throughout the intense contortions present in the swirl structures (see Figure 3.9). Such dependency upon the attitude of the flow layers results in joints of extremely variable strike with dips that are mostly near horizontal, although dips of 40 to 60 degrees and, more rarely, 90 degrees may be recorded. It is believed that this joint type accounts for the high concentration of nearly horizontal joints and for the small-circle concentrations of joints dipping at an average of 45 degrees (Figure 3.7 and 3.8). The strict parallelism of these joints to accompanying flow layers and the absence of such

joints in adjacent areas within the NTS (Reference 7) indicate that these fractures are a local phenomenon. The very complicated joint pattern for the basalt capping Buckboard Mesa appears to result from the superimposing of local patterns upon the regional joint pattern.

The frequency of joints as a function of depth has been calculated and is presented graphically in Figure 3.10 for the five NX-size core holes drilled at the SULKY site. All nonvertical joints were tabulated and plotted at 5-foot-depth intervals. An examination of the plots for individual core holes reveals the high degree of horizontal variability in frequency even between the closely spaced holes at any one site. The equally high degree of vertical variability is a reflection of rather frequent situations in which as many as eight or ten joints occur in a 3- or 4-foot interval, and as few as one or two joints occur in a directly adjacent, similar-size interval.

The joint frequencies for individual borings were averaged to examine overall trends. Three frequency curves were constructed to allow comparison of boring at similar depths. The first composite curve (see Figure 3.10) represents an average of values for NCG 10.1, 10.4, and 10.5 to a depth of approximately 100 feet. Another curve, using information from Borings NCG 10.1, 10.3, 10.4, and 10.5, was constructed for the depth intervals common to all four borings. A similar curve was constructed for Borings NCG 10.1, 10.2, 10.3, 10.4, and 10.5. An examination of the frequency curve for Borings NCG 10.1, 10.4, and 10.5 indicates that although local fluctuations are present, no significant change in the frequency of joints occurs with depth. This also implies that no significant difference

Figure 3.10 Frequency of joints with depth at Site 10.

in joint frequency occurs when comparing the jointing displayed by different rock types.

All available joint data at the SULKY site have been used to develop a cumulative curve showing the spacing of joints in a vertical direction, i.e. as the joints intersected a vertical core hole (Figure 3.11). It can be seen that although there are several instances in which joints are spaced more than 10 feet apart, about 54 percent of the joints are spaced less than 1 foot apart, and about 97 percent less than 5 feet apart. A comparison of this curve with the cumulative frequency curve for Pre-SCHOONER Sites 3, 4, 7, and 11 (see Figure 3.11) indicates that both curves are quite similar, having the same median value, approximately 0.88 foot, and a closely parallel relation. This average joint spacing in the vertical direction is about one-third the average spacing in the horizontal direction, based on preliminary field work. Preliminary analysis indicates that the joint system fractures the basalt in such a way that it produces fragments that tend to have dimensions of approximately 1 by 2.5 by 2.5 feet. Based on investigations at DANNY BOY and Pre-SCHOONER, it is expected that the ejecta sizes will be closely related to the block sizes produced by jointing.

Although no separate analysis has been made to compare the joint spacing in dense basalt with that in vesicular basalt, it is not anticipated that significant differences occur. The rather high frequency of closely spaced joints near the surface in the vesicular basalt is probably balanced by the groups of closely spaced joints which occur at depth in the dense basalt. Joint spacings of about 5 to 10 feet appear to occur with similar frequencies in both types of basalt.

Figure 3.11 Cumulative curves of joint spacing in a vertical direction.

Borehole photography provides, in addition to orientation of the fractures, information about the physical characteristics of the fracture surfaces. Analyses to date reveal no correlation among orientation, depth of rock type, and degree of fracture filling or the amount or kind of fracture filling. The degree of fracture filling is related to the amount of fracture separation. Joints with only minor separation (hairline fractures) tend to be either completely filled (healed) or completely unfilled (open). As the amount of separation increases, the fractures tend to be partially filled; healed or open joints become increasingly rarer as the separation increases.

An analysis of 315 joints measured in the SULKY site drill holes (NCG 10.2, 10.4, and 10.5) revealed the following information: 63, or 20 percent, of these fractures were classified as open joints, i.e. they contained no noticeable joint fillings; 189, or 60 percent, were partially filled; and 63, or 20 percent, were completely filled. Data from NCG 10.3 were excluded from the analysis because of the presence of drilling mud which masked the degree of joint filling. The average percentage of open fractures at the SULKY site is somewhat smaller than the averages for the Pre-SCHOONER sites which varied from 21 to 51 percent (Reference 1). The grand average for both the SULKY and Pre-SCHOONER sites was 30 percent. Such information will be of use in estimating the amount of blast-induced fractures that will be encountered in the postshot cores.

CHAPTER 4

PHYSICAL PROPERTIES OF BASALT

4.1 SAMPLE EXAMINATION

Seven core samples from drill hole NCG 10.1, believed to be representative of the various basalts at the SULKY site, were subjected to detailed examination and physical testing by the WES Concrete Division. A relatively small number of samples were selected for testing, as considerable testing of the Buckboard Mesa basalts had previously been accomplished in connection with other cratering projects. A detailed sketch of each sample from the SULKY site, and descriptions of these samples are shown in Figure 4.1.

The laboratory examinations indicated that the core samples of basalt from Buckboard Mesa can be grouped into five general types: Type I, dense; Type II, fairly dense with bands of vesicles; Type III, slightly vesicular with bands of vesicles; Type IV, vesicular with oriented vesicles; and Type V, vesicular (Reference 2). While this subdivision of basalt does not offer an all-inclusive classification scheme or conclusive evidence regarding the factors which affect the physical properties of basalt, the average value of grouped physical test data does appear to be related to one of these basalt types. It may be noted that the above classification differs somewhat from the classification described in Section 3.3 and used in the preparation of the boring logs in Appendix A. In general, Type I basalt corresponds to dense basalt with relatively few or no vesicles, Type II corresponds to "vesicular basalt with less than 10 percent vesicles," Types III and IV correspond to "vesicular basalt with

Figure 4.1 Descriptive log of samples from NCG 10.1 selected for laboratory testing.

10 to 20 percent vesicles," and Type V corresponds to "vesicular basalt with greater than 20 percent vesicles." Samples of each type, except Type V, were available from the SULKY site for laboratory testing.

4.2 PHYSICAL TESTS

4.2.1 Specific Gravity. The bulk specific gravity G_m under saturated, surface-dry (SSD) conditions was determined on representative samples from Boring NCG 10.1 by Corps of Engineers Test Method CRD-C 107-60 (Reference 20) using the following relation:

$$G_m = \frac{B}{B - C}$$

where

B = weight in grams of saturated, surface-dry sample in air

C = weight in grams of saturated sample in water

The results of the bulk specific gravity determinations are shown in Table 4.1. The bulk density shown in Table 4.1 was calculated by multiplying the bulk specific gravity by the unit weight of water. The bulk specific gravities and corresponding bulk densities for the vesicular basalt are not entirely valid, inasmuch as the saturated, surface-dry weight in air would be slightly less than the correct value because water is not retained in the larger vesicles exposed on the surface of the specimens. Consequently, the true bulk specific gravity for the vesicular materials may be somewhat lower than the values shown in Table 4.1.

The maximum value of bulk specific gravity, 2.74, was determined on a Type I basalt, and the minimum value, 2.40, on a Type IV basalt. The bulk specific gravity of the Type II basalt ranged from a maximum of 2.66 to a minimum of 2.63, and averaged 2.64. The bulk specific gravities of two

TABLE 4.1 RESULTS OF PHYSICAL TESTS ON SAMPLES FROM PRESHOT BORING
NCG 10.1

Duplicate unconfined compression tests were run on samples from depths of 10.0 to 11.4 feet and 130.0 to 130.9 feet.

Depth	Group Type	Bulk Specific Gravity SSD (G_m)	Bulk Density	Unconfined Compression Test Data	
				Compressive Strength	Modulus of Elasticity
feet			pcf	psi	psi $\times 10^6$
3.2 to 4.0	IV	2.40	149.5	10,435	5.30
5.1 to 5.8	II	2.64	164.5	17,905	7.01
10.0 to 11.4	III	2.62	163.2	10,210	7.66
				10,405	7.54
20.4 to 21.0	III	2.64	164.5	10,855	4.48
34.7 to 35.4	II	2.63	163.9	18,610	6.88
59.9 to 60.6	II	2.66	165.7	18,810	4.64
130.0 to 130.9	I	2.74	170.7	21,460	5.24
				19,740	5.00

samples of Type III basalt were 2.64 and 2.62. The bulk density ranged from 170.7 pcf for dense basalt to 149.5 pcf for vesicular basalt.

4.2.2 Static Strength. The compressive strength of the rock was determined by unconfined compression tests. The length-diameter ratio was approximately 2.0 for all specimens. Specimens were capped with a hydrostone compound prior to testing. A uniform loading rate of 50 psi/sec was applied to all specimens. Strain measurements were made by two, diametrically opposed SR-4 strain gages bonded to the specimen. Values of the unconfined compressive strength for core samples from NCG 10.1 are shown in Table 4.1 and in Figure 4.1.

The maximum value of compressive strength, 21,460 psi, was obtained on the dense basalt, and the minimum value, 10,210 psi, was obtained on the Type III vesicular basalt.

The values of static modulus of elasticity, which were derived from stress-strain curves in Figure 4.2 for basalt Types I through IV, are shown in Table 4.1. The moduli were derived from the slope of the line drawn tangentially to the initial portion of the stress-strain curve. The modulus of elasticity varied from 4.48×10^6 to 7.66×10^6 psi, with the values showing no particular relation to the degree of vesicularity.

The average value of the bulk specific gravity, the unconfined compressive strength, and the modulus of elasticity determination for different basalt types from Boring NCG 10.1 at the SULKY site and similar data obtained in an earlier study of Buckboard Mesa (Reference 2) are shown in Table 4.2. A comparison of these values indicated the values for unconfined compressive strength and modulus of elasticity at the SULKY site to be greater than those obtained in an earlier study with one exception,

TABLE 4.2 COMPARISON OF PHYSICAL PROPERTIES OF BASALT FROM SULKY SITE
AND BUCKBOARD MESA

All values in last two columns are averages. Numbers in parentheses indicate the number of values used in computing the average.

Basalt Type	Type Test	Project SULKY Average	Buckboard Mesa Average*
I	Bulk specific gravity	2.74 (1)	2.71 (29)
	Unconfined compressive strength, psi	20,600 (2)	20,200 (23)
	Modulus of elasticity, $\text{psi} \times 10^6$	5.12 (2)	6.52 (23)
II	Bulk specific gravity	2.64 (3)	2.65 (12)
	Unconfined compressive strength, psi	18,440 (3)	16,300 (12)
	Modulus of elasticity, $\text{psi} \times 10^6$	6.18 (3)	5.77 (12)
III	Bulk specific gravity	2.63 (2)	2.57 (33)
	Unconfined compressive strength, psi	10,490 (3)	9,280 (28)
	Modulus of elasticity, $\text{psi} \times 10^6$	6.56 (3)	4.79 (28)
IV	Bulk specific gravity	2.40 (1)	2.47 (30)
	Unconfined compressive strength, psi	10,430 (1)	6,700 (19)
	Modulus of elasticity, $\text{psi} \times 10^6$	5.30 (1)	4.40 (19)

* See Reference 2.

Figure 4.2 Stress-strain curves for Types I, II, III, and IV basalt.

i.e. the value of the modulus of elasticity for Type I basalt. Although limited in number, the values of physical properties as determined for basalt types from the SULKY site were all within the range of similar data scatter from an earlier study (Reference 2) on Buckboard Mesa basalts, which first established average values of physical properties for the basalt types.

CHAPTER 5

GEOPHYSICAL LOGGING AND PRESSURE TESTS

5.1 TECHNIQUES EMPLOYED IN GEOPHYSICAL LOGGING

Various physical properties of in situ materials at the SULKY site were also determined by means of geophysical logging of the drill holes. A brief description of the techniques used to determine each of the various physical properties of in situ material is presented subsequently for those geophysical logs utilized. The techniques employed for various types of geophysical logging have been detailed in trade literature of The Birdwell Company and technical publications (References 15 and 16).

5.1.1 Nuclear Density Logging. To determine the density of the surrounding rock, a collimated source of gamma radiations mounted in a wall skid irradiates the formations. The emitted gamma rays interact with the electrons of matter around the borehole, and a gamma-ray detector above the source responds to the back-scattered rays. The probability of a gamma ray colliding with an electron is proportional to the electron density; hence, the intensity of the back-scattered gamma log varies according to the density of the surrounding medium. Various names have been assigned to this type log, such as scattered gamma-ray log, gamma-gamma log, densilog, or nuclear density log.

5.1.2 Natural Radioactivity Logging. To determine the natural radioactivity of the surrounding rock media, a counter is introduced in the borehole that will register the natural gamma-ray emission through interaction of the gamma rays with matter contained in the counting device by the process of ionization. Through ionization, one or more electrons are

released from a neutral atom, and the electrical unbalance can be detected. The natural radioactivity log is most commonly called a gamma-ray log.

5.1.3 Moisture Logging. To determine the moisture present in the surrounding rock media, a neutron source, mechanically attached to the instrument probe, is used to bombard the rock with neutrons. The neutrons, after emission from the source, are slowed to thermal velocities principally by collisions with hydrogen atoms which are virtually of the same size and mass. After the neutrons have been slowed by these collisions, they may be captured by other atoms which then emit gamma rays of capture. Since all rock voids are filled with either fluid or gas, both of which contain hydrogen atoms, a calibration can be made which will permit a correlation of the gamma-ray count and the moisture in the media. This correlation can also be used to determine the total amount of voids and thereby the density of the media. This type of neutron log is more descriptively called a hydrogen log, and has various trade names such as neutron-gamma log, neutron-slow neutron log, and neutron-fast neutron log.

5.1.4 Three-Dimensional Logging. To determine the elastic properties of the surrounding rock media, an omnidirectional, high-frequency sound pulse is generated and transmitted by refraction along the boundary of a fluid-filled borehole, where at a predetermined distance it is detected and cabled to surface instruments. When amplified, the recorded data represent first and subsequent arrival times of all wave energies resulting from the interaction of the pressure wave at the interface of the fluid and borehole wall. From the recorded data, pressure-wave and shear-wave velocities of the foundation material penetrated by the hole are obtained. These data

are, in turn, used to calculate Poisson's ratio and the elastic modulus of the media.

5.1.5 Caliper Logging. To determine the size of the borehole, an instrument equipped with three large flexible springs which ride against the wall of the borehole is lowered into the borehole. Variations in the size of the borehole cause the springs to position a movable rod inside a pickup coil located within the body of the instrument. The position of the rod governs the amount of inductance between the coil and the rod, which may be recorded as voltages at the surface.

5.2 RESULTS OF GEOPHYSICAL LOGGING

The in situ properties of the basalt in Boring NCG 10.0 were investigated by means of nuclear density logs and three-dimensional (3-D) velocity logs. A caliper log and various other nuclear logs were obtained by the AEC in Borings NCG 10.4 and 10.5.

The geophysical logs obtained by The Birdwell Company were interpreted by Mr. D. M. Christensen (Reference 6). Those obtained by the AEC were interpreted by the Grand Junction Office under the direction of Mr. P. H. Dodd, Chief, Technical Service Branch. The geophysical logs obtained from drill holes NCG 10.0, 10.4, and 10.5 are shown in Figures 5.1, 5.2, and 5.3, respectively.

The values of physical properties for in situ basalt obtained from various geophysical logs were compared with similar values from representative basalt samples tested in the laboratory.

5.2.1 Nuclear Density Logging. The in situ density of basalt in drill hole NCG 10.0 (see Figure 5.1) was calculated by The Birdwell Company. The in situ density of basalt in drill holes NCG 10.4 and NCG 10.5 (see

Figure 5.1 Results of geophysical logging, Boring NCG 10.0, and laboratory tests on Boring NCG 10.1.

Figures 5.2 and 5.3) was calculated by the AEC through the use of its RHOLOG computer program wherein the density log was digitized on 1-foot intervals. No correction was made in either determination for the water content of the rock media; consequently, the density values indicated in Figures 5.1 through 5.3 are wet bulk densities. In general, the density logs exhibit an erratic behavior for the upper few feet, which is probably due to the heterogeneous nature of the top zones of residual soils and weathered basalt. The wet bulk density logs generally indicate an increase in density with depth up to a maximum of about 174 pcf.

Although the wet bulk density log of Boring NCG 10.0 indicated an increase in density with depth, the density values were approximately 10 pcf lower in the dense basalt zones than those in drill holes NCG 10.4 and 10.5 at depths greater than 50 feet. This difference can probably be attributed to the difference in logging techniques used to obtain the in situ density.

Laboratory density values are shown with the density profiles computed from the geophysical logs in Figures 5.1 through 5.3. A fairly good agreement was obtained for Borings NCG 10.4 and 10.5. The log density values at shallow depths, where many more structural discontinuities existed, were consistently lower than laboratory density values; however, at greater depths these values were about the same. The number of discontinuities per unit volume affects the density, and there were comparatively fewer discontinuities in the laboratory samples. Consequently, the density logs tend to indicate lower density values than the small selected sample tested in the laboratory.

It appears that the density values determined by laboratory tests more nearly reflect the true density of the material, excluding mass

defects, and the density values obtained from geophysical logs reflect the mass density of the in situ material.

The porosity computed from the nuclear density logs for NCG 10.4 and 10.5 is shown in Figures 5.2 and 5.3, respectively. The porosity was also computed on the assumption that the moisture content was zero and the dry weight of the material equaled the value previously reported as wet density. The actual value of porosity is dependent on the actual moisture content and is therefore lower than the computed values reported. The computations upon which the porosity plots are based were made assuming an average value of grain density of 2.81 gm/cm^3 (Reference 13).

The unconfined compressive strengths of samples from Boring NCG 10.1 are shown in Figure 5.1 plotted as a function of depth. An insufficient number of tests were conducted to permit any conclusive correlations between the unconfined compressive strength and densities indicated in the geophysical logs. As a general observation, however, it appears that the unconfined compressive strength increases with increases in the density as determined from the density logs; such a variation was previously noted (Reference 1).

5.2.2 Natural Radioactivity Logging. The natural background gamma logs of Borings NCG 10.4 and 10.5 obtained by the AEC are shown in Figures 5.2 and 5.3, respectively. The logs show marked similarity in that the intensity for both logs varied from 30 to 40 counts/sec, and averaged about 35 counts/sec.

5.2.3 Moisture Logging. The neutron-neutron moisture logs of Borings NCG 10.4 and 10.5 obtained by the AEC are shown in Figures 5.2 and 5.3, respectively. The AEC is currently constructing moisture calibration

Figure 5.2 Results of geophysical logging, Boring NCG 10.4.

Figure 5.3 Results of geophysical logging, Boring NCG 10.5.

models for use in interpreting moisture logs. These interpretations will be completed at a later date. In general, the logs of NCG 10.4 and 10.5 showed similar trends in intensity, which varied from 200 counts/sec at the surface to a peak of about 300 counts/sec at about the 55-foot level.

5.2.4 Three-Dimensional Logging. Practically no data were obtained from the three-dimensional logging of NCG 10.0. The basalt surrounding this particular borehole was fractured to the extent that large quantities of cellophane-stringer material were required to maintain the mud level in the hole. The cellophane has a tendency to entrain air, which increases the attenuation of the transmitted energy in addition to processing an attenuation coefficient which approaches unity at audio frequencies. In the region below 60 feet, such a high degree of phasing occurred that the first arrival times were not considered reliable. Consequently, no values of modulus of elasticity or Poisson's ratio are shown in Figure 5.1.

5.2.5 Vibratory and Seismic Measurements. The values of modulus of elasticity determined from laboratory unconfined compression tests on Boring NCG 10.1 are shown in Figure 5.1. These values are in the range of 6.0×10^6 psi. Vibratory and seismic velocity measurements by the WES in connection with Project BUGGY (Reference 23) at a location about 4,000 feet N-NW of the SULKY site indicated moduli of 3 to 30×10^4 psi. Elastic waves propagating from an energy source such as a seismic shot point or a vibrator, and observed on the ground surface a distance from the source, travel essentially in a horizontal direction, although some vertical travel is involved. As previously noted, Buckboard Mesa is intersected by vertical joints with an average spacing in a horizontal plane of 1 to 2 feet. These joints are among the most open of all joints found on the mesa and

probably extend to the base of the basalt. The existence of these open vertical joints tends to reduce the horizontal velocity of elastic waves. As the elastic modulus is estimated by the velocity of wave propagation, the lower measured velocities result in lower elastic moduli. It should also be noted that in situ values are based on the behavior of a volume of material with dimensions in the order of tens to hundreds of feet; thus, values determined on in situ material can be expected to be considerably lower than values determined in the laboratory on small intact specimens.

5.2.6 Caliper Logging. The diameters of Borings NCG 10.4 and 10.5 as determined by AEC caliper logging operations are shown in Figure 5.2 and 5.3, respectively. In both holes, the diameter averages approximately 3 inches throughout the depth, with two exceptions: in the first few feet of both holes and at a depth of 34 feet in NCG 10.4, the diameter is approximately 3.75 inches.

5.3 WATER PRESSURE TESTS

Water pressure tests were conducted in Borings NCG 10.4 and 10.5 in 5-foot vertical intervals. At each interval, the holes were sealed off by expandable rubber packers. The flow rate was determined with a flowmeter by measuring the quantity of water pumped into the hole for a measured period of time, generally about 3 minutes. During the time period, the pressure in the hole was maintained as nearly as possible at a constant value by observing a pressure gage at the surface.

The value of the water pressure tests is in their use as an indirect measure of the "effective porosity" of the rock media, i.e., the porosity based on interconnected voids and joint openings. The effective porosity of the intact vesicular basalt is zero, as the voids are not connected to

to permit a flow of water. If, for example, large quantities of water can be forced into a core hole interval under small pressure, the indication is that the joint openings (or effective porosity) of this section are relatively large. The use of a water-loss coefficient was suggested by de Mello and da Cruz (Reference 10) to express quantitatively the results of pressure tests. The water-loss coefficient P_i may be formulated as follows:

$$P_i = \frac{Q}{L H}$$

where

Q = flow rate in gallons per minute

L = length of borehole interval in feet

H = pressure at the midheight of the borehole interval, in atmospheres

Dimensionally, the water-loss coefficient may be expressed approximately as a coefficient of permeability in centimeters per second by multiplying by 0.0020.

5. 4 POROSITY DETERMINATIONS

The water-loss coefficients computed from field pressure tests on Borings NCG 10.4 and 10.5 are plotted versus depth in Figure 5.4. For comparison, the bulk porosity values shown in Figures 5.2 and 5.3 were averaged over the same intervals subjected to the pressure tests, and the average values plotted in Figure 5.4. Also shown for comparison are the values of effective porosity over the same intervals. The effective porosity was computed based on the percentage of total core hole volume occupied by open spaces at the joints. Borehole camera observations were used for these

Figure 5.4 Water-loss coefficient and porosity versus depth for Borings NCG 10.4 and 10.5.

measurements. It can be seen that the effective porosity is more closely related to the water-loss coefficient than is the bulk porosity which reflects total void spaces in the mass. The effective porosity is of importance in evaluating the overall shear strength of the rock mass. The relation between effective porosity and water-loss coefficient is shown in Figure 5.5. This relation will be of value in estimating the effective porosity in borings where field pressure tests can be conducted and it is not feasible to use the borehole camera.

Figure 5.5 Relation between water-loss coefficient and effective porosity.

CHAPTER 6

SUMMARY

The selected site for Project SULKY, Site 10 on Buckboard Mesa, is underlain by a relatively simple stratigraphic succession. A thin soil layer, 1.4 to 2.5 feet thick, immediately underlies the site. It is predominantly a silty or sandy residual soil containing large fragments of vesicular basalt. A basalt cap at least 192 feet thick lies beneath the soil. This basalt may be subdivided into an upper vesicular basalt zone 47 to 72 feet thick, a middle dense basalt zone at least 128 feet thick, and a lower, thin vesicular basalt zone at least 0.6 foot thick. The percentage of vesicles within the upper vesicular basalt zone generally decreases with depth. A 14-foot-thick zone of cinders separates this basalt cap from an underlying sequence of tuff.

In terms of its mineral constituents, the basalt is quite uniform from one area to another. The vesicular basalt is an olivine basalt of normal composition, while the dense basalt is perhaps most accurately classified as subandesite.

Although there are at least three known faults which have affected the northern and western part of Buckboard Mesa, none were traced through the area of Site 10. This type of structural deformation is therefore of little consequence at Site 10 compared to the well-developed joint system or systems on the mesa. Five major joint sets can be distinguished throughout the mesa, in spite of the extreme variability of the joint orientations. Four of the joint sets, believed to have formed in response to regional

tectonic stresses, are high-angle strike sets that have average strike directions of $N76^{\circ}W$, $N27^{\circ}W$, $N17^{\circ}E$, and $N60^{\circ}E$. These four preferred directions of strike generally persist throughout all investigated areas on the mesa; however, minor variations are to be expected. At Site 10 the joint sets have the following average strikes: Set 1, $N75^{\circ}W$; Set 2, $N17^{\circ}W$; Set 3, $N17^{\circ}E$; and Set 4, $N41^{\circ}E$. Although the relative importance of each strike set varies from one area to another, the $N17^{\circ}E$ strike set is statistically predominant when the results from all areas studied on the mesa are considered. The fifth major set shows a pronounced lithologic control. Since this set parallels the bedding or flow layers, joints of this set tend to be predominantly horizontal except in the vicinity of zones of distortion (swirls) where these joints may assume any attitude.

All the joints observed on Buckboard Mesa are characteristically irregular or wavy, and exhibit frequent changes in width of separation and degree of filling. The frequency and type of joints are variable from one area to another and generally independent of rock type and depth. The average spacing between adjacent joints encountered on the mesa in the vertical direction is about 1 foot, while the spacing in the horizontal direction is approximately 2 to 3 feet. This average spacing is believed to characterize the area of Site 10.

The average bulk specific gravity, unconfined compressive strength, and modulus of elasticity, as determined by laboratory tests on representative samples from the SULKY site, were generally in reasonable agreement with the average values previously determined on Buckboard Mesa for other projects.

The porosity as determined by geophysical logs does not agree very

closely with the water-loss coefficient computed from field pressure tests. On the other hand, a good agreement was obtained between the effective porosity computed on the basis of observed joint openings and the water-loss coefficient.

The physical property values at the SULKY site obtained from geophysical logs and laboratory tests of samples were generally in good agreement. The average bulk density at depths greater than 10 feet was approximately 165 pcf. The bulk porosity obtained from the geophysical logs and based on an assumed grain density of 2.81 gm/cm^3 was in close agreement with those values obtained by laboratory tests. The average porosity at the SULKY site was approximately 8 percent.

The data presented herein provide information on the geologic and engineering properties of the subsurface materials in the project area, and thus form a basis for estimating the changes in these properties to be expected as a result of detonation of a nuclear explosive. These data will also enable an estimate to be made of the degree of stability of the crater slopes.

APPENDIX A

COMBINED LITHOLOGIC AND BOREHOLE PHOTOGRAPHIC
LOGS FOR BORINGS DRILLED AT SULKY SITE 10

LEGEND USED IN APPENDIX A

SOIL		DENSE BASALT
VESICULAR BASALT, > 20% VESICLES		VOLCANIC ASH
VESICULAR BASALT, 10 TO 20% VESICLES		TUFF
VESICULAR BASALT, < 10% VESICLES		CORE LOSS ZONE

ABBREVIATIONS USED IN APPENDIX A

BLDRS	BOULDERS	OCC	OCCASIONAL
BLK	BLACK	OX	OXIDIZED
BRN	BROWN	SCAT	SCATTERED
CAL	CALCITE	SEV	SEVERAL
DEG	DEGREES	SL	SLIGHTLY
DK	DARK	STRAT	STRATIFIED
FRAG	FRAGMENTS	VES	VESICLES
GRY	GRAY	W/	WITH
HD	HARD	WH	WHITE
HORIZ	HORIZONTAL	WTHRD	WEATHERED
JTD	JOINTED		

SYMBOLS USED IN PRESENTATION OF JOINT DATA FROM THE BOREHOLE CAMERA

WIDTH (AMOUNT OF DISPLACEMENT NORMAL TO PLANE OF FRACTURE):

H- (HAIRLINE); 1/32", . . . , 1/2".

FILLING (DEGREE OF JOINT FILLING):

O OPEN
PF PARTIALLY FILLED
F FILLED

* JOINT DATA OBTAINED FROM CORE LOGGING AND USED IN APPENDIX A.

Figure A.1 Log of Boring NCG 10.0.

PROJECT SULKY									
BORING NO.: NCG 10.1									
LOCATION (NEVADA STATE COORDINATES): N 849,207.05 E 594,553.52									
ANGLE OF BORING: Vertical				TYPE OF BORING: NX - DIAMOND					
BEARING:				DRILLING AGENCY: VES					
EL TOP OF HOLE: 5328.8 ft				TOTAL DEPTH: 212.0 ft					
TOTAL CORE RECOVERY: 93.3%				DEPTH TO WATER TABLE: No water encountered					
HOLE STARTED: 13 July 1963				HOLE COMPLETED: 17 July 1963					
EL. FT. MSL	DEPTH FT.	LOG	DESCRIPTION	CORE RECOVERY (%)	JOINT	DATA	WIDTH & FILLING		
					MD. PT.	STRIKE	DIP		
5328.8	0		RESIDUAL SOIL, SILTY SAND, SANDY SILT, 2/3RAG AND SLIRS OF VESICULAR BASALT						
5326.3	2.5		Top of Hole						
5324.8	4.0		VESICULAR BASALT, BK GRY, HD, VES AVERAGE 1/4 IN. LONG, 25 TO 10% OF MASS, DIP 30 TO 50 DEG	100		N00°E	15°	1/32", O	
	5		VESICULAR BASALT, BK GRY-GRY, HD, VES 10 TO 20% OF MASS, RANGE UP TO 2 IN. LONG	100		N15°E	40°NE	H, O	
	10		ves flattened, forming flow lines dipping 20 to 40 deg	100		N70°E	15°SE	1/8", Pr	
	15			100		N15°E	80°NW	1/32", F	
	20		ves dip 0 to 20 deg	100		N60°E	40°SE	1/16", O	
	25			100		N60°E	30°SE	H, F	
	30			100		N65°E	30°SE	H, F	
5298.4	30		VESICULAR BASALT (DENSE) GRY-BRN, HD, VES 5 TO 10% OF MASS, FORM FLOW LINES 1/2 TO 2 IN. APART, DIP 0 TO 10 DEG	100		N65°W	70°SE	H, F	
	35		basalt grades from gry to gry-brown	100		N65°W	70°SE	1/8", Pr	
	40			100		N65°W	70°SE	1/32", Pr	
	45			100		N65°W	70°SE	1/8", Pr	
5281.4	45			100		N65°W	70°SE	1/8", Pr	
	50		DENSE BASALT, GRY-BRN, HD, W/SCAT VES TO 1 IN. LONG	100		N55°E	90°	1/16", Pr	
	55			100		N85°E	60°SE	1/16", Pr	
	60			100		N85°E	60°SE	1/16", Pr	
	65			100		N60°E	0°	1/32", Pr	
5262.6	65			100		N60°E	0°	1/16", Pr	
	70		DENSE BASALT, GRY, HD, MASSIVE W/SCAT VES TO 1 IN. LONG	100		N35°W	60°NE	1/32", F	
	75			99		N85°W	30°SE	1/8", Pr	
	80			100		N30°W	50°SE	1/32", O	
	85			100		N65°W	50°NE	1/16", Pr	
	90			100		N75°W	60°NE	1/16", Pr	
	95			100		N75°W	60°NE	1/16", Pr	
	100			100		N75°W	60°NE	1/16", Pr	
	105			100		N75°W	60°NE	1/16", Pr	
	110			100		N75°W	60°NE	1/16", Pr	
	115			100		N75°W	60°NE	1/16", Pr	
	120			100		N75°W	60°NE	1/16", Pr	
	125			100		N75°W	60°NE	1/16", Pr	
	130			100		N75°W	60°NE	1/16", Pr	
	135			100		N75°W	60°NE	1/16", Pr	
	140			100		N75°W	60°NE	1/16", Pr	
	145			100		N75°W	60°NE	1/16", Pr	
	150			100		N75°W	60°NE	1/16", Pr	
	155			100		N75°W	60°NE	1/16", Pr	
	160			100		N75°W	60°NE	1/16", Pr	
	165			100		N75°W	60°NE	1/16", Pr	
	170			100		N75°W	60°NE	1/16", Pr	
	175			100		N75°W	60°NE	1/16", Pr	
	180			100		N75°W	60°NE	1/16", Pr	
	185			100		N75°W	60°NE	1/16", Pr	
	190			100		N75°W	60°NE	1/16", Pr	
	195			100		N75°W	60°NE	1/16", Pr	
	200			100		N75°W	60°NE	1/16", Pr	
	205			100		N75°W	60°NE	1/16", Pr	
	210			100		N75°W	60°NE	1/16", Pr	
	212			100		N75°W	60°NE	1/16", Pr	

PROJECT SULKY									
BORING NO.: NCG 10.1 (cont.)									
EL. FT. MSL	DEPTH FT.	LOG	DESCRIPTION	CORE RECOVERY (%)	JOINT	DATA	WIDTH & FILLING		
					MD. PT.	STRIKE	DIP		
105				100		N75°E	30°NE	H, O	
110				100		N75°E	30°NE	1/16", Pr	
115				100		N30°E	50°NE	1/16", Pr	
120				100		N15°E	40°NE	H, Pr	
125				100		N75°E	30°NE	1/16", Pr	
130				100		N75°E	30°NE	1/16", Pr	
135				100		N75°E	30°NE	1/16", Pr	
140				100		N75°E	30°NE	1/16", Pr	
145				100		N75°E	30°NE	1/16", Pr	
150				100		N75°E	30°NE	1/16", Pr	
155				100		N75°E	30°NE	1/16", Pr	
160				100		N75°E	30°NE	1/16", Pr	
165				100		N75°E	30°NE	1/16", Pr	
170				100		N75°E	30°NE	1/16", Pr	
175				100		N75°E	30°NE	1/16", Pr	
180				100		N75°E	30°NE	1/16", Pr	
185				100		N75°E	30°NE	1/16", Pr	
190				100		N75°E	30°NE	1/16", Pr	
195				100		N75°E	30°NE	1/16", Pr	
200				100		N75°E	30°NE	1/16", Pr	
205				100		N75°E	30°NE	1/16", Pr	
210				100		N75°E	30°NE	1/16", Pr	
212				100		N75°E	30°NE	1/16", Pr	

Figure A.2 Log of Boring NCG 10.1.

APPENDIX B

LITHOLOGIC LOG FOR EMPLACEMENT CALYX HOLE

DRILLED AT SITE 10

LEGEND FOR CALYX HOLE LOGS

TAN SILTY SAND WITH COBBLES AND BOULDERS OF BASALT

VESICULAR BASALT, 10 TO 20% VESICLES

RED-BROWN CINDERY MATERIAL

VESICULAR BASALT, < 10% VESICLES

VESICULAR BASALT, > 20% VESICLES

DENSE BASALT

LITHOLOGIC CONTACTS

SCHEMATIC REPRESENTATION OF DIRECTION AND AMOUNT OF DIP OF VESICLES. THE DASHES INDICATE THE APPROXIMATE LENGTH OF THE LONGER VESICLES IN A GIVEN ZONE AND DO NOT INDICATE THE PERCENTAGE OF VESICLES PRESENT.

LARGE OPEN VESICLES OR CAVITIES, DRAWN TO SCALE.

JOINT SYMBOLS

HAIRLINE TO 1/32" WIDE, OPEN

1/32" TO 1/8" WIDE, OPEN

1/8" TO 1/4" WIDE, OPEN

1/4" TO 1/2" WIDE, OPEN

1/4" TO 1/2" WIDE, FILLED (DESCRIPTION OF FILLING MATERIAL INDICATED ON LOG)

1/2" WIDE OR GREATER, OPEN

1/2" WIDE OR GREATER, FILLED (DESCRIPTION OF FILLING MATERIAL INDICATED ON LOG)

LOG OF CALYX HOLE

PROJECT: SULKY	SITE NO. 10
HOLE NO.:	LOCATION: N 849,239.36 E 594,540.77
ELEVATION: 5329.0 FT MSL (APPROX)	TOTAL DEPTH: 110 FT
HOLE DIAMETER: 36 IN.

(CONTINUED)

Figure B.1 Log of calyx hole (1 of 3 sheets).

(CONTINUED)

LOG OF CALYX HOLE

PROJECT: SULKY

SITE NO. 10

HOLE NO.:

LOCATION: N849,239.36 E 594,540.77

ELEVATION: 5329.0 FT MSL (APPROX)

TOTAL DEPTH: 110 FT

HOLE DIAMETER: 36 IN.

PHOTOGRAPH

SECTION

REMARKS

(CONTINUED)

Figure B.1 (2 of 3 sheets).

(CONTINUED)

LOG OF CALYX HOLE

PROJECT: SULKY

SITE NO. 10

HOLE NO.:

LOCATION: N849,239.36 E 594,540.77

ELEVATION: 5329.0 FT MSL (APPROX)

TOTAL DEPTH: 110 FT

HOLE DIAMETER: 36 IN.

PHOTOGRAPH

SECTION

REMARKS

Dense vesicular basalt. Vesicles are 0% to 5% of mass and spaced at random. They range from 1/4 in. to 2 ft long and 1/8 to 1/4 in. wide, and are horizontal.

Dense basalt with scattered irregular-shaped vesicles up to 2 in. long and 1 in. wide.

Figure B.1 (3 of 3 sheets).

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