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PHYSICAL PROPERTIES AND CLASSIFICATION OF SEVEN TYPES OF ROCK TARGETS

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ABSTRACT

Seven sites for rock penetration studies are described. The locations and physical rock properties are presented and a rock classification system is used to classify all of the sites.

* Pages 21-24 are missing from original

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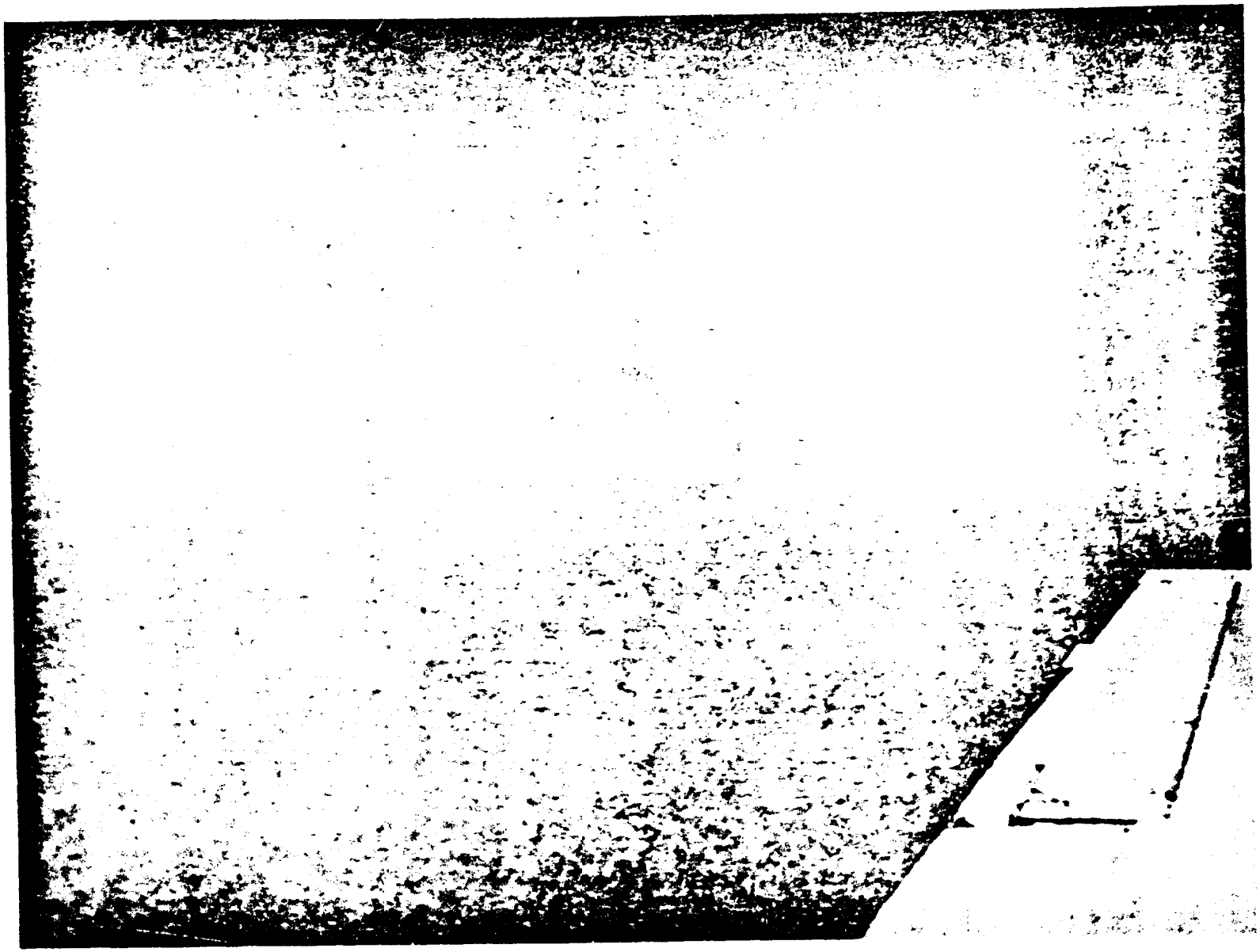
SUMMARY

The description and location of seven sites for use in the Sandia Rock Penetration program are given. Physical properties of intact rock samples from these targets are presented and an appendix giving more detailed data such as test-boring logs and thin-sample analyses is included. The Rock Classification system which was adopted for this program is explained and all of the rock targets are categorized within this system.



Frontispiece. Aerial view of Tres Hermanos sandstone target

PHYSICAL PROPERTIES AND CLASSIFICATION OF SEVEN TYPES OF ROCK TARGETS

Introduction

The need for a method of classifying and defining a particular rock target has been recognized since the first rock penetration test was conducted at the Tonopah Test Range (TTR) in early 1966. To help in selecting a suitable classification system, a literature search was conducted to review as many existing systems as possible. This report defines the rock classification system that will be used on the Estmark* program and presents the physical rock property data collected from all of the rock sites used to date.

Hock Classification

An important lesson learned from the earth penetration program is the necessity of defining the physical properties of the soil penetrated. Because soil properties within a given soil deposit are erratic, it became necessary to perform extensive post-test exploration in the immediate impact area.[1] This experience pointed up the necessity for a suitable classification or definition of the rock penetrated in Estmark tests.

All rock formations, to some degree, have physical discontinuities such as joints, faults, or bedding planes (Figure 1). Deere and Miller[2] state that the strength and deformation characteristics of a rock mass are influenced both by the physical properties of the intact blocks of rock and by the number and nature of discontinuities bounding the individual blocks. The research of Deere and Miller was focused on the physical properties of intact rock. They conducted physical classification tests on core samples that were macroscopically homogeneous and free from fractures, joints, and seams, to obtain numerical results known as index properties. They concluded that intact rock could be satisfactorily classified on the basis of its strength and deformation characteristics. Table I, a reproduction of Table 6.1 from Deere and Miller's "Engineering Classification and Index Properties for Intact Rock," is a summary of their proposed classification.

The maximum resistance to penetration of a particular rock formation would appear to be a function of the physical properties of a macroscopically homogeneous, unfractured sample of intact rock. Comparably, any decrease in penetration resistance should be a function of the type and extent of physical discontinuities in the rock formation.

*Estmark is the name adopted for the Sandia Rock Penetration Study.

Deere[3] presents one method for defining these discontinuities. His method presents a Rock Quality Designation (RQD). RQD values are determined in the following manner: The continuous core sample is examined to determine the length of all pieces of solid unfractured core over 4 inches. This sum, called the Modified Core Recovery, is then divided by the total core run and is multiplied by 100 percent to determine the RQD. Table II4 gives a description of rock quality related to the RQD number.

To describe the rock penetrated, the Estmark program will use the classification system of Deere and Miller and the RQD of Deere. It is believed that, at the present state of the art in rock classification, these two systems will best define the rock penetrated in Estmark tests.

Test Sites

Seven rock sites have been investigated for Estmnrk tests. Penetration tests have been conducted in five of these sites and the physical rock properties of all sites have been examined. Table I I I presents the data collected from these sites. The Appendix presents all o I' the test-boring records and thin-sample analyses available on the sites. The sample numbers in Table III are cross referenced with the sample numbers of the Appendix.

Location and Classification of Test Sites

Tres Hermanos Sandstone

This test site is on the Putncy Mesa near Grants, New Mexico, 10 miles south of Highway 66 (I-40) and adjacent to State Highway 117. A comprehensive report on the geologic and rock properties of this area can be found in Reference 5. From average properties this site is classified as a low-strength rock; DL; RQD = 22 to 37 (see Tables I, II, and III).

Zuni Granite

This site is near Paxton Springs in the Grants area.[5] Classification: DH; RQD = 30.

Thirsty Canyon, Welded Tuff

This site is on the Tonopah Test Range (TTR). A map showing its location is given in the Ap endix as Mt. Helen, Rock Site No. 1. Classification: DL; RQD = 8 .

Tuff, Antelope Target

This site is at TTR. A map showing its location is given in the Appendix as Antelope, Rock Site No. 2. Classification: EL; RQD = 60.

Welded Agglomerate, Cactus Peak Target

This site is at TTR, approximately 7 miies due west of the landing strip. Classification: D; RQD = 60.

Dacite

This rock is found on the edge of the Welded Agglomerate target. Classification: C; RQD not determined.

Amphibolite, Beale AFB

A map showing the location of this site is given in the Appendix. Classification: BH; RQD not determined.

Madera Limestone, White Sands Missile Range

This site is south-east of Socorro, New Mexico, on the North Oscura Site of WSMR. Classification: CH; RQD not determined.

The above RQD values were determined from only two or three core samples from each area. It is believed that the values are representative of the site in general but it is recommended that more core samples be taken in all of the sites except the Putney Mesa area.

Soil overburden exists to some degree on all of the above rock sites. The thickness of the soil layer varies from 1 to 3 feet (Figure 2); however, exposed rock also exists to some degree in all of the sites.

Conclusions

The target description and rock classification given in this report represent simply a first step in establishing a classification that can be used to define the material penetrated in Estmark tests. As this program proceeds, refinements will be incorporated to improve and clarify the classification. One of the objectives of the Estmark program will be to relate penetrability to RQD. It is hoped that this classification will simplify communications within the laboratories when the need for new rock sites arises.

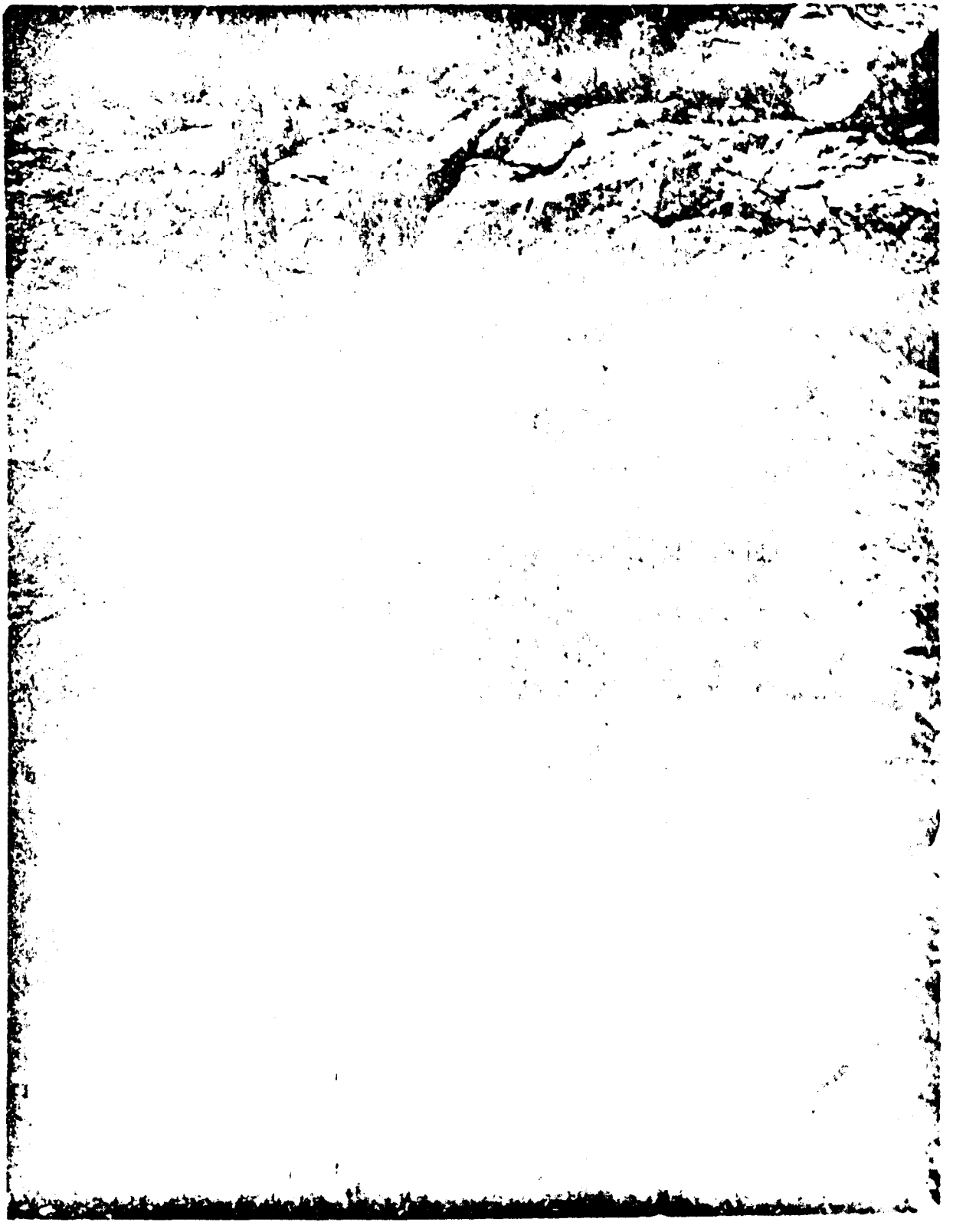


Figure 1. Projectile embedded in Tres Hermanos sandstone showing seam and fracture planes

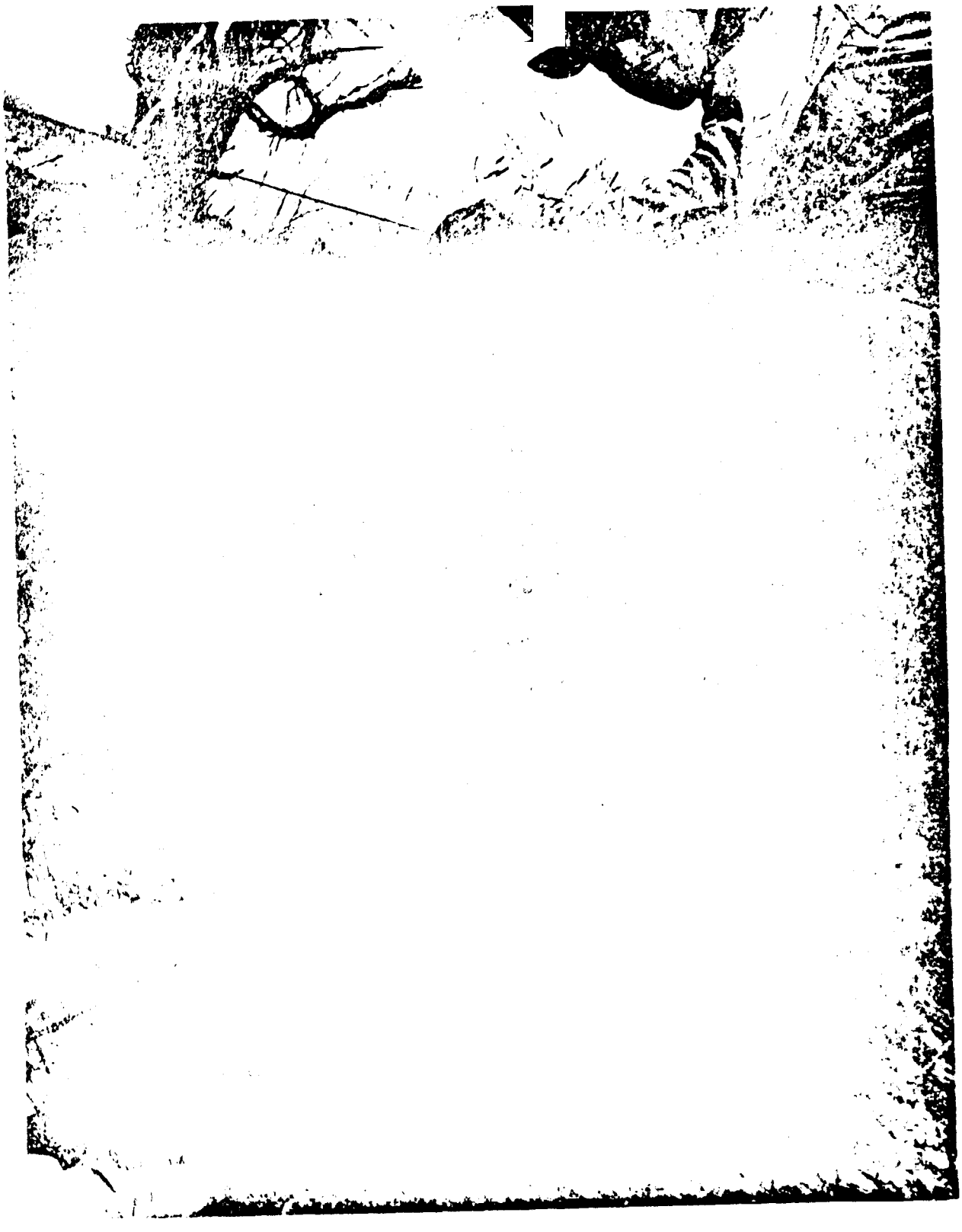


Figure 2. Contact between soil overburden and Tres Hermanos sandstone

TABLE I
(After Deere and Miller)[2]

Engineering Classification For Intact Rock

I. On Basis of Strength

Class	Description	Uniaxial Compressive Strength (lb/in^2)
A	Very high strength	Over 32,000
B	High strength	16,000-32,000
C	Medium strength	8,000-16,000
D	Low strength	4,000-8,000
E	Very low strength	Less than 4,000

II, On Basis of Modulus Ratio

Class	Description	Modulus Ratio*
H	High modulus ratio	Over 500
	Average modulus ratio	200-500
L	Low modulus ratio	Less than 200

Classify rock as B, BH, BL, etc.

*Modulus ratio = E_t/σ_a (ultimate)

where E_t = tangent modulus at 50 percent ultimate strength;

σ_a = uniaxial compressive strength

TABLE II
(After Deere)[3,4]

Rock Quality Designatfon

Rock Quality Designation	Description of Rock Quality
0-25	Very poor
25-50	Poor
50-75	Fair
75-90	Good
90-100	Excellent

TABLE III

Physical Rock Properties

Rock Description and Location	Sample Number	Depth of Sample (ft)	Dry Density (lb/ft^3)	Unconfined Compressive Strength (psi)	Tangent Modulus at 50% x 10^6 (psi)	Poisson s Ratio
Tres Hermanos Sandstone; Grants, New Mexico (Samples taken from penetration test. Sites 120-103, 120-104, and 120-112)	A	7.0	133.9	6000	0.770	0.19
	B	8.5	133.1	5840	0.816	0.19
	D	14.5	134.3	3310		
	E	15.0	137.7	5250	0.870	0.18
	I	16.0	143.5			
	J	16.5	141.4	5970	0.358	0.22
	O	2.0	133.0	6380	2.000	0.21
	P	9.5	132.3	7920	2.300	
	R	11.0	132.6	9550		
	S	12.0	144.1	5740	0.736	0.20
Zuni Granite; Grants, New Mexico	K	9.5	160.3	5470	3.300	
	L	12.0	159.9	5440		
	M	13.0	166.5	7960	7.000	0.20
	N	14.0	165.9			
Thirsty Canyon Welded Tuff; Mount Helen Target, Tonopah Test Range, Tonopah, Nevada	1-1B	8.3	122.7	8770	1.550	0.10
	1-1C	11.0	115.8	7120	1.200	↑ average value ↓
	1-1D	11.5	116.9			
	1-1E	16.6	113.4	5490	0.960	
	1-2A	4.0	112.2	5520	0.890	
	1-2C	8.0	110.0	4140	0.210	0.10

(continued on next page)

TABLE III
(Continued)

Rock Description and Location	Sample Number	Depth of Sample (ft)	Dry Density (lb/ft^3)	Unconfined Compressive Strength (psi)	Tangent Modulus at 50% x 10^6 (psi)	Poisson's Ratio
Thirsty Canyon Welded Tuff; Mount Helen Target, Tonopah Test Range, Tonopah, Nevada (continued)	1-3A	2.1	112.1	4420	0.800	0.10
					0.660	
	1-3B	4.5	107.9	3870		
	1-3C	8.8	79.8	1660	0.260	
	1-4A	4.4	117.1	6900	0.970	
	1-4B	9.0	115.7	5520	0.810	
	1-4D	14.4	119.1	3040	0.880	
	1-4F	18.3	117.2	8560	1.050	
	1-5B	4.2		6420		
	1-5X	5.2	114.0	4680	0.820	
	1-5E	10.5	110.3	2480	0.430	0.10
Tuf f; Antelope Target, Tonopah Test Range, Tonapah. Nevada	2-U	0.6	104.6	2480	0.35	0.10
	2-1BB	10.3	104.1	3060	0.49	
	2-1D	13.3	103.1	2080	0.28	
	2-2A	5.8	99.8	2210	0.45	
	2-2C	14.2	99.7	2350	0.44	
	2-2E	23.2	97.7	1810	0.29	
	2-3A	6.0	93.7	1660	0.44	
	2-3B	8.5	95.5	1930	0.47	
	2-3D	13.3	96.7	2080	0.48	0.10

(continued on next page)

TABLE III
(Continued)

Rock Description and Location	Sample Number	Depth of Sample ft	Density ($lb\ ft^3$)	Unconfined Compressive Strength psi	Tangent Modulus at 50% x 10^6 (psi)	Poisson's Ratio
Tuff; Antelope Target, Tonopah Test Range, Tonopah, Nevada (continued)	2-4A	2.3	93.4	1410	0.27	0.10
	2-4B	3.4	97.s	1830	0.39	
	2-4C	4.9	97.s	1670	0.40	
	2-5A	0.0	-	2790		
	2-5B	7.3	98.7	2620	0.51	
	2-5C	11.8	94.2	2070	0.45	
	2-5D	15.8	100.0	2640	0.51	0.10
Welded Agglomerate; Cactus Peak Target, Tonopah Test Range, Tonopah, Nevada	3-1B	5.5	116.9	3030	0.65	0.20
	3-1C	12.5	118.7	5500	1.11	
	3-1D	13.7	121.4			
	3-1E	15.3	123.2	3860	0.85	
Dacite; Edge of Cactus Peak Target	DR A-l	Surface	147.0	11660	2.80	
	DR B-l	Surface	147.9	12600	2.75	
	DR A-3	Surface	148.6	10340	2.20	0.20
Amphibolite; Beale Air Force Base, California		Surface	182.4	19100	13.20	0.25
Madera Limestone; White Sands Missile Range, North Oscura Site, New Mexico (samples taken from penetration Test 120-127)	1	2.0	172.4	14200		
	2	2.0	168.3	15000		
	3	2.0	166.9	15200		
	4	2.0	171.0	12200		
	5	2.0	167.6	15700		

(continued on next page)

TABLE I.11
(Continued)

Rock Description and Location	Sample Number	Depth of Sample (ft)	Dry Density (lb/ft^3)	Unconfined Compressive Strength (psi	Tangent Modulus at 50% x 10^6 (psi)	Poisson's Ratio
Madera Limestone: White Sands Missile Range, North Oscura Site, New Mexico (samples taken from penetration Test 120-127) (continued)	6	2.0	168.1	11600	11.36	0.32
	7	2.0	168.2	14500	11.76	0.31
	8	2.0	167.6	14500	12.75	0.33
	9	2.0		137GO		
	10	Surface	163.4	10300	2.0	

BIBLIOGRAPHY

1. Colp, J. L., An Earth Penetration Post-Test Soil Exploration Program, SC-RR-66-2617, Sandia Laboratories, Albuquerque, New Mexico, November 1966.

2. Deere, D. U., and Miller, R. P., Engineering Classification and Index Properties for Intact Rock, University of Illinois, Contract AF 29(601)-6319, AFWL-TR 65-116, Kirtland Air Force Base, New Mexico, December 1966.

3. Deere, D. U., "Technical Description of Rock Cores for Engineering Purposes," Rock Mechanics and Engineering Geology, Vol. 1, No. , pp. 17-22, 1964.

4. Deere, D. U., Hendron, A. J., Patton, F. D., and Cording, E. J., "Design of Surface and Near-Surface Construction in Rock," presented at the Eighth Symposium on Rock Mechanics at the University of Minnesota, 1966. Proceedings to be published by AIME.

5. Livingston, C. W., and Smith, F. L., Bomb Penetration Project, Colorado School of Mines Research Foundation, Inc., Golden, Colorado, June 1951.

APPENDIX

Test-Boring Records
and
Thtn-Sample Analyses

This appendix contains selected **data** reproduced directly from reports submitted to Sandia Laboratories by Woodwnrd-Clyde-Shcrard and Associates under Contracts **48-3575** and **48-5915.**

TEST BORING RECORD

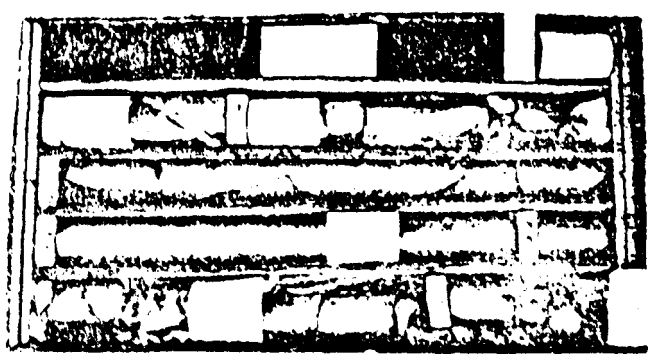
Job No. : S- 10500 Date : February 24, 1967

Name: Hard Rock Site - Sandstone Location : Grants, New Mexico

Hole: 120-103 Type of Boring: Core (nx) Rig: Failing 1500

Description	Depth ft.	Sa. No.	% Rec.	RQD
Sandy soil overburden (not tested)	1 2 3 4			
Sandstone, dense to very dense, fine-grained, fractured, 1" to 3" fragments, brown to light brown	5		55%	
	6 7	A	100%	32.2%
massive sandstone with minor jointing	8	B	100%	
	9 10			
increased joints	11		100%	
	12 13	C	100%	
	14	D		
bottom of core bndly fractured	15	E	60%	

Bottom of core



SAMPLE A - SANDSTONE THIN-SECTION

x 100

x 40

-QUARTZ. . . . . 60% of specimen; grains arc equant, subangular, and nearly in point-to-point contact.

CHALCEDONY. . 20% of specimen; well cemented in local zones but ----- discontinuous in others; possible calcite traces.

FELDSPAR.. . . 10% of specimen; elongated microcline and albite crystals showing soft, corroded out lines.

VOIDS.. . . . . 10% of specimen.

Note. . . . . Minor quartz grain cracking is evident. However, most cracks follow grain boundaries and occur in the chalcedony.

TEST BORING RECORD

Job No, : S-10500 Date : February 24, 1967

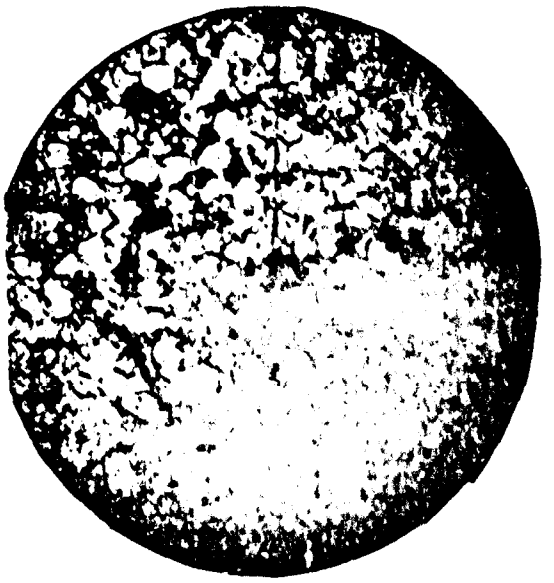
Name: Hard Rock Site • Sandstone Location : Grants, New Mexico

tiole : 120-112 Type of Boring: Core (nx) Rig: Failing 1500

Description	Depth ft.	Sa. No.	% Rec.	ROD
Soil overburden				
Sandstone, medium to fine-grained, sugary texture, light brown, moderately fractured	1			
	2	0	75%	
highly fractured ---	3		10%	
	4			
highly fractured	5		90%	
	6		80%	36.84'
	7			
shaly partings in sandstone ---	8		67%	
Sandstone, fine-grained, sugary texture, light brown, massive	9	P	100%	
	10			
	11	R	100%	
bottom of core	12	s		

SAMPLE S • SANDSTONE THIN-SECTION

x 100



x 40

QUARTZ..... 60-70% of specimen; grains are equant to elongate, angular to subangular.

FELDSPAR..... Albite and microcline comprise about 10% of specimen. Grains are tabular, with one good and one imperfect clevage surface evident. Grain boundaries have some corrosion.

CHALCEDONY..... About 15% of sample. Very few large, wholly cemented areas in the specimen.

VOIDS..... and unknown minerals, about 5%. Voids are filled with balsam. Very few voids are evident.

Note..... This section is a dense, closely packed quartzose sandstone with few voids and apparently a very competent cementing material. Little if any grain corrosion exists.

TEST BORING RECORD

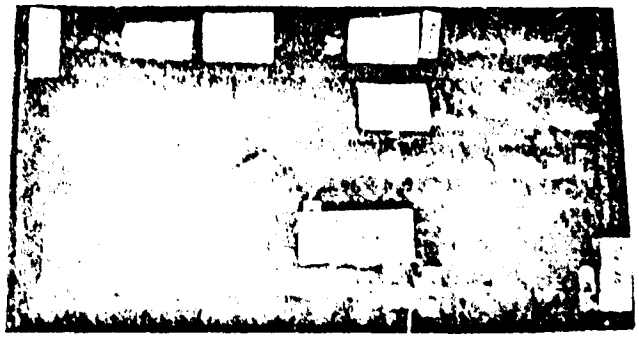
Job No. : S-10500 Date: February 2 3, 1967

Name: Hard Rock Site - Granite Location : Grants, New Mexico

Hole: 120-106 Type of Boring: Core (nx) Rig: Failing 1500

Description	Depth ft.	Sa. No,	% Rec.	RQD
Overburden, soil and cobbles	1			
Quartz feldspar granite, weathered, slight chemical alteration, badly fractured in zones	2		100%	
possible clay seam in rock/-	3		65%	
badly fractured	4, 5		30%	
weathered	6		95%	
	7		100%	
	8			
	9		70%	31.8%
fractures 1" to 3" apart	10	K	88%	
	11			
	12	L	95%	
	13	M		
	14	N	100%	

bottom of core



SAMPLE L - GRANITE THIN-SECTION

x 100

x 40

QUARTZ. . . . . 40% of thin-section; grains are small, equant

FELDSPARS . . . Albitc about 10% of spec imen ; a'bite twinning prominent.

Orthoclase, about 20% of specimen; twins are prominent.

ZIRCON. . . . . About 5%; individual c rystals embedded in the feldspars.

ALLANITE. . . 15% of specimen; vein filling and alteration product.

VOIDS. . . . . About 10% of specimen.

Note. . . . . The quartz grains are slight ly corroded on boundaries with evidence of f ine hair line cracks across large grains. Ihe feIdspars are severely corroded along c leavage sur fa c e and grain boundaries. Cryst al fractures appear offset, and rehealed.

N½, Sec 34, T4S, R47E
LAT. 37°33' LONG. 116°42'

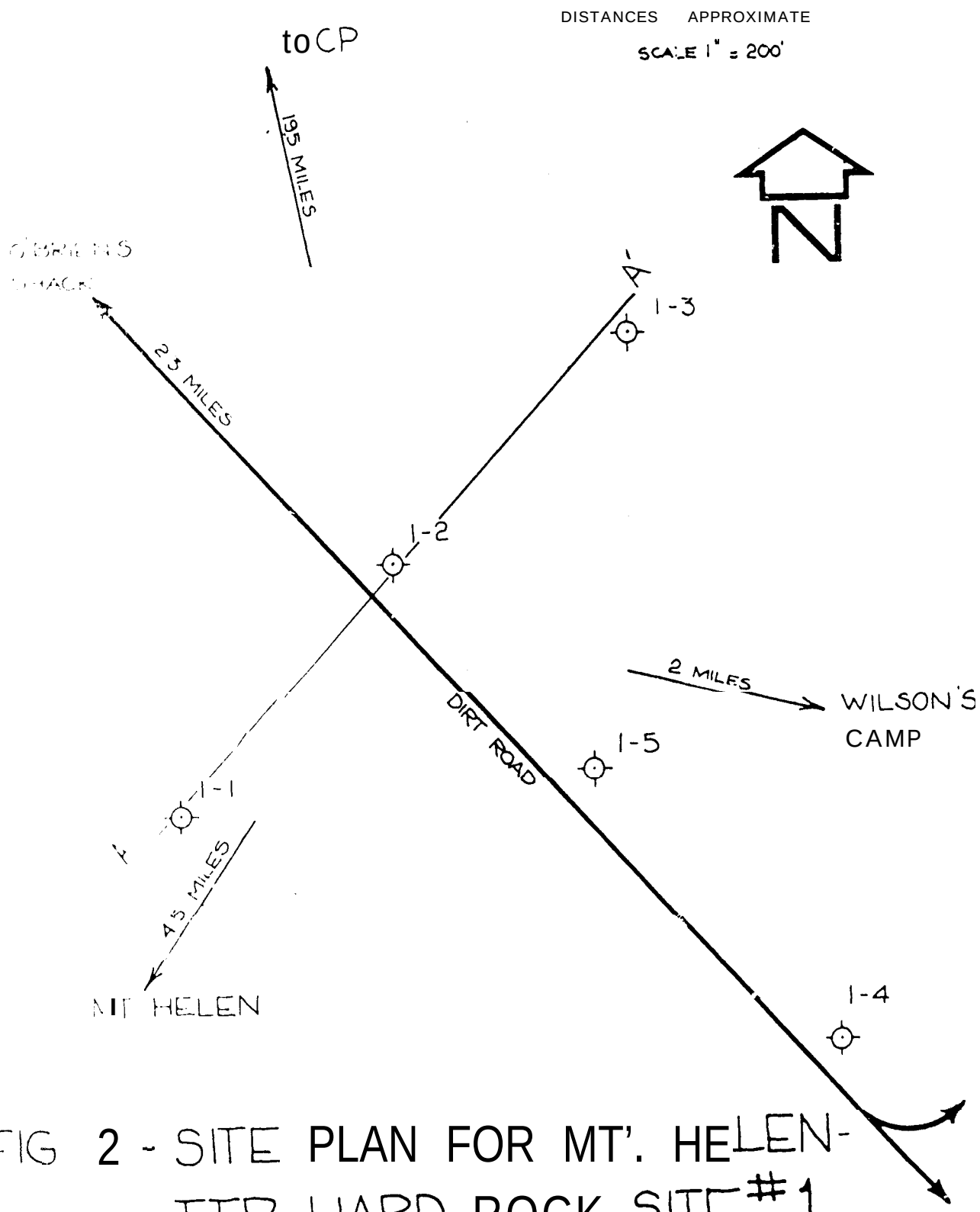


FIG 2 - SITE PLAN FOR MT. HELEN-TTR HARD ROCK SITE #1

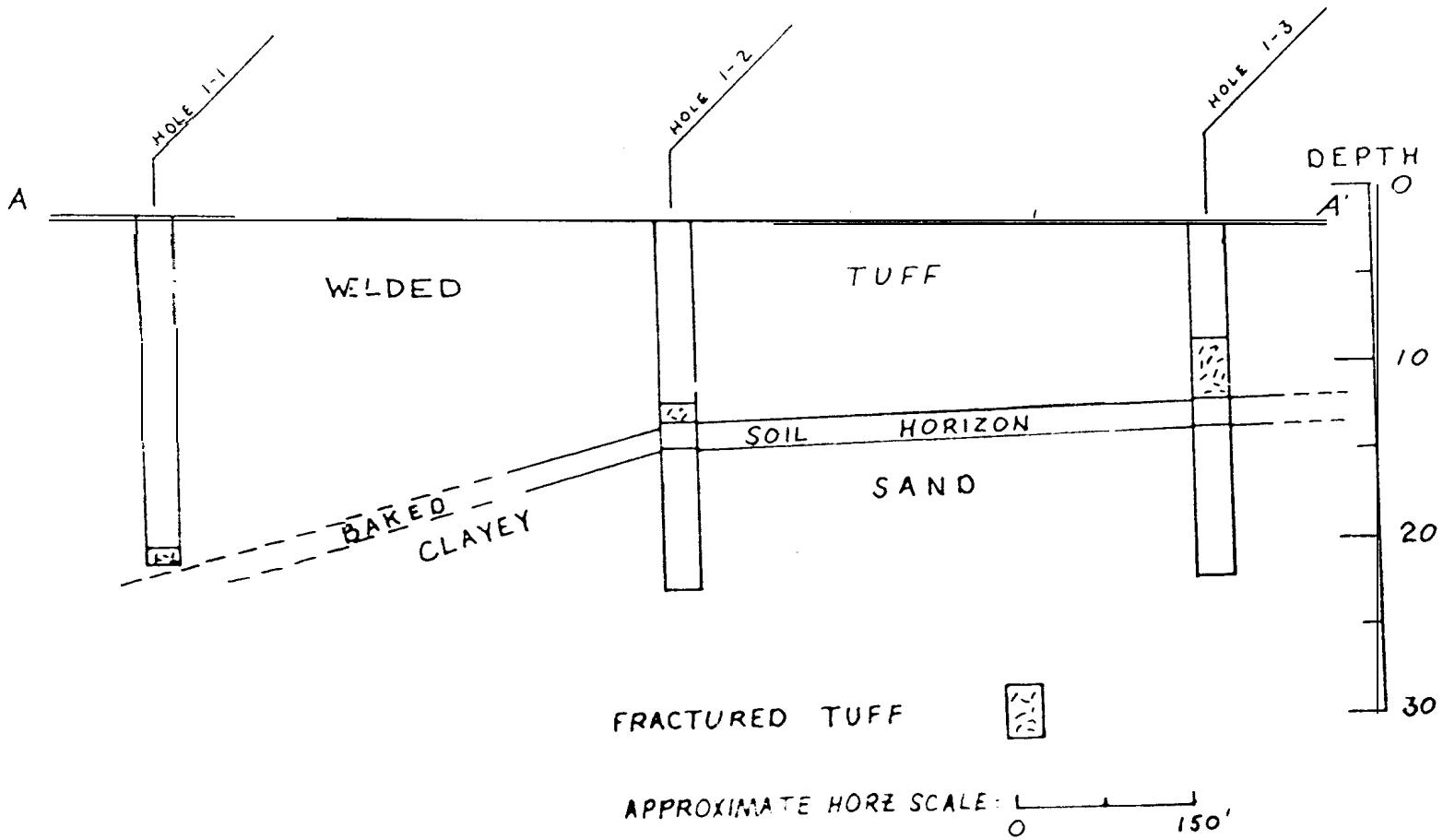


FIG. 3 - CROSS-SECTION, N45E, MT. HELEN - TTR ROCK SITE #1

TEST BORING RECORD

Job No. : S-11076

Name : Mt. Helen Site

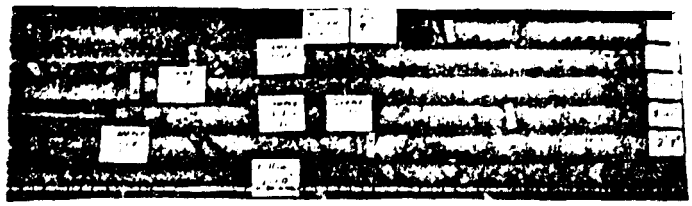
Location: N½, Sec 3 4 , T4S, R47E

Hole No. : 1-1

Rig: Remmil No. 4

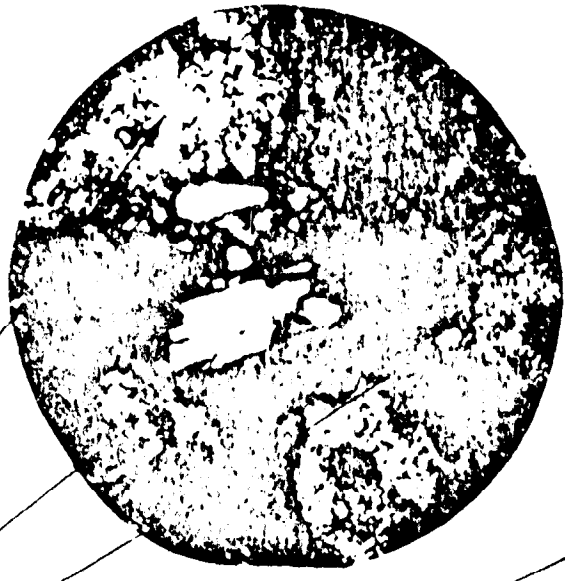
Type of boring: NX Core

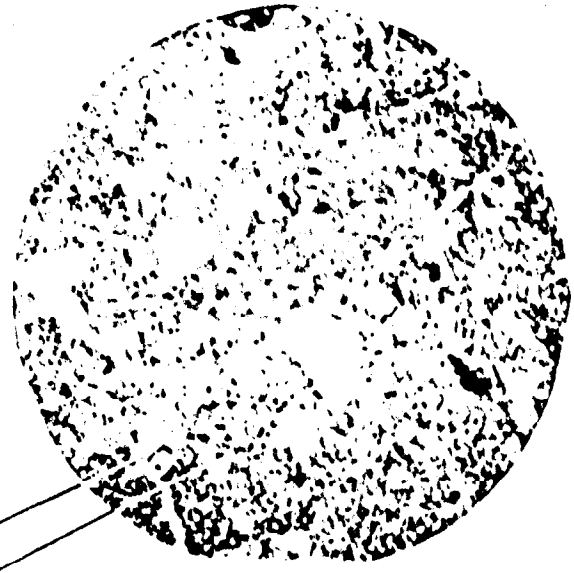
Date Drilled: 19 May 1967



Description	Depth ft.	Sa. No.	% Rec.	RQD	Remarks
Rhyolitic Tuff -- Phenocrysts of quartz and K-feldspar, glassy groundmass, pumice lapilli scattered throughout core, no fractures, hard, brittle, dry, pinkish gray.	1–5	T 1-1A	100%	90%	[indicates location of thin section.
	6–9	1-1B	100%		Static Test
	10–13	1-1C 1-1D T T	98%		Static Test Dynamic Test
	14–16				static Test
Highly fractured, weathered -	17–19	1-1E	90%		18' Easier drillin than material above.
Bottom of Hole	20–35				

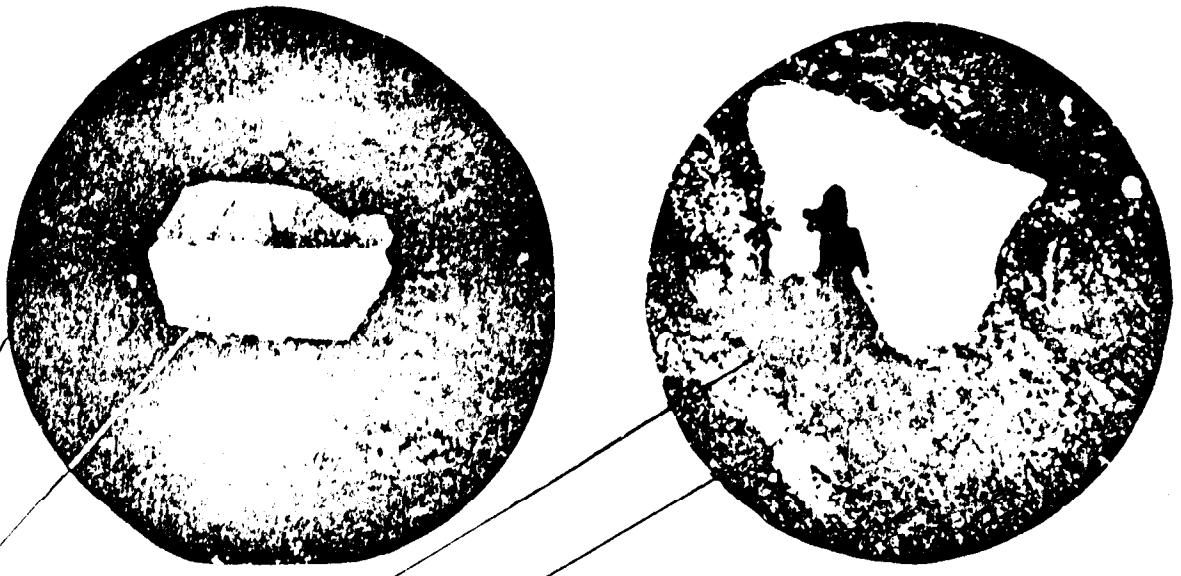
Fig. 8





Feldspar:	
Sanidine	15% of thin section; phenocrysts arc large and badly broken, margins are altered to cpidote.
Plagioclase:	5% of thin section; albite twinning common, grain margins highly altered to chlorite group minerals.
flcrnblendc :	2% of thin section; most grains arc al tered on margins.
Magnetite:	1% of thin section; crystals arc wcll-formed but small.
Quartz:	72% of thin-section; volcanic glass and phcnocrysts of granular quartz, angular phcnocrysts exhibit shat tcrcd corners, quartz present as cnvi ty f i lling, compressed pumice lapi 11 i common.
Voids:	5% of thin section; some cavit ies partially filled. Plucking constitutes a minor fraction of the voids.
Fractures :	Well defined fractures cut across phenocrysts and groundmass; there i s evidence o f fracture healing.

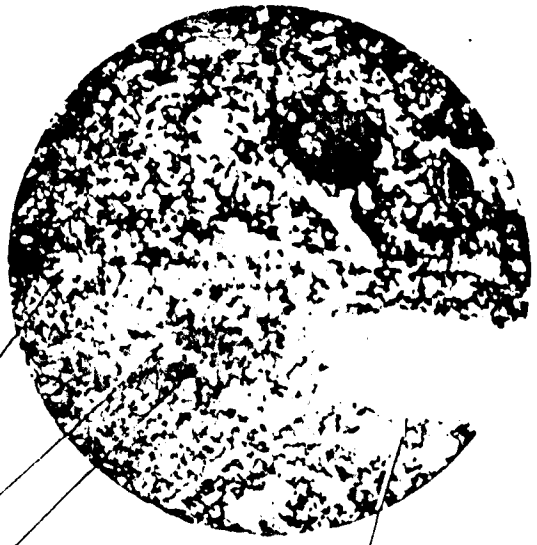
Fig. 11

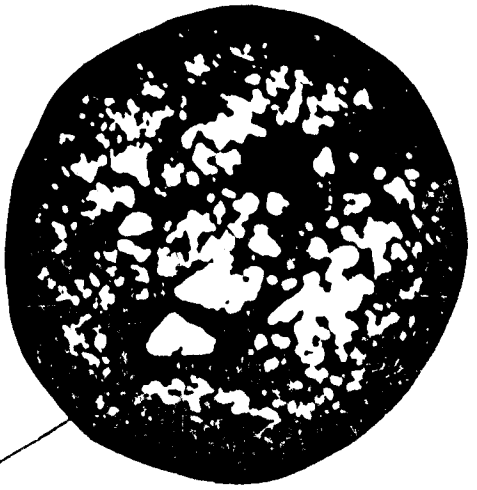


Feldspar:	
——Orthoclase:	5% of thin section; Carlsbad twinning common; phenocrysts up to 1/8-inch in length, grains severely fractured with some offset of boundaries.
Hornblende:	Trace, phenocrysts are altered, and there is little evidence of crystal structures.
Quartz:	78% of thin section; few large quartz phcnocrysts present.
Pumice LapiIli:	10% of thin section; lapilli composed of quartz, clasts arc highly compressed.
Voids:	7% of thin section; intergranular voids most common.
Fractures:	This section was removed from a tested and failed sample, but there were no more fractures than in the untested sample.

Fig. 12

Mt. Helen Site B1-1D





Feldspar:

Plagioclase: 5% of thin section; albitc twinning present, grains arc badly fractured.

Orthoclase: 2% of thin section; grains arc very small, type dcterminntion difficult.

Hornblende: Traces of altered hornblende scattered throughout section.

Biotite: Trace; both hornblende and biotite comprise about 1% of thin section.

Magnet i tc: 1% of rock; poorly defined crystals, opaque to light.

Quartz: 90% of thin section; about 20% of quartz is in the form of pumice lapilli.

Voids: 1% of thin section; most of the voids are in the form of partially filled cavities.

Fractures: Two dominant sets of fractures which arc mutually pcrpcndicular, no fracture healing cvidcnt.

Fig. 13

TEST BORING RECORD

Job No. : S-11076

Same : Mt. Helen Site

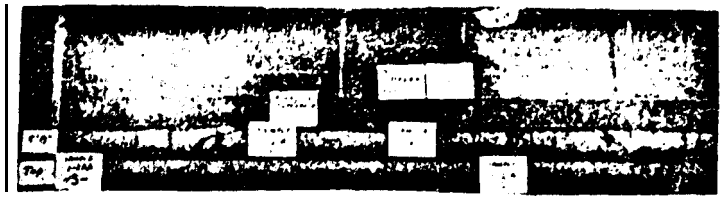
Location: N½, Sec. 34, T4S, R47E

Hole No. : 1-2

Rig: Remmil No. 4

Type of Boring: NX Core

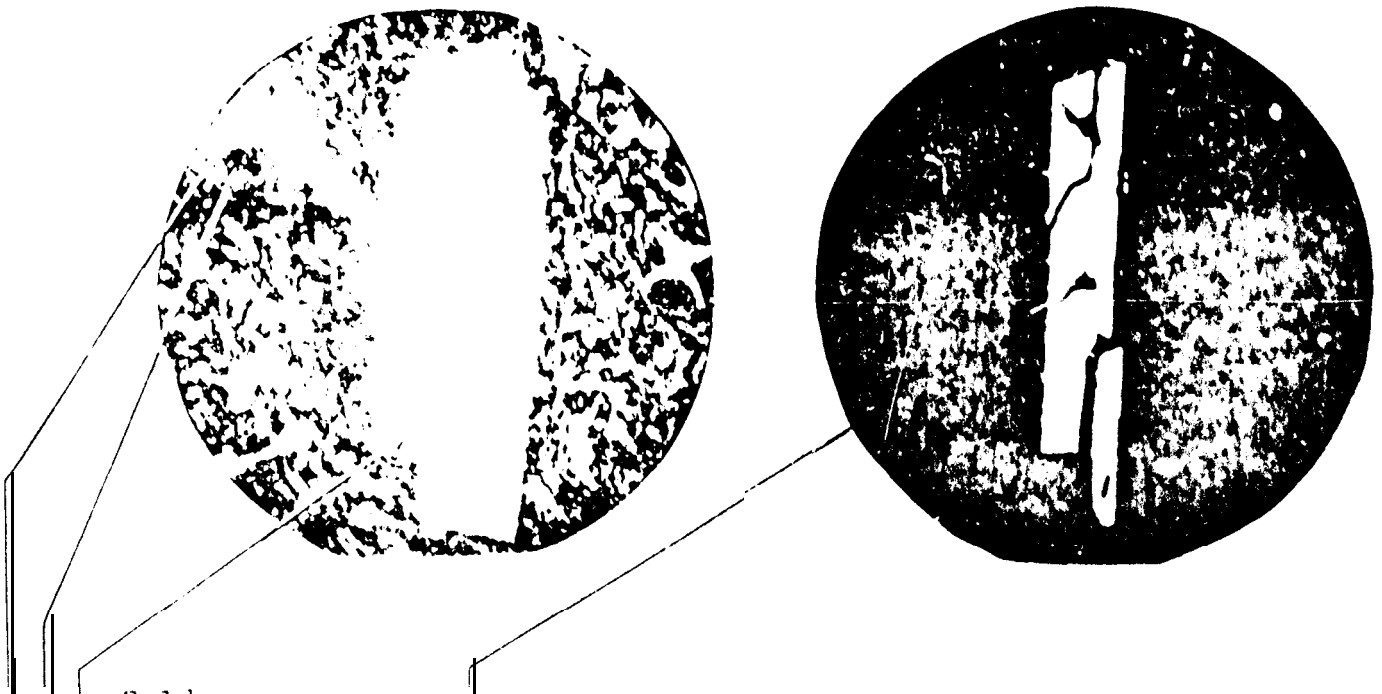
Date Drilled: 18 May 1967



Description	Depth ft.	Sa. No.	% Rec.	RQD	Remarks
Rhyolitic Tuff -- Phenocrysts of quartz and K-feldspar, glassy groundmass, pumice lapilli scattered throughout core, few fractures, hard, brittle, dry pinkish gray.	1	1-2AA	100%		Static *Test*
	4	W	100%		Static Test
	5	1-2A T		83%	Static Test
	8	1-2B			8'9": Drills easier than above.
Very hard, pink i sh brown	9	1-2C T	97%		
Highly fractured, weathered, red	11				Water loss
Baked soil, soft, moist, black.	13		100%		
Sand -- Highly decomposed tuff, angular, reddish brown.	14				T indicates thin section source
	18		0%		
Bottom of Hole	22				

Fig. 14

Mt. Helen Site **B1-2A**



Feldspar:

Orthoclase : 7% of thin section; badly fractured, highly altered, some form inclusions in quartz phenocrysts; intergrowths of crystals common.

Plagioclase : 3% of thin section; very small, highly altered grains.

Pyroxene: 1% of thin section; may be hornblende, fragments are too small for idcntificntion.

Quartz: 79% of thin section; varieties of quartz present are chalcedony, tridymitc, cristobnlitc, and granular quartz. Pumice lapilli constitute about 10% of section;. these arc compressed into elongate features.

Rock fragments: 5% of thin section; mineral content not identifiable, possibly basaltic.

Voids : 5% of thin section; formed by incomplete cavity filling; some plucking cvidcnt.

Fractures : No dominant fractures, but individual grains badly broken.

Fig. 16

Mt. Helen Site Bl-2C

Feldspar:	
Orthoclase:	5% of thin section; fractured phenocrysts, some boundary alteration evident, phenocrysts appear to be loose in the pumiceous matrix.
Plagioclase:	2% of thin section; phenocrysts are altered.
Hornblende & Biotite	3% of thin section; material is highly altered. Some magnetite is present.
Quartz:	87% of thin section; crystal quartz present, granular quartz present as cavity growths.
Voids:	3% of thin section; some plucking of grains is evident.
Fractures:	All phenocrysts are highly fractured, compaction zones are present around grains.

Fig. 17

TEST BORING RECORD

Job No. : S-11076

Name : Mt. Helen Site

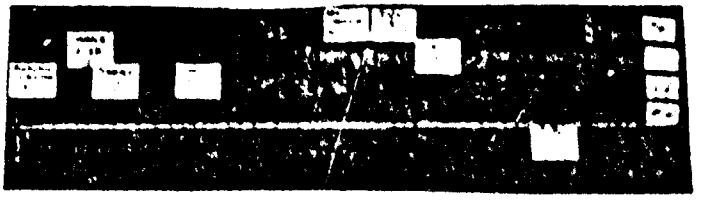
Location: N½, Sec. 34, T4S, R47E

Hole No.: 1-3

Rig: Remmil No. 4

Type of Boring: NX Core

Date Drilled: 19 May 1967



Description	Depth ft.	Sa. No.	% Rec.	RQD	Remarks
Rhyolitic Tuff -- Phcnocrysts of quartz and K-feldspar, glassy groundmass, pumice lnpilli scattered throughout core, hard, brittle, dry, pinkish gray.	1–3		100%		Static Test
	3–5			73%	Static Test
Highly fractured, weathered, reddish.	5–10		88%		Static Test
Baked Soil -- soft to medium hard, ~~dark grayish brown.~~	10–12				Water loss
Sand -- Dense, coarse to medium grained, angular, highly weathered tuff, moist, gray brown to red.	12–15		93%		
	15–20		3%		
Bottom of Hole	20–35				

Fig. 18

TEST BORING RECORD

Job So. : S-11076

Same: Mt. Helen Site

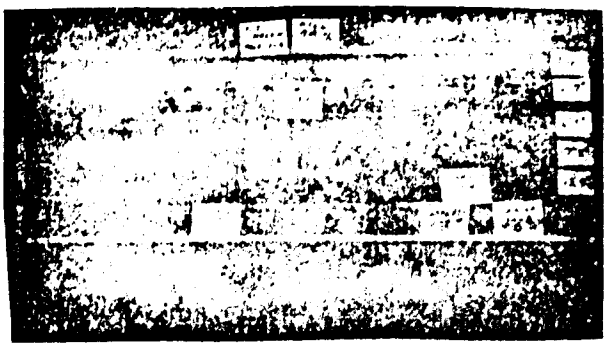
Location: N½, Sec. 34, T4S, R47E

Hole No. : 1-4

Rig: Remmil No. 4

Type of Boring: NX Core

Date Drilled : 20 May 1967



Description	Depth ft.	Sa. No.	% Rec.	RQD	Remarks
hyolitic Tuff - - Phenocrysts of quartz and K-feldspar, glassy groundmass, purr-' e lapilli scattered throughout core, no fractures, very hard, brittle, dry, pinkish gray.	1–5	1-4A	98%		T indicates thin section location. Static Test
	6–10	T	100%	98%	Static Test
	11–13	1-4C	99%		
	14–15	1-4D			Static Test
f Hole	16–22	1-4E	97%		Dynamic Test
	23	1-4F			Static Test
Bottom of Hole	24–33				

Fig. 20

Mt. Helen Site Al-4B

Feldspar:

Orthoclase: 2% of thin section; few phcnocrysts, small imperfect crystals, badly fractured.

Plagioclase: 10% of thin section; phenocrysts occur as clots in rock, highly nltcrcd and unusually intermixed with other minerals.

Hornblende & Biotite: 8% of thin section; phcnocrysts are mixed with plagioclase crystals. Magnetite is uniformly distributed throughout sample.

Quartz: 78% of thin section; few large phcnocrysts, pumice lapilli constitutes about 30% of volume, pumice fragments are highly compressed.

Rock Fragments: Small fragments of fine grained rock arc scattered uniformly throughout sample.

Voids: 2% of thin section; plucking is negligible.

Fractures: One principal fracture direction.

Fig. 23

TEST BORING RECORD

Job No.: S- 11076

Same : Mt. Helen Site

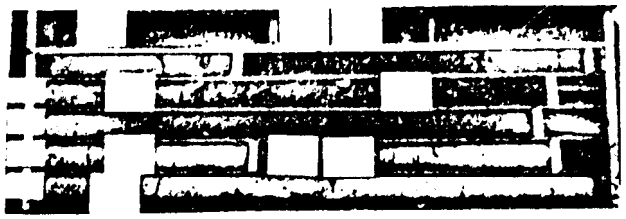
Location: N½, Sec. 34, T4S, R47E

Hole No. : 1-5

Rig : Remmil No. 4

Type of Boring: NX Core

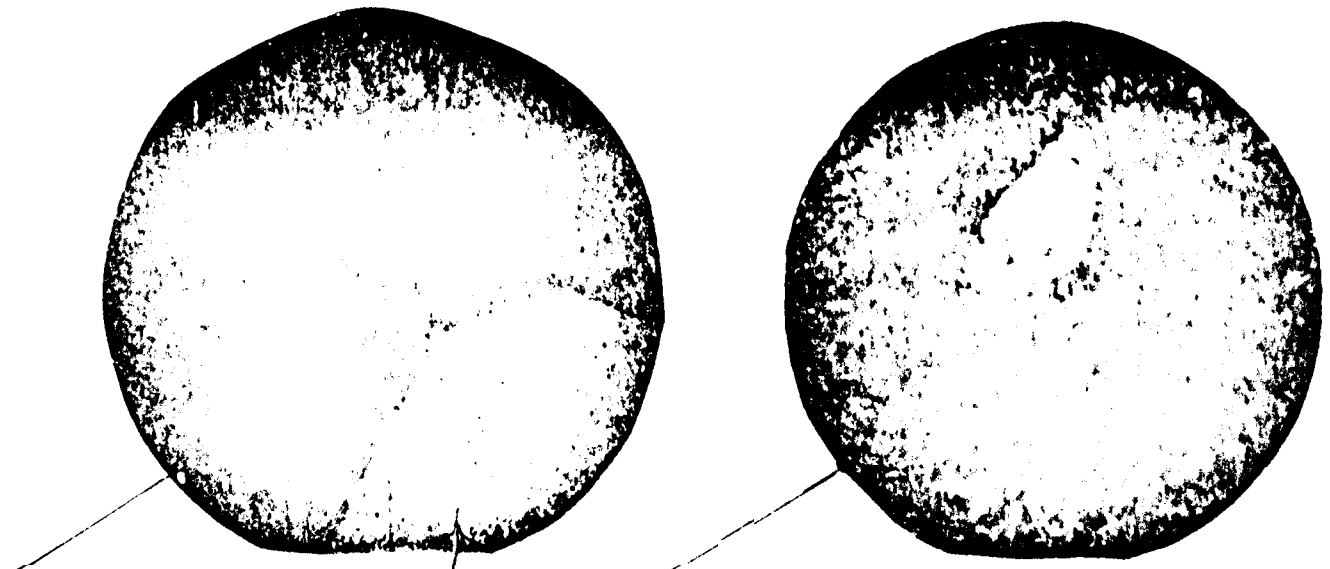
Date Drilled: 19 May 1967



Description	Depth ft.	Sa. No.	% Rec	RQD	Remarks
Rhyolitic Tuff -- Phenocrysts of quartz and K-feldspar, glassy groundmass, pumice lapilli scattered throughout core, few fractures, hard, dry, pinkish gray.	1–7	1-1A, T, 1-5B, 1-5C, 1-5D	99%	96%	T indicates thin section location. Static Test Static Test Dynamic Test
	8–9		100%		
Highly fractured	10–12	T, 1-5E			Static Test
	13–14		93%		Water loss
Baked Soil -- soft, friable, dry, dark Gray.	15–16				
Sand -- medium dense, coarse grained, angular, weakly cemented, moist, gray brown.	17–19		50%		
Sand, Clayey -- dense, some gravel, moist, red.	20–21				
Bottom of Hole	22				

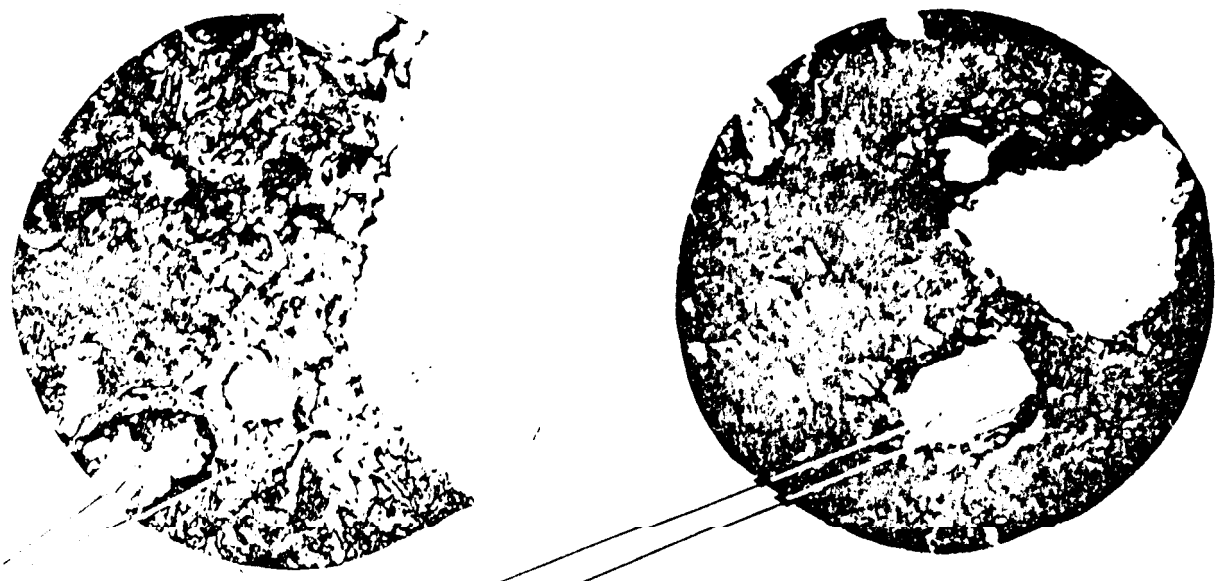
Fig. 24

Mt. Helen Site Al-SB



Feldspar:	
Orthoclnsc:	5% of thin section; phcnocrysts arc badly fractured, no evidence of alteration of grains.
Plagioclase:	10% of thin section; large phcnocrysts arc badly fractured and altered.
Quartz:	83% of thin section; 5% arc large phcnocrysts and the rest is granular quartz, chalcedony, cristobnl ite, nnd tridymite. 20% of thin sec t ion composed of pumice lapilli.
Rock Fragments :	Trace, numerous s m a l l fragments visible.
Voids:	2% of thin section; voids arc uni formly distributed throughout sample.
Fracture!;	Several fracture planes arc' present. Phcnocryst fractures arc common.

Fig. 27



Feldspar:

Orthoclase: 5% of thin section; broad range of phcnocryst sizes, badly fractured.

Plagioclase: 3% of thin section; badly fractured and altered, some voids contain residues of completely altered plagioclase phenocrysts.

Hornblende & Biotite: 7% of thin section; large phenocrysts, highly altered.

Quartz: 65% of thin section; some large phenocrysts, sample predominantly granular quartz. 40% of sample is undeformed pumice lapilli.

Rock Fragments: Trace; small and fine-grained fragments.

Voids: 20% of thin section; very little plucking, some pumice ground out of thin section.

Fractures: Large phenocrysts are highly fractured, compression zones present in matrix around phenocrysts. Thin section indicates that rock mass was very gaseous when deposited.

Fig. 28

S½, Sec 26, T3S, R48E,
LAT. 37°39' - LONG. 116°34'

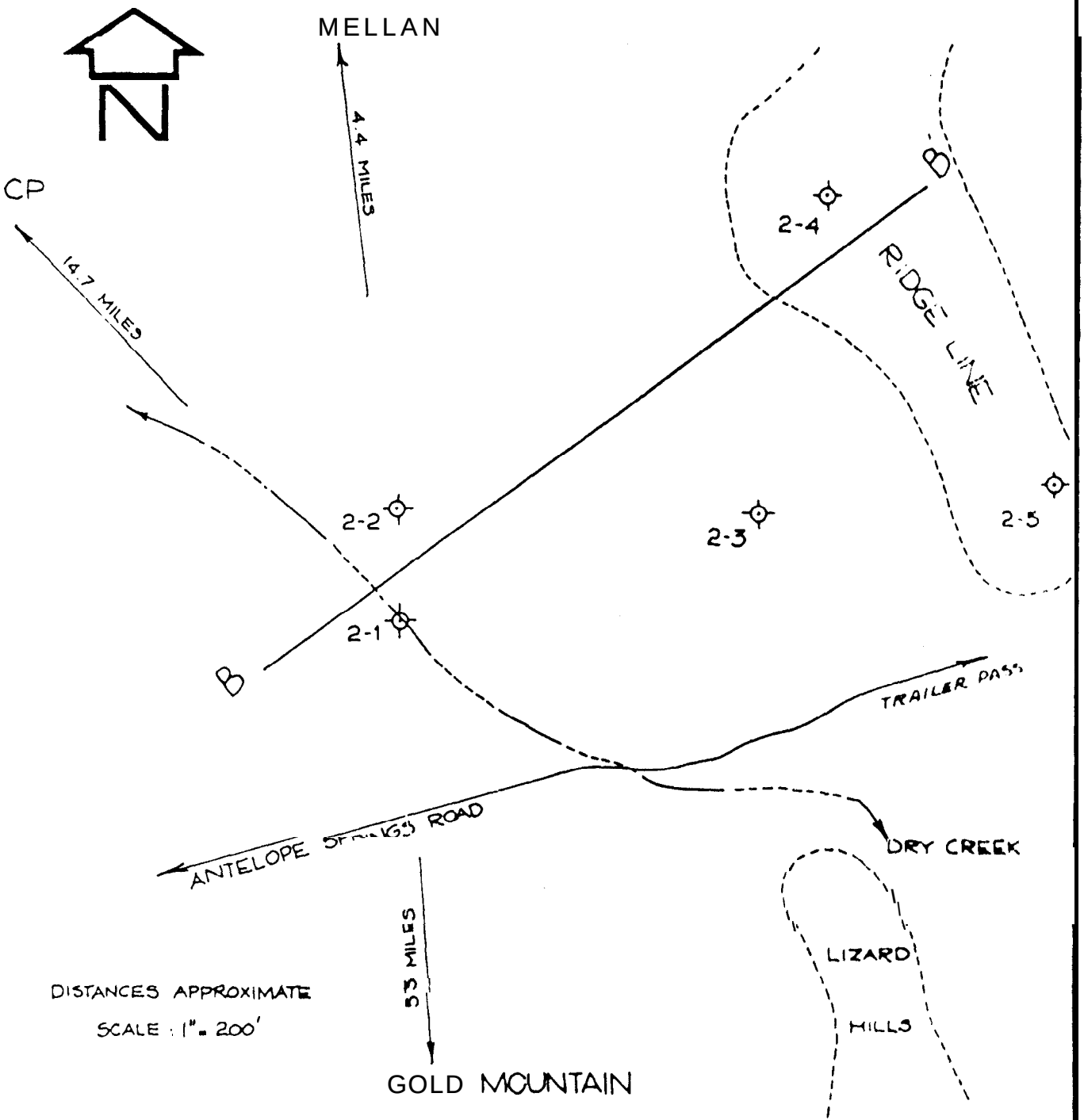


FIG. 30 - SITE PLAN FOR ANTELOPE - TTR HARD ROCK SITE #2

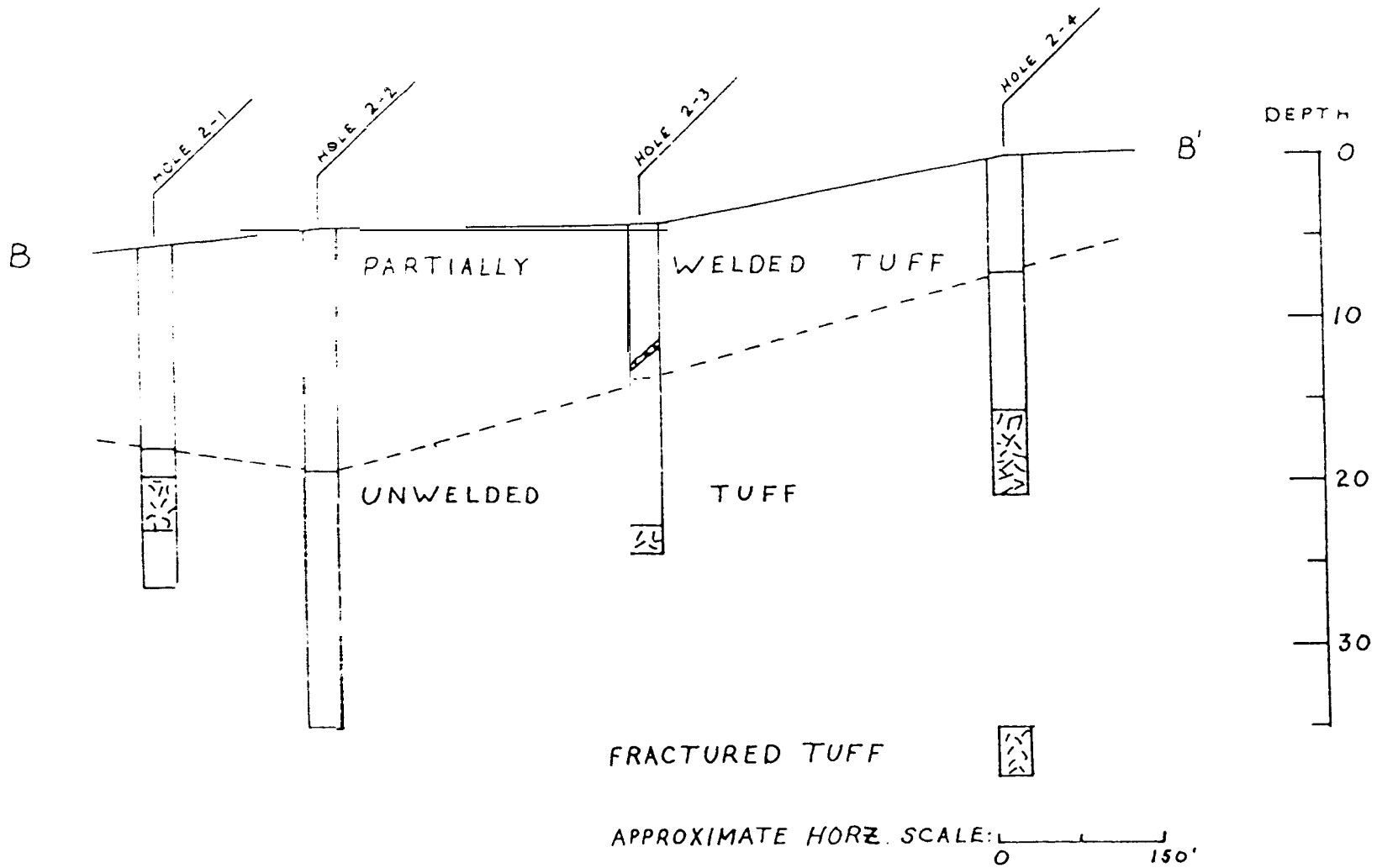


FIG 31 - CROSS SECTION, N45E, ANTELOPE-TTR ROCK SITE #2

TEST BORING RECORD

Job No. : S-11076

Name: Antelope Site

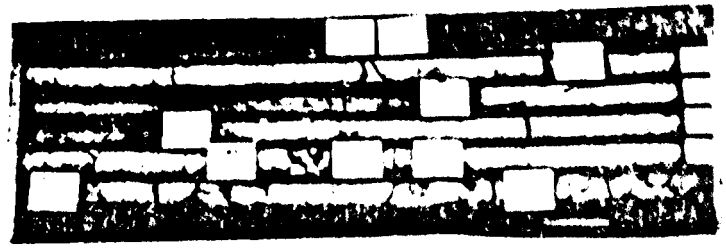
Location: S½, Sec. 26, T3S, R48E

Hole No. : 2-1

Rig: Remmil No. 4

Type of Boring: NX Core

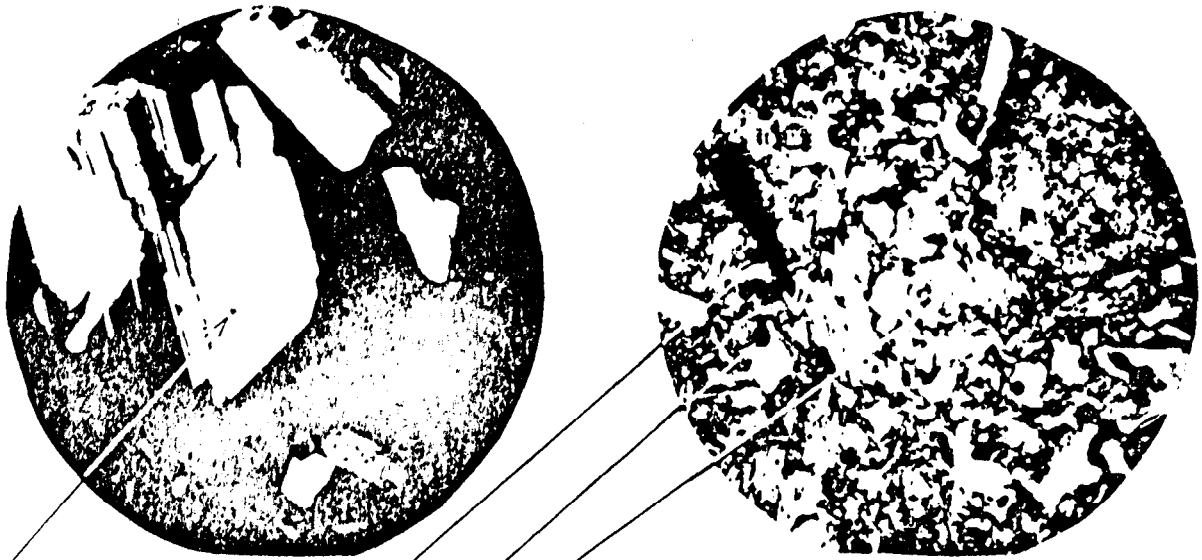
Date Drilled: 16 May 196 7



Description	Depth ft.	Sa. No.	% Rec	RQD	Remarks
Tuff -- Poorly welded, phenocrysts of plagioclase, glassy groundmass, numerous pumice lapilli, brittle, gray.	1–7	2-11	97%		Static Test
	6–7	2-12	90%		Static Test
	8–11	2-13	100%	05%	Static Test
Zone of soft black pumice	12–13	T			Water loss
Unwelded to slightly welded, increased pumice inclusion.+.	13–16	2-15 2-14 2-16	93%		Dynamic Test Static Test
	16–17	2-17			
	17–21		94%		T indicates thin section location
Bottom of Hole	22–35				

Fig. 34

ANTELOPE SITE A2-1C



Feldspar:	
Plagioclase:	10% of thin section; only identifiable feldspar present.
Hornblende:	Trace ; phenocrysts are badly broken into needle-like fragments, grain distribution indicates flowage after crystallization.
Biotite:	Trace ; total amount of biotite and hornblende amounts to about 5% of thin section.
Quartz:	75% of thin section; includes volcanic glass shards and pumice fragments, phenocrysts of quartz comprise about 20% of thin section.
Opaque Minerals	Trace ; magnetite or chloritized hornblende and biotite.
Voids:	15% of thin section area; about 4% of voids are the result of plucking of phenocrysts.
Fractures:	No dominant fracture planes present; phenocrysts are badly shattered, the groundmass around phenocrysts is compressed.

Fig. 37

TEST BORING RECORD

Job No.: S-11076

Name: Antelope Site

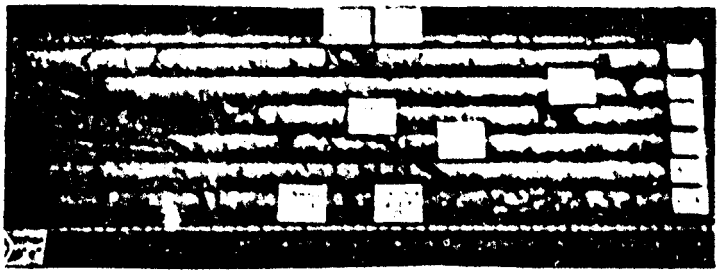
Location: S½, Sec. 26, T3S, R48E

Hole No.: 2-2

Rig : Remmil No. 4

Type of Boring: NX Core

Date Drilled: 17 May 1967



Description	Depth ft.	Sa. No.	% Rec.	RQD	Remarks
Tuff -- Poorly welded, few small phenocrysts of plagioclase feldspar, glassy groundmass, many pumice lapilli, brittle, gray.	1–6		94%		T indicates thin section location. 21.5 Hoots in core.
	6–7	2-A			Static Test
	7–12		100%		
	12–13	2-B			
	13–15		97%		
	15	2-C			Static Test
Tuff -- Unwelded, more pumice lapilli present.	16–20		100%	789	Water loss in drilling.
	20–23				
	23	2-D	100%		Dynamic Test
	24	2-E			Static Test
	25–30		100%		
Bottom of Hole	31				

Fig. 38

ANTELOPE SITE B2-2A

Feldspar:

Plagioclase: 25% of thin section; phenocrysts are badly shattered, albite twinning is prominent.

Hornblende: 3% of thin section; phenocrysts are altered on boundaries and badly broken, some grains are 5mm in length.

Biotite: 2% of thin section; hexagonal plates, incompletely formed, are scattered randomly throughout thin section.

Quartz: 55% of thin section; 15% of section is composed of phenocrysts, volcanic glass and pumice lapilli comprise the remaining percentage.

Opaque Minerals: 5% of thin section; magnetite and sphene appear to be present.

Voids: 10% of thin section area.

Fractures: No major fractures in the groundmass, minor phenocryst fracturing is evident.

Fig. 41

ANTELOPE SITE A2-2D

Feldspar:	
Plagioclase:	15% of thin section; phenocrysts are fractured and appear to have flowed. Intergrowths of feldspar with quartz grains are visible.
Hornblende:	3% of thin section; alteration of grain boundaries is common, grains are badly shattered.
Biotite	2% of thin section; hexagonal flakes are extensively chloritized.
Quartz:	65% of thin section; 10% of phenocrysts are quartz crystal fragments, phenocrysts are fractured, pumice fragments exhibit flow structure.
Voids:	15% of thin section area; voids visible in pumice lapilli, some phenocryst plucking is apparent.
Fractures	No fractures are visible in the ground mass; phenocrysts are extensively shattered and compaction rings around the phenocrysts are present in the groundmass.

Fig. 42

TEST BORING RECORD

Job So. S-11076

Name: Antelope Site

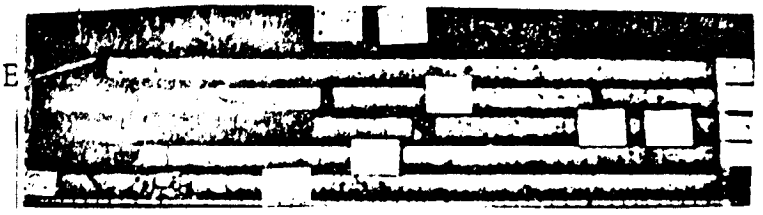
Location: S½, Sec. 26, T3S, R48E

Hole No.: 2-3

Rig: Remmil No. 4

Type of Boring: NX Core

Date Drilled: 17 May 1967



Description	Depth ft.	Sa. No.	% Rec.	RQD	Remarks
Tuff -- Poorly welded, few small plagioclase crystals, glassy groundmass, many pumice iapilli and rock fragments, brittle, gray.	1–6		100%		T indicates thin section location.
	6–7		100%		Static Test
	7–8	2-3A T			
Fractured zone 6" thick	9–10	2-3B 2-3C	95%	87%	Static Test Dynamic Test
	10–14		94%		Static Test
	14–15	2-3D T			
	15–19		92%		
Bottom 1½' fractured	19–20	2-3E			
Bottom of Hole	20–35				

Fig. 43

ANTELOPE SITE B2-3A

Feldspar:

Plagioclase: 17% of thin section; phenocrysts are badly shattered and altered on grain boundaries.

Hornblende: 5% of thin section; phenocrysts are altered, grain size is highly variable.

Biotite: 3% of thin section; flakes are poorly developed or extensively altered.

Quartz: 65% of thin section; feldspar intergrowt in quartz phenocrysts common.

Voids: 10% of thin section area; predominantly pumice voids.

Fractures: The groundmass exhibits no fracture pattern; phenocrysts are badly fractured

Fig. 46

Feldspar:	
Plagioclase:	10% of thin section; phenocrysts are small and exhibit numerous inter-growths of crystals, alteration of grain boundaries is extensive, albi te twinning common.
Hornblende:	8% of thin section; grain sizes highly variable.
Biotite:	2% of thin section; small fragments are randomly scattered throughout thin section.
Quartz:	70% of thin section; quartz phenocrysts contain inclusions of hornblende and plagioclase.
Rock Fragments	1% of thin section; mineral composition of fine-grained fragments not identified.
Voids:	9% of thin section area; pumice lapilli contain most of voids.
Fractures:	No fractures are evident through the groundmass ; phenocrysts are highly fractured.

Fig. 47

TEST BORING RECORD

Job No. : S-11076

Name: Antelope Site

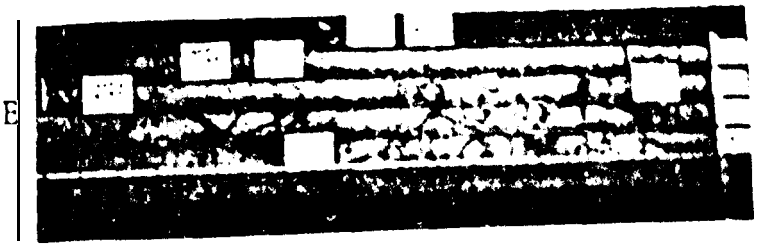
Location: S½, Sec. 26, T3S, R48E

Hole No. : 2-4

Rig : Rcmmil No. 4

Type of Boring: NX Core

Date Drilled: 18 May 1967



Description	Depth ft.	Sa. No.	% Rec.	RQD	Remarks
Tuff -- Poorly welded to unwelded, lax-gc pumicc lapilli present, vc ry few plagioclase crystals, glassy groundmass, brittle, gray with whi tc pumicc, fragments.	1–5	T	99%		T indicates thin section location. Static Test Static Test Static Test
Grea t increase in pumice	6–9		89%	40%	Water loss in drilling.
	10–15		92%		
Very soft and fractured	16–20		27%		
Bottom of Hole	21–35				

Fig. 49

ANTELOPE SITE AZ-4A

Feldspar:	
Plagioclase:	20% of thin section; large, badly shattered phenocrysts are abundant, albite twinning common.
Hornblende:	5% of thin section; altered crystal. fragments are randomly scattered throughout thin section.
Biotite:	Trace; up to 1% of thin section, rock appears to have a 'salt and pepper' texture because of biotite and hornblende content.
Quartz	60% of thin section; 5% of section is composed of quartz phenocrysts, pumice lapilli forms remaining 60% of section.
Voids:	15% of thin section area; porous pumice fragments contain most of the voids.
Fractures:	So fractures are visible in the groundmass; phenocrysts are extensively shattered.

Fig. SO

TEST BORING RECORD

Job No.: S-11076

Name: Antelope Site

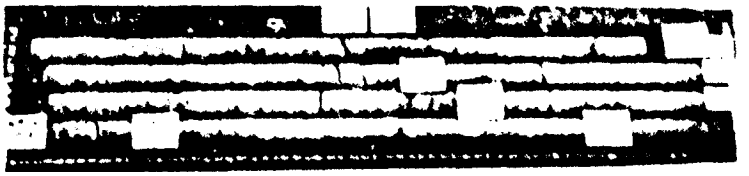
Location: S½, Sec. 26, T3S, R48E

Hole No.: 2-5

Rig: Remmil No. 4

Type of Boring: NX Core

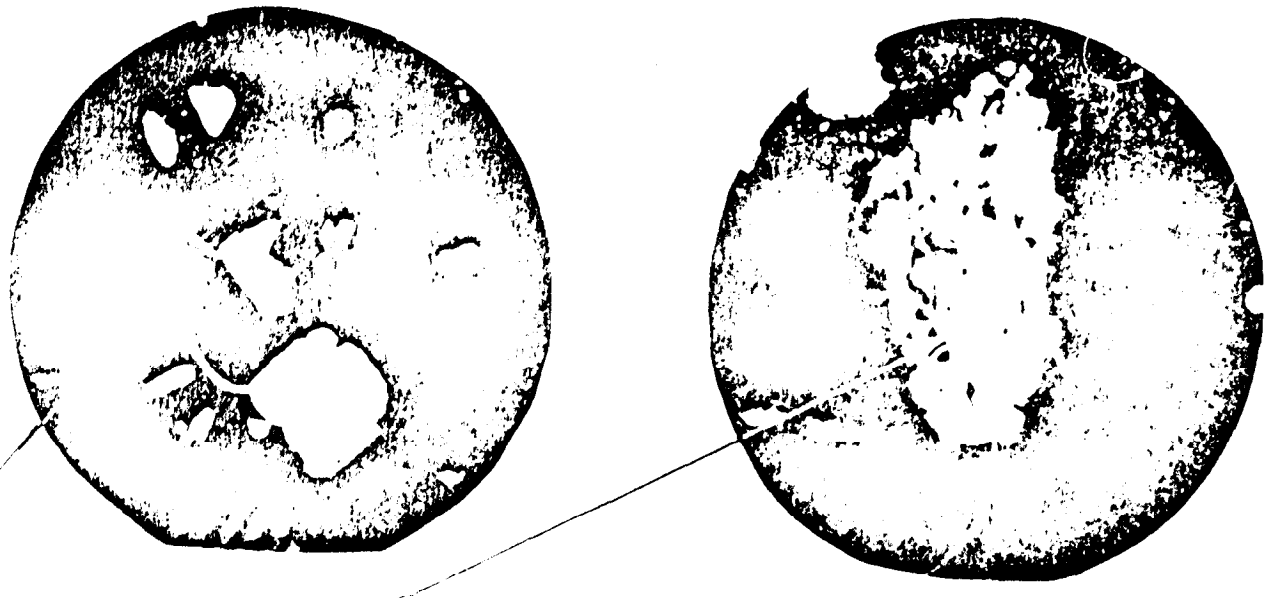
Date Drilled: 18 May 1967



Description	Depth ft.	Sa. No.	% Rec.	RQD	Remarks
Tuff -- Poorly welded to unwelded, large rock fragments present, some small plagioclase crystals, glassy groundmass, brittle, gray with black rock fragments.	1–6		100%		Static test T indicates thin section location.
	7–8	T A-10	100%		Static test
	9–12			97%	Water loss in drilling.
	13–15	A-11	99%		Static test
	16–17	A-12			Static test
	18–20	A-14	100%		
Bottom of Hole	21–35				

Fig. 11

ANTELOPE SITE A2-5B



Feldspar:

Plagioclase: 30% of thin section; albite twinning is common, phenocrysts are highly altered.

Hornblende: 7% of thin section; hornblende intergrowths in feldspar are common.

Biotite: 3% of thin section; flakes are large and well-developed, alteration of grain margins is extensive.

Quartz: 53% of thin section; the few small phenocrysts are scattered throughout the thin section.

Voids: 7% of tnin section area; the size of the void varies greatly.

Fractures: The groundmass does not exhibit any fracture pattern.

Fig. 53

TEST BORING RECORD

Job No. :

Name: Cactus Peak Site

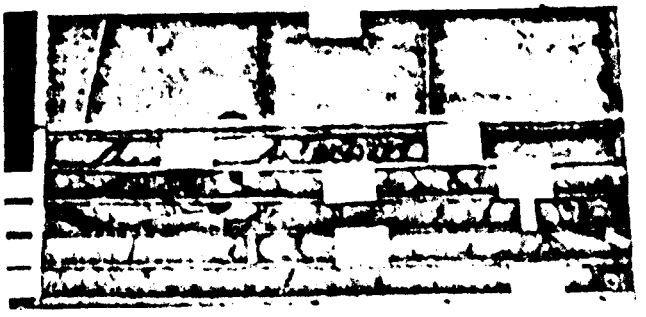
Location: S½, sec. 9 , T2S, R46E

Hole No.: 3-1

Rig : Remmil No. 4

Type of Boring: NX Core

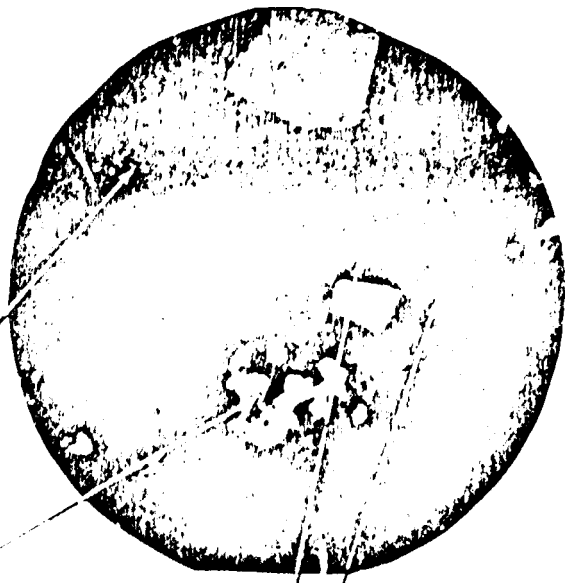
Date Drilled: 20 May 1967



Description	Depth ft.	Sa. No.	% Rec.	RQD	Remarks
Rhyolite ----- Highly welded mass of plagioclase crystals and rock fragments (agglomerate), glassy groundmass, fracture s break core at about 45° to core axis, hard, brittle, dry, pinkish gray.	1–10	T	98%	60%	T indicates thin section location.
	6				Stati c Test
	7–10		98%		
Highly Weathered Zone	11–12		83%		
	13				Stat ic Test
	14				Dynami c Tes t
	15–16		83%		Static Test
Badly fractured	17				
Bottom of Hole	18–35				

Fig. 57

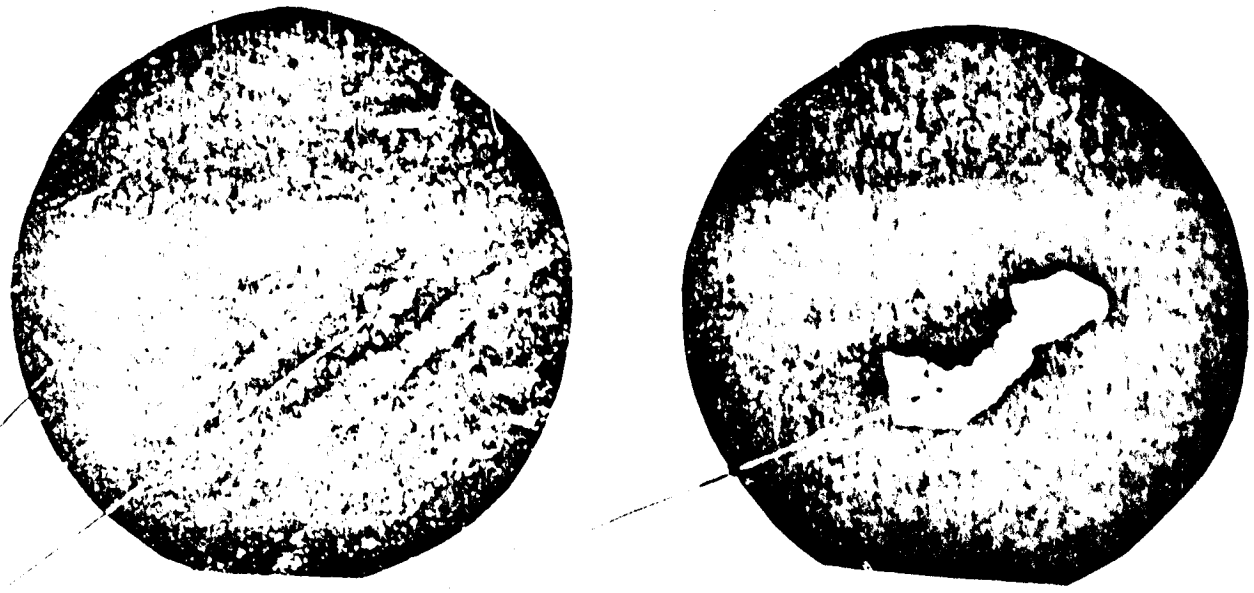
5



Feldspar:	
Orthoclase:	10% of thin section; highly altered; gas pockets, which appear to contain crystal growths (possibly zeolites), are present within some phenocrysts.
Plagioclase:	5% of thin section; albite twinning needed to distinguish piagioclase from orthoclase.
Hornblende:	3% of thin section; alteration halos present on almost all grains.
Biotite:	2% of thin section; biotite is uniformly scattered throughout sample.
Quartz:	60% of thin section, 15% of section composed of pumice lapilli, phenocrysts are large and badly shattered.
Rock Fragments:	3% of thin section; very fine grained.
Opaque Minerals:	2% of thin section; possibly magnetite.
Voids:	15% of thin section area; some plucking is evident,
Fractures:	Three distinct sets of fractures are seen in the thin section; the groundmass exhibits estensive crushing.

Fig. 60

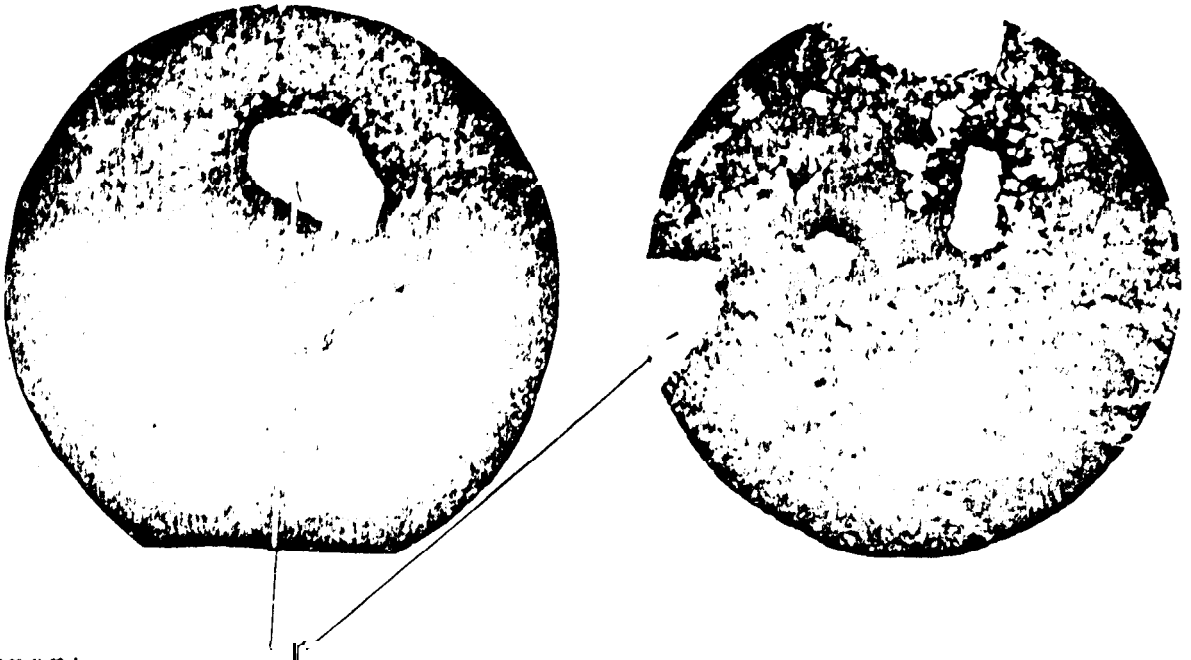
TONOPAH DACITE – SAMPLE A



Feldspar:	
Orthoclase:	10% of thin section; Carlsbad twinning is common, phenocrysts slightly altered on margins.
Plagioclase:	2% of thin section; albite twinning is main indicator of mineral, more altered than orthoclase.
Chlorite Group:	3% of thin section.
Quartz	80% of thin section; much of the volcanic glass has devitrified, some silica veinlets are visible cutting through the feldspar crystals.
Opaque Minerals:	5% of thin section; possibly magnetite.
Voids:	2% of thin section area; thin section and hand specimen exhibit a high degree of welding.
Fractures	Most of large crystals are shattered; no cracking can be seen in the groundmass.

Fig. 63

TONOPAH DACITE – SAMPLE B



Feldspar:	
Orthoclase:	10% of thin section; Carlsbad twins are abundant, phenocrysts are badly fractured.
Plagioclase:	7% of thin section; albite twinning can be seen in most plagioclase phenocrysts, grains arc highly altered on margins.
Hornblende:	1% of thin section.
Chlori tc group:	5% of thin section; alteration halos around some of the feldspar and hornblende phenocrysts.
Quartz:	75% of thin section; the quartz mass appears extremely well welded; the pumice lapilli are compressed and recrystallized.
Opaque Mineral:	2% of thin section; well developed crystals of magnetite.
Voids:	1% of thin section area; rock has been welded to an extreme compact mass.
Fractures:	Very few fractures are seen in the groundmass.

Fig. 64

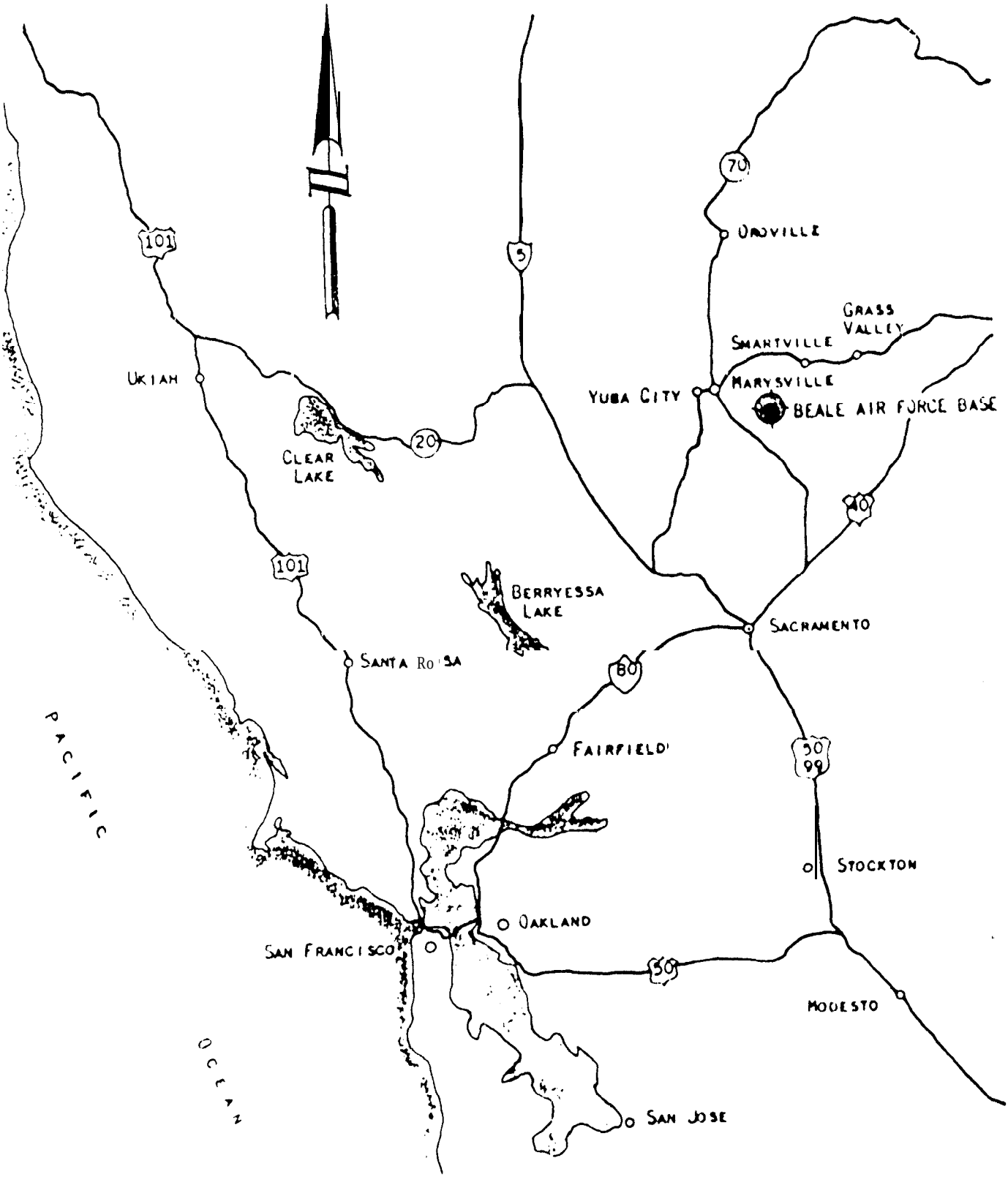


FIG. 1 - VICINITY MAP

BEALE AIR FORCE BASE, CALIFORNIA

10 5 0 10 20

SCALE IN MILES

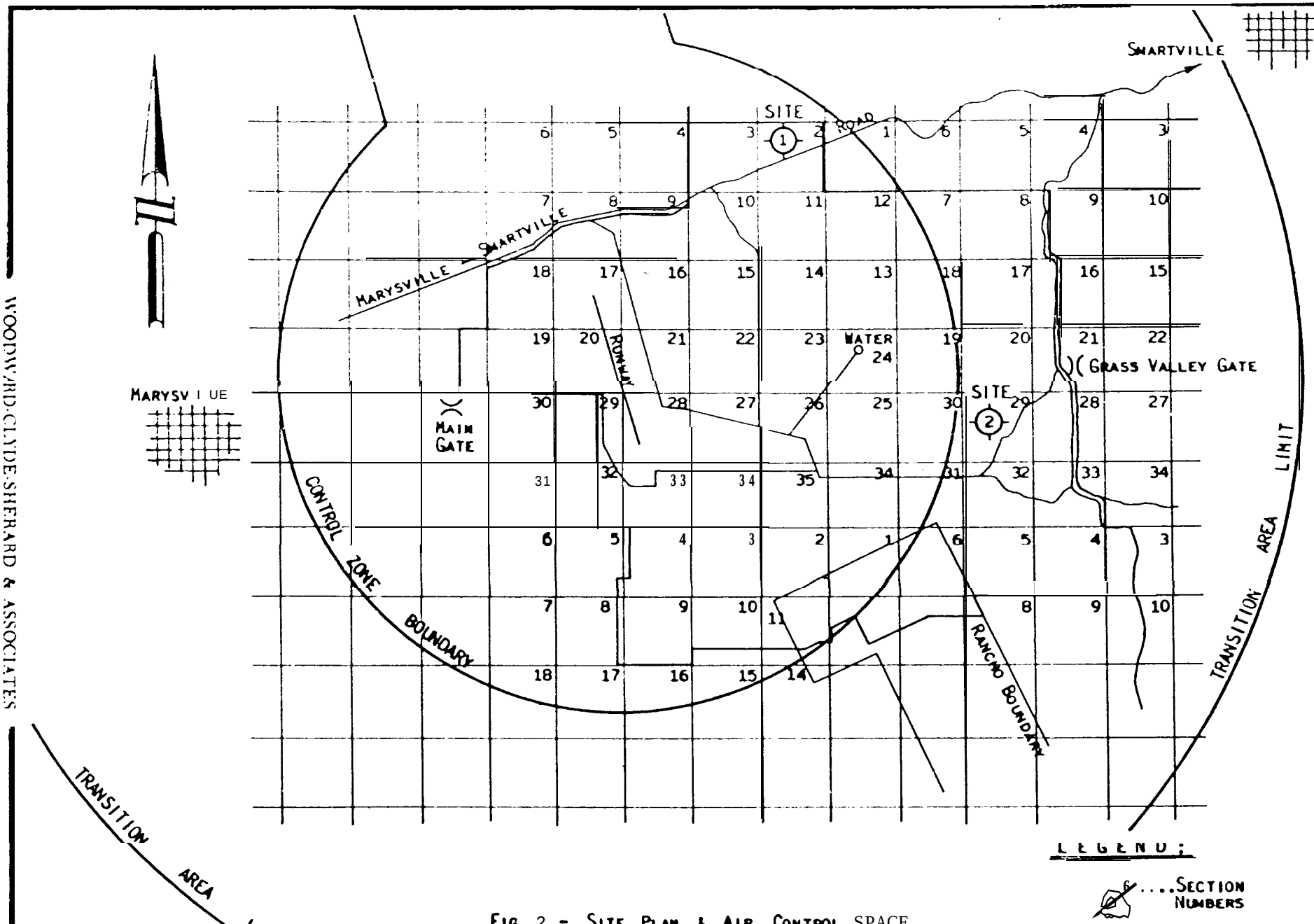


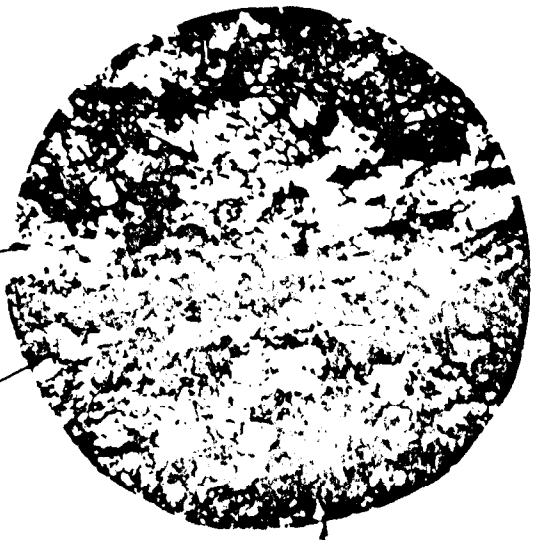
FIG. 2 - SITE PLAN & AIR CONTROL SPACE

SCALE: 1" = 2 MILES

BEALE AIR FORCE BASE, CALIFORNIA

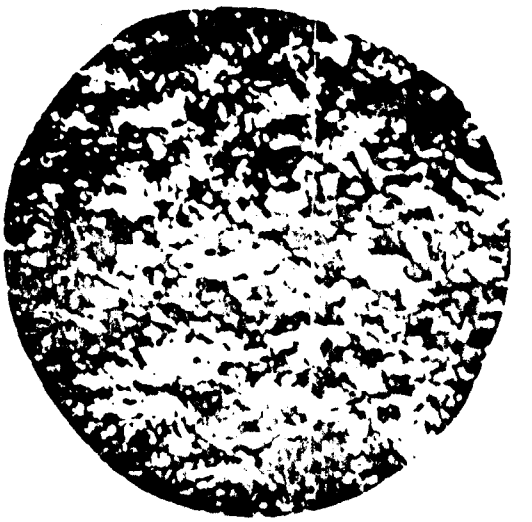
WOODWARD-CLYDE-SHERARD & ASSOCIATES

Fig. 2



X 100

Foliation indistinct; close-knit mineral crystals indicative of high strength. No fractures.



X 40

Foliation trends from upper left to lower right. Fine grained rock texture very distinct in this photo.

Hornblende — 40%; crystals have ragged terminations which are intergrown with quartz and plagioclase. Color is a light blue-green.

Diopside: — 30%; crystals are poorly formed, and have grown around the hornblende. Color is pale green.

Plagioclase: — 20%; crystal habit is indistinct; crystal orientation is obscure.

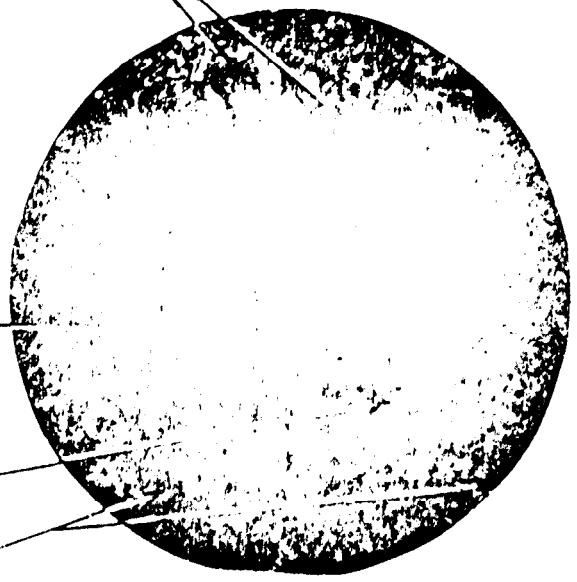
Quartz: — 5%; presence is determined by its relief compared to other minerals.

Epidote: — 3%; very small crystals; some appear to form alteration halos around other minerals.

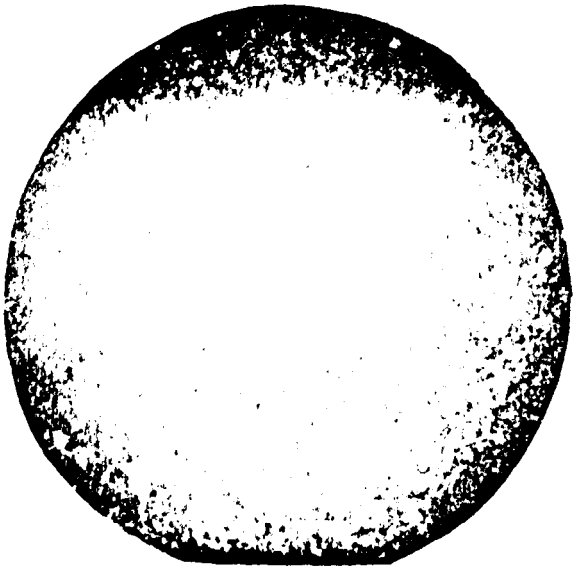
Sphene: — 2%; wedge shaped crystals which exhibit high relief.

FIG. 4 - Amphibolite Thin Section
Beale-Sitc 2

SAMPLE WSMR- MADERA LIMESTONE



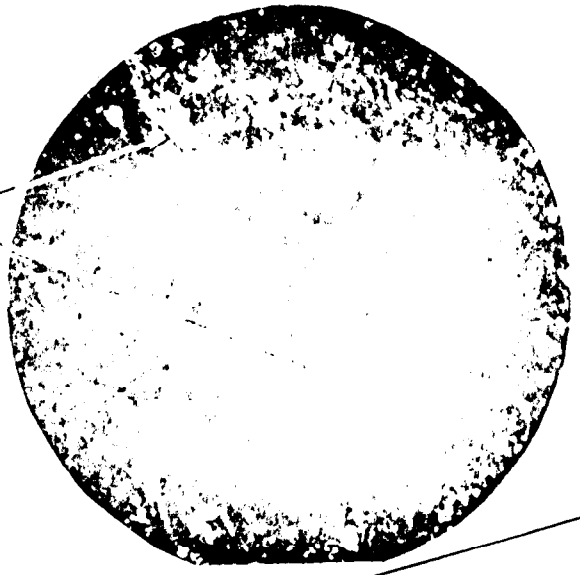
x 40 Photo 1



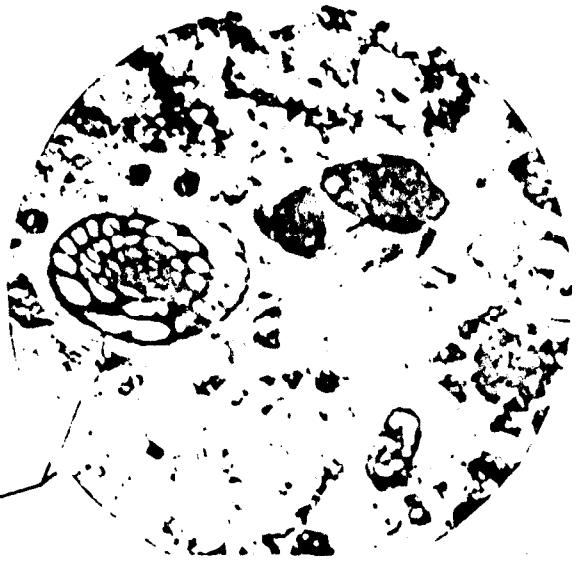
x 40 Photo 2

Calcite:	70% of thin-section; takes the form of fornminifera casts and small rhombohedral crystals; some traces of aragonite (unstable calcite).
Quartz:	2% of thin-section; small detridal grains finely disseminated throughout sample.
Feldspar:	5% or more of thin-section; a few crystal fragments; highly variable in size.
Dolomite:	10% (?) of thin-section; extremely difficult to differentiate from calcite; dolomite appears to line voids; crystals are much more transparent than calcite.
Clay:	3% of thin-section; causes the thin-section to be brownish in color and rather opaque to light.
Voids:	10% or less of thin-section; voids form zones of weakness.

SAMPLE WSMR - MADERA LIMESTONE (continued)



x 40 Photo 3



x 40 Photo 4

Fractures: Minute fractures across feldspar grains, voids tend to control fracturing.

Fossils: Index fossils of the Pennsylvanian era are abundant (Fusulinid foraminitera). Photo 4 Fusulinid type is 3/16 inch across in section. Lesser fossils of a greater age span are "Climacammina", "Endothyra", and "Endothyranella". Use of these index fossils would verify selection of identical beds.

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