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Stop 954, Box 25046
Federal Center, Denver, Colorado 80225

SUMMARY OF THE GEOLOGY AND PHYSICAL PROPERTIES OF THE CLIMAX STOCK, NEVADA TEST SITE

By

Florian Maldonado

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ABSTRACT

The Climax stock is a composite stock of Cretaceous age, composed of quartz monzonite and granodiorite, which intrudes sedimentary rocks of Paleozoic and Precambrian age. Tertiary rocks consisting of tuff, welded tuff, and breccia overlie the stock and sedimentary rocks.

Hydrothermal alteration of the granodiorite and quartz monzonite is found mainly along joints and is extensive, but the intensity of alteration varies from place to place. The surrounding sedimentary rocks (carbonates) have been metasomatically altered to tactite and marble as much as 1,500 feet (457 m) from contact with stock; the degree of metamorphism decreasing away from the intrusive.

The major faults found in the vicinity of the Climax stock are the Tippinip fault, the Boundary fault, and the Yucca fault. In the stock three prominent joint sets and their average attitudes are N. 32° W., 22° NE.; N. 64° W., vertical; and N. 35° E., vertical.

Two major tunnel complexes have been driven into the Climax stock--the Tiny Tot tunnel complex and Pile Driver-Hard Hat tunnel complex. In the Pile Driver-Hard Hat tunnel complex two underground nuclear tests have been conducted.

INTRODUCTION

This report summarizes geologic information on the Climax stock. The geologic information and physical property data have been extracted and in some cases summarized from earlier published and unpublished reports.

The Nevada Test Site is approximately 70 miles (112.7 km) northwest of Las Vegas, Nev., in Nye County. Discussed in this report is Area 15 which is in the extreme north end of the test site (fig. 1). The Climax stock is exposed over an area approximately 1 1/2 miles (2.4 km) long in a north-south direction, and 1 mile (1.6 km) across in the widest east-west dimension.

The topography of the stock rises northward from an elevation of about 4,900 feet (1,495 m) on the south to about 5,800 feet (1,770 m) at the northern boundary.

CLIMAX STOCK

General Statement

The Climax stock (fig. 2a) has intruded rocks of the Pogonip Group (Ordovician), composed mainly of limestone, dolomite, and shale, and the Stirling Quartzite (Precambrian). The Stirling Quartzite is not shown in figure 2a because outcrop exposure covers a very small area.

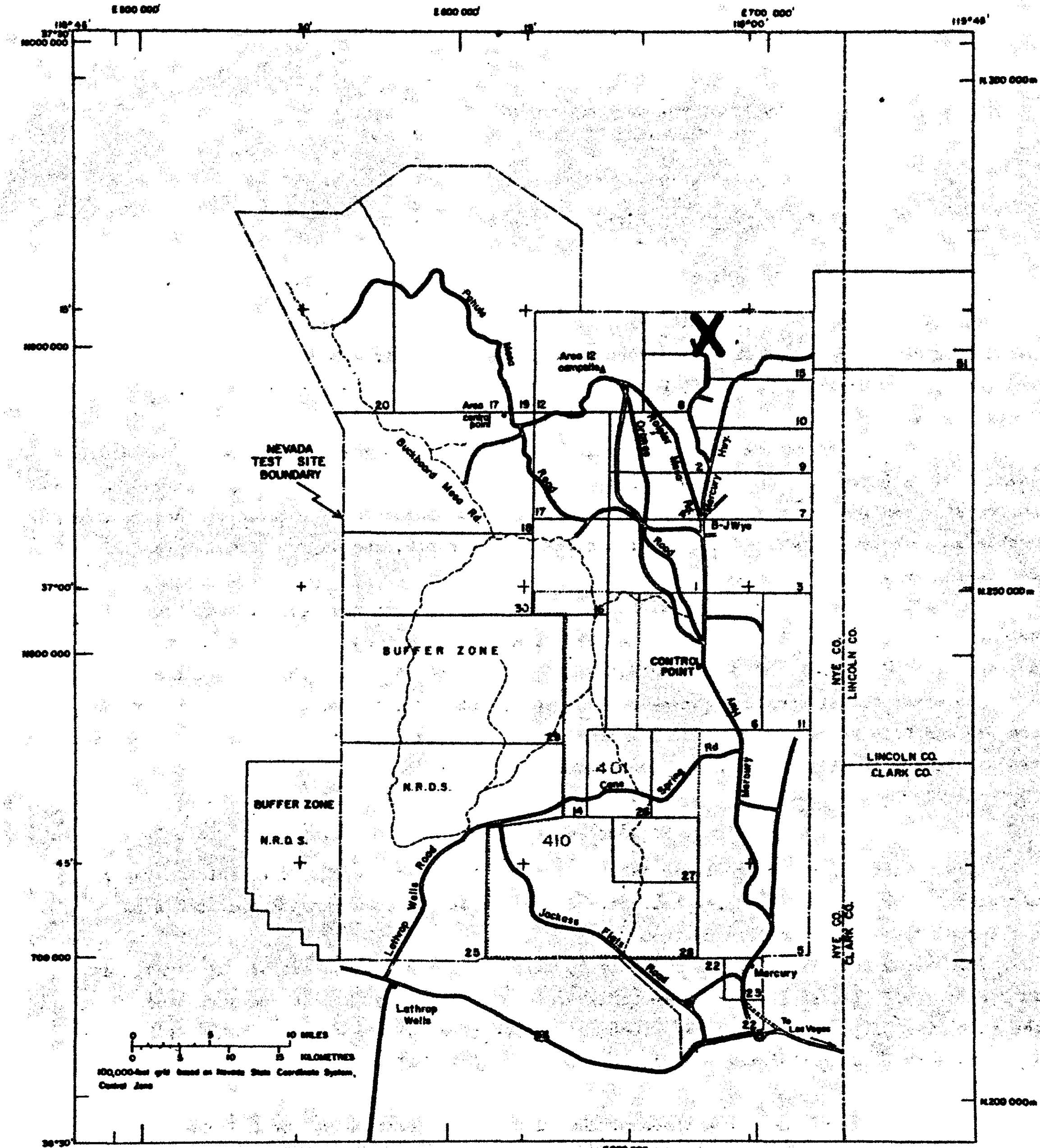

Figure 1.--Index map showing location of Climax stock (X) in Area 15, Nevada Test Site.

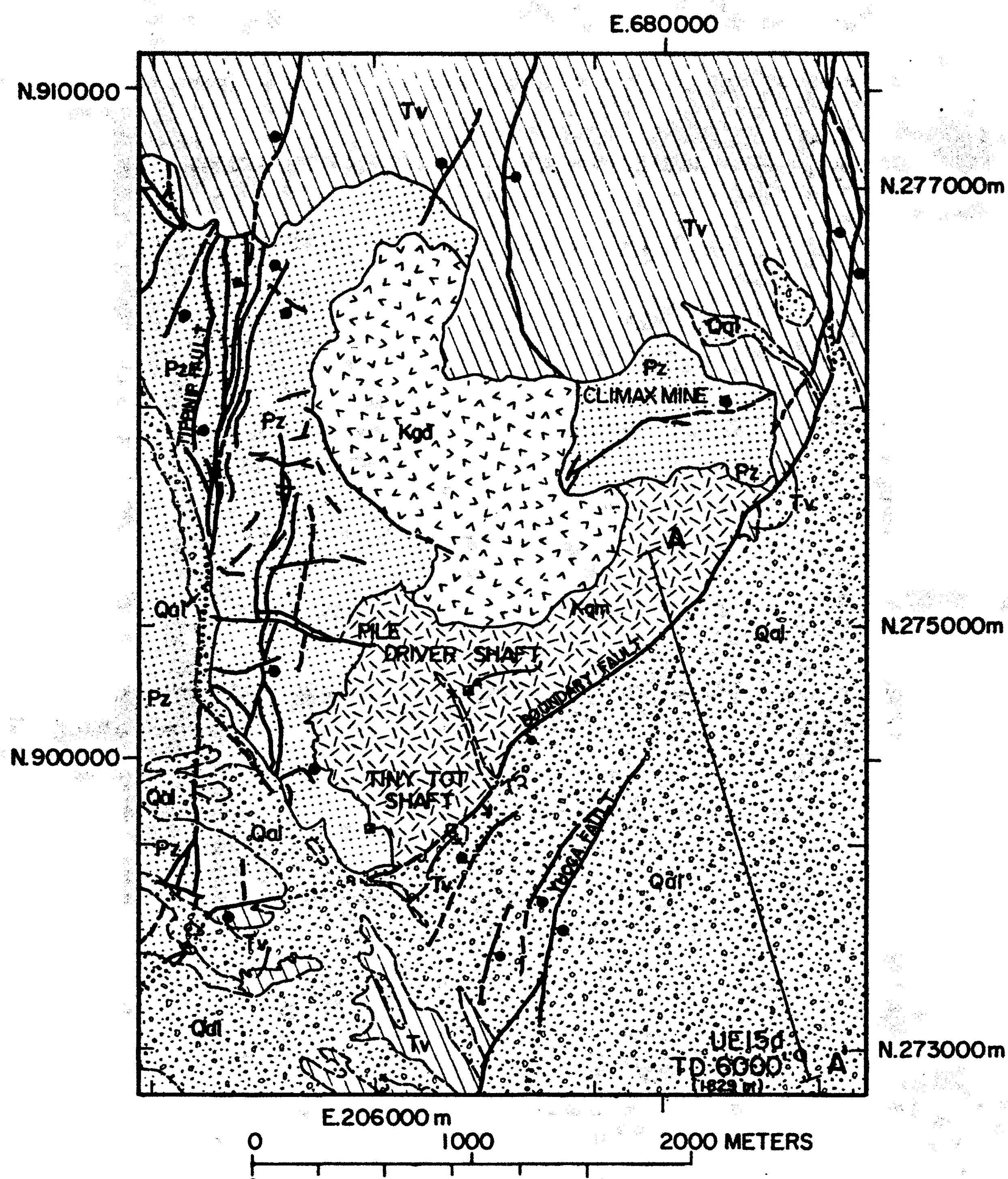

Figure 2a.--Geologic map of Climax stock. (Modified from Barnes and others, 1963)

EXPLANATION

Qal	ALLUVIUM (QUATERNARY)
Tv	VOLCANIC TUFF, UNDIFFERENTIATED (TERTIARY)
Kqm	QUARTZ MONZONITE, CLIMAX STOCK (CRETACEOUS)
Kgd	GRANODIORITE, CLIMAX STOCK (CRETACEOUS)
Pz	LIMESTONE, DOLOMITE, SHALE, AND QUARTZITE, UNDIVIDED (PALEOZOIC)
	CONTACT--Dashed where approximately located
	FAULT--Dashed where approximately located. Dotted where concealed. Bar and ball on downthrown side
	SHAFT
UE15d TD 6,000 (1,829 m)	DRILL HOLE--Showing total depth in feet, meters in parenthesis

Figure 2b.--Geologic explanation for figure 2a. Cross section A-A' shown on figure 3.

The stock and the intruded sedimentary rocks are overlain unconformably by Tertiary pyroclastic rocks that consist of tuff, welded tuff, and breccia (Allingham and Zietz, 1961). The pyroclastic rocks were called the Indian Trail Formation by Barnes, Houser, and Poole (1963), and later redefined as the Belted Range Tuff by Dixon, Sargent, and Carr (1976). Erosion has removed much of the pyroclastic and sedimentary rocks that expose the underlying stock.

The Climax is a composite stock formed of quartz monzonite and granodiorite and intruded by numerous dikes and sills. Houser and Poole (1961, p. B-176) concluded that the quartz monzonite is younger than the granodiorite mass. A potassium-argon age of 93 m.y. (Cretaceous) was obtained from six samples of biotite from the quartz monzonite (Harley Barnes, E. N. Hinrichs, F. A. McKeown, and P. P. Orkild, written commun., 1963, p. 76).

Granodiorite

The granodiorite is light gray to greenish medium gray, equigranular, medium grained, and slightly porphyritic; quartz phenocrysts average about 3 mm across. The average grain size is about 2 mm, but the common range is from 1/2 to 4 mm. The average composition, based on 19 modal analyses, is 28 percent quartz, 16 percent potassium feldspar, 45 percent plagioclase, and 9 percent biotite. Accessory minerals, mainly apatite, sphene, opaque iron oxides, and zircon, constitute 1-2 percent of the rock (Houser and Poole, 1961). Average modal and chemical analyses and normative mineral composition are shown in tables 1, 2, and 3, respectively.

Quartz monzonite

The quartz monzonite is light to medium gray, fine to medium grained, highly porphyritic, containing about 5 percent by volume potassium feldspar phenocrysts as much as 15 cm across and averaging about 5 cm in length, and 5-10 percent by volume quartz phenocrysts averaging about 4 mm across.

The quartz monzonite has been divided by Houser and Poole (1961, p. B-176) on the basis of grain size into a fine-grained variety, in which the average subhedral grains are from 1/4 to 1 mm across, and a medium-grained variety in which they are 1-1 1/2 mm across. The fine-grained quartz monzonite occurs in a zone that parallels the border of the intrusives; the medium-grained variety makes up the remainder of the intrusive. In some places the varieties are intermixed; Houser and Poole (1961, p. B-176) interpreted this mixing of grain sizes as the result of auto-intrusion of older fine-grained material by younger medium-grained material.

Granodiorite-quartz monzonite relationship

Modal analyses (table 1) show that the quartz monzonite contains more K-feldspar and biotite and less plagioclase than the granodiorite.

Table 1.--Average modal analyses for rocks of the Climax stock

[From Houser and others, 1961, p. 3]

Essential minerals[1]	Granodiorite	Quartz monzonite
Quartz	28	28
Potassium and(or) sodium feldspar	16	25
Plagioclase	45	40
Biotite	9	6

[1] Accessory minerals, mainly apatite, sphene, opaque iron oxides, and zircon, which together constitute 1 to 2 percent of rock, are not reported here.

Table 2.--Average chemical composition in weight percent of granodiorite and quartz monzonite from the Climax stock

[From Harley Barnes, E. N. Hinrichs, F. A. McKeown, and P. P. Orkild, written commun., 1963]

	Granodiorite (24 samples)	Quartz monzonite (24 samples)
SiO_2	67.6	69.1
Al_2O_3	15.8	15.8
Fe_2O_3	1.8	1.5
FeO	1.6	1.3
MgO	.82	.6
CaO	3.7	3.2
Na_2O	3.1	3.0
K_2O	3.5	3.9
H_2O	1.0	.89
TiO_2	.39	.40
P_2O_5	.18	.21
MnO	.07	.04
CO_2	.20	.10
Sum	100	100

Table 3.--Normative mineral compositions[1] for igneous rocks from the Climax intrusive mass. Amounts shown are weight percent.

[From Houser and Poole, 1959a. Leaders (---) indicate data not available.]

Sample		1	2	3	4	5	6	7	8	9	10	11	12
Rock	Type [2]	Granodiorite					Quartz monzonite						Granite
	Facies [3]	m	m[4]	m	m	sill[5]	m	m	m	f	f	f[6]	a
Sample no.[7]		HG-7	FP-65	FP-62	G-800-0	HT-8	G-70	FP-63	HG-10	G-277-0	HG-8	HG-19	H-367-1
Orthoclase (or)		19.5	21.3	20.1	23.1	16.0	20.1	30.1	23.6	33.1	20.7	72.7	46.1
Albite (ab)		26.2	28.7	27.0	25.4	33.0	28.7	25.3	25.4	22.8	26.2	4.6	16.9
Anorthite (an)		16.7	14.8	18.2	16.2	20.5	17.4	8.1	13.5	13.6	15.2	.8	2.8
Ilmenite		.7	.6	.9	.7	.9	.7	.4	.6	.7	.8	.8	.1
Magnetite		2.5	2.3	2.8	2.5	2.5	1.9	.5	2.2	1.6	2.5	.8	.2
Hematite		---	---	---	---	---	---	.3	---	---	---	.1	---
Quartz		29.3	28.6	26.6	27.2	20.7	25.6	30.2	31.0	22.7	29.1	16.6	31.3
Corundum		.8	.6	.6	1.0	.2	.4	2.5	.7	1.0	1.6	2.1	1.1
Hypersthene		2.7	2.1	2.5	2.9	4.4	3.6	.4	2.1	2.6	2.0	.3	.1
Apatite		.2	.2	.2	.2	.3	.2	.2	.2	.3	.2	.2	.1
Sum[8]		98.6	99.2	98.9	99.2	98.5	98.6	98.0	99.3	98.4	98.3	99.0	98.7
or/ab + an + or		31	33	31	36	23	30	47	38	48	33	93	70
an/ab + an		39	34	40	39	38	38	24	35	37	37	15	14
Rock type as determined from norm[9]		g	g	g	q	g	g	q	q	q	g-q	gr	gr

[1] Weight percent. Theoretical mineral composition based on chemical analysis. CIPW system used in computations.

[2] Name assigned to original unaltered rock on the basis of megascopic petrology, chemical analyses, and norms.

[3] Determined megascopically for granodiorite or quartz monzonite: f = fine-grained facies, m = medium-grained facies; for granite dikes: a = aplitic (fine grained).

[4] Hydrothermally(?) altered.

[5] No facies designated but rock is medium grained.

[6] Hydrothermally altered--predominant product is secondary potassium-feldspar.

[7] All samples with prefix "G" are from exploration hole and number indicates depth. Zero following depth number distinguishes specific series of samples. All other samples are from the surface.

[8] Sum of normative minerals in rock is less than 100 percent, as H_2O, MnO, and CO_2 determined in chemical analysis were not used in these CIPW norm calculations.

[9] g = granodiorite, q = quartz monzonite, and gr = granite.

Chemical analyses (table 2) show that the chemical difference between the two rock types is not great. The quartz monzonite in respect to the granodiorite contains: (1) more K_2O, (2) slightly more SiO_2, (3) less total Fe ($FeO+Fe_2O_3$ recomputed to FeO) and CaO, and (4) very slightly less Na_2O (Houser and Poole, 1959a).

The contact between the granodiorite and quartz monzonite is generally vertical or very steep. It is highly irregular and shows mutually penetrating fingers of each rock type. The penetrating fingers are measurable in inches or feet in width and length (Houser and Poole, 1961, p. B-176). No glassy chilled zone has been observed in either rock type.

Dikes and sills

The stock and country rocks have been cut by dikes and sills as much as 500 feet (152 m) long and 50 feet (15 m) thick (Barnes and others, 1963). The dikes and sills have no predominant trend except in the central part of the granodiorite where they strike northwest. The texture of the dikes and sills ranges from aplitic to pegmatitic, and composition ranges from alaskite to syenite (Harley Barnes, E. N. Hinrichs, F. A. McKeown, and P. P. Orkild, written commun., 1963, p. 74).

Hydrothermal alteration and mineralization

Hydrothermal alteration of the granodiorite and quartz monzonite is extensive, but the intensity of alteration varies from place to place (Houser and others, 1961).

Hydrothermal alteration is found mainly along joints and includes the following minerals: clay minerals, chlorite, secondary feldspar, sericite, quartz, epidote, and sulfide minerals, mainly pyrite (Houser and Poole, 1959a).

Pervasive hydrothermal alteration of the granodiorite and quartz monzonite has formed clays, sericite, albite, orthoclase, pyrite, and quartz (F. N. Houser and F. G. Poole, written commun., 1961) in the U15a site area.

Pyrite and chalcopyrite occur disseminated in the granodiorite (W. L. Emerick, unpub. data, 1966). Pyrite also occurs as fracture filling, commonly with the following minerals: limonite, manganese, and secondary feldspar.

The surrounding carbonate rocks have been metasomatically altered to tactite and marble as much as 1,500 feet (457 m) from contact with stock (Houser and Poole, 1961). Tactite mineralogy consists of garnet, quartz, epidote, green mica (chlorite), limonite, calcite, and idocrase. Small amounts of pyrite, copper carbonate minerals, scheelite and powellite have been found in tactite zones. The Climax mine (fig. 2a) and other workings are found along tactite zones and are part of the Oak Spring mining district which produced mainly tungsten.

Structure

Faults

Three major faults are found in the vicinity of the Climax stock (fig. 2a) and are the Tippinip fault, the Boundary fault, and the Yucca fault.

The Tippinip fault is located west of the Climax stock outcrop and trends north-northeast displacing the Paleozoic sedimentary rocks, the west block down relative to the east block. The Tippinip fault intersects the Boundary fault southwest of the stock.

The Boundary fault, which trends northeast, is located on the southeast side of the stock, placing the stock in fault contact with alluvium end tuff. In the southern part of the stock, the dip of the fault has been measured at 75° SE. (C. H. Miller and D. R. Miller, written commun., 1973, p. 6), the southeast block is displaced downward relative to the northwest block. A gravity survey was conducted across the Boundary fault by C. H. Miller and D. R. Miller (written commun., 1973). Their interpretation showed quartz monzonite faulted against tuff and Precambrian rocks, and no igneous rocks of the Climax stock are shown east of the Boundary fault (fig. 3). Millar and Miller's cross-section line (A-A', fig. 3) goes through drill hole UE15d where 290 feet (88 m) of alluvium, 1,483 feet (452 m) of Belted Range Tuff, and 4,227 feet (1,288 m) of Precambrian meda-sedimentary rocks were penetrated without encountering igneous rocks of the Climax stock.

The Yucca fault, the principal exposed structural feature within the Yucca Flat area, is located south of the Climax stock. It trends northward through the middle of Yucca Flat and northeastward near the Climax stock, displacing the east block downward relative to the west block, and possibly joins the Boundary fault just south of the stock.

Other minor faults found mainly in the sedimentary rocks overlying the stock are high angle, predominantly with strikes of northwest and north-northeast; north-trending faults are less common in the area. The faults have been interpreted as later than the igneous intrusion by F. N. Houser and F. G. Poole (written commun.,1961), and possibly before the deposition of the volcanic tuff. Minor postvolcanic faults are present, possibly representing Basin and Range faulting.

Joints

In the stock three prominent joint sets and their average attitudes are N. 32° W., 22° NE.; N. 64° W., vertical; and N. 35° E., vertical (F. N. Houser and F. G. Poole, written commun., 1961, p. 2). Joints in outcrops are weathered and open, but in the subsurface the joints are commonly filled and, in some instances, are healed complately with chlorite, quartz, secondary feldspar, clay minerals, calcareous clay, calcite, and sulfide minerals (Houser and Poole, 1959a).

J. R. Ege and R. E. Davis (written commun., 1964) mapped the joints on the surface at the Tiny Tot site (fig. 2a) approximately 1,400 feet (427 m) S. 82° W. of the Hard Hat-Pile Driver shaft (fig. 4, in pocket). The area has three trends of joints as follows: N. 62° W., dip 20° NE.; N. 30° E., dip vertical; and N. 69° W., dip 85° NE to vertical.

PHYSICAL PROPERTIES

Porosity, grain-density, bulk-density, and powder-density measurements were made on core samples from the U15a exploration hole by Izett (1960). Cored rock porosities range between 0.4 and 0.9 percent; average porosity is 0.6 percent. Dry-bulk densities range between 2.65 g/cm^3 and 2.69 g/cm^3 and average about 2.68 g/cm^3. Grain densities range from

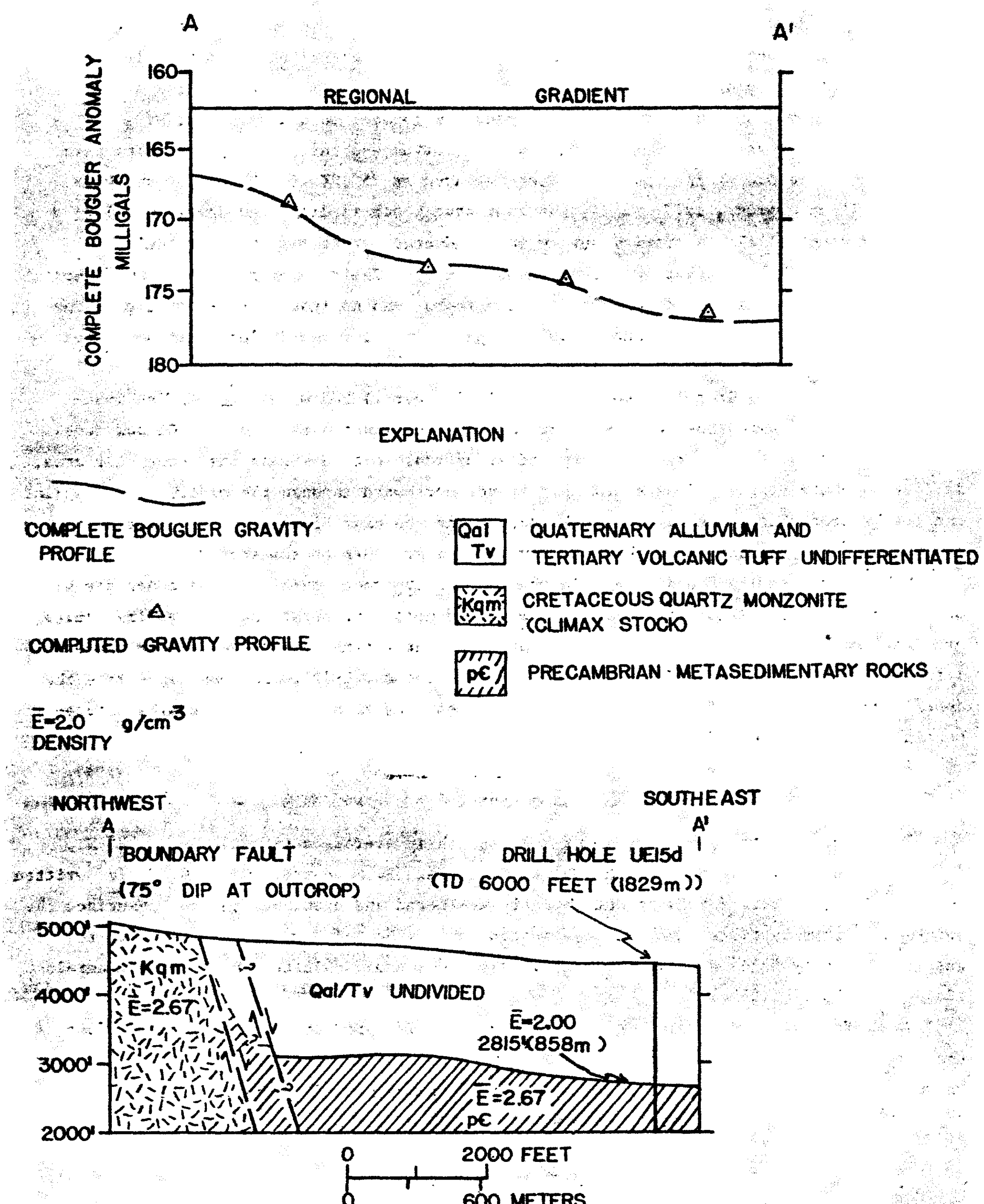

FIGURE 3--Generalized geologic section, along line A-A' of figure 2a, determined by two-dimensional analysis of gravity data. (from C.H.Miller and D.R.Miller, written commun., 1973.)

2.66 g/cm^3 to 2.72 g/cm^3 and average 2.68 g/cm^3. Powder densities range from 2.67 g/cm^3 to 2.71 g/cm^3 and average 2.69 g/cm^3. Table 4 gives a summary of the data. Outcrop samples were also measured for porosity and density (table 5). The greater porosity values for outcrop samples probably resulted from change in volume as result of weathering. Additional measurements of samples obtained in and near the U15a site, which consists of tunnel, drifts, drill-hole and surface samples, were made by F. N. Houser (written commun., 1962) and are summarized in table 6.

Permeability measurements were conducted on one fresh core sample from U15a and one outcrop sample. Izett (1960, p. 17) stated that permeability of the outcrop samples (10^{-4} millidarcies) was found to be considerably higher than the permeability of the core sample (10^{-13} millidarcies), possibly due to weathering of outcrop sample.

Thermal conductivity measurements have been conducted on core samples from U15a and results are listed in table 7. Thermal conductivity values range from 23.4 to 33.9 W/m·K (Watts per meter Kelvin).

Table 8 lists some physical properties of other granites and is presented here for comparison with rocks of the Climax stock.

DRILL HOLES IN THE CLIMAX STOCK

The drill holes in the Climax stock and the vicinity of the stock are listed in table 9; some of the drill holes are plotted on figure 4 (in pocket). Lithologic logs are available for some of the drill holes and are referenced in table 9.

PILE DRIVER TUNNEL COMPLEX

General statement

Two major tunnel complexes, the Tiny Tot and the Pile Driver-Hard Hat, were driven into the Climax stock (fig. 4, in pocket). The Pile Driver tunnel level is approximately 1,367 feet (417 m) below the collar of a shaft at Nevada State coordinates N. 901,147 (N. 274,670 m) and E. 677,016 (E. 206,354 m).

Structure

Faults

The Pile Driver tunnel complex (fig. 5, in pocket) was driven in quartz monzonite and granodiorite of the Climax stock. The dominant trend of the faults in both rocks is northwest-southeast (W. L. Emerick, unpub. data, 1966). The dominant fault set in the quartz monzonite has average orientations of N. 46° W., 78° NE. dip, and in the granodiorite, N. 48° W., 78° NE. dip, resulting in an average orientation of N. 47° W., 78° NE. dip. The four major fault sets in order of frequency of occurrence in the quartz monzonite are the following: N. 46° W., 78° NE. dip; N. 50° W., 82° SW. dip; N. 49° W., 90° dip; and N. 44° E., 68° E. dip. In the granodiorite the most frequent fault sets are the following: N. 48° W., 78° NE. dip; N. 36° E., 69° SE. dip; N. 44° W., 45° NE. dip; and N. 49° W., 90° dip (W. L. Emerick, unpub. data, 1966). Strikes and dips of fault sets common to both quartz monzonite

Table 4.—Summary of porosity and density of Climax granite[1] samples from the U15a#31 (Granite hole) drill hole, Climax stock

[Modified from Izett, 1960]

Percent porosity:	
Average	0.6
Range	0.4–0.9
Number of samples	23
Density, dry bulk (g/cm^3):	
Average	2.68
Range	2.65–2.69
Number of samples	23
Density, grain (g/cm^3):	
Average	2.68
Range	2.66–2.72
Number of samples	23
Density, powder (g/cm^3):	
Average	2.69
Range	2.67–2.71
Number of samples	23

[1] Composition not accurately known in range from quartz monzonite to granodiorite.

Table 5.—Average porosity and density of Climax granite[1] outcrop samples

[Modified from Izett, 1960]

Sample No.	Porosity (percent)	Density, dry bulk (g/cm^3)	Density, grain (g/cm^3)	Density, powder (g/cm^3)
FP-62	1.8	2.66	2.71	2.70
FP-63	1.3	2.65	2.70	2.70
HG-7	1.9	2.66	2.71	2.68
HG-8	1.7	2.62	2.66	2.65

[1] Composition not accurately known in range from quartz monzonite to granodiorite.

Table 6.--Summary of measured physical properties of samples from the U15a#31 (Granite hole) site, Climax stock

[Modified from F. N. Houser, written commun., 1962]

Rock type	Number of samples	Porosity (percent)		Dry-bulk density (g/cm³)		Grain density (g/cm³)	
		Range	Average	Range	Average	Range	Average
Fine-grained quartz monzonite	16	0.2-2.6	0.71	2.6-2.7	2.66	2.6-2.7	2.68
Medium-grained quartz monzonite	15	0.3-5.0	1.08	2.5-2.7	2.64	2.6-2.7	2.67
Granodiorite	8	0.3-3.6	1.55	2.6-2.7	2.64	2.6-2.7	2.69

Table 7.--Measured thermal conductivities of granite[1] samples from the U15a#31 (Granite hole) drill hole, Climax stock

[From Izett, 1960]

Sample No. and depth (feet)	Thermal conductivity W/m·K units
G-63	25.1×10^{-1}
G-144	23.9×10^{-1}
G-236	24.3×10^{-1}
G-277	23.9×10^{-1}
G-400	33.9×10^{-1}
G-500	27.6×10^{-1}
G-600	30.1×10^{-1}
G-700	23.4×10^{-1}
G-800	26.4×10^{-1}
G-854	24.3×10^{-1}
G-900	26.4×10^{-1}
G-1000	29.7×10^{-1}
G-1100	23.9×10^{-1}
G-1200	23.9×10^{-1}

[1] Composition not accurately known in range from quartz monzonite to granodiorite.

Table 8.--Some physical properties of granites

[From Gibbons and others, 1959]

Property	Number of determinations	Value	Reference
Porosity (percent)	5	0.3-2.6	Daly, 1933
Specific gravity	155	2.516-2.809	Do.
Water content (percent by weight)	184	0.84	Do.
Mean elasticities			
Bulk modulus ($dynes/cm^2$)	7	$3.03X10^{11}$	Do.
Rigidity modulus ($dynes/cm^2$)	7	$2.067X10^{11}$	Do.
Young's modulus ($dynes/cm^2$)	7	$5.05X10^{11}$	Do.
Poisson's ratio	7	0.222	Do.
Thermal conductivity (W/m·K)			
0°C		$24.3-35.2X10^{-1}$	Birch and others, 1942
100°C		$22.7-30.1X10^{-2}$	Do.
Average strengths at atmospheric pressure (kg/cm^2)			Daly, 1933
Compressive		1,000-2,800	
Shearing		150-300	
Tensile		30-50	

Table 9.--Drill holes in the Climax stock and vicinity

[Leaders (---) indicate data not available]

Hole No.	Location	Depth (ft/m)	Spud date	Hole No.	Location	Depth (ft/m)	Spud date
U15a [1 2 3]	N. 901,906 E. 676,827	963/294	9/23/59	U15 GZ #15-S2	N. 903,705 E. 680,314	1,553/473	10/25/64
U15a#28 Rad Chem	N. 901,925 E. 676,812	949/289	6/24/60	U15 GZ #24 [1]	N. 901,270 E. 679,690	1,439/439	8/8/64
U15a#31 [1 2 3] Granite Hole	N. 901,907 E. 676,827	1,200/366	?	U15 GZ #25 [1]	N. 900,879 E. 680,421	1,525/465	8/1/64
U15a#32 [1]	N. 902,161 E. 677,798	908/277	8/11/60	U15b [1]	N. 903,058 E. 677,367	1,323/403	1/6/61
U15a#33 [1]	N. 901,688 E. 678,857	987/301	8/25/60	U15b GZ [1 4] (Ex.)	N. 903,065 E. 677,436	1,800/549	12/13/60
U15a#34 [1]	N. 902,884 E. 677,108	987/301	7/25/60	U15b Ex.#1 [1 4]	N. 903,879 E. 678,046	1,800/549	12/16/60
U15a#35 [1]	N. 900,469 E. 677,180	822/251	8/9/60	U15b Ex.#2 [1 4]	N. 902,570 E. 678,355	1,800/549	12/10/60
U15a#37 [1]	N. 901,311 E. 676,943	1,667/508	8/8/60	UE15d [5] Water Well	N. 895,709 E. 682,084	6,001/1,829	9/27/61
U15a#38-1 [1]	N. 900,992 E. 677,053	386/118	7/28/60	UE15e [1 6]	N. 900,982 E. 676,015	600/183	7/2/64
U15a#38-2	N. 900,994 E. 677,046	2,001/610	8/14/60	U15e#1 [1]	N. 900,874 E. 677,517	325/99	2/17/65
U15aPS#1	N. 901,906 E. 676,827	963/294	3/18/62	Marble #1 [1] (ME-1)	N. 902,475 E. 675,331	378/115	5/17/59
U15a28s PS	N. 901,915 E. 676,816	1,016/310	3/18/62	Marble #2 [1] (ME-2)	N. 903,676 E. 675,845	274/84	---
U15a29PS#1	N. 901,925 E. 676,852	724/221	2/18/62	Marble #3 [1 7] (ME-3)	N. 903,096 E. 674,866	978/298	6/12/59
U15a29s PS	N. 901,966 E. 676,838	402/123	3/19/62	Marble #4 [8] (ME-4)	N. 904,480 E. 973,758	1,187/362	7/13/59
U15.01PS #1V	N. 902,201 E. 677,927	655/200	7/19/67	USGS Hole #36 (Seismic)	N. 901,565? E. 677,755?	204/62	?
U15 GZ (Inst.)	N. 902,207 E. 677,923	1,213/370	9/29/64	U15e PS #1V	N. 900,866 E. 677,526	322/98	8/27/65
U15 GZ #14 [1]	N. 903,267 E. 679,619	3,573/1,089	9/8/64	UE15f [1 9]	N. 900,912 E. 677,907	653/199	8/5/64
U15 GZ #15 [1]	N. 903,705 E. 680,315	46/14	8/31/64	UE15g [1]	N. 901,010 E. 677,685	655/200	9/16/64
U15 GZ #15-S	N. 903,702 E. 680,315	41/13	10/23/64	UE15h	N. 901,088 E. 677,686	606/185	10/16/64

[1] Location plotted on figure 4.

[2] +U15a is in same location as U15a#31; hole diameter widens to 963 feet (294 m).

[3] Houser, F. N., and Poole, F. G., 1959b.

[4] Houser, F. N., 1961.

[5] Dickey, D. D., and Emerick, W. L., written commun., 1961; Cole, T. H., and Williams, W. P., written commun., 1962.

[6] Ege, J. R., written commun., 1965.

[7] Houser, F. N., and Poole, F. G., 1959b.

[8] McKeown, F. A., and Wilmarth, V. R., 1959.

[9] Ege, J. R., and Davis, R. E., written commun., 1965.

and granodiorite are as follows: N. 46°-48° W., 78° NE.; N. 50°-51° W., 82°-83° SW.; N. 49° W., 90°; N. 23°-27° E., 45°-46° SE.; and N. 36°-44° E., 68°-69° SE. (W. L. Emerick, unpub. data, 1966). Fault statistics are summarized in table 10 and figure 6.

A major normal fault offsets the quartz monzonite and is intersected by the tunnel complex in several localities (fig. 5). In the vicinity of the shop tunnel (fig. 5) the fault has a N. 20° E. trend, dipping 65° SE. The fault has downdropped the southeast block (hanging wall) relative to the northeast block (footwall).

Joints

The joints in the Pile Driver tunnel complex were mapped by W. L. Emerick (unpub. data, 1966). Table 11 shows the density of joints mapped in the Pile Driver tunnel and figure 7 shows bearing frequencies of joints for the quartz monzonite and granodiorite. W. L. Emerick (unpub. data, 1966) found three definite sets which are:

(1) Most prominent: from N. 30° W. to N. 75° W., with greatest concentration from N. 30° W. to N. 45° W.

(2) Less prominent: striking northeast and dipping 45°-80° SE.

(3) Least prominent: due north or due west and dipping from 15°-40° NE.

Emerick concludes that the difference in rock composition appears to have little effect on either the orientation or the density of joints found in the Pile Driver tunnel complex.

Alteration

W. L. Emerick (unpub. data, 1966) concluded that the quartz monzonite and granodiorite in the Pile Driver complex are essentially unaltered; alteration, when present, is confined to fault zones or areas adjacent to the faults. Alteration adjacent to fault zones consists mainly of saussuritization (replacement of plagioclase by albite, epidote, calcite, zoisite, sericite, and zeolites) and sericitization along high-angle faults. The dominant materials filling the fault zones are tectonic rubble, calcite, and clay. Other minor filler minerals are chlorite, limonite, hematite, sericite, quartz, feldspar, and pyrite. The filled openings range from less than 1/16 inch to 1 foot in width (W. L. Emerick, unpub. data, 1966). Figures 8 and 9 show volume percent of types of filling in faults in quartz monzonite and granodiorite, respectively.

Nuclear tests in the Pile Driver-Hard Hat tunnel complex

A low-intermediate yield underground nuclear test was conducted at the Pile Driver site; ground zero (fig. 4) was located at Nevada Central coordinates N. 902,200 (274,991 m) and E. 677,980 (206,648 m), 1,500 feet (457 m) below the surface.

The test produced a moderate number of surface fractures but no sink (P. J. Barosh, written commun., 1967). Most of the explosion-produced fractures are on roads and pads and appear to be unrelated to geology. Some north-northeast-trending fractures formed along the Yucca fault zone. Some fractures also formed along the Boundary fault where it is crossed by roads. The effects from the test were mapped by P. J. Barosh (written commun., 1967) and are shown on figure 4.

Table 10.--Statistics of faults in the Pile Driver tunnel

[W. L. Emerick, unpub. data, 1966. Leaders (---) indicate data not available.]

		Fault sets	Faults per set	Percent of total faults	Strike of set (range)	Dip of set (range)	Average strike & dip of set
Quartz monzonite (239 faults)							
NE. strike	NW. dip	3	6	2.5	20°-56°	69°-87°	N. 37° E., 75° NW.
			1	.4	---	---	N. 83° E., 23° NW.
			2	.8	---	85°-90°	N. 86° E., 87 1/2° NW.
	SE. dip	4	31	13.0	31°-66°	55°-83°	N. 44° E., 68° SE.
			7	2.9	79°-86°	84°-87°	N. 84° E., 86° SE.
			1	.4	---	---	N. 23° E., 45° SE.
			1	.4	---	---	N. 51° E., 13° SE.
	Vertical	1	3	1.3	9°-39°	---	N. 24° E., 90°
NW. strike	NE. dip	3	89	37.2	12°-77°	63°-89°	N. 46° W., 78° NE.
			5	2.1	22°-39°	48°-55°	N. 31° W., 50° NE.
			4	1.7	15°-64°	15°-27°	N. 40° W., 21° NE.
	SW. dip	2	49	20.5	5°-78°	68°-88°	N. 50° W., 82° SW.
			3	1.3	21°-60°	50°-56°	N. 42° W., 53° SW.
	Vertical	1	37	15.5	24°-79°	---	N. 49° W., 90°
Granodiorite (137 faults)							
NE. strike	NW. dip	3	8	5.8	1°-26°	57°-70°	N. 9° E., 67° NW.
			4	2.9	51°-56°	63°-86°	N. 54° E., 72° NW.
			1	.7	---	---	N. 76° E., 70° NW.
	SE. dip	3	14	10.2	11°-63°	59°-80°	N. 36° E., 69° SE.
			11	8.0	6°-46°	40°-51°	N. 27° E., 46° SE.
			1	.7	---	---	N. 21° E., 18° SE.
	Vertical	1	4	2.9	26°-56°	---	N. 46° E., 90°
NW. strike	NE. dip	3	49	35.9	9°-77°	70°-87°	N. 48° W., 78° NE.
			14	10.2	26°-69°	29°-55°	N. 44° W., 45° NE.
			11	8.0	5°-59°	58°-69°	N. 32° W., 65° NE.
	SW. dip	2	5	3.7	39°-69°	75°-86°	N. 51° W., 83° SW.
			2	1.5	67°-70°	50°-66°	N. 68° W., 58° SW.
	Vertical	1	13	9.5	7°-85°	---	N. 49° W., 90°

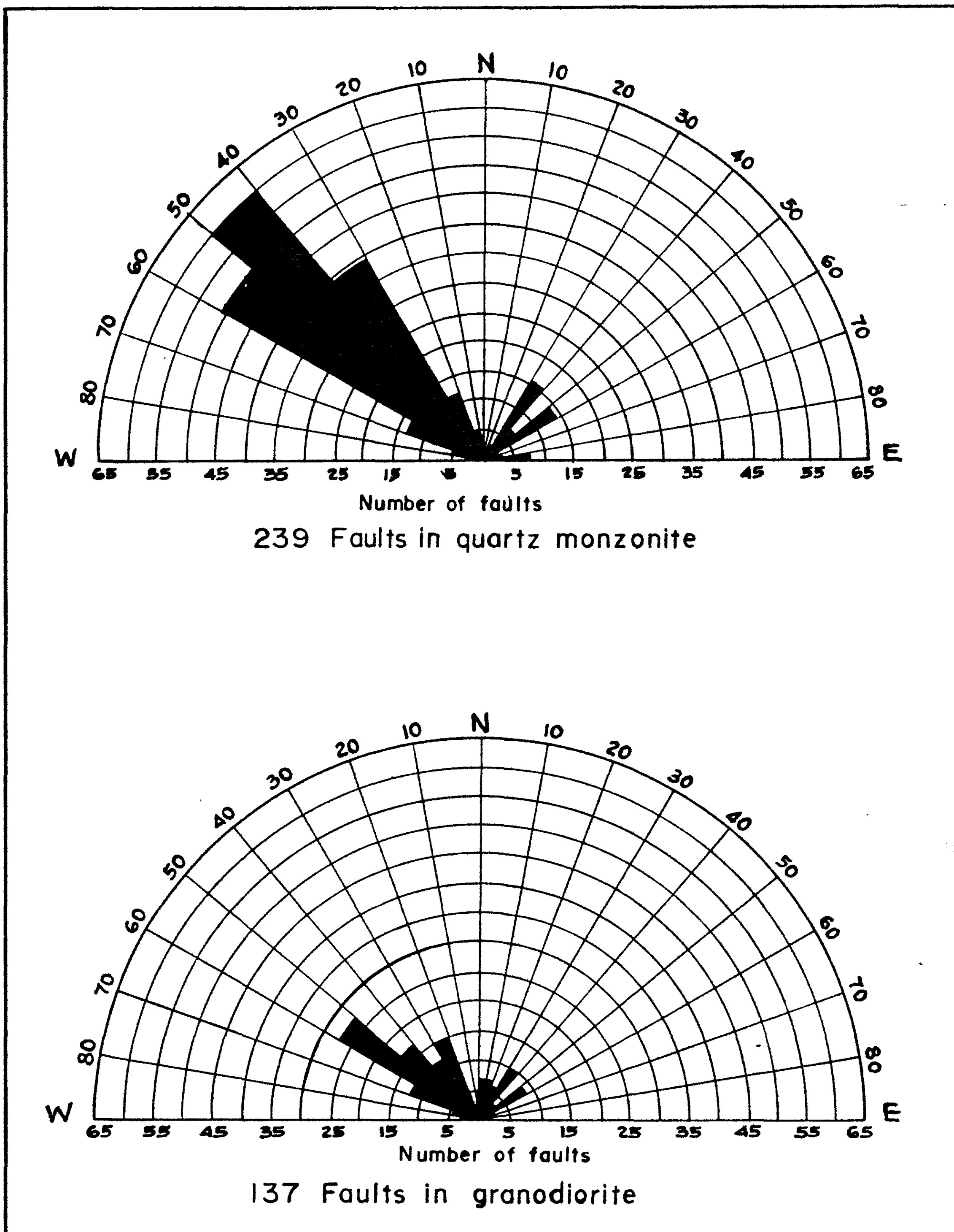

FIGURE 6.--Strike of faults in the quartz monzonite porphyry and granodiorite, Pile Driver tunnel. (From W.L.Emerick, unpub. data, 1966.)

Table 11.--Density of joints in Pile Driver tunnel

[W. L. Emerick, unpub. data, 1966.
qm, quartz monzonite; gd, granodiorite.]

Tunnel interval	Number of joints	Joints/foot	Rock type
Main tunnel			
0+00 to 1+00	127	1.27	qm
1+00 to 2+00	96	.96	qm
2+00 to 3+00	119	1.19	qm
3+00 to 4+00	91	.91	qm
4+00 to 5+00	107	1.07	qm
5+00 to 6+00	183	1.83	qm
6+00 to 7+00	98	.98	qm
7+00 to 8+00	29	.29	qm
8+00 to 9+00	20	.20	qm
9+00 to 10+00	23	.23	qm & gd
10+00 to 11+00	19	.19	gd
11+00 to 12+00	7	.07	gd
12+00 to 13+00	11	.11	gd
13+00 to 14+00	15	.15	gd
Tail drift			
0+00 to 1+05(face)	52	.49	qm
Explosives drift			
0+00 to 1+00	47	.47	qm
1+00 to 1+65(face)	128	1.97	qm
Shop tunnel			
0+00 to 2+20	140	0.64	qm
AR drift			
0+00 to 1+00	123	1.23	qm & gd
1+00 to 2+00	156	1.56	qm
2+00 to 2+95	109	1.15	qm
AL drift			
0+00 to 1+00	158	1.58	gd
CR drift			
0 to 0+81	40	.49	qm
XL drift			
0 to 0+75(face)	83	1.11	gd
DL drift			
0 to 0+75(face)	37	.49	qm
YR drift			
0 to 0+54(face)	53	.98	gd
BL drift			
0+00 to 1+00	90	.90	qm
BR drift			
0+00 to 1+00	92	.92	qm
1+00 to 2+00	124	1.24	qm

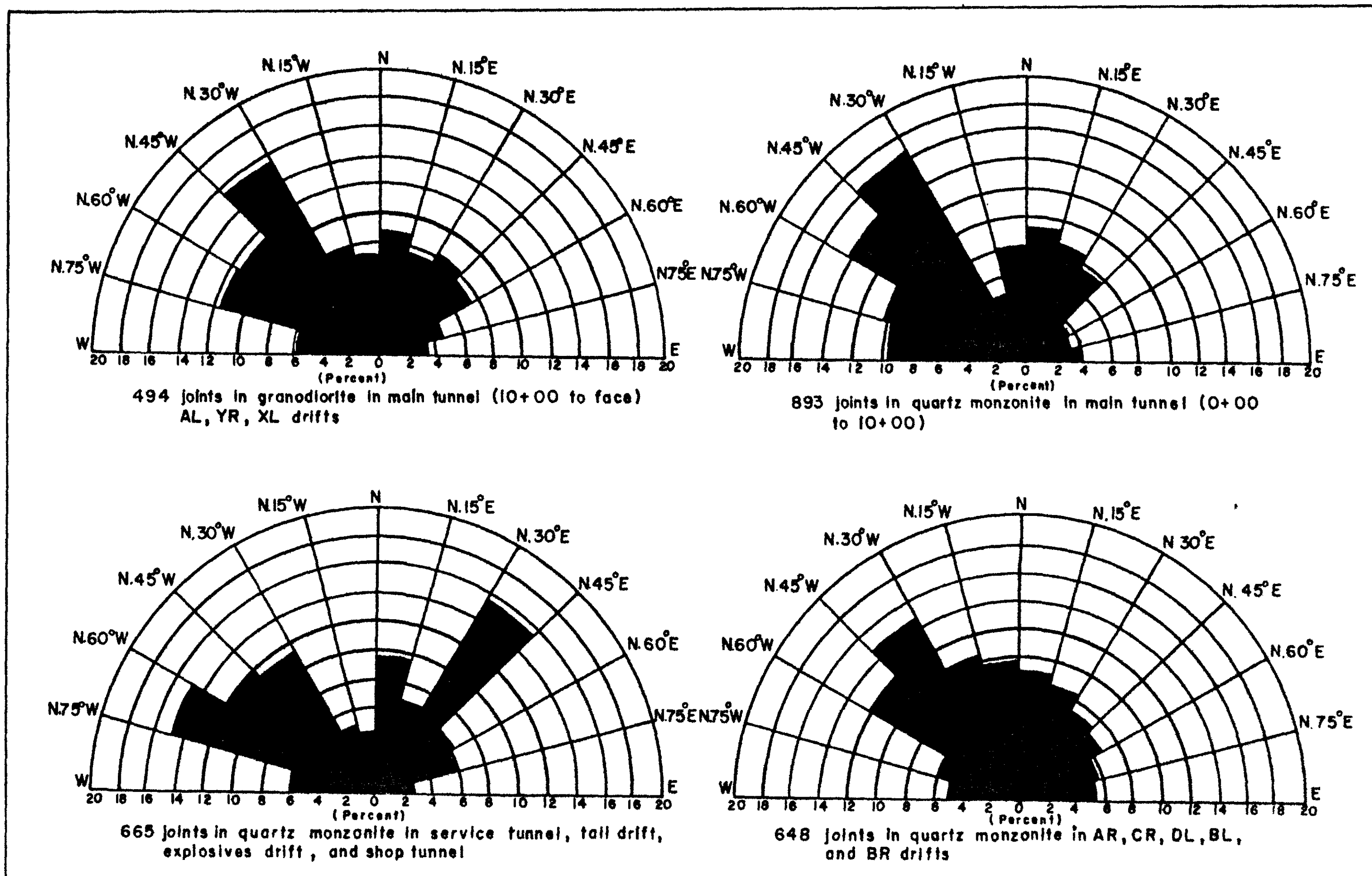

FIGURE 7.--Bearing frequencies of joints in Pile Driver tunnel. (From W.L.Emerick, unpub. data, 1966.)

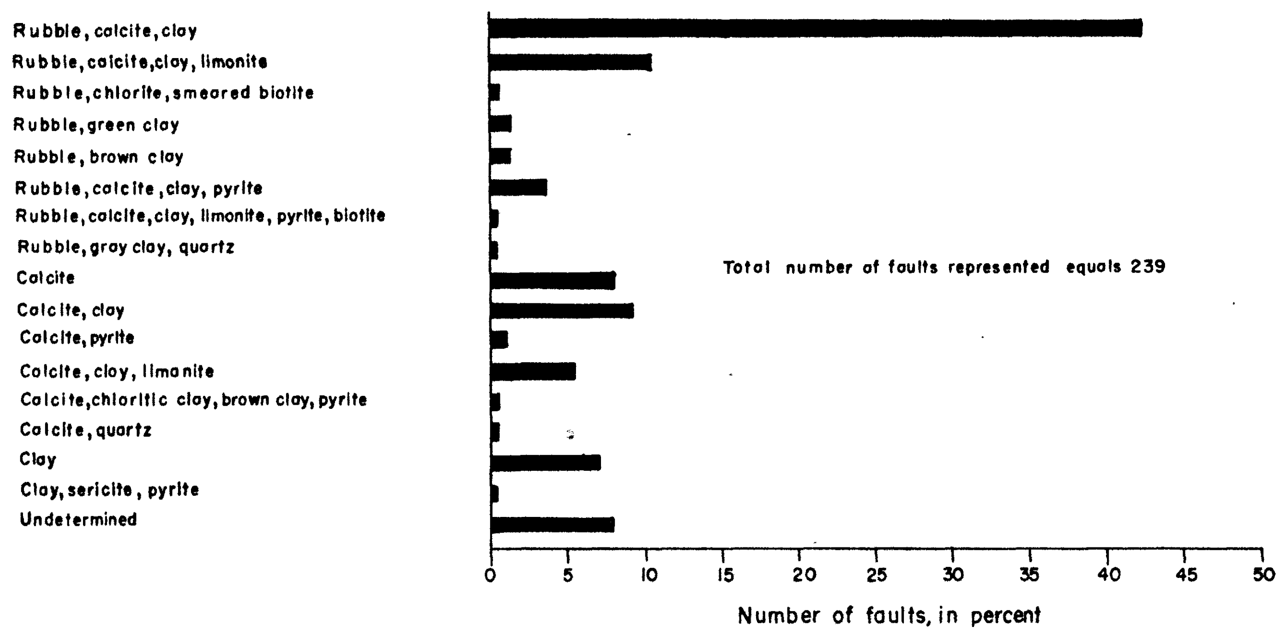

FIGURE 8-- Histogram showing types of fillings in faults in quartz monzonite and number of faults, in percent. (From W.L.Emerick, unpub. data, 1966.)

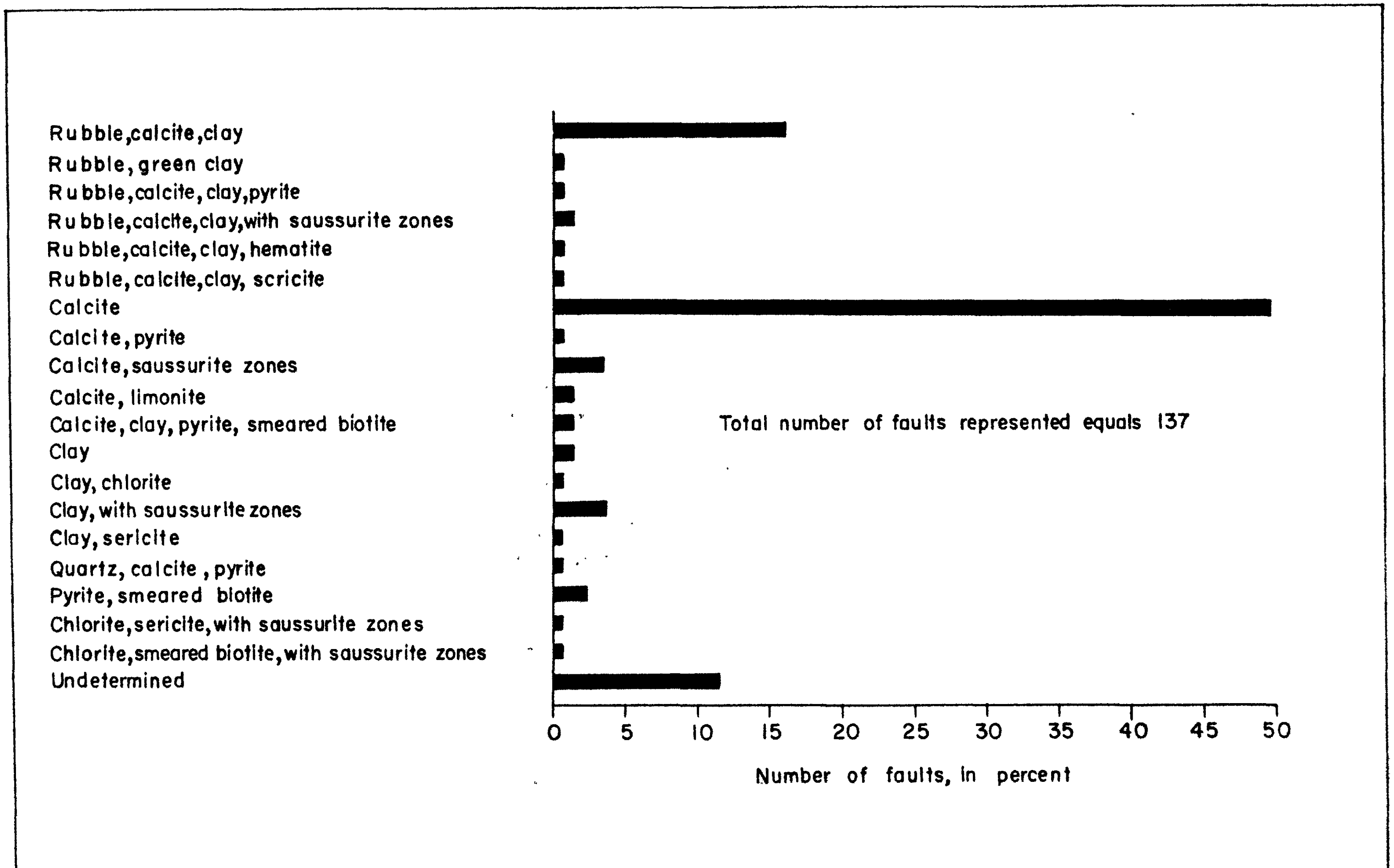

FIGURE 9-- Histogram showing types of fillings in faults in granodiorite and number of faults, in percent. (From W.L.Emerick, unpub, data, 1966.)

A nuclear device yielding approximately 5 kt (low yield) was detonated in the Hard Hat tunnel (fig. 5). The working point was located in a drill hole (U15a, U15a#31; hole diameter reamed down to 963 feet (294 m)) 181 feet (55 m) horizontally and 89 feet (27 m) vertically below the end of the Hard Hat tunnel. The effects from the event were mapped by W. L. Emerick, R. P. Snyder, and W. E. Bowers (written commun., 1962).

SELECTED REFERENCES

Allingham, J. W., and Zietz, Isidore, 1961, Geophysical data on the Climax stock, Nevada Test Site, Nye County, Nevada: U.S. Geol. Survey TEI-794, 24 p.

______1962, Geophysical data on the Climax stock, Nevada Test Site, Nye County, Nevada: Geophysics, v. 27, no. 5, p. 599-610.

Baker, J. H., Beetem, W. A., and Wahlberg, J. S., 1964, Adsorption equilibria between earth materials and radionuclides, Cape Thompson, Alaska: U.S. Geol. Survey Open-file Report, 40 p.

Barnes, Harley, Houser, F. N., and Poole, F. G., 1963, Geologic map of the Oak Spring quadrangle, Nye County, Nevada: U.S. Geol. Survey Geol. Quad. Map GQ-214.

Birch, Francis, and others, ed., 1942, Handbook of physical constants: Geol. Soc. America, Special Paper 36, 325 p.

Boardman, C. R., 1967, Results of an exploration into the top of the Pile Driver Chimney: Lawrence Livermore Lab., Livermore, Calif., Rept. UCRL-50385, 26 p.

Carr, W. J., 1974, Summary of tectonic and structural evidence for stress orientation at the Nevada Test Site: U.S. Geol. Survey Open-file Report 74-176, 53 p.

Carroll, R. D., and Scott, J. H., 1966, Uphole seismic measurements as an indication of stress relief in granitic rock tunnels: U.S. Geol. Survey Prof. Paper 550-D, p. D138-D143.

Daly, R. A., 1933, Igneous rocks and depth of the earth: McGraw-Hill, New York and London, 586 p.

Dixon, G. L., Sargent, K. A., and Carr, W. J., 1976, Abandonment of the Indian Trail Formation and distribution of certain equivalent ash-flow tuffs, eastern Nevada Test Site, in Changes in stratigraphic nomenclature by the U.S. Geological Survey, 1975: U.S. Geol. Survey Bull. 1422-A, p. A49-A54.

Ege, J. R., 1968, Stability index for underground structures in granitic rocks, in E. B. Eckel, Nevada Test Site: Geol. Soc. America Mem. 110, p. 185-250.

Gibbons, A. B., Hinrichs, E. N., Dickey, D. D., McKeown, F. A., Poole, F. G., and Houser, F. N., 1959, Engineering geology of test sites in granite and dolomite at Gold Meadows, Climax, and Dolomite Hill, Nevada Test Site, Nye County, Nevada--Preliminary report: U.S. Geol. Survey TEM-884, 42 p.

Gumper, F. J., and Scholz, Christopher, 1971, Microseismicity and tectonics of the Nevada seismic zone: Seismol. Soc. America Bull., v. 61, no. 5, p. 1413-1432.

Houser, F. N., 1961, Lithologic logs of three exploration core holes, U15b area, Climax stock, Nevada Test Site, Nye County, Nevada: U.S. Geol. Survey TEI-792, 67 p.

Houser, F. N., Davis, R. E., and Emerick, W. L., 1961, Geologic reconnaissance of granitic intrusive masses at Gold Meadows, Tem Piute, and Trappman's Camp, Lincoln and Nye Counties, Nevada, and comparison with the Climax stock of the Nevada Test Site: U.S. Geol. Survey TEI-793, 20 p.

Houser, F. N., and Poole, F. G., 1959a, "Granite" exploration hole, Area 15, Nevada Test Site, Nye County, Nevada--Interim report, Part A, Structural petrographic and chemical data: U.S. Geol. Survey TEM-836, 58 p.

Houser, F. N., and Poole, F. G., 1959b, Lithologic log and drilling information for the Marble Exploration Hole 3, U15 area, Nevada Test Site, Nye County, Nevada: U.S. Geol. Survey TEM-1031, 22 p.

______1960, Preliminary geologic map of the Climax stock and vicinity, Nye County, Nevada: U.S. Geol. Survey Misc. Inv. Map I-328.

______1961, Age relations of the Climax composite stock, Nevada Test Site, Nye County, Nevada, in Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424-B, p. B176-B177.

Izett, G. A., 1960, "Granite" exploration hole, Area 15, Nevada Test Site, Nye County, Nevada--Interim report, Part C, Physical properties: U.S. Geol. Survey TEM-836-C, 36 p.

Johnson, M. S., and Hibbard, D. E., 1957, Geology of the Atomic Energy Commission Nevada proving grounds area, Nevada: U.S. Geol. Survey Bull. 1021-K, p. 335-359.

Keough, D. D., and Wilkinson, W., 1967, DOD Piezoresistive stress-time transducer development and granite adiabat measurements for project Pile Driver: Defense Atomic Support Agency, DASA-2131, 100 p.

McKeown, F. A., and Wilmarth, V. R., 1959, Geology of the Marble Exploration Hole 4, Nevada Test Site, Nye County, Nevada: U.S. Geol. Survey TEM-1036, 26 p.

Obert, L., 1963, Operation Nougat, shot Hard Hat--Static stress determinations: Defense Atomic Support Agency, POR-1804 (WR-1804), 69 p.

______1964, In situ stresses in rock, Rainier Mesa, Nevada Test Site: Applied Physics Lab., U.S. Bur. Mines, College Park, Md., WT-1869, 95 p.

Preston, R. G., 1969, Some observations on the asymmetrical growth in the vertical direction of the Pile Driver cavity: Lawrence Livermore Lab., Livermore, Calif., UCID-15460, 10 p.

Price, C. E., 1960, "Granite" exploration hole, Area 15, Nevada Test Site, Nye County, Nevada--Interim report, Part B, Hydrologic data: U.S. Geol. Survey TEM-836-B, 20 p.

Rabb, D. D., 1970, Particle-size distribution study--Pile Driver event, in Symposium on engineering with nuclear explosives, v. 2, p. 888-908.

Sterrett, T. S., 1969, Drilling investigation of the lower part of the Pile Driver cavity: Lawrence Livermore Lab., Livermore, Calif., UCRL-50765, 20 p.

Walker, G. E., 1962, Ground water in the Climax stock, Nevada Test Site, Nye County, Nevada: U.S. Geol. Survey TEI-813, 48 p.