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U.S. GEOLOGICAL SURVEY INVESTIGATIONS IN THE U12n.03 DRIFT, RAINIER MESA, AREA 12, NEVADA TEST SITE

By

John R. Ege, R. D. Carroll, J. E. Magner, and D. R. Cunningham

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ABSTRACT

The U12n.03 drift was designed for a nuclear test site and mining was started on April 18, 1966, and completed May 22, 1967. The drift was driven along a bearing of N. 26° W. at an elevation of 1,849.2 m (6,067 ft) to a total length of 660.2 m (2,166 ft). The drift lies entirely within tunnel bed 4 of Tertiary age and crosses at nearly right angles, the Aqueduct syncline, a prominent geologic feature in Rainier Mesa. A combination of faults cutting nearly parallel to the drift, weak clay-rich tuff, and excessive ground water, all occurring in the trough of the syncline caused severe construction and support problems. These geologic factors created weak plastic rock that resulted in swelling and squeezing ground. Remedial measures were initiated that only temporarily stabilized ground and water conditions. The drift was eventually abandoned for the purposes of a nuclear test site and was subsequently used as a water storage facility.

The U.S. Geological Survey performed seismic velocity, electrical resistivity, and geologic surveys in the U12n.03 drift to provide information needed for site evaluation. Geophysical measurements were made in the interval CS 6+35 to CS 21+32. Seismic compressional-wave velocities range from 2,088 to 2,667 m/s (6,850 to 8,750 ft/s) and electrical resistivities range from 6.0 to 48 ohmmeters beneath a thin surface layer generally characterized by higher resistivities.

Electrical resistivity measurements indicate that sections of rock which may be potentially unstable for tunnel construction due to the presence of clay may be defined by this technique.

INTRODUCTION

The U12n.03 drift in Rainier Mesa, NTS (Nevada Test Site) (fig. 1) was investigated by the USGS (U.S. Geological Survey) over a decade ago as the proposed site of a Defense Atomic Support Agency (now Defense Nuclear Agency) nuclear weapon effects test. The drift was never utilized for its intended purpose; however, the data obtained are of value in light of the extensive clay-altered tuff encountered during mining. Consequently, these historical data are of value for both the observations connected with large intervals of pervasive clay alteration in tunnelling in Rainier Mesa as well as providing comparative data on clay-altered tuff at the NTS. Where the hindsight gained after many years of tunnelling in Rainier Mesa aids in amplifying observations in the U12n.03 drift, such data are also included in this report.

Mining of the U12n.03 drift started on April 18, 1966, and was completed May 22, 1967. The point of intersection of the U12n.03 portal is located at CS 32+42[1] in the U12n extension,

[1]CS 32+42 refers to construction stations in the tunnel complex in accordance with surveying practice and is measured in English units. To convert to meters, multiply 3242 by 0.3048.

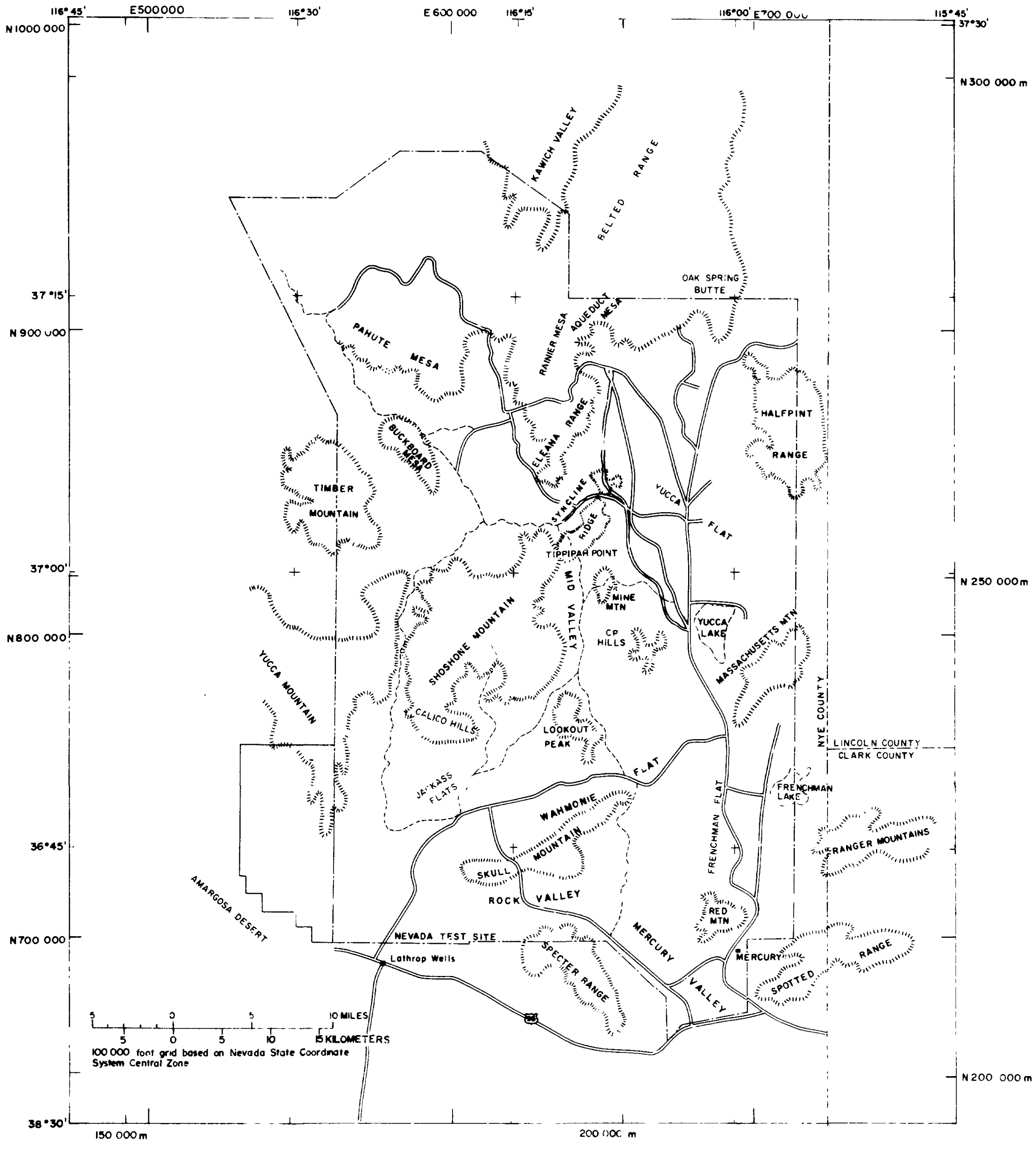

Figure 1.--Index map showing location of Rainier Mesa, Nevada Test Site.

Rainier Mesa, Nev. (fig. 2). The U12n.03 drift was driven N. 26° W. to a total length of 660.2 m (2,166 ft) at a 0.5 percent upward grade. The drift was not utilized for any nuclear tests.

D. L. Healey, C. H. Miller, and F. E. Currey provided the gravity data used to construct the pre-Tertiary surface structural contour map. F. M. Byers, Jr., R. P. Snyder, and D. R. Townsend (Fenix & Scisson, Inc.) mapped the surface geologic structures on Rainier Mesa over the U12n tunnel complex.

GEOLOGY

The U12n.03 drift passes through the Aqueduct syncline, a prominent feature in Rainier Mesa reflecting the deposition of volcanic tuff in an erosional valley in the pre-Tertiary rocks (Gibbons and others, 1963). The synclinal axis cuts the drift perpendicularly at CS 13+00, causing a repetition of the stratigraphic units on either side of the axis between the U12n.03 portal and the drift face (fig. 3, in pocket).

The stratigraphy found in Rainier Mesa is shown on figure 4. The U12n.03 drift lies entirely within tunnel bed 4 of Tertiary age, beginning at the portal in subunit 4AB (oldest), passing upsection to subunit 4K (youngest) in the synclinal axis and then proceeding downsection to subunit 4F at the face. The lithology is comprised of ash-fall tuff interbedded with reworked ash-fall tuff and tuffaceous sandstone. The tuff is bedded, zeolitized, and in places altered to a high percentage of clay.

There are two significant structural features that distinguish the U12n.03 drift: (1) a set of prominent northwest and north-northwest faults that cut the area surrounding the U12n.03 drift, and (2) a broad shallow syncline that trends about N. 65° E. The strike of the northwest faults intersects the drift at relatively low angles that range from 10° to 20° and can be best seen between CS 0+00 and CS 12+00. The axis of the syncline crosses the drift at nearly 90° near CS 13+00 feet.

Between CS 12+00 and CS 16+75 feet are yellowish-gray to yellowish-brown pumiceous tuff beds of subunit 4K. Some of the beds in 4K have been altered to an incompetent clayey, zeolitized, fully water-saturated tuff that has created heaving ground conditions in this interval. Incompetent spalling tuff obliterated most of the fault traces in the interval; however, it is inferred that a fault zone exists at around CS 17+00 feet. Beyond CS 17+00 the tuff becomes stronger and the proposed WP (working point) at CS 21+50 feet is in competent rock. No major faults were observed between CS 17+00 and CS 21+50. An exploratory core hole, U12n.03 UG-4, drilled 137.2 m (450 ft) ahead of the WP and parallel to the drift centerline, confirms that competent rock exists to CS 26+00 feet (fig. 5).

The surface structural map over the U12n.03 drift, shown on figure 6, locates the traces of three northwest-trending faults and the axis of the northwest-trending structural syncline. The pre-Tertiary surface below the U12n.03 drift is a broad north-northeast-trending valley having moderately steep sides. The northwest side of the valley, over which the drift lies, rises at about a 26 percent grade, or 15° slope. The drift starts above the center of the pre-Tertiary valley and then passes over its northwest side. The pre-Tertiary structure immediately below the drift is shown on figure 7. The distance between the drift and the

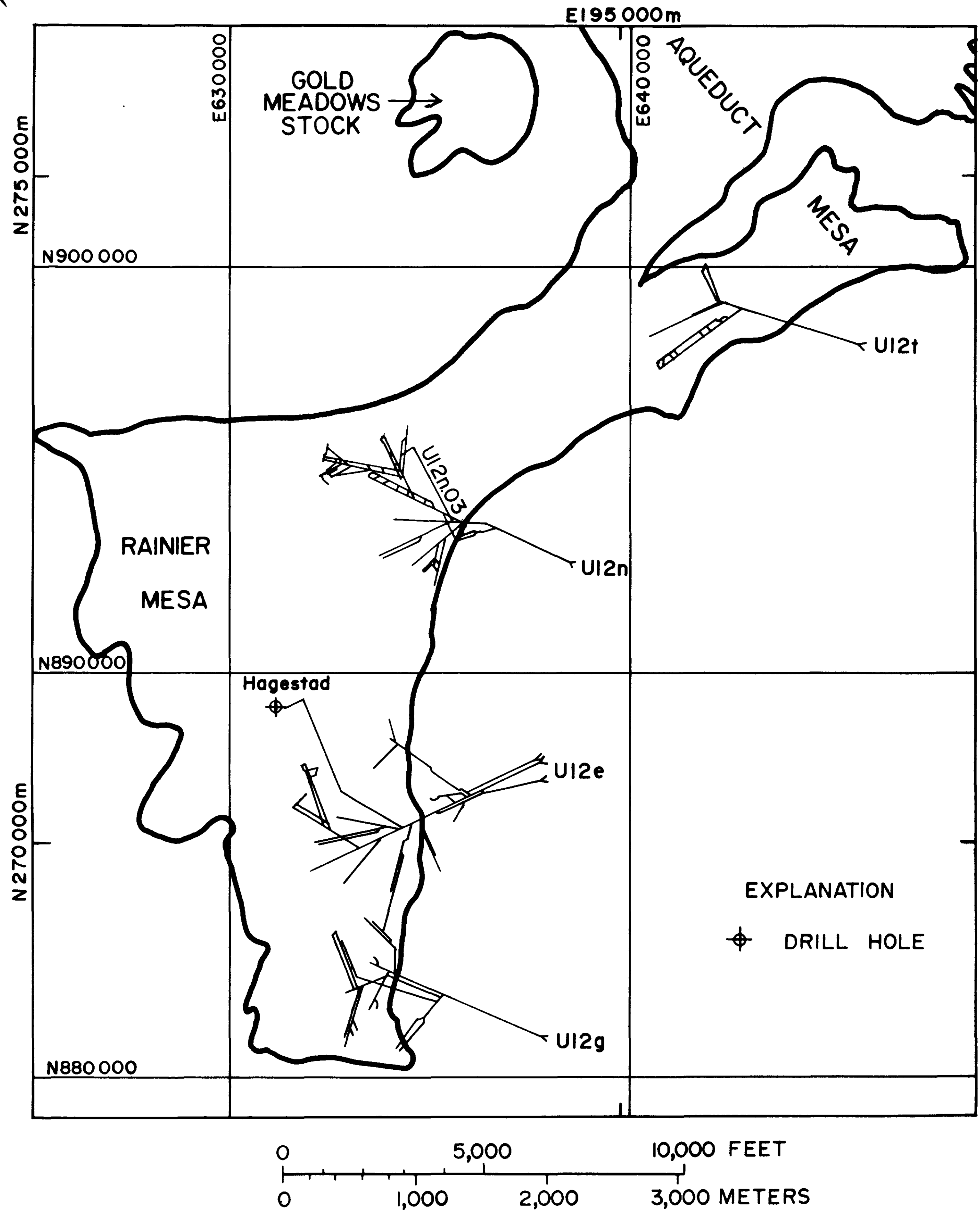

Figure 2.--Map showing location of U12n tunnel complex.

Era	System	Series	Formation	Member or unit and symbol
		Pliocene	Timber Mountain Tuff	Rainier Mesa Member Tmr
			Paintbrush Tuff	Tiva Canyon Member Tpc — Tp
			Stockade Wash Tuff	Tsw
			Bedded and ash-flow tuffs of Area 20	Trab
			Bedded tuff of Dead Horse Flat	Tdhb
			Belted Range Tuff	Grouse Canyon Member Tbg
			Tunnel beds	Unit 5 Tt5
CENOZOIC	Tertiary	Miocene		Unit 4 Tt4 Subunits AB, CD, E, F, G, H, J, K[1]
				Unit 3 Tt3 Subunits A, BC, D[2]
			Belted Range Tuff	Tub Spring Member Tbt
			Tunnel beds	Unit 2 Tt2
			Crater Flat Tuff	Tcf
			Tunnel beds	Unit 1 Tt1
			Redrock Valley Tuff	Trv
			Older tuffs	Tot
			Paleocolluvium	Tc
MESOZOIC	Cretaceous		Gold Meadows stock	Kqm
PALEOZOIC	Devovian Silurian Ordovician Cambrian		Paleozoic rocks, undivided	Pz[3]
			Wood Canyon Formation	€p€w — p€[3]
PRECAMBRIAN			Stirling Quartzite	p€s

[1]K is the youngest.
[2]D is the youngest.
[3]In some drill holes, paleocolluvium of Tertiary age (Tc) rests on Paleozoic or Precambrian rocks.

Figure 4.--General stratigraphy of Rainier Mesa area, Nevada Test Site.

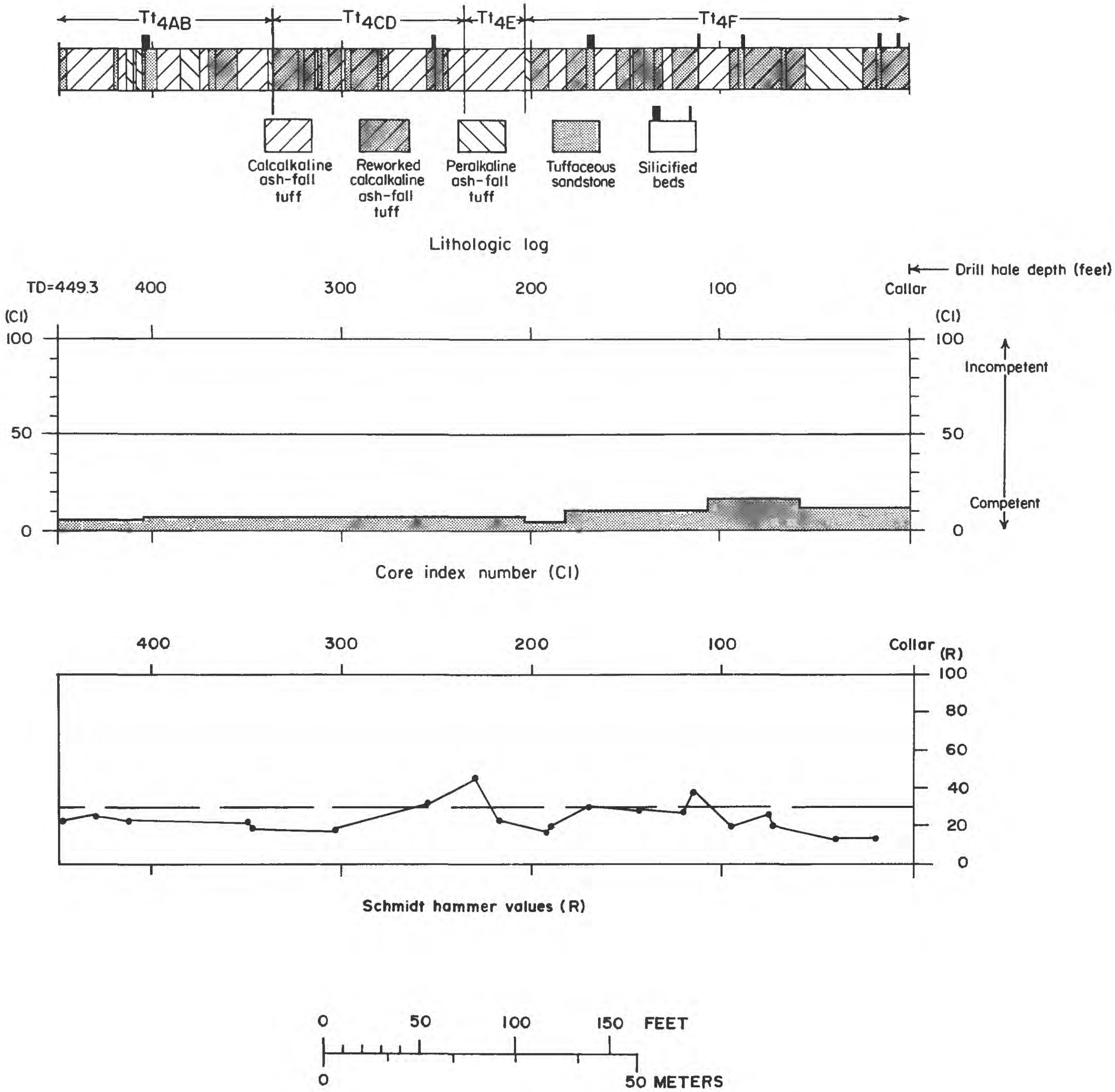

Figure 5.--Geology of the U12n.03 UG-4 drill hole.

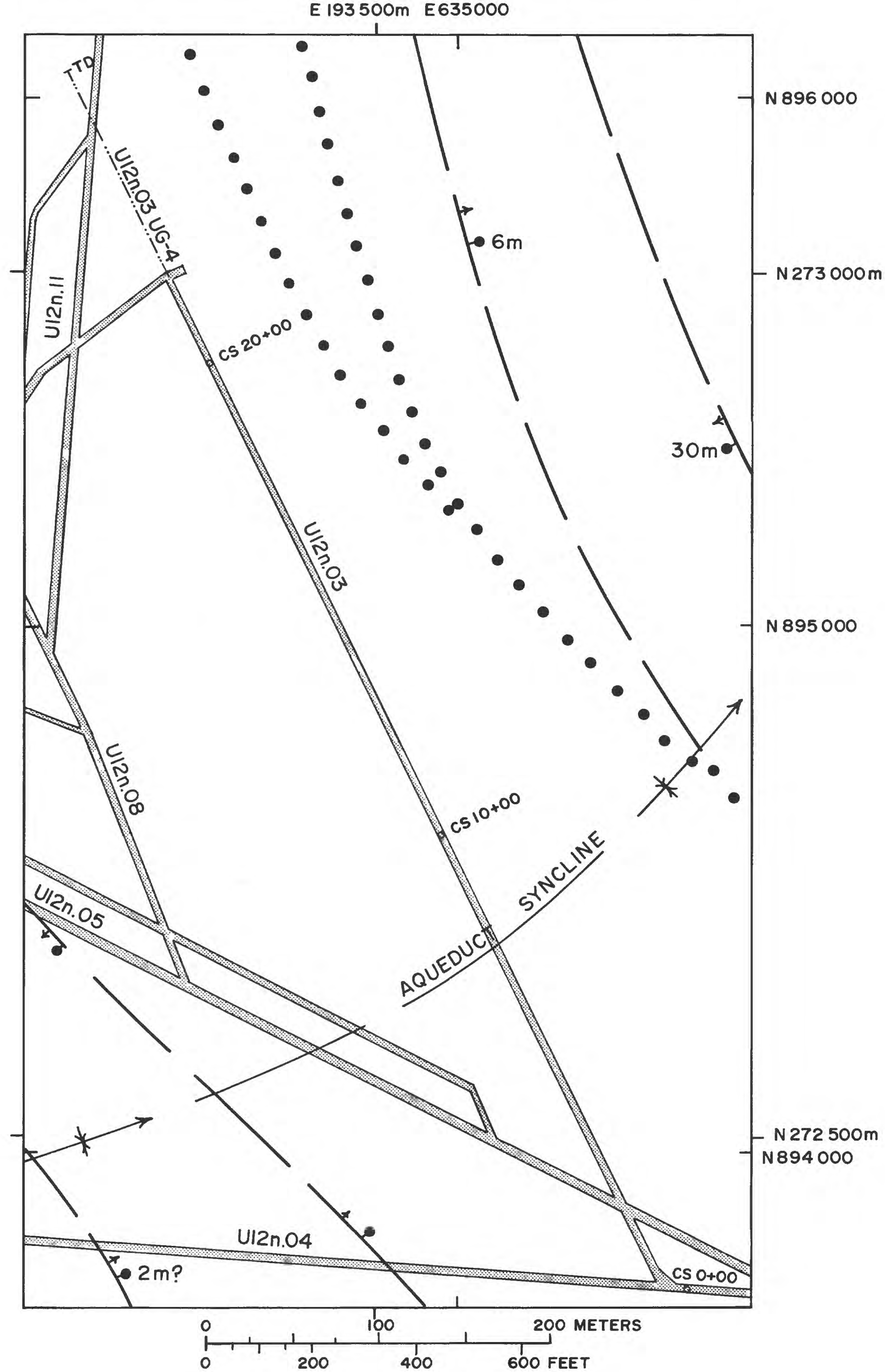

Figure 6.--Surface structure over the U12n.03 drift.

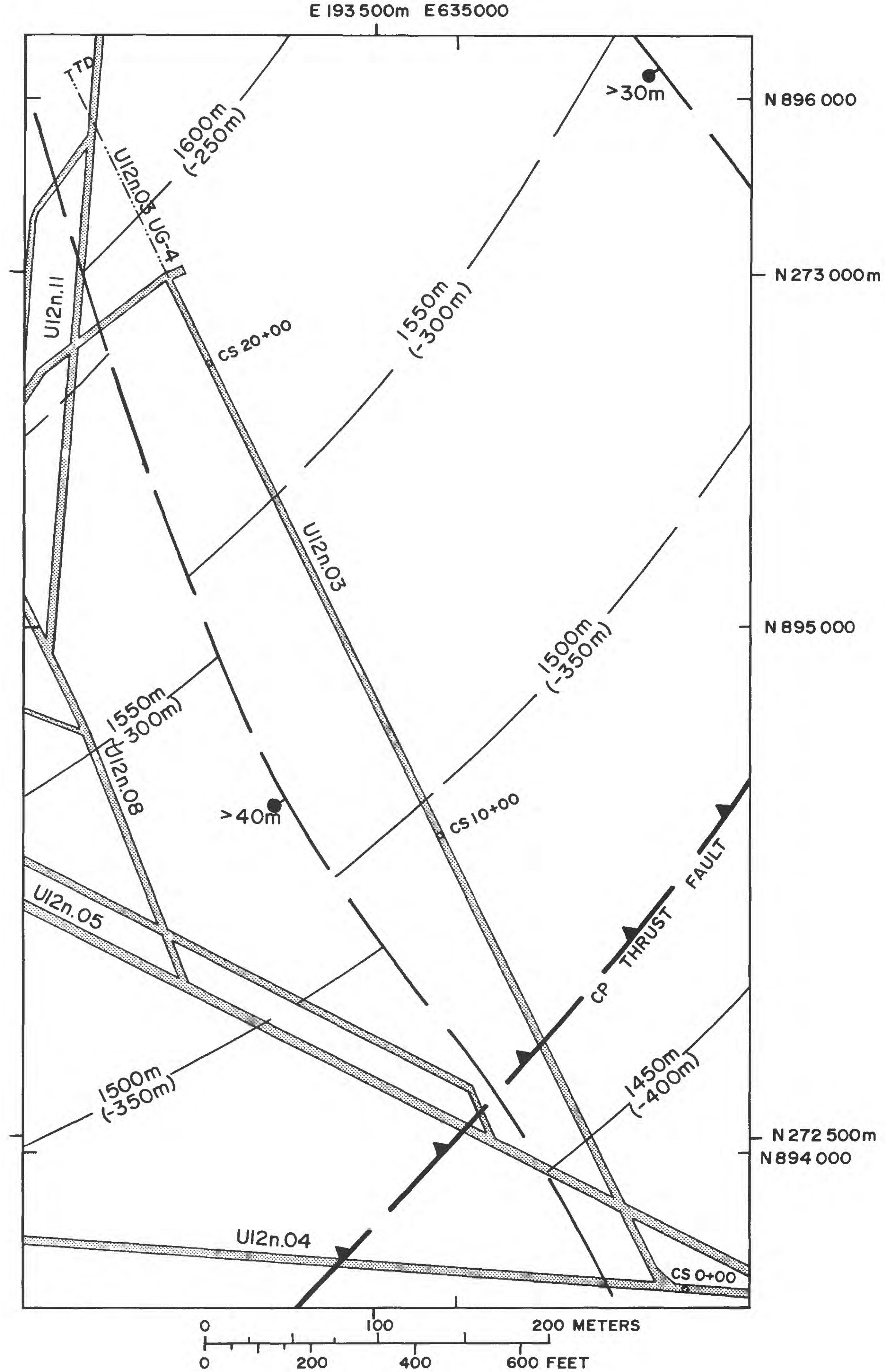

Figure 7.--Pre-Tertiary surface below the U12n.03 drift.

pre-Tertiary surface below it ranges between greater than 304.8 m (1,000 ft) at the portal to approximately 260 m (852 ft) at the face of the drift. The pre-Tertiary CP thrust fault lies beneath the drift at about CS 5+35. This fault thrusted an older quartzite block from the west over a younger dolomite surface.

ENGINEERING GEOLOGY

A combination of weak clay-rich tuff, ground water that collected in the syncline, and faults that parallel the drift alinement created very weak rock and unstable ground conditions in the U12n.03 drift. On July 5, 1966, "heavy ground" was first reported in the vicinity of CS 12+00, and squeezing and swelling ground conditions continued during mining to CS 15+25. The interval of unstable rock is in a strongly faulted zone of tunnel bed subunit 4K that lies in the trough of the syncline (fig. 3). Ground water in this zone seeped into the drift along joint and fault planes in quantities as much as 18.9 L/min (5 gal/min).

Tunnel bed subunit 4K consists of thin-bedded to massive yellowish-gray to moderate-reddish-brown ash-fall and reworked ash-fall tuff and minor amounts of tuffaceous sandstone. In the interval between CS 10+00 and CS 16+75, the tuff of subunit 4K has been strongly altered to clay through the action of the ground water that collected in the synclinal region. X-ray crystallographic analyses of core samples taken from the U12n.03 UG-7 boring at CS 14+87 indicated the presence of calcium-montmorillonite clay, a clay mineral that readily expands with the addition of water (table 1). Atterburg consistency limits were also determined for a sample taken from the U12n.03 UG-7 core hole. The results gave a liquid limit (LL) of 48, a plastic limit (PL) of 29, and a plasticity index (PI) of 19. These values indicate a highly plastic rock.

The U12n.03 drift was mined nearly parallel to a series of faults that intersect it between CS 0+00 and CS 15+00. This geometry creates unstable underground conditions in terms of geologic structures. Moreover, the drift instability is further increased in the synclinal trough where the fault system cut the very weak clay-rich tuff of subunit 4K.

During a 2-week period in the summer of 1966, measurements made of track and set movements after mining between CS 11+99 and CS 15+25 showed displacements as much as 91.4 cm (36 in). The cause for this squeezing can be attributed to plastic flow and swelling of the clayey tuff. The circumferential stresses in the drift walls, back, and invert are related to the in situ stress in the rock medium. The depth to drift level from the surface is about 335.3 m (1,100 ft). The bulk density of tuff above the U12n.03 drift is estimated at 1.85 g/cm^3 (115 lb/ft^3) which yields a figure of nearly 62 bars (900 lb/in^2) for the free-field vertical stress at drift level. The stress concentration factor around the drift ranges between 2 and 3. Using the arbitrary factor of 2.5, the circumferential stress in the walls due to assumed overburden stresses becomes nearly 155 bars (2,250 lb/in^2), a value that exceeds the tested compressive strength of the rock from the syncline (table 2). The stresses generated by the clay moving into the tunnel were reportedly sufficient to pop rock-bolt plates.

Table 1.--X-ray crystallographic analyses of core samples from the U12n.03 UG-7 drill hole

[Listed as parts in ten; tr=trace=<5 percent; <1=5-9 percent; analyses by U.S. Geological Survey laboratory]

Sample depth (m)	Rock unit	Montmorillonite	Illite-mica	Clinoptilolite	Quartz	Feldspar	Cristobalite (opaline silica)	Carbonate (acid reaction)	Amorphous (ash)
9.1	Tt 4K	~25 percent illite mixed layers 4+	tr	<1	tr	2+	<1	tr	1+
23.7	Tt 4K	20-30 percent illite mixed layers 2+	tr	2+	tr	3	<1	tr	1+
28.7	Tt 4K	20-30 percent illite mixed layers 3+	tr	1+	tr	2+	<1	tr	1

Table 2.--Natural-state physical properties of tuff samples from the U12n.03 UG-3 vertical (down) core hole. The hole is located at CS 16+00 in the U12n.03 drift

[Leaders, ---, indicate no data]

Sample depth (meters)	Rock unit	Density (g/cm^3)	Unconfined compressive strength (kbars)	Static Young's modulus (kbars)
1.5	Tt 4K	2.10	26.5	1.4
6.6	Tt 4J	1.90	81.4	11.7
6.8	Tt 4J	1.97	109.5	---
6.9	Tt 4J	1.95	83.8	---
11.2	Tt 4J	1.91	67.4	9.6
11.2	Tt 4J	1.89	85.7	15.9
13.7	Tt 4J	1.86	145.5	---
14.6	Tt 4J	1.91	19.9	---
15.1	Tt 4J	1.92	93.1	---
17.5	Tt 4J	1.92	158.6	24.1
18.4	Tt 4J	1.89	142.7	---
18.4	Tt 4J	1.91	150.3	---

GROUND-WATER INFLOW AT PROPOSED WORKING POINT

On September 21, 1966, ground water was encountered flowing from fractures in the face of the drift at the invert. Initial flow was measured at 208 L/min (55 gal/min). After 10 days of dewatering the rate of flow decreased to 151 L/min (40 gal/min); after 50 days the rate of flow was 95 L/min (25 gal/min). The water apparently was coming from a fracture zone at shallow depth below the invert that cut the drift at an angle of 60° and dipped 75°-90° toward the portal. Three 2.5-7.6 cm (1-3 in.) wide fractures were observed issuing water. A sump was dug through the aquifer zone and water pumped at varying rates ranging between 151 L/min and 227 L/min (40 and 60 gal/min). On January 3, 1968, after several months of pumping, the flow rate was measured at 30 L/min (8 gal/min). A bulkhead was subsequently constructed at the entrance of the drift and the drift used as a water supply for many years. The drift was reentered in 1979 for a limited distance at both ends during investigations in connection with the U12n.11 (Miners Iron) site. In April 1979, a weir installed at the WP end of the U12n.03 drift indicated the flow rate had reduced to approximately 1.3 L/min (0.35 gal/min) (Mark Henne, Desert Research Institute, oral commun.).

PHYSICAL AND CHEMICAL PROPERTIES

Physical properties, chemical, and semiquantitative spectrographic analyses were run on core and grab samples taken from drill holes in the U12n.03 drift (tables 2-4, 8-9). Lithologic and engineering logs of U12n.03 drill cores are shown on figure 5 and tables 5-7. Chemical and semiquantitative spectrographic analyses of water samples collected September 30, 1966, from the face of the drift are listed in tables 10-13.

GEOPHYSICAL SURVEYS

Seismic Velocity Survey

Compressional-wave velocity measurements were made in the interval from CS 6+35 to CS 21+32 along the east invert of the drift using a 12-trace portable refraction seismograph (Porta-seis model ER-75-12[2]). The reversed-profile method of shooting was used, in which geophones are arranged in a straight line and dynamite detonated at alternate ends of the line. Five geophone lines were used with the standard 12 geophones per line (fig. 8, in pocket). Four lines were utilized with geophones on 7.6-m (25-ft) centers. A fifth line, with geophones on 6.1-m (20 ft) centers, was used in the interval CS 9+70 to CS 12+20 to obtain greater detail in the area of a proposed overburden plug. Geophones were placed in shallow holes dug in the fill material of the drift floor to a depth where compact fill was reached within a foot of bedrock. Shotholes were drilled to a depth of 1.5 m (5 ft) at the ends of the individual geophone lines, and at offset distances of approximately 61.0 m (200 ft) beyond one spread. This was done to check if any high-velocity horizon might exist

[2]Use of brand name is for identification purposes and does not necessarily constitute endorsement by the U.S. Geological Survey.

Table 3.--Chemical analysis of core samples from U12n.03 UG-7 drill hole

[U.S. Geological Survey laboratory; H_2O-: water loss at temperature <110°C; H_2O+: water loss at temperature >110°C]

Sample depth (m)	Sample depth (ft)	Rock unit	SiO_2 (percent)	Al_2O_3 (percent)	Fe_2O_3 (percent)	FeO (percent)	MgO (percent)	CaO (percent)	N_2O (percent)	K_2O (percent)	H_2O- (percent)	H_2O+ (percent)	TiO_2 (percent)	P_2O_5 (percent)	MnO (percent)	CO_2 (percent)
3.05	10	Tt 4K	56.2	15.2	5.5	0.28	1.9	4.2	1.9	2.2	7.4	3.9	0.93	0.27	0.07	<0.05
9.45	31	Tt 4K	55.3	16.6	5.8	.44	2.0	4.3	2.1	1.8	6.4	4.0	.90	.27	.00	<.05
15.85	52	Tt 4K	53.6	15.8	8.2	.88	3.0	4.9	2.2	1.7	4.3	3.5	1.3	.28	.00	<.05
21.03	69	Tt 4K	57.8	16.2	4.7	.32	1.8	3.8	2.1	2.2	5.1	4.6	.84	.20	.00	<.05
27.43	90	Tt 4K	58.5	15.6	4.9	.36	1.6	4.1	2.1	2.5	4.5	4.7	.86	.19	.06	<.05

Table 4.--Semiquantitative spectrographic analysis of core samples from the U12n.07 UG-3 drill hole

[U.S. Geological Survey laboratory]

Sample depth (m)	Sample depth (ft)	Rock unit	Ba (percent)	Be (percent)	Ce (percent)	Co (percent)	Cr (percent)	Cu (percent)	Ga (percent)	La (percent)	Nb (percent)	Ni (percent)	Pb (percent)	Sc (percent)	Sr (percent)	V (percent)	Y (percent)	Yb (percent)	Zn (percent)	Nd (percent)
3.05	10	Tt 4K	0.07	0.0003	0.02	0.001	0.002	0.001	0.0015	0.015	0.0007	0.001	0.0007	0.0007	0.05	0.003	0.0015	0.00015	0.02	0.015
9.45	31	Tt 4K	.07	.0002	.02	.0005	.002	.0015	.0015	.015	.0007	.001	.0007	.001	.07	.003	.0015	.00015	.02	.015
15.85	52	Tt 4K	.1	.0002	.03	.0015	.002	.0005	.0015	.02	.0005	0	.0015	.0015	.1	.01	.003	.0003	.03	.02
21.03	69	Tt 4K	.1	.0002	.02	.001	.001	.0007	.0015	.015	.0007	0	.0015	.0007	.1	.005	.0015	.00015	.02	.015
27.43	90	Tt 4K	.1	.0003	.02	.0007	.0007	.0005	.0015	.015	.0007	0	.0007	.0007	.07	.005	.002	.0002	.02	.015

Table 5.--Lithologic log of the U12n.03 UG-2 drill hole

Description	Thickness of interval meters (feet)		Depth to base of interval meters (feet)	
Tunnel beds, unit 4				
Subunit 4G				
Tuff, calc-alkaline ash-fall, grayish-orange-pink; core disks into 7.6-cm (3-in.) segments-------------	1.22	(4)	1.22	(4)
Subunit 4F				
Tuff, calc-alkaline ash-fall, very light gray to yellowish-gray; contains light-gray pumice (6 mm, 0.25 in.) and sparse black lithic fragments (3 mm, 0.12 in.). Silicified layer at top of unit--	9.30	(30.5)	10.52	(34.5)
Tuff, calc-alkaline (and peralkaline?) ash-fall, moderate-reddish-brown and pale-yellowish-brown; contains sparse to common pumice (3-6 mm, 0.12-0.25 in.) and sparse black lithic fragments (<3 mm, <0.12 in.)----------------------------------	2.59	(8.5)	13.11	(43)
Tuff, calc-alkaline (reworked?) ash-fall, very light gray to yellowish-gray; contains sparse pumice and abundant black lithic fragments (3-10 mm, 0.12-0.5 in.), salt-and-pepper texture-----------------------	5.49	(18)	18.60	(61)
Total depth--------			18.60	(61)

Table 6.--Lithologic log of U12n.03 UG-4 drill hole

Description	Thickness of interval meters (feet)	Depth to base of interval meters (feet)
Tunnel bed 4		
Subunit 4F		
Tuff, calc-alkaline reworked ash-fall, scattered tuffaceous sandstone, and peralkaline ash-fall, grayish-yellow, very pale orange and scattered pale-reddish-brown and light-red; zeolitized, thick- to thin-bedded lithic fragments (1-10 mm), salt-and-pepper texture between 17.68-32.31 m (58-106 ft) and 55.47-61.87 m (182-203 ft), silicified beds at 1.83 m (6 ft), 4.88 m (16 ft), 25.52 m (87 ft), 33.83 m (111 ft), and 50.60-51.51 m (166-169 ft)-----------------------------------	61.87 (203)	71.87 (203)
Subunit 4E		
Tuff, calc-alkaline ash-fall, pale-reddish-brown; zeolitized, thick bedded, fine texture----------	9.76 (32)	71.63 (235)
Subunit 4CD		
Tuff, calc-alkaline reworked ash-fall, ash-fall and tuffaceous sandstone, very pale orange to grayish-yellow; thick- to thin-bedded, zeolitized, slightly friable, silicified layer at 76.50 m (251 ft)----------------------------	31.09 (102)	102.72 (337)
Subunit 4AB		
Tuff, calc-alkaline ash-fall, reworked ash-fall, tuffaceous sandstone and peralkaline ash-fall, grayish-yellow and moderate-reddish-brown; generally coarse textured, massive to thin bedded, silicified between 122.53-123.45 m (402-405 ft)-----------------------------------	34.23 (112.3)	136.95 (449.3)
Total depth----------		136.95 (449.3)

Table 7.--Lithologic log of the U12n.03 UG-7 drill hole

Description	Thickness of interval meters (feet)	Depth to base of interval meters (feet)
Tunnel beds, unit 4		
Subunit 4K		
Tuff, calc-alkaline ash-fall, light-brown to pale-yellowish-brown; contains abundant very light gray argillized pumice fragments (5-25 mm); core is intensely altered to clay and is incompetent------------------------	29.60 (97.1)	29.60 (97.1)
Total depth------------		29.60 (97.1)

Table 8.--Physical properties of core samples from the U12n.03 UG-4 drill hole

[Analyses by U.S. Geological Survey laboratory; leaders, ---, indicate no data]

		Density					Static [Measurements made on as-received and dry core]					Sonic [Measurements made on as-received and dry core]					
Sample depth (meters)	Rock unit	Dry bulk (g/cm^3)	Grain[1] (g/cm^3)	Saturated[1] (g/cm^3)	Porosity[1] (percent)	Shore hardness[2]	Unconfined compressive strength (kbars)	Young's modulus secant (kbars)	Shear modulus (kbars)	Bulk modulus (kbars)	Poisson's ratio	Compressional velocity (m/s)	Shear velocity (m/s)	Young's modulus (kbars)	Shear modulus (kbars)	Bulk modulus (kbars)	Poisson's ratio
5.8	Tt4F	1.44	2.30	1.81	37	14	---	---	---	---	---	2,431	1,463	94	39	55	0.21
							---	---	---	---	---	[2]1,954	[2]1,222	[2]51	[2]21	[2]27	[2].18
12.2	Tt4F	1.34	2.17	1.71	38	14	103.4	23	9	21	0.32	2,402	1,393	83	33	54	.25
							[2]168.9	[2]47	[2]21	[2]22	[2].15	[2]2,125	[2]1,450	[2]60	[2]28	[2]23	[2].07
22.6	Tt4F	1.48	2.21	1.81	33	20	---	---	---	---	---	2,640	1,353	88	33	82	.32
							[2]717.0	[2]203	[2]85	[2]109	[2].19	[2]2,431	[2]1,440	[2]67	[2]30	[2]28	[2].09
22.9	Tt4F	1.56	2.20	1.85	29.	26	---	---	---	---	---	2,635	1,058	58	21	101	.40
							---	---	---	---	---	[2]2,478	[2]1,706	[2]95	[2]46	[2]35	[2].05
29.0	Tt4F	1.49	2.24	1.82	34	20	---	---	---	---	---	2,618	1,682	119	52	57	.15
							[2]248.2	[2]57	[2]25	[2]26	[2].14	[2]2,378	[2]1,547	[2]81	[2]35	[2]37	[2].14
35.1	Tt4F	1.66	2.16	1.90	23	37	---	---	---	---	---	3,078	1,807	154	62	97	.24
							---	---	---	---	---	[2]2,753	[2]1,838	[2]123	[2]56	[2]51	[2].10
36.6	Tt4F	1.51	2.21	1.83	32	27	---	---	---	---	---	2,850	---	---	---	---	---
							---	---	---	---	---	[2]2,370	[2]1,635	[2]85	[2]41	[2]32	[2].05
43.9	Tt4F	1.60	2.15	1.86	26	29	144.8	50	22	23	.13	2,935	1,737	138	56	85	.23
							---	---	---	---	---	[2]2,285	[2]1,608	[2]84	[2]41	[2]28	[2].01
51.8	Tt4F	1.51	1.90	1.72	20	30	179.3	65	26	45	.26	2,621	1,024	51	18	94	.41
							---	---	---	---	---	[2]2,206	[2]1,302	[2]63	[2]26	[2]39	[2].23
57.9	Tt4F	1.40	2.17	1.75	36	20	---	---	---	---	---	2,691	1,460	97	37	77	.29
							---	---	---	---	---	[2]2,061	[2]1,407	[2]59	[2]28	[2]23	[2].06
58.5	Tt4F	1.27	2.16	1.68	41	16	---	---	---	---	---	2,466	1,457	88	36	54	.23
							[2]55.2	[2]58	[2]23	[2]36	[2].23	[2]2,152	[2]1,485	[2]59	[2]28	[2]22	[2].05
66.4	Tt4E	1.67	2.29	1.94	27	23	---	---	---	---	---	2,777	1,777	141	61	68	.15
							[2]1,378.9?	[2]121	[2]55	[2]50	[2].10	[2]2,589	[2]1,712	[2]109	[2]49	[2]47	[2].11
76.2	Tt4CD	1.83	2.22	2.01	18	45	617.1	177	74	98	.20	3,664	1,951	199	77	168	.30
							---	---	---	---	---	[2]3,137	[2]2,169	[2]180	[2]85	[2]67	[2].05
77.7	Tt4CD	1.70	2.35	1.98	28	31	---	---	---	---	---	3,042	1,807	159	65	97	.23
							---	---	---	---	---	[2]2,832	[2]2,000	[2]136	[2]68	[2]46	[2].01
92.7	Tt4CD	1.53	2.28	1.86	33	18	---	---	---	---	---	2,765	1,719	130	55	69	.19
							[2]668.8	[2]196	[2]90	[2]81	[2].10	[2]2,412	[2]1,610	[2]87	[2]39	[2]37	[2].10
105.8	Tt4AB	1.58	2.33	1.91	33	19	137.9	42	17	29	.26	2,450	---	---	---	---	---
							---	---	---	---	---	[2]2,256	[2]1,452	[2]75	[2]33	[2]35	[2].14
106.7	Tt4AB	1.60	2.31	1.91	31	23	---	---	---	---	---	2,770	---	---	---	---	---
							---	---	---	---	---	[2]2,436	[2]1,523	[2]88	[2]37	[2]46	[2].18
125.9	Tt4AB	1.40	2.18	1.78	36	23	---	---	---	---	---	2,496	1,622	106	47	48	.14
							---	---	---	---	---	[2]2,456	[2]1,477	[2]75	[2]31	[2]45	[2].22
131.1	Tt4AB	1.54	2.23	1.85	31	25	193.1	68	29	36	.18	2,679	1,716	125	54	60	.15
							---	---	---	---	---	[2]2,492	[2]1,570	[2]90	[2]39	[2]47	[2].18
136.2	Tt4AB	1.54	2.19	1.84	30	22	---	---	---	---	---	2,687	1,146	67	24	101	.39
							[2]951.5	[2]216	[2]97	[2]92	[2].11	[2]2,467	[2]1,570	[2]89	[2]38	[2]45	[2].17

[1] Measured by kerosene-saturated method.
[2] Measured on dry core.

(page 19 in back of report--Table 9)

Table 10.--Chemical analysis of water sample from U12n.03 drift

U. S. DEPT. OF THE INTERIOR -- GEOLOGICAL SURVEY
Statement of Water Analysis

Source U12n.03 tunnel
Location NW of Mercury, Nye Co., Nevada N 892,739 E 638,485
¼ ¼ Sec T R Field Office No.

Date col. 9-30-66 Time 1100 P.d.t.
Col. by J. E. Weir
Field detns: Temp (°F) 68 pH
Sp. Cond. (µmhos) Eh
Appearance Clear

Well Type Use
Depth (ft.) Cased to
Diam. (in.) Date drilled
Water level (ft.)
Discharge
W. B. F.
Owner

Chemical components	ppm	epm
Silica (SiO_2)	51	
Aluminum (Al) 1/	.02	
Iron (Fe) 1/	.00	
Manganese (Mn) 1/	<.01	
Calcium (Ca)	1.1	0.05
Magnesium (Mg)	.2	.02
Strontium (Sr)	.02	.00
Sodium (Na)	51	2.22
Potassium (K)	2.8	.07
Lithium(Li)	.030	.00
Zinc (Zn)	<.01	
Copper (Cu)	<.01	
Selenium (Se)	.01	
Cations (epm)		2.36

1/ In solution at time of analysis.

	ppm	epm
Bicarbonate (HCO_3)	110	1.80
Carbonate (CO_3)	0	.00
Sulfate (SO_4)	12	.25
Chloride (Cl)	9.6	.27
Fluoride (F)	.3	.02
Nitrate (NO_3)	1.3	.02
Phosphate (PO_4)	.00	
Boron (B)	.08	
Anions (epm)		2.36

Physical characteristics and computed values	
Dissolved Solids (ppm)	
Res. on evap. at 180°C	180
Calculated	183
Suspended solids (ppm)	
Hardness as $CaCO_3$ (ppm)	
Total	4
Non-carbonate	0
Specific conductance (µmhos at 25°C)	230
pH	8.0
Color	
Percent sodium	94
SAR	12

Remarks:

Lab. No. 67-180 Analysts G. F. Scarbro Date Checked 12-9-66

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Table 11.--Radiochemical analysis of water sample from U12n.03 drift

U. S. DEPT. OF THE INTERIOR--GEOLOGICAL SURVEY
Statement of Water Analysis - Radiochemical

Source U12n.03 tunnel
Location NW of Mercury, Nye Co., Nevada N 892,739 E 638,485
1/4 1/4 1/4 Sec T R Field/Office No.

Date Col. 9-30-66 Time 1100 P.d.t.
Col. By J. E. Weir
Field detns: Temp. (°F) 68 pH
Sp. Cond. (µmhos) Eh
Appearance Clear

Well Type Use
Depth (ft) Cased to
Diam. (in) Date Drilled
Water level (ft)
Discharge
W.B.F.

Owner

Elements	pc/l	pc/g	Date determined
Uranium µg/l			
Radium as Ra^{226}			
Gross β (as Sr^{90} - Y^{90})	2.9		10-28-66
Gross α as U equivalent µg/l	5.5		10-28-66
Net extr. α, U equivalent µg/l			
Gross γ (as Cs^{137})			
$Strontium^{90}$ *			
Gross gamma scan			

Isotopic Analysis	
$Barium-lanthanum^{140}$	
$Cerium-praseodymium^{144}$	
$Cesium^{137}$	
$Chromium^{57}$	
$Cobalt^{60}$	
$Ruthenium-rhodium^{106}$	
Tritium µc/ml	
$Zinc^{65}$	
$Zirconium-niobium^{95}$	

Date sample received 10-6-66
Date data released
Program classification

Analyst R.S.D.
Date checked 11-4-66
Checked by V.J.J.

***Analyzed only when indicated by gross β count.**

Revised 3-24-66

Table 12.--Spectrographic analysis of water sample from U12n.03 drift

U. S. DEPT. OF THE INTERIOR -- GEOLOGICAL SURVEY
Statement of Water Analysis - Spectrographic

Source: U12n.03 tunnel

Location: NW of Mercury, Nye Co., Nevada N 902,730 E 638,485

¼ ¼ ¼ Sec T R Field/Office No.

Date Col. 9-30-66 Time 1100 P.d.t.
Col. By J. E. Weir
Field dems: Temp. (°F) 68 pH
Sp. Cond. (µmhos) Eh
Appearance Clear

Well Type Use
Depth (ft) Cased to
Diam. (in.) Date drilled
Water level (ft.)
Discharge
W.B.F.

Owner

Element	µg/l	Element	µg/l
Aluminum (Al)	17	Strontium (Sr)	6
Barium (Ba)	5	Tin (Sn)	ND
Beryllium (Be)	<3	Titanium (Ti)	<5
Boron (B)	80	Vanadium (V)	<5
Chromium (Cr)	<5	Ytterbium (Yb)	--
Cobalt (Co)	<5	Yttrium (Y)	--
Copper (Cu)	<2	Zinc (Zn)	ND
Iron (Fe)	25	Zirconium (Zr)	ND
Lanthanum (La)	--		
Lead (Pb)	<5		
Lithium (Li)	--		
Manganese (Mn)	<4		
Molybdenum (Mo)	<2		
Nickel (Ni)	<5		
Phosphorus (P)	--		
Rubidium (Rb)	--		
Scandium (Sc)	--	Dissolved solids	
Silver (Ag)	<.7	R.O. E. at 180° C	246
		Acidified (HNO_3) sample	

-- Not determined
< Detected, but less than figure shown

ND Specifically sought, not detected.
X Semiquantitative estimate in the digit order shown

Additional elements specifically sought but not detected by methods used:

~~As~~ ~~Au~~ Bi Cd ~~Ce~~ ~~Os~~ ~~Pd~~ ~~Pr~~ ~~Pt~~ ~~Re~~
~~Cs~~ ~~Dy~~ ~~Er~~ ~~Eu~~ Ga Ge ~~Rh~~ ~~Ru~~ ~~Sb~~ ~~Sm~~ ~~Ta~~
~~Gd~~ ~~Ge~~ ~~Hf~~ ~~Hg~~ ~~Ho~~ ~~Tb~~ ~~Te~~ ~~Th~~ ~~Tl~~ ~~Tm~~
~~In~~ ~~Ir~~ ~~Lu~~ ~~Nb~~ ~~Nd~~ ~~U~~ ~~W~~

Plate No. 523, 524, 527 Date 12-2-66 Analyst P.B. and D.G.
Checked GSB

Table 13.--Tritium analysis of water sample from U12n.03 drift

U. S. DEPT. OF THE INTERIOR -- GEOLOGICAL SURVEY
Statement of Water Analysis

Source: U12n.03 tunnel
Location: NW of Mercury, Nye Co., Nevada   N 892,739 E 638,485
¼ ____ ¼ ____ ¼ Sec ____ T ____ R ____ Field/Office No. ____

Date Col. 9-30-66 Time 1100 P.d.t.	Well Type ____ Use ____
Col. By J. E. Weir	Depth (ft.) ____ Cased to ____
Field detns: Temp. (°F) 68 pH ____	Diam. (in.) ____ Date drilled ____
Sp. Cond. (µmhos) ____ Eh ____	Water level (ft.) ____
Appearance Clear	Discharge ____
	W. B. F. ____
	Owner ____

Tritium ND x 10 µc/ml Date 1-4-67

Date sample received 10-6-66

Lab. No. 67-180 Analysts E. Villasana Date Checked ____

QW - 1A

beyond the radius of investigation of the shorter spreads. Explosive charges were from one-half to one stick of dynamite (40 percent) placed at the bottoms of the shotholes which were stemmed with water.

Arrival times and the velocities determined from regression lines drawn through the plotted points, are shown on figure 8. The velocities noted on figure 8 represent least-squares regression velocities plus or minus one standard error of the slope of the regression line. The third figure listed on the long-offset segment of the time-distance plot obtained from the shotpoint at CS 9+65 is the slope of the least-squares regression line fitted to the entire geophone line. The results indicate a range of seismic velocity of 2,088-2,667 m/s (6,850-8,750 ft/s) characterizes the rock in the vicinity of the drift. The zone of heaving ground (fig. 8), a clayey section of the drift in which the original supports were inadequate to completely prevent rock from moving into the drift, exhibits a lower velocity throughout much of its length. The lower velocities in this region may be due to some disassembly of the drift walls in response to the action of the stress field on the clayey tuff. The long offset velocities indicate more competent tuff further out from the drift.

The interval CS 13+40 to CS 15+00 on figure 8 is also characterized by an anomalously high-velocity segment 4,694 m/s (15,400 ft/s) on the long offset portion of the travel-time plot recorded from the shotpoint at CS 9+65. A unique explanation for this phenomenon is not apparent, but it is considered most likely to be due to construction features in the drift at the time of the survey.

Electrical Resistivity Survey

Electrical resistivity soundings were made at 30.5-m (100-ft) intervals from CS 6+00 to CS 21+00 along the walls of the U12n.03 drift. Portable resistivity equipment (ABEM) was used for the electrical surveys. Electrical contact was made by pressing small (1-in. diameter) sponge-rubber electrodes, saturated with a mixture of brine and bentonite clay, against the rock. Electrodes were placed in horizontal alinement approximately 1.5 m (5 ft) above the track level in the Wenner configuration. Apparent resistivity values were obtained by expanding electrode spacings from 0.3 to 9.1 m (1 to 30 ft). The resulting resistivity readings were then corrected for the effect of the tunnel geometry by using empirical graphs (Scott and others, 1968). The curves of geometry-corrected resistivity were then plotted against electrode spacing, and true resistivities and depths of interfaces were interpreted by using Roman's two-layer curves for the Wenner electrode configuration (Roman, 1960). The interpreted results are presented on figure 8. The results indicate that a shallow, high-resistivity layer generally exists on the drift periphery, underlain by a low-resistivity layer. This condition is attributed to increased resistivity due to slabbing and to aeration of the rock close to the drift walls. A reversal of the high-low resistivity measurement normally observed, occurs at CS 10+00. No electrical layering was observed at CS 8+00. Measurements at CS 18+00, CS 19+00, and CS 20+00 indicate that three layers may exist around the drift at those locations.

The resistivity of the undisturbed rock surrounding the drift--the deepest layer--ranges from 6 to 40 ohmmeters.

DISCUSSION OF GEOPHYSICAL RESULTS WITH RESPECT TO PREDICTION-CRITERIA FOR UNSTABLE GROUND

The U12n.03 drift is unique among the Rainier Mesa tunnels in that a section of unstable clayey ground of relatively large extent caused buckling of the sets used for drift support[3]. The results of the in situ geophysical measurements bear examination in light of the extent the properties measured might be considered predictive when compared with experience in unaltered ground.

At the time of the seismic survey in U12n.03, the compressional velocities were not considered particularly anomalous based on available experience. With hindsight, the compressional velocity near the drift between CS 12+00 to CS 15+00 would be considered low for the tunnel bed of interest and would suggest additional geologic effects are superimposed on the basic volcanic tuff matrix. However, the compressional velocity is not dramatically lowered and probably should not be expected to be, as compressional velocity is a gross sample of compressive, rather than shear, strength[4].

On the other hand, because the zone of poor quality rock is associated with clayey tuff the electrical resistivity may be expected to be anomalously low in rock of this type. Electrical resistivity of a saturated rock (which is essentially the condition in the tuffs in the Rainier Mesa tunnels) is a function of rock porosity when contained water is of high salinity. When contained water is appreciably fresh, however, rock resistivity is also highly affected by the presence of alteration products, in this case chiefly clay and zeolites, which can lower rock resistivity by an order of magnitude or more compared with a similar rock free of alteration. Some suggestion of this may be deduced by comparing the resistivity of the water sample obtained from fractures in the face of the drift and given in table 10 (43 ohm-meters) with the resistivity range of the undisturbed rock in the drift (6-40 ohmmeters)[5]. A detailed discussion of electrical resistivity of volcanic rocks from NTS in connection with this phenomenon has been presented elsewhere (Carroll and Cunningham, 1980).

The resistivities of the bulk tuff, i.e., the deeper layer resistivity shown on figure 8, have been plotted as a histogram on figure 9. The section of bad ground appears as a distinct low-resistivity anomaly due to the presence of clay minerals in the tuff. The ability to recognize clayey tuffs on the basis of their characteristically low resistivity has been used successfully for several years in conjunction with borehole electric logging at the NTS. A rule-of-thumb at NTS has been that resistivities less than 20 ohmmeters on electric logs indicate that the tuff in that part of the borehole contains clay. Geophysical logs from the

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[3]The U12n.03 drift was the first indication that the syncline in this region is associated with extensive clay alteration of the tuff, a condition resulting in remedial expense in a subsequent drift (U12n.05) which was used for a weapon test. This condition was also one of the reasons for an extensive exploratory program involving horizontal drilling (Carroll and Cunningham, 1980).

[4]Techniques for measuring shear-wave velocity were not in use at the time of the U12n.03 seismic survey. Given that the greatest effects on strength properties due to clay would be in reduction of shear strength, this is unfortunate.

[5]A direct comparison of the water and rock resistivity is nebulous because the rock resistivity is a function of the resistivity of the water in the pores as well as the nature of the alteration products or minerals in the rock. A sample of water of this nature is difficult to obtain because of the extremely low permeability of the tuff and samples are generally obtained from fractures as was the sample described in table 10. The resistivity of the pore fluid has yet to be adequately defined.

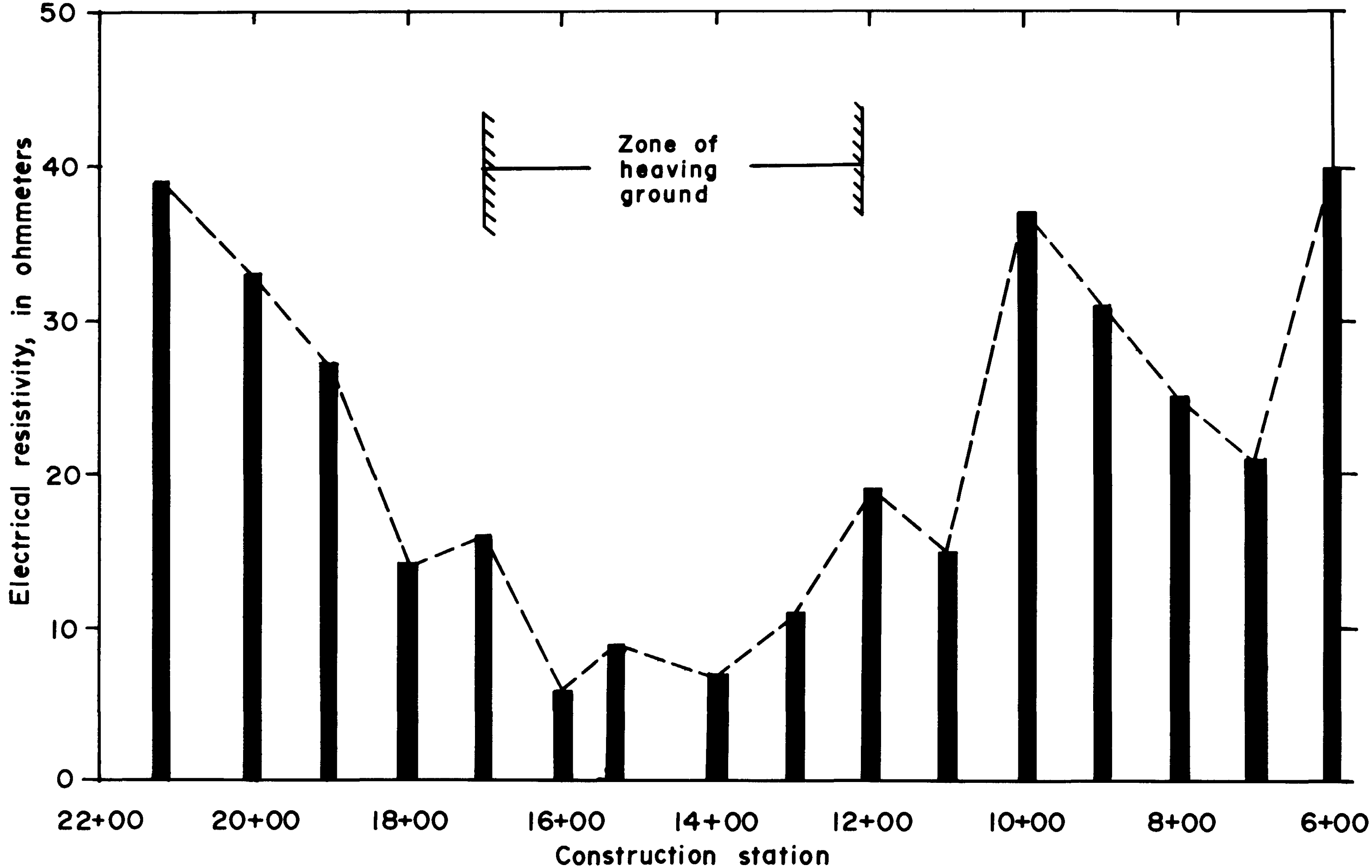

Figure 9.--Histogram of electrical resistivities of rock in the U12n.03 drift.

Hagestad hole drilled on Rainier Mesa can be used as an example (fig. 10). The intervals labeled "A," "B," and "C" on the logs are intervals which can be expected to contain clay material. Knowledge gained in correlating electric logs from Rainier Mesa in the years subsequent to the U12n.03 investigations indicates that these horizons are tunnel bed 4J (A), the tunnel bed 3A/Tub Spring Member (B), and the typically weathered base on the top of the pre-Tertiary rocks (C). X-ray analyses at other locations indicate at most 20 percent montmorillonite in the tunnel beds 4J and the 3A/Tub Spring Member contact. Tunnels containing tuff with clay contents in these amounts have been mined without difficulty. When clay horizons are of large lateral extent, as in portions of the Aqueduct syncline, or electric resistivity of the tunnel beds becomes less than 10-15 ohmmeters, potentially troublesome ground should be anticipated.

 (page 28 in back of report--Fig. 10)

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