DOE/NV/10845-36
UC-703

ER-12-1 COMPLETION REPORT

Prepared by

Charles E. Russell, David Gillespie
James C. Cole
S.L. Drellack, L.B. Prothro, P.H. Thompson, R.L. McCall
Gayle A. Pawloski, and Richard Carlson

Submitted to

Nevada Operations Office
U.S. Department of Energy

December 1996

Publication #45120

DISCLAIMER

DOE/NV/10845-36
UC-703

ER-12-1 COMPLETION REPORT

by

Charles E. Russell, David Gillespie[1]
James C. Cole[2]
S.L. Drellack, L.B. Prothro, P.H. Thompson, R.L. McCall[3]
Gayle A. Pawloski and Richard Carlson[4]

Publication No. 45120

prepared for

Nevada Operations Office
U.S. Department of Energy
Las Vegas, Nevada

December 1996

[1]Desert Research Institute
[2]U.S. Geological Survey
[3]Raytheon Services Nevada
[4]Lawrence Livermore National Laboratory

The work upon which this report is based was supported by the U.S. Department of Energy under Contract #DE-AC08-90NV10845.

CONTENTS

FIGURES

TABLES

ABSTRACT

The objective of drillhole ER-12-1 was to determine the hydrogeology of paleozoic carbonate rocks and of the Eleana Formation, a regional aquitard, in an area potentially downgradient from underground nuclear testing conducted in nearby Rainier Mesa. This objective was addressed through the drilling of well ER-12-1 at N886,640.26 E640,538.85 Nevada Central Coordinates. Drilling of the 1094 m (3588 ft) well began on July 19, 1991 and was completed on October 17, 1991. Drilling problems included hole deviation and hole instability that prevented the timely completion of this borehole. Drilling methods used include rotary tri-cone and rotary hammer drilling with conventional and reverse circulation using air/water, air/foam (Davis mix), and bentonite mud.

Geologic cuttings and geophysical logs were obtained from the well. The rocks penetrated by the ER-12-1 drillhole are a complex assemblage of Silurian, Devonian, and Mississippian sedimentary rocks that are bounded by numerous faults that show substantial stratigraphic offset. The final 7.3 m (24 ft) of this hole penetrated an unusual intrusive rock of Cretaceous age. The geology of this borehole was substantially different from that expected, with the Tongue Wash Fault encountered at a much shallower depth, paleozoic rocks shuffled out of stratigraphic sequence, and the presence of an altered biotite-rich microporphyritic igneous rock at the bottom of the borehole.

Conodont CAI analyses and rock pyrolysis analyses indicate that the carbonate rocks in ER-12-1, as well as the intervening sheets of Eleana siltstone, have been thermally overprinted following movement on the faults that separate them. The probable source of heat for this thermal disturbance is the microporphyritic intrusion encountered at the bottom of the hole, and its age establishes that the major fault activity must have occurred prior to 102.3+0.5 Ma (middle Cretaceous).

Geophysical logs run in the saturated and unsaturated sections of the borehole were invaluable for interpretation of stratigraphy and structure. Problems encountered during logging were lack of service tables for stacked logs, lack of calibration tables for the ER-12-1 hole size, and lack of written procedures for running these logs in the field.

Hydrologic investigations consisted of water level monitoring, flow logging, aquifer tests, and drill-stem tests. The results indicate that the static composite fluid level in well ER-12-1 was 469 m (1540 ft) below land surface. Drill-stem tests and flow logs determined that the lower two intervals in the well are underpressured relative to the upper zones by approximately 396 m (1300 ft). Aquifer tests, drill-stem tests, and flow logs determined that the transmissivity of the well ranged from 7.5 x 10^{-6} to 4 x 10^{-4} m^2/s, with the most transmissive zone being 518 to 555 m (1700 to 1820 ft) below land surface followed by the 914 to 963 m (3000 to 3160 ft). The pressure differential between these zones allowed for substantial crossflow to occur while the well was open.

Two types of geochemical samples were acquired from this well. Water quality samples taken during drilling and testing indicated very few problems associated with the well. Those identified consisted of elevated quantities of volatile and semivolatile organics (sample 10006) and metals (sample 10007) associated with the drilling process. Geochemical characterization samples were taken only from the uppermost zone, 518 to 555 m (1700 to 1820 ft). The results from this sample

indicate anomalous chemistry, which is most likely due to residual drilling fluids contaminating the sample. Trace quantities of tritium were detected. Origin of the tritium was hypothesized to be from residual drilling fluids entrained in the well, from tritiated surface water that infiltrated in the nearby tunnel ponds, or, less likely, from the underground nuclear tests conducted within Rainier Mesa. Existing data does not differentiate between the various hypotheses.

INTRODUCTION

Objective of ER-12-1

The objective of drillhole ER-12-1 was to determine the hydrogeology of Paleozoic carbonate rocks and of the Eleana Formation, a regional aquitard, in an area potentially down–gradient from underground nuclear testing conducted in nearby Rainier Mesa.

Surficial Setting

Coordinates for ER-12-1 were surveyed as N886,640.26 ft E640,538.85 ft (Nevada Central Coordinates). This location is in Area 12 of the Nevada Test Site (NTS) (Figure 1) near the base of the eastern slope of Rainier Mesa, alongside the U12e tunnel access road where it passes the base of Dolomite Hill. The drill site is at an elevation of 1773.51 m (5817.12 ft) and is collared in a thin veneer of alluvium that overlies the Sevy Dolomite. It is approximately 610 m (2000 ft) northwest of the surficial expression of the Tongue Wash Fault, a northeast-trending sinistral-reverse fault that dips approximately 45° to the west.

Surface water from the ER-12-1 site drains into Tongue Wash, which eventually flows into other ephemeral channels draining east into Yucca Flat.

Geologic Setting

The ER-12-1 borehole location was chosen to allow penetration of dolomite for one to two hundred meters below the water table, and to reach Eleana Formation in the footwall of the Tongue Wash fault within the 1070 m (3500 ft) design depth (Cole, unpublished). A detailed prediction of the geology beneath ER-12-1 is contained in Cole (unpublished), which has been included herein as Appendix A.

Hydrologic Setting

The ER-12-1 drill site is located within the Ash Meadows groundwater subbasin defined by Winograd and Thordarson (1975) and Waddell *et al.* (1984). Interpretations based upon Winograd and Thordarson's (1975) subbasin boundary have groundwater beneath ER-12-1 ultimately discharging at Ash Meadows and perhaps Death Valley. A detailed prediction of the ER-12-1 hydrogeology is contained in Russell (1991, unpublished), which has been included in this report as Appendix B.

Location with Respect to Testing

The drill site for ER-12-1 is located approximately 2.1 km (1.3 mi) southeast and east of underground nuclear tests conducted within Rainier Mesa. Some of these tests were conducted in a saturated groundwater lens that is perched/semiperched a maximum of 600 m (2000 ft) above the regional groundwater table (Thordarson, 1965). The drill site is also located 460 m (1500 ft) east of the inactive U12e tunnel effluent ponds. These ponds contained tritiated effluent while the tunnel was active, and since they were unlined ponds, some of the tritiated fluid may have entered the underlying carbonate rocks.

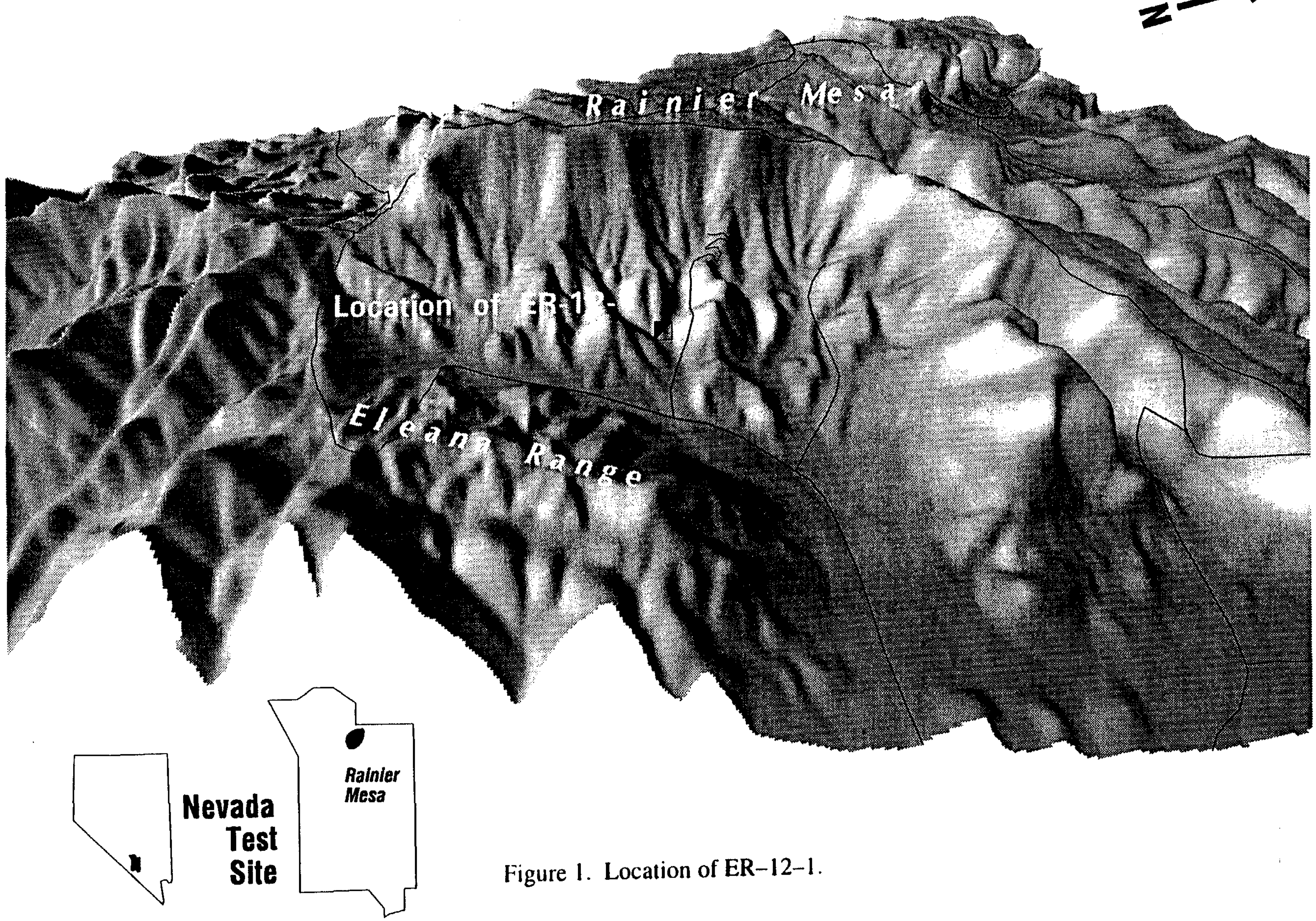


Figure 1. Location of ER–12–1.

Previous Investigations

The Dolomite Hill hole, drilled in 1959, is located approximately 580 m (1900 ft) west of the ER-12-1 drillhole. The hole penetrated 365 m (1200 ft) of unsaturated dolomite. The lithology of the borehole and a geologic map of the surrounding area were published by Dickey and McKeown (1959). A detailed, 1:24,000 scale geologic map of the Rainier Mesa quadrangle was published by Gibbons *et al.* (1963). U12e.M-1, an exploratory corehole, was drilled within the U12e tunnel complex, spudding at an elevation of 1877 m (6158 ft). This borehole encountered 297 m (974 ft) of Tertiary volcanics and 161 m (527 ft) of Paleozoic dolomites. A detailed lithologic log from this borehole was reported by Schoff and Winograd (1961) along with some preliminary results of hydrologic investigations of this and other carbonate-penetrating boreholes. Three additional boreholes (U12e.06A, U12e.06B, and U12e.06R/C) penetrated the Paleozoic dolomites in the area of ER-12-1 (Miller, 1970). The hydrogeology of some of the aforementioned boreholes were included in Thordarson's (1965) report on the hydrogeology of Rainier Mesa.

Over 90 boreholes, listed in Table 1, have been drilled within 2590 m (8500 ft) of ER-12-1 (Drellack *et al.*, 1991). The majority of these boreholes were completed in Tertiary volcanics and provide only limited information relevant to the conditions at ER-12-1. The unpublished reports of Cole and Russell (Appendix A and Appendix B, respectively) represent the most recent compilation and interpretation of the geology and hydrology of the area surrounding ER-12-1.

PRE-DRILLING ACTIVITIES

Environmental Surveys

Three types of surveys, land, cultural resources, and biological, were conducted prior to ER-12-1 drill pad and access road construction. Land surveying activities began on March 30, 1990 with an initial survey of a site 300 m (1000 ft) east of the current location. The original location was moved approximately 300 m (1000 ft) to the west to ensure the presence of saturated dolomites at depth. A survey of the new location was conducted on July 16, 1990. Two additional, yet minor relocations of the drill site were conducted on August 2, 1990 and September 24, 1990 to accommodate construction criteria associated with the placement of the drill rig on location. Final as-built-coordinates of the wellhead are (N886,640.26 E640,538.85 ft) Nevada Central Coordinates. The ground level elevation at the wellhead is 1773.51 m (5817.12 ft).

Cultural resources surveys of the ER-12-1 drill pad and construction sites were conducted by Desert Research Institute (DRI) personnel on August 29, 1990. The results of the survey determined that much of the area encompassed by the drill site had been disturbed by previous construction and use as an equipment yard. A two-track road runs along the western side of the site location, and entrenched drainage runs along the eastern margin. No cultural resources predating the construction and use of the equipment yard were identified during the survey (DRI, 1990).

Biological surveys of the ER-12-1 drill pad and construction site were conducted by EG&G personnel on August 29, 1990. The results of the survey indicated Blackbrush (*Coleogyne*

Table 1. Drill Holes and Tunnels within 2590.8 m (8500 ft) Radius of ER-12-1 (Revised from Drellack et al., 1991 to account for updated ER–12–1 coordinates).

HOLE / TUNNEL NAME	NORTH	EAST	DISP-FT	NS	BEARING	EW
		DISPLACEMENT AND BEARING FROM EMP. HOLE TO TARGET				
Mac Exploratory Co. #1	886,712 -	638,632	1908.4	N	87.8	W
Effinger #2	886,283 -	643,089	2574.9	S	82.0	E
U-12e Tunnel	887,459 -	637,961	2705.0	N	72.4	W
Effinger #4	886,025 -	643,216	2746.7	S	77.1	E
U-12es Tunnel	887,420 -	637,808	2840.2	N	74.1	W
U-12e Tunnel Water Conduit	887,342 -	637,527	3092.7	N	76.9	W
U-12b #4	889,683 -	636,773	4841.8	N	51.1	W
U-12e.02-J	886,350 -	635,608	4939.5	S	86.6	W
U-12b Tunnel	889,759 -	636,481	5118.2	N	52.5	W
U-12f Tunnel	889,667 -	636,115	5360.5	N	55.6	W
U-12c Tunnel	889,768 -	636,138	5399.4	N	54.6	W
U-12d Tunnel	889,615 -	636,033	5399.5	N	56.6	W
UE-12n #5	890,127 -	636,331	5465.0	N	50.4	W
U-12b #2	889,947 -	636,111	5526.6	N	53.3	W
U-12b #1	890,432 -	636,186	5773.0	N	48.9	W
U-12n Ext. Tunnel	892,487 -	638,583	6165.5	N	18.5	W
U-12e.04-1 Vent	885,782 -	634,316	6281.9	S	82.2	W
U-12g.08 Tunnel	881,027 -	637,708	6286.5	S	26.8	W
U-12g Tunnel	881,027 -	637,708	6286.5	S	26.8	W
U12n Tunnel	892,667 -	638,645	6317.6	N	17.4	W
U-12n.10A Reentry Mining	892,739 -	638,485	6435.6	N	18.6	W
U-12e.04 #22	885,163 -	634,216	6493.2	S	76.9	W
U-12e.05 Hagestad #3	887,086 -	634,009	6545.2	N	86.1	W
U-12e CH #1	886,112 -	633,885	6674.9	S	85.5	W
U-12e CH #3	886,073 -	633,888	6675.1	S	85.1	W
U-12e CH #2	886,092 -	633,886	6675.5	S	85.3	W
U-12b R-4	890,571 -	635,027	6770.1	N	54.5	W
Unidentified	884,755 -	634,033	6773.6	S	73.8	W
U-12b R-8	890,551 -	635,003	6778.1	N	54.8	W
U-12b.04A Vent	890,271 -	634,814	6779.4	N	57.6	W
U-12b R-7	890,561 -	635,003	6783.9	N	54.7	W
U-12b R-3	890,573 -	635,006	6788.4	N	54.6	W
U-12b R-2	890,571 -	635,003	6789.7	N	54.6	W
U-12b R-1	890,570 -	635,000	6791.6	N	54.6	W
U-12b R-5	890,574 -	635,000	6793.9	N	54.6	W
U-12b R-9	890,596 -	635,003	6804.2	N	54.5	W
U-12b R-6	890,581 -	634,992	6804.5	N	54.6	W
U-12e.04 #21	884,683 -	634,012	6814.1	S	73.3	W
U-12e.04 #32 (USGS)	884,669 -	634,015	6815.2	S	73.2	W
U-12b Unknown #1	890,574 -	634,971	6817.5	N	54.8	W
U-12e.04 #24	884,675 -	634,006	6822.1	S	73.3	W
Unidentified	884,441 -	634,020	6879.9	S	71.4	W
U-12b #3	890,617 -	634,913	6889.7	N	54.7	W
Unidentified	884,404 -	634,013	6898.4	S	71.1	W
Unidentified	884,395 -	634,014	6900.4	S	71.0	W
U-12e.03aa PS	887,716 -	633,675	6947.8	N	81.1	W
U-12b.04-1	890,215 -	634,558	6968.0	N	59.1	W
U12b.04C Sample & Vent	890,230 -	634,554	6979.1	N	59.0	W
U-12b.04-2	890,250 -	634,558	6986.0	N	58.9	W
U-12b.04B	890,232 -	634,545	6987.9	N	59.1	W

Table 1. Drill Holes and Tunnels within 2590.8 m (8500 ft) Radius of ER-12-1 (Drellack et al., 1991) (continued).

HOLE NAME	NORTH	EAST	DISP-FT	NS	BEARING	EW
U-12b.04-4	890,215 -	634,523	6998.1	N	59.3	W
U-12e.M1	886,644 -	633,532	7007.0	N	90.0	W
U-12e.03ac PS	887,652 -	633,598	7014.4	N	81.7	W
U-12b.04-3	890,250 -	634,523	7016.0	N	59.0	W
U-12e.05 Hagestad #4	887,609 -	633,451	7153.9	N	82.2	W
U-12b.04 PS	890,101 -	634,271	7160.1	N	61.1	W
U-12b.04-5	890,123 -	634,261	7179.5	N	61.0	W
U-12b Unknown #2	890,128 -	634,256	7186.3	N	61.0	W
UE-12n #7	892,004 -	635,755	7187.4	N	41.7	W
UE-12n #4	892,035 -	635,753	7211.9	N	41.6	W
U-12g.01-1 Vent	881,814 -	635,178	7213.2	S	48.0	W
U-12g.07 Ch #1	883,336 -	633,951	7370.1	S	63.4	W
U-12e.04 #29S	883,636 -	633,731	7441.3	S	66.2	W
U-12e.04 #29	883,638 -	633,728	7443.2	S	66.2	W
U-12b.09a PS	890,023 -	633,880	7469.1	N	63.1	W
U-12b.09-1 Vent	890,621 -	634,188	7495.6	N	57.9	W
U-12b.09d PS	889,979 -	633,826	7497.6	N	63.6	W
U-12b.08-1 Vent	890,795 -	634,110	7654.8	N	57.1	W
U-12b.07-1	891,222 -	634,404	7657.2	N	53.2	W
U-12g.07 Tunnel	883,930 -	633,350	7682.8	S	69.4	W
U-12g.07 PS #1V	883,930 -	633,350	7682.8	S	69.4	W
U-12e.03ab PS	887,849 -	632,911	7723.2	N	81.0	W
U-12e.03a-BS Ps	887,849 -	632,911	7723.2	N	81.0	W
U-12n.07 Tunnel	892,249 -	634,984	7894.2	N	44.7	W
U-12b.08-3 PSb.08-4 PS	890,265 -	633,514	7905.1	N	62.7	W
U-12b.08-2 R/C	890,256 -	633,509	7905.5	N	62.8	W
U-12e.10 PS #1V	886,497 -	632,609	7931.3	S	89.0	W
U-12e.10 Tunnel	886,497 -	632,609	7931.3	S	89.0	W
U-12b.08-4 PS W/S	890,182 -	633,442	7931.8	N	63.5	W
U-12b.09b PPS	890,328 -	633,505	7942.2	N	62.3	W
U-12e.11 Tunnel	884,808 -	632,786	7966.5	S	76.7	W
U-12e.11 PPS #1V	884,808 -	632,786	7966.5	S	76.7	W
U-12g.06 Tunnel	882,815 -	633,526	7988.3	S	61.4	W
U-12b.07-3 Vent	891,533 -	634,217	7994.3	N	52.3	W
U-12e.07-6 Vent	887,478 -	632,578	8005.0	N	84.0	W
U-12g.06 PS #1V	882,792 -	633,516	8008.1	S	61.3	W
U-12e.17 Tunnel	885,289 -	632,494	8157.6	S	80.5	W
U-12n.09 Tunnel	892,520 -	634,765	8241.0	N	44.5	W
U-12e.16 Tunnel	885,250 -	632,401	8255.9	S	80.3	W
U-12e.15 Tunnel	885,204 -	632,312	8351.4	S	80.1	W
UE-12g.10 #3	882,944 -	633,034	8365.7	S	63.8	W
U-12n.01-2 R/C	893,208 -	635,333	8381.0	N	38.4	W
U-12b.10-2 PS W/S	890,915 -	633,328	8383.0	N	59.3	W
U-12n.01-4 PPS	893,116 -	635,214	8384.2	N	39.4	W
U-12n.01-3 PPS	893,206 -	635,322	8386.3	N	38.5	W
U-12b.10-5 PS	890,853 -	633,258	8412.0	N	59.9	W
U-12b.10-1 R/C	890,853 -	633,248	8420.7	N	60.0	W
U-12b.10-4 PS	890,854 -	633,238	8429.9	N	60.0	W
U-12n.01-5 CH	893,374 -	635,463	8432.8	N	37.0	W
U-12e.20 Tunnel	887,646 -	632,161	8438.2	N	83.2	W
U-12g.10 Tunnel	883,643 -	632,607	8479.3	S	69.3	W
U-12g.10 Reentry Mining	883,643 -	632,607	8479.3	S	69.3	W
U-12n.06 PS #1	892,551 -	634,459	8479.8	N	45.8	W

Data, including hole nomenclature, from RSN Nevada Test Site Drilling and Mining Summary
*Mac Exploratory is equivalent to "Dolomite Hill"

ramosissima) dominates the floral community. Smaller amounts of sagebrush (*Artemisia nova*), little rabbitbrush (*Chrysothamnus spp.*), four-wing saltbush (*Atriplex canescens*), cliffrose (*Cowania mexicana*), Mormon tea (*Ephedra nevadensis*), and rice grass (*Oryzopsis hymenoides*) were also present. One hawk and one lizard were seen. Rabbit scat was noted in the area, but no rabbits were observed (DRI, 1990).

Site Preparation

Environmental surveys were followed by drill pad and access road construction. Construction was initiated on May 28, 1991 and completed on June 5, 1991. The original mud pit was enlarged on June, 19, 20, and 21 and was lined with sand and a polypropylene liner on July 11, 1991.

DRILLING TECHNIQUES AND HOLE HISTORY

ER-12-1 was drilled using the Cardwell 500 rotary drill rig. The hole was spudded on July 19, 1991, and reached a total depth of 1093.6 m (3588 ft) on October 17, 1991. During construction of the hole, surface casing with an outside diameter of 0.51 m (20 in) was set to a depth of 15.8 m (52 ft), and an intermediate casing string 0.34 m (13 3/8 in) in diameter was placed from the surface to 449.3m (1474 ft) (Figure 2). A summary of drilling data, hole diameters, total depths (TDs), drilling techniques, and casing records for ER-12-1 is contained in Appendix C of this report.

Drilling techniques employed at ER-12-1 included rotary tri-cone and rotary hammer drilling with conventional and reverse circulation using air/water, air/foam (Davis mix), or bentonite mud. Four cores were also obtained at various depths in the borehole. Table 2 lists the specific techniques used in drilling this hole.

Twenty-six drill bits of various types and diameter were used in drilling ER-12-1. These bit types included tri-cone button and tooth bits, hammer bits, and coring bits. The diameter, manufacturer, footage drilled, dates, and formation drilled for each bit used in ER-12-1 are summarized in Table 3. The large variety of drill bits and drilling techniques were due to experimentation with optimizing penetration rates in carbonate rocks.

Single-shot hole deviation surveys were run throughout the drilling of ER-12-1. Additionally, following the completion of drilling, a gyroscopic hole deviation survey was obtained by Schlumberger Formation Micro-scanner survey, which recorded hole deviation data over the saturated portion of the borehole. Selected survey depths, amount of deviation, and the date the surveys were conducted are listed in Table 4.

The first six surveys conducted by Reynolds Electrical Engineering Co., Inc. (REECo) during drilling were not accurate as the survey tool was run in an inverted position. The hole deviation survey record for ER-12-1 obtained by REECo during drilling indicates the hole to be apparently straight with fairly consistent deviation survey readings of less than 2°. However, the hole deviation survey obtained by Schlumberger (Formation Micro-scanner) following completion of the drilling indicated a significant increase in hole deviation below approximately 610 m (2000 ft). The

(text continues on page 13)

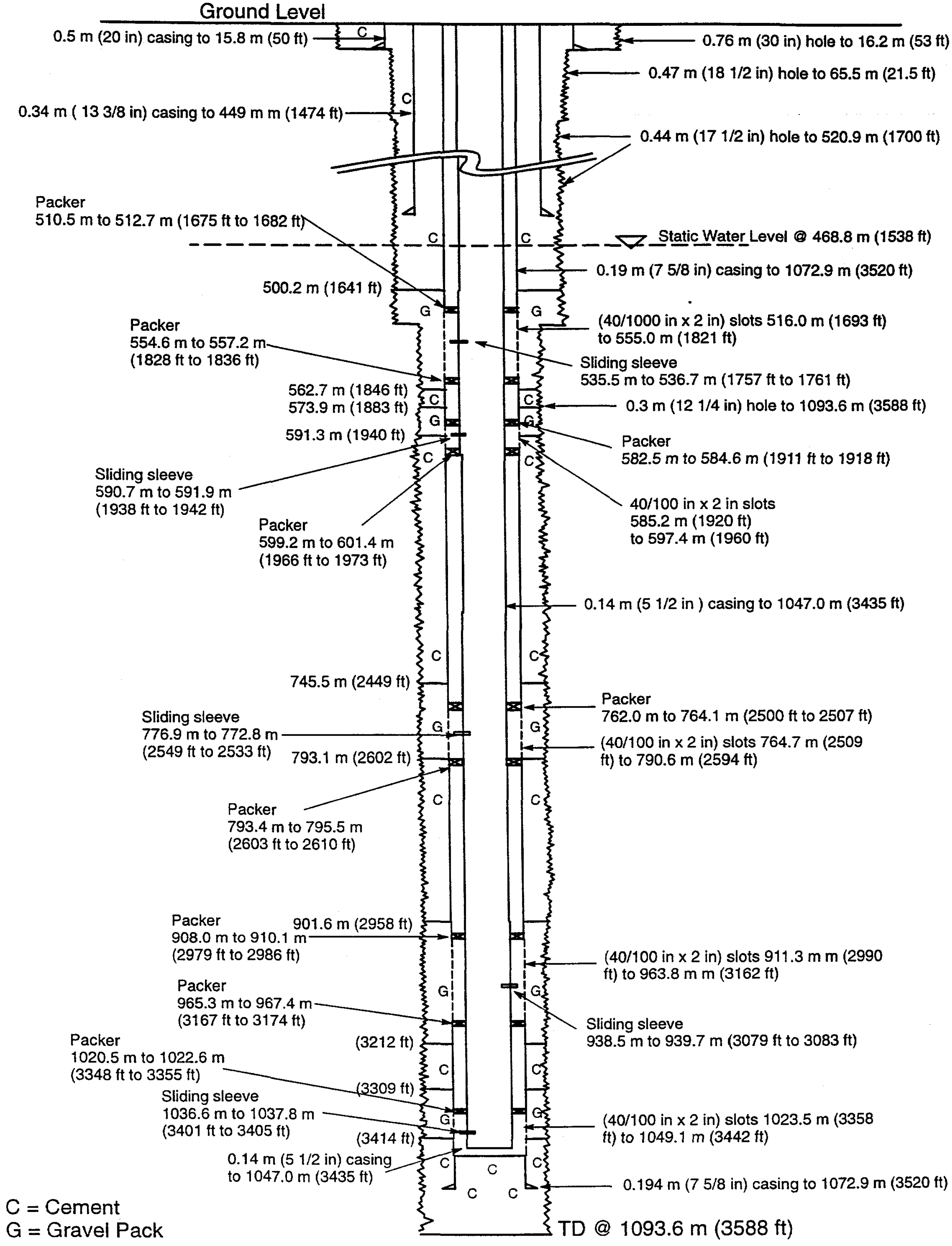


Figure 2. Schematic of ER–12–1 hole construction.

Table 2. Drilling Techniques used at ER-12-1.

Depth Interval	Drilling Technique
0 - 16.2 m (0 - 53 ft)	Rotary drilled surface hole using mud and conventional circulation
16.2 - 30.5 m (53 - 100 ft)	Rotary drilled a 0.47 m (18-1/2 in) hole using water and conventional circulation
30.5 - 65.5 m (100 - 215 ft)	Rotary drilled using air/water and reverse circulation
65.5 - 520.9 m (215 - 1709 ft)	Rotary drilled a 0.445 m (17-1/2 in) hole using an air hammer bit with conventional circulation and air/foam
520.9 - 539.2 m (1709 - 1769 ft)	Rotary drilled a 0.311 m (12-1/4 in) hole using conventional circulation and air/foam
539.2 - 543.8 m (1769 - 1784 ft)	Rotary cored using a 22.2 cm (8-3/4 in) diamond core bit (Core #1); reamed to 0.311 m (12-1/4 in)
543.8 - 548.0 m (1784 - 1798 ft)	Rotary drilled a 0.311 m (12-1/4 in) hole using dual-string reverse circulation and air/foam
548.0 - 556.3 m (1798 - 1825 ft)	Rotary cored using a 21.6 cm (8-1/2 in) four-cone bit and marine core barrel (Core #2); reamed to 0.311 m (12-1/4 in)
556.3 - 556.9 m (1825 - 1827 ft)	Rotary drilled a 0.311 m (12-1/4 in) hole using conventional circulation and air/foam
556.9 - 751.0 m (1827 - 2464 ft)	Rotary drilled a 0.311 m (12-1/4 in) hole using conventional circulation and bentonite mud
751.0 - 757.7 m (2464 - 2486 ft)	Rotary cored using a 21.6 cm (8-1/2 in) four-cone bit and marine core barrel (Core #3); reamed to 0.311 m (12-1/4 in)
757.7 - 895.2 m (2486 - 2937 ft)	Rotary drilled a 0.311 m (12-1/4 in) hole using conventional circulation and bentonite mud
895.2 - 903.1 m (2937 - 2963 ft)	Rotary cored using a 22.2 cm (8-3/4 in) diamond core bit (Core #4); reamed to 0.311 m (12-1/4 in)
903.1 - 1093.6 m (2963 - 3588 ft) TD	Rotary drilled a 0.311 m (12-1/4 in) hole using conventional circulation and bentonite mud

Table 3. Bit Records for ER–12–1.

Bit No.	Bit Diameter	Bit Type	Manufacturer	Date In	Depth Interval Drilled	Footage Drilled	Hours Drilled	Lithology(s) Drilled	Comments/ Bit Grade
1	66.0 cm (26 in)	Retip BTN	SEC	07–19–91	0 – 6.4 m (0 – 21.0 ft)	6.4 m (21 ft)	NA	Alluvium	Hole not straight
2	76.2 cm (30 in)	Retip MT	STC–Smith	07–19–91	6.4 – 16.2 m (21 – 53 ft)	9.8 m (32 ft)	NA	Dolomite	
3	47.0 cm (18–1/2 in)	BTN	Hughes	07–24–91	16.2 – 30.5 m (53 – 100 ft)	14.3 m (47 ft)	22.5	Cement/ dolomite	
4	47.0 cm (18–1/2 in)	BTN 44R	Hughes	07–26–91	30.5 – 65.5 m (100 – 215 ft)	35.1 m (115 ft)	67.5	Dolomite	
5	44.5 cm (17–1/2 in)	Hammer Q5MJ	Smith	08–07–91	3.4 – 65.5 m (11 – 215 ft)	62.2 m (204 ft)	NA	Cement	Drilled casing cement
6	44.5 cm (17–1/2 in)	BTN Q5MJ	Smith	08–08–91	65.5 – 73.2 m (215 – 240 ft)	7.6 m (25 ft)	6	Cement/ dolomite	
7	44.5 cm (17–1/2 in)	Hammer SD–12	Smith	08–09–91	73.2 – 521.0 m (240 – 1709 ft)	447.8 m (1469 ft)	77	Dolomite/ siltstone	
8	31.1 cm (12–1/4 in)	BTN J–55	Hughes	08–26–91	521.0 – 556.9 m (1709 – 1827 ft)	36.0 m (118 ft)	NA	Dolomite (& 1440 – 1709 ft sand/cement)	
core #1	22.2 cm (8–3/4 in)	Conventional diamond core	Christensen	08–30–91	539.2 – 543.8 m (1769 – 1784 ft)	4.6 m (15 ft)	NA	Dolomite	6.1 cm (.2 ft recovery)
core #2	22.2 cm (8–3/4 in)	Marine core 4–cone	NA	09–03–91	548.0 – 556.3 m (1798 – 1825 ft)	8.2 m (27 ft)	NA	Dolomite/ quartzite &siltstone	No recovery
9	31.1 cm (12–1/4 in)	BTN	Hughes	09–05–91	556.9 – 565.1 m (1827 – 1854 ft)	8.2 m (27 ft)	NA	Quartzite & siltstone	Bit 0.5 in under guage
10	31.1 cm (12–1/4 in)	BTN E–55	Hughes	09–09–91	565.1 – 643.7 m (1854 – 2112 ft)	78.6 m (258 ft)	35.5	Quartzite, siltstone &shale	
11	31.1 cm (12–1/4 in)	BTN HH–55	Hughes	09–11–91	643.7 – 704.1 m (2112 – 2310 ft)	60.4 m (198 ft)	32	Quartzite, siltstone & shale	

Table 3. Bit Records for ER–12–1 (continued).

Bit No.	Bit Diameter	Bit Type	Manufacturer	Date In	Depth Interval Drilled	Footage Drilled	Hours Drilled	Lithology(s) Drilled	Comments/ Bit Grade
12	31.1 cm (12–1/4 in)	BTM HH–44	Hughes	09–16–91	704.1 – 732.7 m (2310 – 2404 ft)	28.7 m (84 ft)	25.5	Quartzite siltstone & shale	
13	31.1 cm (12–1/4 in)	BTN Q7J	Smith	09–17–91	732.7 – 751.0 m (2404 – 2464 ft)	18.3 m (60 ft)	12	Siltstone	
core #3	22.2 cm (8–3/4 in)	Marine core 4–cone	NA	09–23–91	751.0 – 757.7 m (2464 – 2486 ft)	6.7 m (22 ft)	NA	Argillaceous quartzite	Recov. 10 ft, lost lower 12 ft of core
14	21.6 cm (8–1/2 in)	BTN AZ016	RBI "Reed"	09–23–91	751.0 – 757.7 m (2464 – 2486 ft)	6.7 m (22 ft)	NA	Argillaceous siltstone	
15	31.1 cm (12–1/4 in)	BTN Q55	Smith	09–24–91	751.0 – 757.7 m (2464 – 2486 ft)	6.7 m (22 ft)	NA	Argillaceous quartzite	Bit rerun on 09–26–91
16	31.1 cm (12–1/4 in)	MT MXWR	Hughes	09–25–91	757.7 – 771.8 m (2486 – 2532 ft)	14.0 m (46 ft)	13.5	Siltstone & shale	
15	31.1 cm (12–1/4 in)	BTN Q55	Smith	09–26–91	771.8 – 795.2 m (2532 – 2609 ft)	23.5 m (77 ft)	NA	Shale & siltstone	
17	31.1 cm (12–1/4 in)	BTN 05J	Smith	10–01–91	795.2 – 846.1 m (2609 – 2776 ft)	50.9 m (167 ft)	NA	Shale, siltstone, & quartzite	T–8, B–8, under gauge
18	31.1 cm (12–1/4 in)	05J	Smith	10–03–91	846.1 – 885.7 m (2776 – 2906 ft)	39.6 m (130 ft)	NA	Siltstone & dolomite	T–2, B–8, G–2
19	31.1 cm (12–1/4 in)	BTN 05J	Smith	10–04–91	855.7 – 927.5 m (2906 – 3043 ft)	41.8 m (137 ft)	20	Dolomite	T–1 B–8 in
core #4	22.2 cm (8–3/4 in)	Conventional diamond core	Christensen	10–07–91	895.2 – 903.1 m (2937 – 2963 ft)	7.9 m (26 ft)	NA	Dolomite	Recovered 7.8 m (25.5 ft) from 7.9 m (26 ft) cut.
20	31.1 cm (12–1/4 in)	BTN/05J	Smith	10–09–91	927.5 – 941.5 m (3043 – 3089 ft)	14.0 m (46 ft)	5.5	Dolomite	T–1, B–2, in gauge

Table 3. Bit Records for ER–12–1 (continued).

Bit No.	Bit Diameter	Bit Type	Manufacturer	Date In	Depth Interval Drilled	Footage Drilled	Hours Drilled	Lithology(s) Drilled	Comments/ Bit Grade
21	31.1 cm (12–1/4 in)	BTN BH–80	Hughes	10–10–91	941.5 – 967.4 m (3089 – 3174 ft)	25.9 m (85 ft)	31.5	Dolomite	T–3, B–2, in gauge
22	31.1 cm (12–1/4 in)	BTN BH–80	Hughes	10–11–91	967.4 – 969.6 m (3174 – 3181 ft)	2.1 m (7 ft)	4	Dolomite	T–1, B–4, in gauge
23	31.1 cm (12–1/4 in)	BTN 05J	Smith	10–14–91	969.6 – 1018.6 m (3183 – 3342 ft)	49.0 m (161 ft)	21	Dolomite	T–1, B–4, in gauge
24	31.1 cm (12–1/4 in)	BTN 05J	Smith	10–15–91	1018.6 – 1092.4 m (3342 – 3588 ft)	75.0 m (246 ft)	34.5	Dolomite*	T–6, B–8, in gauge

Bit Statistics

No. of Bits	Bit Diameter	Avg. Drilled	Hours Drilled/Bit
2 bits	47.0 cm (18–1/2 in)	24.7 m (81 ft)	45 hrs/bit (for the 2 bits with data)
3 bits	44.5 cm (17–1/2 in)	227.7 m (747 ft)	41.5 hrs/bit (for the 2 bits with data)
18 bits	31.1 cm (12–1/4 in)	367 m (120.4 ft)	21.4 hrs/bit (for the 11 bits with data)

* Includes 4.9 m (16 ft) altered lamprophyre porphyry intrusive rock at bottom of hole.
NA – Not readily available from REECo drilling records.

Table 4. Hole Deviation Survey Records for ER-12-1.

Survey Depth	Deviation REECo	Deviation Schlumberger	Survey Date REECo	Survey Date Schlumberger
28.3 m (93 ft)	*1° 16' reported	N/A	07-30-91	NA
35.7 m (117 ft)	*off scale using a 2° tool	N/A	07-31-91	NA
53.3 m (175 ft)	*3° 14' reported	N/A	07-31-91	NA
26.2 m (86 ft)	*1° 11' reported	N/A	08-07-91	NA
32.6 m (107 ft)	*1° 16' reported	N/A	08-07-91	NA
51.5 m (169 ft)	*3° 48' reported	N/A	08-07-91	NA
44.2 m (145 ft)	0° 25'	N/A	08-08-91	NA
62.2 m (204 ft)	0° 17'	N/A	08-08-91	NA
101.2 m (332 ft)	0° 18'	N/A	08-09-91	NA
130.1 m (427 ft)	0° 12'	N/A	08-09-91	NA
195.7 m (642 ft)	0°36'	N/A	08-13-91	NA
301.1 m (988 ft)	0° 55'	N/A	08-14-91	NA
393.5 m (1291 ft)	1° 10'	N/A	08-16-91	NA
480.1 m (1575 ft)	0° 40'	1.35°	08-19-91	10-22-91
515.1 m (1690 ft)	1° 5'	1.1°	08-20-91	10-22-91
580.6 m (1905 ft)	1° 55'	1.8°	09-09-91	10-22-91
680.9 m (2234 ft)	1° 12'	4.75°	09-12-91	10-22-91
780.3 m (2560 ft)	1° 10'	6.4°	09-26-91	10-22-91
831.2 m (2727 ft)	1° 18'	8.4°	10-03-91	10-22-91
897.6 m (2945 ft)	1° 10'	7.2°	10-08-91	10-22-91

* Readings invalid, improper use of tool (upside down)

Schlumberger survey indicated an increase in hole deviation from approximately 2° to almost 9.5° at 865.6 m (2840 ft). Below 865.5 m, hole deviation gradually decreased to slightly more than 3° near total depth (TD) at 1092 m (3582 ft). The fairly consistent hole deviation values recorded by REECo during drilling appear to indicate there was a problem with the tool, which prevented the measurement of hole deviations greater than approximately 2°. The measurements by Schlumberger are, where run, a more accurate representation.

Fluids used in drilling ER-12-1, including dates, depth intervals, and quantities, are listed in Table 5. Bentonite drilling mud was used in ER-12-1 from approximately 548.6 m (1800 ft) to TD. The use of drilling mud was necessitated by loss of circulation and difficulty cleaning the hole due to the use of inadequate diameter (for reverse circulation) integral dual string drill pipe. Mud weights and viscosity measurements are listed in Table 6.

Additional problems encountered during construction of ER-12-1 included insufficient bit life, hammer drill foot valve failures, fishing operations for parted drill pipe and rotary bit cones, poor core recovery, stuck drill pipe, and, finally, deteriorating hole conditions after the removal of the bentonite drilling fluid during initial well development. Many of these problems, along with other important information about the drilling of ER-12-1, are listed in the excerpts from the "Driller's notes" in Table 7.

Following completion of drilling at ER-12-1, initial attempts were made to develop the well by circulating a sodium tetraphosphate solution in the hole to disperse the bentonite-based drilling mud used during construction. The types of development fluids used in ER-12-1, including dates and quantities, are presented in Table 8. Initial well development activities were abandoned due to excessive fill produced in the hole upon removal of the bentonite mud.

To remove the fill and restabilize the wellbore, the hole was cleaned and conditioned on Jan. 13, 1992, using first a bentonite-based drilling mud, and then a polymer mud. Once the wellbore stabilized on Jan. 24, 1992, 19.4–cm (7 5/8 in) steel casing with five slotted intervals was gravel packed and cemented within the hole (Figure 2) to stabilize the hole during further well development and initial hydrologic testing of the well. The five slotted intervals were placed opposite representative intervals of the formations encountered in the borehole. The representative intervals were chosen, at a meeting on October 31, 1991 (attended by RSN, DRI, and USGS), to represent various formations within the borehole and their associated permeability. The zones of interest, geologic formation, and rationale for completing these intervals are shown in Table 9. As illustrated in Figure 2, some difficulty was encountered in placing the cement within the well. Cement extends 8.5 m (28 ft) above the bottom of the slotted interval in the lowermost zone. At the middle and second-from-top zones, cement extends 2.4 m (8 ft) and 6.1 m (20 ft), respectively, above the slotted intervals. These errors in cement placement probably resulted from fill from the wellbore wall falling into the well during the cementing operation, resulting in an excessive rise in cement.

With the hole stabilized by the placement of the slotted casing, it was possible to place a submersible pump within the hole and complete an initial phase of well development. A record of the amounts of fluids removed from the hole, along with dates, methods, and comments is contained in Table 10.

(text continues on page 22)

Table 5. Drilling Fluid Records for ER-12-1.

Date	Approximate Depth	Volume, Fluid Type, Comments
07-18-91	0	312m^3 (1962 bbls) of water to circulation pit
07-19-91	0	286m^3 (1800 bbls) of water
07-22-91	6.1 m (20 ft)	19m^3 (120 bbls) of 50 vis mud, 129 kg (286 lbs) of water
07-23-91	6.1 m (20 ft)	19m^3 (120 bbls) of 50 vis mud, no water
07-24-91	6.1 m (20 ft)	32m^3 (200 bbls) of water
07-25-91	21.3 m (70 ft)	32m^3 (200 bbls) of water
07-30-91	39.6 m (130 ft)	68m^3 (429 bbls) of water
07-31-91	53.3 m (175 ft)	222m^3 (1400 bbls) of water
08-01-91	64.0 m (210 ft)	127m^3 (800 bbls) of water
08-05-91	64.0 m (210 ft)	38m^3 (240 bbls) of Davis Mix, 45.3 kg (100 lbs) of water
08-07-91	64.0 m (210 ft)	57m^3 (360 bbls) of Davis Mix
08-08-91	64.0 m (210 ft)	38m^3 (240 bbls) of Davis Mix
08-09-91	121.9 m (400 ft)	114m^3 (720 bbls) of Davis Mix
08-12-91	152.4 m (500 ft)	57m^3 (360 bbls) of Davis Mix
08-13-91	213.4 m (700 ft)	96m^3 (600 bbls) of Davis Mix
08-14-91	304.8 m (1000 ft)	76m^3 (480 bbls) of Davis Mix
08-15-91	365.8 m (1200 ft)	38m^3 (240 bbls) of Davis Mix
08-16-91	411.5 m (1350 ft)	38m^3 (240 bbls) of Davis Mix
08-19-91	487.7 m (1600 ft)	114m^3 (720 bbls) of Davis Mix
08-27-91	457.2 m (1500 ft)	153m^3 (960 bbls) of water; drilling sand & cement from casing
08-28-91	457.2 m (1500 ft)	96m^3 (600 bbls) of water; drilling sand & cement from casing
08-29-91	518.2 m (1700 ft)	67m^3 (420 bbls) of Davis Mix; drilling formation
09-03-91	548.6 m (1800 ft)	76m^3 (480 bbls) of Davis Mix
09-04-91	548.6 m (1800 ft)	19m^3 (120 bbls) of Davis Mix
09-05-91	548.6 m (1800 ft)	153m^3 (960 bbls) of water; 490 kg (1080 lbs) of 60 vis mud
09-06-91	548.6 m (1800 ft)	306m^3 (1920 bbls) of mud
09-09-91	579.1 m (1900 ft)	172m^3 (1080 bbls) of mud
09-10-91	609.6 m (2000 ft)	172m^3 (1080 bbls) of mud
09-11-91	640.1 m (2100 ft)	19m^3 (120 bbls) of 60 vis mud
09-12-91	670.6 m (2200 ft)	76m^3 (480 bbls) of 60 vis mud

Table 5. Drilling Fluid Records for ER-12-1 (continued).

Date	Approximate Depth	Volume, Fluid Type, Comments
09-16-91	701.0 m (2300 ft)	150m^3 (940 bbls) of 60 vis mud
09-17-91	731.5 m (2400 ft)	198m^3 (120 bbls) of mud
09-18-91	731.5 m (2400 ft)	57m^3 (360 bbls) of mud
09-23-91	731.5 m (2400 ft)	19m^3 (120 bbls) of water; 54 kg (120 lbs) of mud
09-25-91	731.5 m (2400 ft)	76m^3 (480 bbls) of mud
09-26-91	762.0 m (2500 ft)	19m^3 (120 bbls) of 60 vis mud
10-02-91	792.5 m (2600 ft)	76m^3 (480 bbls) of mud
10-03-91	823.0 m (2700 ft)	114m^3 (720 bbls) of mud
10-04-91	853.4 m (2800 ft)	76m^3 (480 bbls) of mud
10-07-91	883.9 m (2900 ft)	38m^3 (240 bbls) of mud
10-08-91	883.9 m (2900 ft)	38m^3 (240 bbls) of mud
10-09-91	914.4 m (3000 ft)	134m^3 (840 bbls) of mud
10-10-91	944.9 m (3100 ft)	538m^3 (3380 bbls) of mud; lost circulation
10-11-91	944.9 m (3100 ft)	395m^3 (2480 bbls) of 60 vis mud; 109 kg (240 lbs) of 120 vis mud
10-14-91	975.4 m (3200 ft)	251m^3 (1580 bbls) of mud
10-15-91	1005.8 m (3300 ft)	191m^3 (1200 bbls) of mud
10-16-91	1036.3 m (3400 ft)	134m^3 (840 bbls) of mud
10-17-91	1066.8 m (3500 ft)	57m^3 (360 bbls) of mud; ER-12-1 reaches TD
10-23-91	1093.6 m (3588 ft)	777m^3 (4880 bbls) of water
10-24-91	1093.6 m (3588 ft)	595m^3 (3740 bbls) of water

Miscellaneous Fluids

Date	Approximate Depth	Additive/Comments
08-14-91	354.2 m (1162 ft)	While out of hole, put 2 gallons of oil down drill collars to lubricate bit
08-15-91	354.2 m (1162 ft)	Rigged up circulating system to blend in lithium bromide tracer; used 1 gallon lithium bromide per 79m^3 (500 bbls) of water.

Table 6. Drilling Mud Data for ER-12-1.

Date	Depth	Vis In	Vis Out	Weight	Comments
09-06-91	556.9 m (1827 ft)	NA	NA	NA	Pumped 169m^3 (1060 bbls) of mud down hole with no returns
09-09-91	617.8 m (2027 ft)	68	78	NA	Drilling with partial returns
09-12-91	693.7 m (2276 ft)	60	NA	NA	Drilling with full returns
09-18-91	751.0 m (2464 ft)	70	NA	NA	
10-01-91	798.9 m (2621 ft)	56	56	8.5	
10-03-91	876.6 m (2876 ft)	52	52	8.7	
10-04-91	885.7 m (2906 ft)	56	56	8.7	
10-07-91	895.2 m (2937 ft)	49	52	8.6	
10-08-91	927.5 m (3043 ft)	44	44	8.9 in/ 8.6 out	
10-09-91	942.7 m (3093 ft)	50	47	8.7	Fluid loss at drilling break at 935.1 m (3068 ft)
10-10-91	958.0 m (3143 ft)	60	NA	8.5	Received 538 m^3 (3380 bbls) of mud
10-11-91	967.4 m (3174 ft)	120	144	8.7 in/ 8.8 out	Drill bit hit void from 962.9-963.8 m (3159 -3162 ft); received 280 m^3 (1760 bbls) of mud
10-14-91	968.7 m (3178 ft)	110	NA	8.7	Dirty-black water being displaced out of hole
10-14-91	991.5 m (3253 ft)	75	NA	8.7	
10-15-91	1030.5 m (3381 ft)	58	69	8.7 in/ 8.9 out	Received 172 m^3 (1080 bbls) of 80 vis mud
10-16-91	1066.8 m (3500ft)	90	68	8.4 in/ 8.7 out	
10-17-91	1093.6 m (3588 ft)	75	75	9.0 in/ 8.8 out	Mud check taken at 0920 hrs
10-17-91	1093.6 m (3588 ft)	47	57	8.8 in/ 8.9 out	Mud check taken at 1400 hrs; ER-12-1 TD'd

Table 7. Driller's Notes.

Date	Depth	Comments
07-19-91	3.7 m (12 ft)	Spud date
07-22-91	9.1 m (30 ft)	Hole not straight
07-25-91	22.6 m (74 ft)	Geolograph calibrated and deficiency noted
07-26-91	30.5 m (100 ft)	Problem cleaning hole so change circulation systems to reverse air/water
07-29-91	30.5 m (100 ft)	3.7 m (12 ft) of fill after weekend; tight hole, drive line snapped
08-01-91	65.5 m (215 ft)	Receive orders at 1700 hrs to plug hole
08-07-91	58.2 m (191 ft)	Hammer drill (bit #6) not working properly, pin from float had jammed; survey tool problem corrected, tool had been run upside down
08-12-91	179.8 m (590 ft)	Foot valve broke in hammer drill (bit #7); button bit is used but won't go past 18.3 m (60 ft) depth so ream hole from 18.3 - 24.4 m (60 to 80 ft); stabilizer drags 2.2 - 4.5K kg (5-10K lbs) when going through bottom of surface casing
08-13-91	238.7 m (783 ft)	Bit #7 and bottom reamers are .64 cm (1/4 in) under gauge
08-15-91	370.9 m (1217 ft)	No fill after event (rig secured <24 hrs)
08-16-91	423.7 m (1390 ft)	Replace foot valve on hammer drill (bit #7)
08-30-91	539.2 m (1769 ft)	Cored 4.6 m (15 ft) recovered 0.06 m (0.2 ft) from core #1 using the conventional core barrel
09-03-91	556.9 m (1827 ft)	Cored 8.2 m (27 ft), recovered 0.0 m (0 ft) from core run #2; ream & clean hole to 656.9 m (1827 ft), then pipe gets stuck
09-04-91	546.8 m (1794 ft)	10.1 m (33 ft) of fill at 1794 ft
09-05-91	544.1 - 556.9 m (1785 - 1827 ft)	Reverse circulation not cleaning hole, pipe gets stuck
09-06-91	556.9 m (1827 ft)	Added 169m^3 (1060 bbls) of mud with no returns (total hole volume was approximately 53 m^3 (333 bbls))
9-11-91	653.8 m (2145 ft)	Trip in hole with new bit (#11); encountered 4.9 m (16 ft) of fill after event (rig secured <24 hrs)
09-16-91	693.7 m (2276 ft)	No fill after event on weekend (rig secured for 3 days)
09-18-91	737.0 m (2418 ft)	Ream tight hole from 548.3 - 556.9 m (1799 - 1827 ft) and from 723.9 - 732.7 m (2375 - 2404 ft) after trip for new bit
09-23-91	751.0 m (2464 ft)	Swap out duplex mud pump for triplex mud pump and pick up core barrel for core #3, 751.0 -757.7 m (2464 - 2486 ft)

Table 7. Driller's Notes (continued).

Date	Depth	Comments
09-25-91	757.7 m (2486 ft)	Measured drill pipe while tripping in hole-no depth correction; left button rotary cones from marine core bit in hole; retrieved using mill tooth bit and globe basket
09-27-91	795.2 m (2609 ft)	Drill pipe twisted off after connection at 792.8 m (2601 ft); pipe broke at weld 7.62 cm (3 in) above pipe collar; successfully retrieved fish in four trips
10-02-91	795.2 m (2609 ft)	Laid down 13.97 cm (5-1/2 in) dual string drill pipe and picked up 16.83 cm (6-5/8in) full-hole drill pipe; began drilling 31.12 cm (12-1/4 in) hole with 19.69 cm (7-3/4 in) Dynadrill
10-03-91	846.1 m (2776 ft)	21.3 m (70 ft) of fill after trip for new bit
10-03-91	853.4 m (2800 ft)	Changed out mud pumps to duplex
10-08-91	895.2 - 903.1 m (2937 - 2963 ft)	Recovered 7.8 m (25.5 ft) from 7.9 m (26 ft) cut on core run #4; change out mud pumps
10-09-91	833.6 - 935.1 m (2735 - 3068 ft)	Ream tight hole from 833.6 - 860.5 m (2735 to 2823 ft); drilling break and fluid loss at 935.1 m (3068 ft); drilled 1.5 m (5 ft) in 8 minutes
10-11-91	962.9 - 963.8 m (3159 - 3162 ft)	Drill bit hit void in this interval; lost complete returns
10-14-91	948.5 - 967.4 m (3112 - 3174 ft)	Tight spot, hole was reamed within this interval
10-16-91	982.1 m (3222 ft)	Tight hole at this depth, reamed 18.3 m (60 ft)
10-17-91	1093.6 m (3588 ft)	ER-12-1 reaches TD
10-24-91	973.8 - 976.9 m (3195 - 3205 ft)	Ream tight hole, then trip in to TD
10-28-91	1001.0 m (3284 ft)	Tagged fill with core barrel
10-29-91	652.3 m (2140 ft)	Hit bridge with tubing
10-30-91	627.6 - 634.0 m (2059 - 2080 ft)	Placed cement plug in washout
11-12-91	549.2 m (1802 ft)	Caliper tool on run #5 hits bridge

Table 8. Completion and Well Development Fluids and Materials Injected into ER-12-1.

Date	Quantity (m^3 (bbls))	Fluid/Material	Comments/Activity
10-22-91	76 (480)	Water	Well Development
10-23-91	478 (3000)	Water w/100 lb Sodium-tetraphosphate	Well Development
10-24-91	229 (1440)	Water w/450 lb Sodium-tetraphosphate	Well Development
10-25-91	1 (6)	Soap	Well Development
10-25-91	153 (960)	Water	Well Development
10-30-91	19 (120)	Water	Well Development
01-13-92	96 (600)	Mud	Clean hole/remove fill
01-14-92	153 (960)	Mud	Clean hole/remove fill
01-15-92	114 (720)	Mud	Clean hole/remove fill
01-16-92	96 (600)	Mud	Clean hole/remove fill
01-16-92	38 (240)	Water	Clean hole/remove fill
01-17-92	19 (120)	Mud	Clean hole/remove fill
01-21-92	134 (840)	Mud	Clean hole/remove fill
01-22-92	76 (480)	Water	Condition hole
01-23-92	153 (960)	Polymer	Condition hole
01-24-92	38 (240)	Water	Condition hole
01-24-92	19 (120)	Polymer	Condition hole
01-25-92	133 (840)	Water	Cement Job/set casing
01-26-92	19 (120)	Water	Cement Job/set casing
01-27-92	60 (380)	Water	Cement Job/set casing
01-28-92	19 (120)	Water	Cement Job/set casing
01-29-92	38 (240)	Water	Cement Job/set casing
01-29-92	57 (360)	Polymer	Cement Job/set casing
01-30-92	134 (840)	Water	Cement Job/set casing
01-31-92	38 (240)	Water	Cement Job/set casing
02-21-92	153 (960)	Water	Well Development
02-24-92	38 (240)	Water	Well Development
02-26-92	19 (120)	Water	Well Development
08-26-92	57 (360)	Water	Well Development
08-27-92	32 (200)	Water	Well Development
08-28-92	96 (600)	Water	Well Development
08-30-92	19 (120)	Water	Well Development
08-31-92	166 (1040)	Water	Well Development
09-01-92	129 (810)	Water	Well Development
09-03-92	32 (200)	Sodium Acid Pyrophosphate	Well Development
09-04-92	32 (200)	Sodium Acid Pyrophosphate	Well Development
09-09-92	48 (300)	Sodium Acid Pyrophosphate	Well Development
09-10-92	19 (120)	Water	Well Development

Table 9. Rationale for Completion of Intervals in Well ER–12–1.

Completion Interval	Geologic Formation	Rationale for Completion
516 to 555 m (1700 to 1820 ft)	Upper Simonson or Lower Guilmette Formation Upper 3 m (10 ft) is Eleana Formation	Multiple faults, over 3000 barrels of mud lost in this interval. May be highly permeable section
585 to 598m (1920 to 1960 ft)	Eleana Formation, Unit J	Representative shaley section of Eleana Formation as indicated by gamma log and cuttings. Zone should be representative of a tight shaley section of Eleana Formation
765 to 790 m (2510 to 2590 ft)	Eleana Formation, Unit J	Representative silty section of Eleana Formation, purpose is to evaluate one of the potentially least permeable sections of the Eleana Formation
911 to 963 m (3000 to 3160 ft)	Lower Simonson Dolomite	Cavernous openings, mud lost, possible permeable section
1024 to 1049m (3360 to 3440 ft)	Upper Sevy Dolomite	Representative section of unfaulted tight dolomite, as determined from dual induction, caliper, epithermal neutron logs and cuttings

Table 10. Fluid Recovery Record for ER–12–1.

Date	Volume (m^3 (bbls))	Activity	Comments
10–25–91	<16 (<100)	Air–lifting	Attempt to develop well by air–lifting fluid from hole
2–25–92	<16 (<100)	Dip–sticking (dual string)	Attempt to develop well by air–lifting fluid from hole
2–26 through 28–92	94 (594)	Swabbing	Attempt to develop well by swabbing fluid from hole
3–5–92	2 (15)	Pumping	Attempt to pump well with 750 lpm (200 gpm) pump
3–12 through 15–92	466 (2925)	"	Develop well with 56–227 lpm (15–60 gpm) pump
3–16–92	8 (50)	"	Test aquifer monitoring equipment
3–19–92	16 (100)	"	"
3–20–92	21 (135)	"	"
3–24–92	25 (156)	"	Aquifer testing
4–1 through 5–92	620 (3895)	"	"
9–14 through 21–92	438 (2755)	Dip–sticking (dual string)	Well development
1–5 and 6–93	304 (1910)	Pumping	Aquifer test (upper zone only)

Following initial hydrologic testing and composite geochemical sampling, further well development was conducted by flushing the wellbore with sodium acid pryophosphate to remove bentonite from the borehole then air-lifting approximately 436m^3 (2738 bbls) of fluid from the well (Tables 8). Straddle-packer tests were conducted on the three middle intervals.

To isolate the five slotted intervals, a 139.7 mm (5 1/2 in) diameter casing string was placed within the well. This casing included five sliding sleeves separated by packers (Figure 2), which serve to isolate the five gravel-packed intervals within the well.

After placement of the 139.7 mm (5 1/2 in) casing with sliding sleeves, the TAM Inc. sliding sleeve shifter tool was used to close all sleeves, and then open the uppermost sleeve. This effectively sealed off the lower four intervals from the wellbore. A submersible pump was then placed within the well and a 24-hour aquifer test was conducted on the isolated upper interval. Prior to the conclusion of the pumping phase of the 24-hour aquifer test, geochemical samples were obtained from the fluids produced from the uppermost zone within the well.

An outline of the sequence of events during drilling, completion, development and testing of ER-12-1 is presented in Appendix D of this report.

According to fluid records supplied by REECo and RSN, a total of 8423 m^3 (52,920) barrels of fluids were delivered to the ER-12-1 well site. Approximately 620 m^3 (3895 barrels) of fluid were removed from the well and discharged to land surface during aquifer testing. A total of 6270 m^3 (39,370 barrels) of used drilling and development fluids were removed from the mudpit at ER-12-1 and hauled by truck to a disposal site. Approximately 318 m^3 (2000 barrels) of fluid were left in the sump at ER-12-1. Neglecting losses from the sump by evaporation and dilution of drilling fluids by formation water, 1218 m^3 (7655 barrels) of unrecovered fluids remain in ER-12-1.

GEOLOGY OF ER-12-1 BASED ON MACROSCOPIC OBSERVATIONS

Surface Geology

The geologic setting for ER-12-1 is different from typical weapons-related sites in that the hole was drilled almost entirely through Paleozoic sedimentary rocks. Figure 3 is a geologic map of the ER-12-1 area, which was extracted from the "Geologic Map of the Rainier Mesa Quadrangle, Nye County, Nevada" (Gibbons *et al.*, 1963). While the geologic interpretations presented in this map are rather old and in some cases changed since publication, the gross geologic characteristics are still viable. Table 11 correlates the old stratigraphic nomenclature used on this map with the more recent nomenclature used elsewhere in this report.

As can be noted from the map, the geology is quite complex due to the extensive faulting (thrust and normal) the area has undergone. Another complication in the geologic interpretation is that compared to the Tertiary volcanic rocks of the NTS, the Paleozoic rocks are less studied, and therefore less familiar to the general NTS geologic community.

Figure 3 illustrates some of the major geologic features of the area. Stockade Wash Road runs through Tongue Wash, which is an erosional feature superimposed upon the Mesozoic Tongue Wash

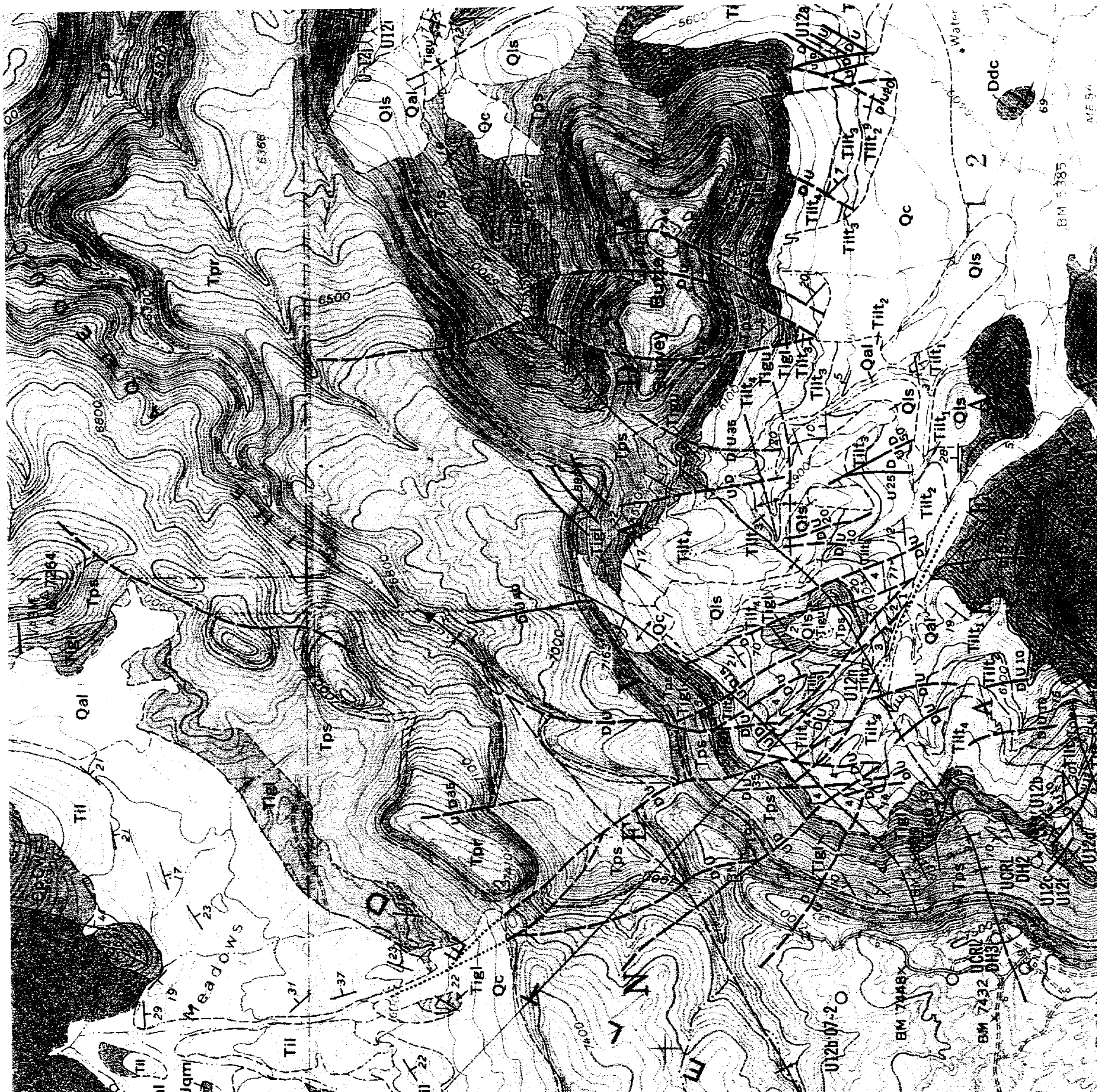


Figure 3. Geologic map of the ER–12–1 vicinity. (Extracted from G

ıns et al., 1963 "Geologic map of the Rainier Mesa Quandrangle")

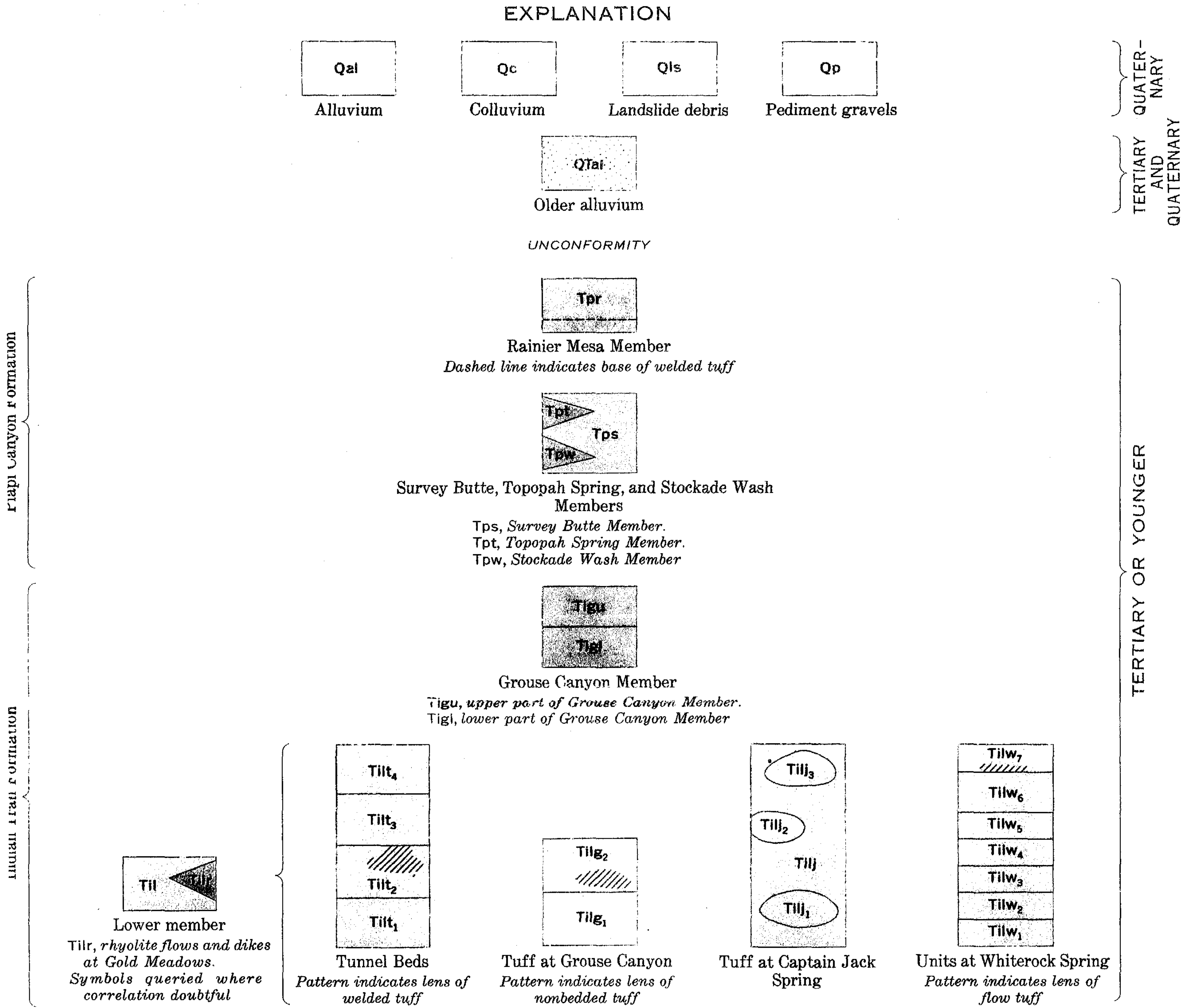


Figure 3. Geologic map of the ER–12–1 vicinity. (Extracted from Gibbo

Table 12. Sample Disposition Log for ER-12-1.

Sample Type	Depth Interval	Receiving Lab or Location	Preservation or Storage Container
Washed drill cuttings	3.05 to 1093.6 m (10 to 3588 ft) at 3.05 m (10 ft) intervals	USGS Core Library Mercury, NV	Cardboard sample boxes
Unwashed drill cuttings with custody seal	3.05 to 1093.6 m (10 to 3588 ft) at 3.05 m (10 ft) intervals	USGS Core Library Mercury, NV	One-pint ice cream cartons
Washed drill cuttings "Paleo" samples	15.2 to 1082.0 m (50 to 3550 ft) at 15.2 m (50 ft) intervals	A. G. Harris USGS MS 970 Reston, VA 22092	One-gallon metal cans
Core	543.7 to 543.8 m ? (1783.8 to 1784 ft ?)	USGS Core Library Mercury, NV	Cardboard core boxes
Core	751.0 - 754.1 m (2464 - 2962.5 ft)	USGS Core Library Mercury, NV	Cardboard core boxes
Core	895.2 - 903.0 m (2937 - 2962.5 ft)	USGS Core Library Mercury, NV	Cardboard core boxes
Polished thin sections	(See Table 14 for list of depths)	RSN Geology Bldg. 155 Mercury, NV	Boxes
Polished thin sections	1091.2 m (3580 ft)	R. G. Warren LANL, MS F659 Los Alamos, NM	Box
Standard covered thin sections	15.2 to 1082.0 m (50 to 3550 ft)	J. C. Cole USGS, MS 913 Denver, CO	Boxes

Drilling operations and subsequent sampling for this drillhole have been extensively documented, including the implementation of a chain-of-custody procedure (with samples sealed on location), and photo–documentation.

Stratigraphy and Lithology of ER-12-1

ER-12-1 penetrated 1093.6 m (3588 ft) of sedimentary rocks ranging in age from Ordovician to Mississippian, minor Cretaceous intrusive rock and surficial gravel. Table 19 lists the pre-Tertiary stratigraphic nomenclature used in this report. Table 20 is the stratigraphic log for ER-12-1. These rocks have been deformed by both Mesozoic compression and Tertiary extension. This combined structural activity has resulted in a complex shuffling of the stratigraphic sequence in the vicinity of ER-12-1. Units encountered at ER-12-1 were initially assigned to formations primarily on the basis of lithologic characteristics (Table 21), but final assignment was made on the basis of paleontologic studies completed after drilling ceased. Detailed descriptions of cored intervals are presented in Tables 22, 23

Table 11. Correlation of Stratigraphic Nomenclature used in this Report with that used in Figure 3.

Figure 3 (adapted from Gibbons et al., 1963)	This Report (adapted from Cole, 1991)
Qal - Alluvium	QTa - Alluvium
PMe - Eleana Formation (Units A-J)	MDe - Eleana Formation (Units A-J)
Dd (Units A-C) - Dolomite	DSs - Sevy Dolomite
DSO1 - Dolomitic Limestone	

fault. Rainier Mesa is evident in Figure 3, and is indicated where the Tertiary Rainier Mesa Tuff caps the less resistant, older underlying units along the western and northern margins of the map. The Eleana Range, a ridge of mostly Paleozoic sediments, is best defined in the southeast corner of Figure 3, where the Devonian to Mississippian rocks of the Eleana Formation predominate.

Sample Inventories and Additional Data

Cuttings and core samples were collected during the drilling phase of ER-12-1. Drill cuttings samples were collected by the roughneck at 3.04 m (10 ft) intervals. From the same depth intervals a custody-sealed sample was also collected and placed in 0.47 L (one-pint) containers. At 15.24 m (50 ft) intervals, a 3.8 L (one-gallon) metal container was filled with sample cuttings to be used for micro-paleontologic studies. Table 12 lists the sample types available from ER-12-1 and the archival location or custodian. Cores were attempted at four different depth intervals but only three of the core runs produced core. Table 13 lists the cored intervals, recoveries, and core barrels used.

Thin sections were made by REECo from the drill cuttings at selected depths. Polished thin sections were made for RSN, and a set of standard covered thin sections were made for the USGS at 15.24 m (50 ft) intervals throughout the hole. Table 14 shows the depth, sample number, lithology, and formation of each of the 15 polished thin sections.

X-ray diffraction analysis was performed on drill cuttings samples from four depths to identify mineral constituents. The percentages of the various minerals in each sample are listed in Table 15.

Physical properties (unconfined compressive strength, bulk density, and porosity) were measured on several globe-basket samples from approximately 754.4 m (2475 ft) depth. Table 16 contains these data along with the lithology of each sample.

A downhole camera was run from the surface to 486.3 m (1596 ft) in ER-12-1. Features observed include casing, fractures, washouts, and fluid level. A problem was encountered due to the camera overheating, which resulted in poor resolution over several intervals. A summary of observations from the downhole camera run are presented in Table 17. 35 –mm slides were taken to document selected equipment, activities, and all the samples. A list of these can be found in Table 18.

Table 12. Sample Disposition Log for ER-12-1.

Sample Type	Depth Interval	Receiving Lab or Location	Preservation or Storage Container
Washed drill cuttings	3.05 to 1093.6 m (10 to 3588 ft) at 3.05 m (10 ft) intervals	USGS Core Library Mercury, NV	Cardboard sample boxes
Unwashed drill cuttings with custody seal	3.05 to 1093.6 m (10 to 3588 ft) at 3.05 m (10 ft) intervals	USGS Core Library Mercury, NV	One-pint ice cream cartons
Washed drill cuttings "Paleo" samples	15.2 to 1082.0 m (50 to 3550 ft) at 15.2 m (50 ft) intervals	A. G. Harris USGS MS 970 Reston, VA 22092	One-gallon metal cans
Core	543.7 to 543.8 m ? (1783.8 to 1784 ft ?)	USGS Core Library Mercury, NV	Cardboard core boxes
Core	751.0 - 754.1 m (2464 - 2962.5 ft)	USGS Core Library Mercury, NV	Cardboard core boxes
Core	895.2 - 903.0 m (2937 - 2962.5 ft)	USGS Core Library Mercury, NV	Cardboard core boxes
Polished thin sections	(See Table 14 for list of depths)	RSN Geology Bldg. 155 Mercury, NV	Boxes
Polished thin sections	1091.2 m (3580 ft)	R. G. Warren LANL, MS F659 Los Alamos, NM	Box
Standard covered thin sections	15.2 to 1082.0 m (50 to 3550 ft)	J. C. Cole USGS, MS 913 Denver, CO	Boxes

Drilling operations and subsequent sampling for this drillhole have been extensively documented, including the implementation of a chain-of-custody procedure (with samples sealed on location), and photo–documentation.

Stratigraphy and Lithology of ER-12-1

ER-12-1 penetrated 1093.6 m (3588 ft) of sedimentary rocks ranging in age from Ordovician to Mississippian, minor Cretaceous intrusive rock and surficial gravel. Table 19 lists the pre-Tertiary stratigraphic nomenclature used in this report. Table 20 is the stratigraphic log for ER-12-1. These rocks have been deformed by both Mesozoic compression and Tertiary extension. This combined structural activity has resulted in a complex shuffling of the stratigraphic sequence in the vicinity of ER-12-1. Units encountered at ER-12-1 were initially assigned to formations primarily on the basis of lithologic characteristics (Table 21), but final assignment was made on the basis of paleontologic studies completed after drilling ceased. Detailed descriptions of cored intervals are presented in Tables 22, 23, and 24. Table 25 lists other nearby holes that penetrated pre-Tertiary rocks.

(text continues on page 30)

Table 13. ER–12–1 Core Inventory Record.

Core No.	Date	Archive Box No.	Cored Interval	Cut	Recovered	Percent	Core Barrel Recovery	Remarks
1	08–03–91	1	539.2 to 543.8 m (1769 to 1784 ft)	4.6 m (15 ft)	0.06 m (0.2 ft)	1.3	Conventional core barrel	Core barrel jammed
2	09–03–91	N/A	548.0 to 556.3 m (1798 to 1825 ft)	8.2 m (27 ft)	0 m (0)	0	Marine core barrel	
3	09–23–91	1 & 2	751.0 to 757.7 m (2464 to 2486 ft)	6.7 m (22 ft)	3.0 m (10 ft)	45.5	Marine core barrel	Left bit cones in hole
4	10–08–91	3, 4, 5, 6, & 7	895.2 to 903.1 m (2937 to 2963 ft)	7.9 m (26 ft)	7.8 m (25.5 ft)	98	Conventional core barrel	Core barrel jammed

Table 14. List of Polished Thin Sections Available from Selected ER-12-1 Cuttings Samples.[1]

Sample ID No.	Depth	Lithology	Formation
ER-12-1 730	222.5 m (730 ft)	Dolomite	Sevy Dolomite[3]
ER-12-1 800	243.8 m (800 ft)	Dolomite	Antelope Valley Limestone
ER-12-1 1000	304.8 m (1000 ft)	Dolomite	Sevy Dolomite
ER-12-1 1050	320.0 m (1050 ft)	Calcareous Siltstone	Eleana Formation, Unit J (?)
ER-12-1 1080	329.2 m (1080 ft)	Siltstone	Eleana Formation, Unit J (?)
ER-12-1 1140	347.5 m (1140 ft)	Siltstone	Eleana Formation, Unit J (?)
ER-12-1 1650	502.9 m (1650 ft)	Siltstone	Eleana Formation, Unit J (?)
ER-12-1 1800	548.6 m (1800 ft)	Dolomite	Upper Simonson or Lower Guilmette Formation[3]
ER-12-1 1960	597.4 m (1960 ft)	Quartzite	Eleana Formation, Unit J (?)
ER-12-1 2240	682.8 m (2240 ft)	Shale	Eleana Formation, Unit J (?)
ER-12-1 2370	722.4 m (2370 ft)	Quartzite	Eleana Formation, Unit J
ER-12-1 2850	868.7 m (2850 ft)	Calcareous Siltstone	Eleana Formation, Unit J (?)
ER-12-1 2930	893.1 m (2930 ft)	Dolomite	Upper Sevy or Lower Simonson Dolomite[3]
ER-12-1 3570	1088.1 m (3570 ft)	Dolomite	Upper Sevy or Lower Simonson Dolomite[3]
ER-12-1[2] 3580	1091.2 m (3580 ft)	Biotite Lamprophyre	Lamprophyre Dike, (Middle Cretaceous) intrudes Sevy Dolomite

[1]An independent set of thin sections has been established by Jim Cole. USGS-Denver, for the entire borehole at 15.2 m (50 ft) depth intervals.

[2]A polished thin section was made for the purpose of microprobe work by R. G. Warren, LANL, of the 1091.2 m (3580 ft) cuttings sample.

[3]Stratigraphic assignment based on paleontological investigations by A.G. Harris. USGS - Reston, VA.

Table 15. X–ray Diffraction Analyses for Selected ER–12–1 Cuttings Samples.[1]

Depth	Mica %	Hornblende %	Chlorite %	Quartz %	Feldspar %	Calcite %	Dolomite %	Glass/Amorph %
463.3 m (1520 ft)	4±1	0	0	44±2	0	47±3	9±1	0
627.9 m (2060 ft)	15±5	0	3±1	46±2	12±1	0	0	24±6
655.3 m (2150 ft)	2±1	0	trace	81±4	2±1	0	12±1	0
1091.2 m (3580 ft)	40±12	2±1[2]	8±1	20±2[2]	13±2	11±2	0	0

[1]Analyses by Steve Chipera, LANL, Dec. 1991

[2]These results are not observed in thin section

Table 16. Physical Properties Measurements on Selected ER-12-1 Samples.

Sample[1] Depth	Unconfined Compressive Strength (psi)	Bulk Density (g/cc)	Apparent Porosity to Water (%)	Lithology
754.4 m (2475 ft)	8220	NA	NA	Argillaceous quartzite
754.4 m (2475 ft)	3720[2]	NA	NA	Argillaceous quartzite
754.4 m (2475 ft)	4160	NA	NA	Argillaceous quartzite
754.4 m (2475 ft)	11820	NA	NA	Argillaceous quartzite
754.4 m (2475 ft)	7300	NA	NA	Argillaceous quartzite
754.4 m (2475 ft)	NA	2.68[3]	0.4	Argillaceous quartzite
754.4 m (2475 ft)	NA	2.67[3]	0.5	Argillaceous quartzite

Analyses by E. Aamodt, RSN Materials Test Lab, Sept. and Oct., 1991

[1]Globe-basket samples after Core #3 (751.0 - 757.7 m (2464 - 2486 ft))
[2]Sample failed at a vein or healed fracture (?)
[3]Bulk density testing yielded identical results (saturated and unsaturated) indicative of a very low porosity rock

ER-12-1 was spudded in Quaternary/Tertiary alluvium. This alluvium unconformably overlies the Sevy Dolomite and consists of 7.9 m (26 ft) of silt- to boulder-size debris eroded from the surrounding hills.

The Sevy Dolomite (late Silurian to early Devonian) was encountered in three separate intervals in the ER-12-1 borehole: 7.9 - 237.8 m (26 - 780 ft), 274.3 - 312.4 m (900 - 1025 ft), and 975.4 - 1086.3 m (3200 - 3564 ft).

Dolomite assigned to mid to late Devonian upper Simonson Dolomite or lower Guilmette formation were encountered twice during the drilling of ER-12-1. A 29.6 m (97 ft) thick section of intensely faulted and fractured, light-gray to medium-light-gray dolomite was penetrated from 521.2 - 550.8 m (1710 -1807 ft). This section lies between two relatively thick intervals of the

(text continues on page 39)

Table 17. Downhole Camera Video Log for ER-12-1 (Surface to 486.3 m (1596 ft) Interval, (08-21-91).

Tape Time (Hr Min Sec)	Depth	Comments
<u>Tape #1; Run #1</u>		
0:0:00	N/A	Start of Tape #1 and Run #1; 0 - 365.8 m (0 - 1200 ft)
0:1:00	N/A	Camera at rig floor
0:2:00 - 0:5:00	N/A	Calibration
0:6:00	N/A	Going into surface casing
0:6:25	0	Ground level
0:8:00	0	Ground level
0:13:22	15.3 m (50.3 ft)	Base of surface casing
0:14:15	16.7 m (54.8 ft)	Change from cement to formation (Simonson Dolomite)
0:22:25	36.0 m (118 ft)	Minor hole enlargement
0:22:53	37.5 m (123 ft)	Fracture trending N-S (NE-SW fracture also)
0:24:19	38.6 m (126.5 ft)	Intersecting fractures trend SE-NW and NE-SW
0:25:20	42.2 m (138.5 ft)	White reflective calcite(?)-filled fracture on left side of screen (north side of borehole)
0:26:23	43.6 m (143 ft)	N-S–trending fracture
0:26:50	45.1 m (148 ft)	N-S–trending fracture
0:27:15	45.7 m (150 ft)	Gyro reading (readings every 15.2 m (50 ft))
0:31:12 - 0:34:40	58.5 - 60.0 m (192 - 197 ft)	Adjusting sheave on derrick floor resulting in negative 1.2 m (4 ft) depth correction for 61.0 - 221.0 m (200 - 725 ft) interval
0:36:20	64.2 m (210.5 ft)	NE-SW–trending fracture
0:39:20	70.7 m (232 ft)	NW-SE–trending fracture
0:40:13	73.6 m	Rough borehole due to breakout in (241.4 ft) fractured interval
0:42:43	77.1 m (253 ft)	Fracture trending N-S
0:43:30	78.9 m (259 ft)	Fracture
0:45:00	82.6 m (271 ft)	Borehole enlargement due to N-S and NE-SW–trending fractures

Table 17. Downhole Camera Video Log for ER-12-1 (Surface to 486.3 m (1596 ft) Interval, 08-21-91) (continued).

Tape Time (Hr Min Sec)	Depth	Comments
0:51:30	104.2 m (342 ft)	Fractures with NE-SW hole enlargement
1:00:00	121.9 m (400 ft)	Resolution becoming progressively worse (camera system overheating?)
1:07:07	152.4 (500 ft)	Gyro reading; video quality is only marginally useful
1:18:10	213.4 m (700 ft)	Video is useless
1:19:53	221.1 m (725.5 ft)	Max depth for Run #1
Tape #1; Run #2		
1:20:00	213.4 m (700 ft)	Pulled out of hole to cool camera
1:20:30	214.3 m (703 ft)	Highly reflective fracture fill in upper left corner
1:22:20	223.1 m (732 ft)	N-S –trending fracture-controlled breakout
1:22:59	227.1 m (745 ft)	Camera rate has increased to 6.1 m (20 ft)/minute
1:23:53	233.6 m (766.5 ft)	Fracture in lower left corner of screen
1:24:30	237.7 m (780 ft)	Possible contact, moderate dip
1:24:39	239.0 m (784 ft)	Patches of orange/red staining exposed behind wall cake
1:25:00	241.4 m (792 ft)	Base of red stain
1:25:07	242.2 m (794.5 ft)	Parabolic fracture trace?
1:25:48	245.1 m (804 ft)	Fracture on lower left corner of screen
1:26:00	246.0 m (807 ft)	Reddish stain still seen
1:26:57	251.0 m (823.5 ft)	Fracture
1:27:20	253.0 m (830 ft)	Hole enlargement possibly fracture controlled; one set is N-S, the other E-W
1:28:25	256.3 m (841 ft)	NW-SE fracture-controlled breakout
1:29:23	259.1 m (850 ft)	Hole back in gauge

Table 17. Downhole Camera Video Log for ER-12-1 (Surface to 486.3 m (1596 ft) Interval, 08-21-91) (continued).

Tape Time (Hr Min Sec)	Depth	Comments
1:30:52	265.8 m (872 ft)	Orange-red stain behind wall cake still persists
1:31:40	266.6 m (874.8 ft)	Fracture-controlled breakout
1:32:33	272.2 m (893 ft)	Fractures on right side of screen
1:33:00	278.9 m (915 ft)	Darker-brown–colored planar facets, possible fractures; camera overheating
1:34:00	281.9 m (925 ft)	Fractures
1:34:14	282.9 m (928 ft)	Fracture-controlled breakout on upper right corner of screen; two sets within 10° of N-S
1:34:50	285.0 m (935 ft)	Possible parabolic fracture traces
1:36:35	290.8 m (954 ft)	N-S hairline fracture trace (?)
1:37:20	290.5 m (953 ft)	Possible indistinct bedding on upper left side of screen
1:39:05	304.8 m (1000 ft)	Gyro check
1:40:48	311.8 m (1023 ft)	Parabolic trace through borehole
1:43:03	326.0 m (1069.5 ft)	Hint of intersecting fracture on left side of screen
1:43:25	326.1 m (1070 ft)	Several fracture sets
1:45:36	335.0 m (1099 ft)	Several fracture sets at high angle; video quality is deteriorating
1:46:54	339.1 m (1112.6 ft)	High-angle fracture plane trending N-S
1:47:28	341.7 m (1121 ft)	Spiral traces along borehole
1:47:37	342.3 m (1123 ft)	Dipping parabolic trace
1:47:58	344.4 m (1130 ft)	High-angle linear fracture (?) trace
1:48:10	345.8 m (1134.5 ft)	High-angle linear fracture (?) trace
1:48:22	346.9 m (1138 ft)	Parabolic trace dipping SW
1:49:19	349.3 m (1146 ft)	Fracture on lower left screen

Table 17. Downhole Camera Video Log for ER-12-1 (Surface to 486.3 m (1596 ft) Interval, 08-21-91) (continued).

Tape Time (Hr Min Sec)	Depth	Comments
1:49:30	350.5 m (1150 ft)	Fracture
1:50:40	356.3 m (1169 ft)	Fractures on right side of screen
1:51:06	359.1 m (1178 ft)	Partial parabolic ring on right side of screen
1:52:26	365.8 m (1200 ft)	Stop to cool camera for better resolution, unsuccessful; pull out of hole; end of Tape #1
Tape #2, Run #3		
0:0:00	357.8 m (1174 ft)	Start of tape
0:0:36	365.8 m (1200 ft)	Run #3, Tape #2
0:1:20	367.9 m (1207 ft)	Top of fracture interval; high–angle fracture evident by planar facets in borehole wall
0:3:20	374.6 m (1229 ft)	Gyro reading; on left is N-S–trending high-angle fracture; in upper right is parabolic fracture trace
0:3:36	375.5 m (1232.9)	Several red stains; fractures on right side of screen
0:4:25	378.6 m (1242 ft)	Rough-textured borehole
0:5:18	381.3 m (1251 ft)	Breakout on right (SE) side
0:6:39	386.8 m (1269 ft)	Near-vertical fracture on right side of screen with SE-NW trend
0:7:43	388.3 m (1274 ft)	Several fractures on upper right screen
0:8:31	392.6 m (1288 ft)	Light-colored band appears truncated by light-colored parabolic trace
0:8:58	394.7 m (1295 ft)	Two light–colored parabolic traces with low to moderate dip
0:9:13 - 0:10:11	395.9 - 400.2 m (1299 - 1313 ft)	Several irregular parabolic traces within this interval (low to moderate bedding dip)
0:10:27	401.4 m (1317 ft)	Fracture sets trend E-W and dip N; other fracture sets trend NE-SW
0:11:08	423.7 m (1390 ft)	Possible low-angle bedding
0:11:50	405.4 m (1330 ft)	Light and dark color of borehole possibly due to washout
0:12:45	410.6 m (1347 ft)	Two parabolic fracture traces

Table 17. Downhole Camera Video Log for ER-12-1 (Surface to 486.3 m (1596 ft) Interval, 08-21-91) (continued).

Tape Time (Hr Min Sec)	Depth	Comments
0:13:18	413.5 m (1356.6 ft)	Parabolic fracture trace
0:13:35	414.8 m (1361 ft)	Breakout on left due to fracture with SW-NE trend; small influx of water at base
0:16:44	419.4 m (1375.9 ft)	Several more parabolic fracture traces
0:17:51	422.4 m (1386 ft)	Several fractures
0:18:56	427.0 m (1401 ft)	Borehole surface has well-fractured appearance
0:20:25	433.4 m (1422 ft)	High-angle parabolic trace, reddish in color
0:22:00	439.5 m (1442 ft)	Washout on right side
0:22:42	442.3 m (1451 ft)	Light-colored calcite (?) veins on right side of screen
0:24:07	448.6 m (1471.9 ft)	Fracture-controlled breakout on left side of screen (NE-SW trend)
0:24:54	451.1 m (1480 ft)	Light-colored calcite (?) veins
0:25:23	453.5 m (1488 ft)	Rough washout on left
0:29:00	467.0 m (1532 ft)	Looking down at fluid level several feet below
0:30:00	467.0 m (1532 ft)	Gyro drift check
0:36:54	N/A	Change out ringlight to system with light source below lens for observation below water table
Tape #2; Run #4		
NA	NA	Start of run #4; black and white
NA	467.1 m (1532.5 ft)	Looking down at water level
NA	486.3 m (1595.4 ft)	Deepest penetration below fluid level; visibility is very poor to useless

Downhole camera contractor: Westech Engineering
Onsite engineer/operator: Greg Lianville
Date Run: 08-21-91
Commentator: Lance Protho, RSN

Table 18. List of 35-mm Slides Documenting Drilling Activities, Equipment, and Samples at ER-12-1.* (Photography by RSN Geology/Hydrology Section)

Slide No.	Date	Description
ER0003	08-06-91	View from Dolomite Hill
ER0004	08-06-91	Looking back up Dolomite Hill
ER0005	08-12-91	Samples and sample log book on desk in sample skid shack
ER0006	08-12-91	Locked sample box for "custody samples" at ER-12-1
ER0007	08-12-91	Locked sample box and previous locked-pipe sample holder
ER0008	08-30-91	Cardwell 500 rig; pulling core barrel, Core #1
ER0009	08-30-91	Unscrewing inner core barrel, Core #1
ER0010	08-30-91	Laying down fiberglass inner core barrel onto rig catwalk, Core #1
ER0011	08-30-91	Conventional core barrel, Core #1
ER0012	08-30-91	Close-up of marine core bit
ER0014	08-30-91	Marine core barrel and bit
ER0016	08-30-91	14cm (5-1/2 in) dual-string drill pipe used at ER-12-1
ER0018	08-30-91	Looking across reserve pit at Cardwell 500 while drilling
ER0020	08-30-91	Radsafe and geologist trailer at ER-12-1
ER0021	08-30-91	Cardwell 500 rig
ER0023	08-30-91	DRI van
ER0024	08-30-91	Cardwell 500 rig from E-Tunnel access road
ER0026	08-30-91	Cardwell 500 rig at distance from E-Tunnel access road
ER0027	08-30-91	Core #1 recovered 0.06 m (0.2 ft) of dolomite
ER0029	08-30-91	Marine core barrel and bit on rig catwalk; used for Core #2
ER0031	09-12-91	Rig geolograph (depth recorder)
ER0033	09-12-91	Shale shaker and steel mud tank
ER0035	09-12-91	Rotating head/well head assembly
ER0037	09-12-91	Shaleshaker, top view
ER0039	09-12-91	Steel mud tank
ER0041	09-12-91	Rotary table
ER0043	09-12-91	Driller's console rig controls and weight indicator
ER0045	09-16-91	ER-12-1 location from side of hill 6355.0, looking north
ER0047	09-16-91	Area 12 camp from E-Tunnel access road, looking northeast
ER0048	09-16-91	ER-12-1 location from side of hill 6355.0, looking north-northeast
ER0050	09-16-91	ER-12-1 location from side of hill 6355.0, looking north-northwest
ER0051	09-16-91	Cardwell 500 drill rig, truck-cab end
ER0052	09-16-91	Tritium analyzer used at ER-12-1
ER0053	09-16-91	Tritium lab test equipment at ER-12-1
ER0054	09-16-91	Alpha detector at ER-12-1
ER0056	09-16-91	Drilling fluid filtrate press and N_2 bottle arrangement used at ER-12-1
ER0058	09-16-91	Radsafe and geologist trailer as equipped at ER-12-1
ER0060	09-16-91	44.4 cm (17-1/2 in) button bit
ER0062	09-16-91	31.1 cm (12-1/4 in) button bit used at ER-12-1

Table 18. List of 35-mm Slides Documenting Drilling Activities, Equipment, and Samples at ER-12-1.* (Photography by RSN Geology/Hydrology Section) (continued).

Slide No.	Date	Description
ER0064	10-08-91	"Full-hole" drill pipe on pipe racks at ER-12-1
ER0065	10-08-91	Derrick full of pipe after Core #4
ER0067	10-08-91	22.2 cm (8-3/4 in) diamond core bit used for Core #4
ER0069	10-08-91	Using rock saw to cut fiberglass inner barrel with Core #4 inside
ER0071	10-08-91	Examining Core #4 in core trough
ER0073	10-08-91	Core barrel laying in V-door ramp after Core #4
ER0075	10-08-91	Geologist examining Core #4
ER0078	10-08-91	Core #4, Box #7; 902.3 - 903.2 m (2959.5 - 2962.5 ft)
ER0080	10-08-91	Core #4, Box #6; 900.5 - 902.3 m (2953.8 - 2959.5 ft)
ER0082	10-08-91	Core #4, Box #5; 898.9 - 900.5 m (2948.5 - 2953.8 ft)
ER0084	10-08-91	Core #4, Box #4; 897.5 - 898.9 m (2943.7 - 2948.5 ft)
ER0086	10-08-91	Core #4, Box #3; 895.4 - 897.5 m (2937.0 - 2943.7 ft)
ER0088	10-19-91	AWS logging sheave at ER-12-1; lower sheave at rig floor
ER0090	10-19-91	31.1 cm (12-1/4) in button bit used at ER-12-1
ER0092	10-19-91	AWS flat bed truck with logging tools at ER-12-1
ER0094	10-19-91	View of AWS logging truck from ER-12-1 rig floor
ER0096	10-19-91	AWS logging truck at ER-12-1, side view
ER0098	10-19-91	AWS logging truck at ER-12-1, front view with rig in background
ER0100	10-19-91	AWS pickup truck with logging tools and lead pig for storing radioactive logging sources
ER0102	10-19-91	AWS logging sheave attached to traveling blocks at ER-12-1
ER0104	10-19-91	AWS instrument-control trailer for VSP surveys at ER-12-1
ER0106	10-19-91	Calibration box for ENP logging tool
ER0108	10-19-91	Inside of VSP instrument trailer, Steve Molnar operator at ER-12-1
ER0110	10-19-91	AWS VSP truck at ER-12-1
ER0112	10-19-91	AWS VSP truck, seismic-source pad
ER0114	10-19-91	Compressor and motor instruments at back of VSP truck
ER0116	10-19-91	Air filters used while drilling with air at ER-12-1
ER0117	10-19-91	Betaman tritium instrument at ER-12-1
ER0118	10-19-91	Bromide measuring instrument at ER-12-1
ER0120	10-19-91	Turbidity meter at ER-12-1
ER0121	12-05-91	Intergraph CADD work station in the RSN Geology Building
ER0122	12-05-91	Geologic work station in the "GCP Room" at the USGS Core Library
ER0124	12-05-91	Closeup of microscope work station in the "GCP Room" at the USGS Core Library
ER0126	12-05-91	ER-12-1 "paleo" samples on drying tray in the "GCP Room" at the USGS Core Library
ER0128	12-05-91	ER-12-1 boxed drill cuttings on sample cart in the "GCP Room" at the USGS Core Library

Table 18. List of 35-mm Slides Documenting Drilling Activities, Equipment, and Samples at ER-12-1.* (Photography by RSN Geology/Hydrology Section) (continued).

Slide No.	Date	Description
ER0130	12-05-91	Work area (sink & counter top) in the "GCP Room" at the USGS Core Library
ER0131	12-05-91	ER-12-1 washed drill cuttings, 3.0 - 64.0 m (10 - 210 ft) interval
ER0133	12-05-91	ER-12-1 washed drill cuttings, 67.1 - 128.0 m (220 - 420 ft) interval
ER0135	12-05-91	ER-12-1 washed drill cuttings, 131.1 - 192.1 m (430 - 630 ft) interval
ER0137	12-05-91	ER-12-1 washed drill cuttings, 195.1 - 259.1 m (640 - 850 ft) interval
ER0139	12-05-91	ER-12-1 washed drill cuttings, 262.2 - 323.2 m (860 - 1060 ft) interval
ER0141	12-05-91	ER-12-1 washed drill cuttings, 326.2 - 387.2 m (1070 - 1270 ft) interval
ER0143	12-05-91	ER-12-1 washed drill cuttings, 390.2 - 451.2 m (1280 - 1480 ft) interval
ER0145	12-05-91	ER-12-1 washed drill cuttings, 454.3 - 515.3 m (1490 - 1690 ft) interval
ER0147	12-05-91	ER-12-1 washed drill cuttings, 518.3 - 585.4 m (1700 - 1920 ft) interval
ER0149	12-05-91	ER-12-1 washed drill cuttings, 588.4 - 649.4 m (1930 - 2130 ft) interval
ER0151	12-05-91	ER-12-1 washed drill cuttings, 652.4 - 713.4 m (2140 - 2340 ft) interval
ER0153	12-05-91	ER-12-1 washed drill cuttings, 716.5 - 777.4 m (2350 - 2550 ft) interval
ER0155	12-05-91	ER-12-1 washed drill cuttings, 780.5 - 841.5 m (2560 - 2760 ft) interval
ER0157	12-05-91	ER-12-1 washed drill cuttings, 844.5 - 905.5 m (2770 - 2970 ft) interval
ER0159	12-05-91	ER-12-1 washed drill cuttings, 908.5 - 972.6 m (2980 - 3190 ft) interval
ER0161	12-05-91	ER-12-1 washed drill cuttings, 975.6 - 1033.5 m (3200 - 3390 ft) interval
ER0163	12-05-91	ER-12-1 washed drill cuttings, 1036.6 - 1081.7 m (3400 - 3584 ft) interval
ER0165	12-05-91	ER-12-1 washed drill cuttings with custody seal
ER0167	12-05-91	ER-12-1 Core Run #3 with Formation Micro-Scanner log
ER0168	12-05-91	ER-12-1 Core Run #3, Box #1, 751.2 - 753.2 m (2464 - 2470.7 ft) interval
ER0170	12-05-91	ER-12-1 Core Run #3, Box #2, 753.2 - 754.3 m (2470.7 - 2474 ft) interval
ER0172	12-05-91	ER-12-1 Core Run #1, Box #2, 539.3 - 543.9 m (1769 - 1784 ft) interval
ER0174	12-05-91	ER-12-1 Core Run #4, Box #3, 895.4 - 897.5 m (2937 - 2943.7 ft) interval
ER0175	12-05-91	ER-12-1 Core Run #4, Box #4, 897.5 - 898.9 m (2943.7 - 2948.5) ft interval
ER0176	12-05-91	ER-12-1 Core Run #4, Box #5, 898.9 - 900.5 m (2948.5 - 2953.8) ft interval
ER0177	12-05-91	ER-12-1 Core Run #4, Box #6, 900.5 - 902.3 m (2953.8 - 2959.5) ft interval
ER0178	12-05-91	ER-12-1 Core Run #4, Box #7, 902.7 - 903.2 m (2959.5 - 2962.5) ft interval
ER0179	12-05-91	ER-12-1 Core Run #4, close up of macrofossil fragments at 897.8 - 898.4 m (2945 and 2947 ft)
ER0180	12-05-91	ER-12-1 Core Run #4, close up of macrofossil fragments at 897 m (2942 ft)
ER0181	12-05-91	Intergraph CADD work station in the RSN Geology building, Mercury

*A set of color photos were taken by a LLNL staff photographer at the direction of "D" Donithan, DRI, of the ER-12-1 location and selected equipment. All slides in possession of DOE-ERD, Las Vegas, NV.

Table 19. Stratigraphic Nomenclature used in this report for the pre-Tertiary rocks at the NTS. (Formerly used nomenclature for roughly equivalent units shown parenthetically.)

Ki.	Cretaceous Intrusive (dike)	Oe	Eureka Quartzite
Kg.	Cretaceous Plutonic Rocks	Oa	Antelope Valley Limestone
Kgg	Gold Meadows Stock	On	Ninemile Formation
Kgc	Climax Stock	Og	Goodwin Formation
Kgt.	Twinridge Stock	Cn	Nopah Formation
PPbs. . . .	Bird Spring Formation (Tippipah Limestone)	Cnd . . .	Dunderberg Shale
MDe . . .	Eleana Formation	Cb	Bonanza King Formation
Dg.	Guilmette Formation (Devils Gate Limestone)	Cc	Carrara Formation
Ds	Simonson Dolomite (Nevada Formation)	Cz	Zabriskie Quartzite
DSs	Sevy Dolomite	CZw . .	Wood Canyon Formation
Sl	Laketown Dolomite (Lone Mountain Dolomite)	Zs	Stirling Quartzite
Oes	Ely Springs Dolomite	Zj	Johnnie Formation

Mississippian Eleana Formation. Another section of (lower) Simonson Dolomite occurs from 874.2 - 975.4 m (2868 - 3200 ft) and consists of 101.7 m (332 ft) of light-gray bedded dolomite. This lower Simonson Dolomite conformably overlies the upper Sevy Dolomite at 975.4 - 1086.3 m (3200 - 3564 ft).

A sliver of Antelope Valley Limestone (middle Ordovician) at 237.7 - 274.3 m (780 - 900 ft) lies in fault contact between two intervals of Sevy Dolomite (late Silurian). This fractured, varicolored dolomite and dolomite breccia would not have been identified as Antelope Valley Limestone if it were not for its middle Ordovician conodont assemblage (A.G. Harris, USGS-Reston, VA).

Two intervals of the Mississippian Eleana Formation were penetrated at ER-12-1. The assignments of these rocks to Unit J of the Eleana is chiefly based on the uniformly fine-grained nature of both sections encountered in ER-12-1 and to the fact that Unit J defined by Poole and others (1961) consists of several thousand feet of siltstone, shale, and argillite. However, it should be noted

(text continues on page 48)

Table 20. Stratigraphic Log for ER–12–1 (November 1991).

Depth Meters	Depth Feet	Lithology	Formation	Symbol	Thickness Meters	Thickness Feet
0 – 7.9	0 – 26	Alluvium	Alluvium	QTa	7.9	26
7.9 – 237.8	26 – 780	Dolomite	Sevy Dolomite	DSs	230.0	754
237.8 – 240.8	780 – 790	Dolomite Breccia	Fault Zone	——	~3.0	~10
240.8 – 274.3	790 – 900	Dolomite Breccia	Antelope Valley Limestone	Oa	33.5	110
274.3 – 312.4	900 – 1025	Dolomite	Sevy Dolomite	DSs	38.1	125
312.4 – 521.2	1025 – 1710	Interbedded calcareous, siltstone, siliceous siltstone and shale	Eleana Formation, Unit J (?)	MDej	208.8	685
521.2 – 550.8	1710 – 1807	Dolomite	Upper Simonson Dolomite or Lower Guilmette Formation	Ds – Dg	29.6	97
550.8 – 856.8	1807 – 2811	Interbedded siltstone, Chert sandstone, and shale	Eleana Formation, Unit J (?)	MDej	306.0	1004
856.8 – 874.2	2811 – 2868	Calcareous siltstone	Eleana Formation, Unit J (?)	MDej	17.4	57
874.2 – 975.4	2868 – 3200	Dolomite	Lower Simonson Dolomite	Ds	101.2	332
975.4 – 1086.3	3200 – 3564	Dolomite	Upper Sevy Dolomite	DSs	110.9	364
1086.3 – 1093.6	3564 – 3588	Biotite Lamprophyre	Intrusive	n/a	>7.3	>24

Table 21. Lithologic Log for ER-12-1. (Logged by S. L. Drellack and L. B. Prothro, RSN, 11/91)

Unless otherwise noted, the following descriptions refer to washed cuttings samples at 3.05 m (10 ft) intervals. Colors are determined by comparing wet sample color to the Geological Society of America Rock-Color Chart. Stratigraphic contacts and lithologic divisions are tied to geophysical logs whenever possible. Note: Several new stratigraphic assignments, based on recent conodont age brackets (A.G. Harris, USGS - Reston, VA) have been applied to the original 11/91 lithologic log. Inclusion of XRD and micropaleontological analyses have modified original lithologic description.

Depth	Lithologic Description	Stratigraphic Unit
0 - 6.1 m (0 - 20 ft)	Alluvium consisting of 90% tuffaceous fragments and 10% carbonate fragments. Tuffaceous fragments are zeolitic, devitrified, and range in color from grayish-yellow (zeolitic fragments) to pale-reddish-brown (devitrified fragments). Carbonate fragments consist of predominantly grayish-black, finely crystalline dolomite.	Alluvium
6.1 - 7.9 m (20 - 26 ft)	Alluvium consisting of 90% carbonate fragments and 10% tuffaceous fragments. Carbonate fragments consist of yellowish-gray and grayish-black, finely to cryptocrystalline dolomite. Tuffaceous fragments are similar to interval 0 - 6.1 m (0 - 20 ft).	Alluvium
7.9 - 15.2 m (26 - 50 ft)	Dolomite: Dusky-yellowish-brown; well indurated; finely crystalline;no visible porosity; weak fetid odor when broken. Moderate-brown, very fine-grained, moderately indurated dolomitic sandstone at approximately 12.2 m (40 ft).	Lower Sevy[1] Dolomite
15.2 - 36.6 m (50 - 120 ft)	Dolomite: Grayish-red (10 R 4/2); moderately to well indurated; finely crystalline; saccharoidal; sandy in parts, more apparent after etching in HCL; slightly argillaceous; no visible porosity; weak fetid odor when broken.	Lower Sevy[1] Dolomite
36.6 - 183.5 m (120 - 602 ft)	Dolomite: Varicolored, but mostly olive-gray and medium-dark-gray to black, some mottled with dusky-red; well indurated; finely crystalline to cryptocrystalline; dense; veinlets of white dolomite, generally less than 1 mm thick, occur at various depths throughout interval; trace dusky-red and dark yellowish-orange staining associated with veinlets; no visible porosity; darker color dolomite yields weak fetid odor when broken. Color changes imply bedding on the order of a few meters thick. The 88.4 m (290 ft) sample shows an increase in dusky-red staining and several pieces of recemented breccia with some vuggy and interfragment porosity. An increase in dusky-red and dark-yellowish-orange stain in the 106.7 m (350 ft) sample may correspond to an increase in uranium on the Spectralog at 104.5 m (343 ft). Fractures were also observed at this depth on the downhole camera.	Lower Sevy[1] Dolomite

Table 21. Lithologic Log for ER-12-1. (Logged by S. L. Drellack and L. B. Prothro, RSN, 11/91) (continued).

Depth	Lithologic Description	Stratigraphic Unit
183.5 - 237.7 m (602 - 780 ft)	Dolomite: Varicolored, medium-light-gray to medium-dark-gray, dark-olive-gray, and olive-gray, but with an overall lighter appearance than overlying interval; well indurated; medium to finely crystalline; sandy and silty; moderate-red (5 R 5/4) and trace of dark-yellowish-orange iron oxide staining at various depths throughout interval, but particularly from approximately 185.9 - 192.0 m (610 - 630 ft).	Lower Sevy Dolomite[1]
237.7 - 259.1 m (780 - 850 ft)	Dolomite: Various shades of red and yellow (color is the result of prevalent iron oxide staining); well indurated; coarsely to finely crystalline; sandy and silty in part (more apparent after etching in HCL); some fragments appear intensely fractured; no visible porosity. Also, common pale- to dark-yellowish-orange, moderately indurated fault breccia fragments. Faulted lower contact.	Antelope Valley Limestone[1], Aysees Peak member and fault breccia
259.1 - 274.3 m (850 - 900 ft)	Dolomite: Light-gray to medium-light-gray and mottled, becoming medium-dark-gray below 268.2 m (880 ft); well indurated; coarsely crystalline, some finely to medium crystalline; appears intensely fractured; common pale- to dark-yellowish-orange iron oxide staining; no visible porosity; moderate fetid odor when broken. Also, minor pale- to dark-yellowish-orange, poorly to moderately indurated fault breccia fragments. Slickensides on fault breccia fragment noted in the 271.3 m (890 ft) sample. Faulted upper contact.	Antelope Valley Limestone[1] Aysees Peak member
274.3 - 289.2 m (900 - 949 ft)	Dolomite: Dark-gray to grayish-black; well indurated; medium crystalline; no visible porosity; weak fetid odor when broken. Spectralog and downhole camera indicate possible fault and/or fracture(s) at approximately 285.3 m (936 ft).	Lower Sevy Dolomite
289.2 - 312.4 m (949 - 1025 ft)	Dolomite: Light-brownish-gray to medium-gray; well indurated; medium crystalline; no visible porosity. Faulted lower contact.	Lower Sevy Dolomite

Table 21. Lithologic Log for ER-12-1. (Logged by S. L. Drellack and L. B. Prothro, RSN, 11/91) (continued).

Depth	Lithologic Description	Stratigraphic Unit
312.4 - 322.5 m (1025 - 1058 ft)	Grayish calcareous siltstone; well indurated; finely crystalline; argillaceous (becoming increasingly more argillaceous towards base); silty; laminated (more apparent after etching in HCL); moderate-red (5 R 4/6) and dark-yellowish-orange iron oxide coatings on some fragments; no visible porosity. Trace calcite fracture fill. Stained slickensides on fragment in 320.0 m (1050 ft) sample. Faulted upper contact.	Eleana Formation[1], Unit J (?)
322.5 - 348.7 m (1058 - 1144 ft)	Siltstone with minor interbedded and interlaminated limestone. Siltstone is grayish-black to black; moderately to well indurated; argillaceous; pyritic; weakly calcareous; laminated; exhibits a bright sheen on partings; fragments cut by numerous white calcite veinlets; common grayish-orange to dark-yellowish-orange iron oxide staining from approximately 326.1 - 341.4 m (1070 - 1120 ft). Minor interlaminated, medium-dark-gray, argillaceous, finely crystalline calcareous siltstone; more common in upper 9.1 m (30 ft). Thin interbeds of grayish-black, argillaceous, finely crystalline calcareous siltstone below 338.3 m (1110 ft). Numerous fragments of fault breccia are present in sample at 326.1 m (1070 ft).	Eleana Formation[1], Unit J (?)
348.7 - 368.8 m (1144 - 1210 ft)	Shale with interbedded and interlaminated limestone. Shale is grayish-black, moderately indurated, silty, pyritic, may grade into siltstone in places, breaks into thin platy fragments that exhibit a bright sheen on surfaces of partings, common lenses and veinlets of white calcite. Calcareous siltstone is similar to interval 312.4 - 322.5 m (1025 - 1058 ft). Dark-yellowish-orange and light-brown (5 YR 5/6) iron oxide staining below approximately 374.9 m (1230 ft).	Eleana Formation[1], Unit J (?)
368.8 - 400.2 m (1210 - 1313 ft)	Calcareous siltstone with interbedded and interlaminated shale. Calcareous siltstone is grayish-black, finely crystalline, dense, argillaceous. Shale is similar to interval above.	Eleana Formation[1], Unit J (?)

Table 21. Lithologic Log for ER-12-1. (Logged by S. L. Drellack and L. B. Prothro, RSN, 11/91) (continued).

Depth	Lithologic Description	Stratigraphic Unit
400.2 - 521.2 m (1313 - 1710 ft)	Siltstone and calcareous siltstone interbeds with minor interbedded shale. Siltstone is grayish-black to black, well indurated, argillaceous, pyritic, laminated, and exhibits a bright sheen on partings. Light-brown (5 YR 5/6) to dark-yellowish-orange staining common particularly in sample at 472.4 m (1550 ft). Pyrite is finely disseminated but also occurs as individual striated cubes up to 1/2 mm in size. Calcareous siltstone is medium-dark-gray to dark-gray, well indurated, finely to cryptocrystalline, silty and argillaceous, slightly pyritic, laminated in part, and randomly cut by veinlets of white calcite, many of which have been stained dark-yellowish-orange. Cuttings indicate that the 454.2 - 463.3 m (1490 - 1520 ft) interval is predominately calcareous siltstone. Shale occurs as interbeds and laminae and is black, moderately indurated, pyritic, and weakly fissile. An increase in argillaceous siltstone with very thin shaley laminae in 487.7 -521.2 m (1600 - 1700 ft) interval. XRD data for the 463.3 m (1520 ft) sample is given in Table 15. Faulted lower contact.	Eleana Formation[1], Unit J (?)
521.2 - 550.8 m (1710 - 1807 ft)	Dolomite: Similar to interval 259.1 - 274.3 m (850 - 900 ft); light-gray to medium-light-gray and mottled, becoming olive-gray below 542.5 m (1780 ft); well indurated; generally finely to medium crystalline, some recrystallized and coarsely crystalline; appears intensely fractured; abundant pale-yellowish-orange to dark-yellowish-orange iron oxide staining imparts a grayish-yellow color to samples below 542.5 m (1780 ft); trace of vugular porosity; moderate fetid odor when broken. Also, common pale-yellowish-orange to dark-yellowish-orange, poorly to moderately indurated fault breccia fragments. Samples 530.3 and 533.4 m (1740 and 1750 ft) contain abundant fault breccia and heavy iron oxide staining. The 545.6 m (1790 ft) sample contains a significant percent of black argillaceous siltstone and quartzite similar to underlying interval at 550.8 - 619.7 m (1807 - 2033 ft). See Table 22 for detailed description of Core #1, 539.2 - 539.3 m (1769.0 - 1769.2 ft). Possible faults and/or fractured zones at 528.2 m (1733 ft), 533.4 m (1750 ft), and 543.1 m (1782 ft). Faulted upper and lower contacts.	Upper Simonson Dolomite or Lower Guilmette Formation[1]

Table 21. Lithologic Log for ER-12-1. (Logged by S. L. Drellack and L. B. Prothro, RSN, 11/91) (continued).

Depth	Lithologic Description	Stratigraphic Unit
550.8 - 619.7 m (1807 - 2033 ft)	Chert sandstone and minor Siltstone. Chert sandstone is medium-dark-gray to dark-gray, very well indurated and dense, and consists of fine- to medium-grained, subrounded, and moderately sorted clear quartz grains, scarce feldspar, and medium-light-gray to white chert. Chert fragments are often the largest grains (up to 1 mm) in size. The chert sandstone is also argillaceous containing scarce to common clasts of black shale, pyritic, and very weakly calcareous and/or weakly dolomitic. Very scarce very-light-gray silica/chert veins. Siltstone is dark-gray, moderately indurated, argillaceous, pyritic, and occurs mostly as platy fragments with a bright sheen on surfaces of partings. Sample 560.8 m (1840 ft) is heavily contaminated with tuffaceous fragments. These fragments appear to be zeolitized tuffs typical of southern Yucca Flat and were incorporated into the drilling fluid from the mud system (steel mud pit, shale shaker, and mud pump). Spectralog indicates possible fault and/or fracture(s) at 591.3 m (1940 ft). Faulted upper contact.	Eleana Formation, Unit J (?)
619.7 - 657.1 m (2033 - 2156 ft)	Shale with interbedded chert sandstone and siltstone. Shale is black, moderately indurated, fissile, with a waxy texture on partings. The other lithologies are similar to the overlying interval with the exception of the chert sandstone, which is mostly fine-grained and is randomly cut by veinlets of white silica. XRD data for the 627.9 m (2060 ft) and 655.3 m (2150 ft) samples are given in Table 15.	Eleana Formation, Unit J (?)
657.1 - 686.7 m (2156 - 2253 ft)	Shale: Lithology similar to shale in above interval. Trace argillaceous siltstone. Scarce fragments containing rare scattered clear quartz grains "floating" in shale matrix.	Eleana Formation, Unit J (?)
686.7 - 712.3 m (2253 - 2337 ft)	Interbedded chert sandstone, siltstone, and shale. Lithologies are similar to above intervals.	Eleana Formation, Unit J (?)

Table 21. Lithologic Log for ER-12-1. (Logged by S. L. Drellack and L. B. Prothro, RSN, 11/91) (continued).

Depth	Lithologic Description	Stratigraphic Unit
712.3 - 760.2 m (2337 - 2494 ft)	Chert sandstone and siltstone. Chert sandstone is massive from 714.1 to 723.6 m (2343 - 2374 ft) and from 749.8 to 760.2 m (2460 - 2494 ft) and, for the most part, is similar to above intervals but tends to be slightly coarser and contains conspicuous white chalky grains. The siltstone is also similar to the above intervals. See Table 23 for detailed description of Core #3, 751.0 - 757.7 m (2464 - 2486 ft).	Eleana Formation, Unit J (?)
760.2 - 800.1 m (2494 - 2625 ft)	Shale with interbedded chert sandstone and siltstone. Lithologies similar to above intervals. Minor very-light-gray chert fragments in the 777.2 m (2550 ft) sample. The Formation Micro-scanner log indicates that bedding within the interval 765.0 - 789.4 m (2510 - 2590 ft) has a mean strike of N22°E and a mean dip of 27°NW.	Eleana Formation, Unit J (?)
800.1 - 827.8 m (2625 - 2716 ft)	Chert sandstone and siltstone. Lithologies similar to above intervals. Formation Micro-scanner log indicates that the base of the quartzite bed at 816.9 m (2680 ft) strikes N15°E and dips 28°NW.	Eleana Formation, Unit J
827.8 - 856.8 m (2716 - 2811 ft)	Shale with minor siltstone and chert sandstone. Lithologies similar to above intervals. Increase in light-gray chert fragments in the 835.2 m (2740 ft) sample. Faulted lower contact. Formation Micro-scanner log indicates that this fault strikes N30°E and dips 78°NW.	Eleana Formation, Unit J
856.8 - 874.2 m (2811 - 2868 ft)	Calcareous siltstone: Grayish-black; moderately to well indurated; argillaceous; pyritic; calcareous; common coarsely crystalline, white calcite as fracture fillings and free fragments. Rare light-gray chert fragments. Spectralog indicates interval is possibly fractured throughout. Faulted upper and lower contacts.	Eleana Formation[1], Unit J (?)
874.2 - 932.7 m (2868 - 3060 ft)	Dolomite: Grades from light-gray at top of interval to grayish-black at base; well indurated; finely to coarsely crystalline, lighter color tends to be coarse crystalline; scarce pyrite; no visible porosity; moderate fetid odor when broken. Thin, irregular, "tight" dark-gray fracture traces.	Lower Simonson Dolomite[1]

Table 21. Lithologic Log for ER-12-1. (Logged by S. L. Drellack and L. B. Prothro, RSN, 11/91) (continued).

Depth	Lithologic Description	Stratigraphic Unit
874.2 - 932.7 m (2868 - 3060 ft) cont.	Macrofossil fragments noted in Core #4 are not readily recognizable in cuttings. Possible fault or fracture zone at 901.0 - 910.1 m (2956 - 2986 ft). See Table 24 for description of Core #4 from 895.2 - 903.0 m (2937.0 - 2962.5 ft). Faulted upper and lower contacts.	
932.7 - 949.4 m (3060 - 3115 ft)	Dolomite: Medium-gray at top of interval to grayish-black at base, medium crystalline. Possible repeat of interval 915.9 - 932.7 m (3005 -3060 ft). Faulted upper and lower contacts.	Lower Simonson[1] Dolomite
949.4 - 975.4 m (3115 - 3200 ft)	Dolomite: Generally light-gray but varies from very light-gray to medium-gray; well indurated; medium crystalline, some coarsely crystalline; very scarce pyrite; very thin medium-dark-gray fractures and styolites; no visible porosity; moderate fetid odor when broken. Samples from 969.3 - 978.4 m (3180 -3210 ft) are contaminated with dolomite from 542.5 - 550.8 m (1780 -1807 ft) and quartzite, siltstone, and shale from 550.8 - 856.8 m (1807 - 2811 ft). Probable fault at 962.6 m (3158 ft). Faulted upper contact.	Lower Simonson Dolomite[1]
975.4 - 1086.3 m (3200 - 3564 ft)	Dolomite: Generally light-gray but varies from very- light-gray to medium-gray; well indurated; medium crystalline, some coarsely crystalline; very scarce pyrite; very thin medium- dark-gray fractures and styolites; no visible porosity; moderate fetid odor when broken. Transitional contact with overlaying Simonson Dolomite. Stratigraphic assignment based on conodont studies.	Upper Sevy Dolomite [1]
1086.3 - 1093.6 m (3564 - 3588 ft) TD	Biotite lamprophyre intrusion: Greenish-black (5 GY 2/1);moderately to well indurated; coarsely crystalline; very abundant booklets of mica; common chlorite; abundant quartz; common feldspar; initially moderately calcareous, decreasing after a few minutes to very weakly calcareous; magnetic. XRD data for the 1091.2 m (3580 ft) sample is given in Table 15. Formation Micro-scanner indicates that the upper contact strikes north and dips 65° W.	Intrusive

[1]Stratigraphic assignment based on paleontological investigations by A.G. Harris, USGS-Reston, VA.

Table 22. Description of Core #1 (539.2 to 543.8 m).

Depth	Lithologic Description	Stratigraphic Unit
539.2 - 539.3 m (1769.0-1769.2 ft)	Dolomite: Medium-light-gray to medium-gray and light-olive-gray mottled; well indurated; finely crystalline; numerous "tight" hairline fractures with dark-yellowish-orange stain; succrosic dolomite fracture fill on some surfaces. Two small, slightly rounded core fragments recovered.	Upper Simonson Dolomite or Lower Guilmette Formations[1]
539.3 - 543.8 m (1769.2-1784.0 ft)	No core recovery.	

[1]Stratigraphic assignment based on paleontological investigations by A.G. Harris, USGS, Reston, VA.

that Unit E of Poole and others (1961) is also characterized by fairly uniformly fine-grained sediments and is several hundred feet thick in the northern Eleana Range to the east of ER-12-1, and as much as 2400 ft thick to the northeast in Quartzite Ridge. In the absence of more definitive lithologic or paleontologic information, the correlation of fine–grained siltstone and sandstone in ER-12-1 with Unit J is considered tentative.

An igneous intrusive dike was encountered at 1086.3 m (3564 ft). Unfortunately, only 7.3 m (24 ft) were penetrated before total depth was reached within the unit at 1093.6 m (3588 ft). The Schlumberger Formation Micro-scanner log shows the upper contact dipping 65° to the west. This orientation is consistent with structural orientations in the region. An age of 102.3 $\pm$ 0.5 Ma was determined by Ar40 - Ar39 analysis of biotite separated from cuttings samples representing this bottom hole unit (M.A. Lanphere, USGS, Menlo Park, CA). This is consistent with emplacement ages for nearby Gold Meadows and Climax granite stocks. Table 26 is a list of the nearest drill holes in the area that penetrated Mesozoic quartz monzonite. Additional discussion regarding this intrusive is given in the following lithology, stratigraphy and paleontology section of this report.

Structural Data

The structures encountered at ER-12-1 are related to a complex system of faults that are largely the result of Mesozoic Sevier thrust faulting and more recent Basin and Range normal faulting (see preliminary west-east geologic cross section, Figure 4). Tables 27 and 28 provide data on the faults and fracture zones intersected in the ER-12-1 borehole. These faults are probably part of the same system as the Tongue Wash Fault. The Tongue Wash Fault is a west-dipping thrust fault exposed approximately 640.1 m (2100 ft) southeast of ER-12-1. The fault has placed the Devonian Simonson Dolomite over the Mississippian Eleana Formation. Pre-drill estimates indicated that the Tongue Wash Fault would be intercepted in ER-12-1 at approximately 630.9 m (2070 ft) based on measured dips of slip surfaces along the fault zone at the surface (Cole, unpublished). Based on the stratigraphy encountered in ER-12-1, the fault intercepted at 312.4 m (1025 ft) is probably the westward extension of the Tongue Wash Fault. This suggests the Tongue Wash Fault flattens at a shallower depth then previously thought. Since the thrust fault at 550.8 m (1807 ft) is probably related to the Tongue Wash Fault, it likely has a similar orientation. Significant fracturing appears to be confined

Table 23. Description of Core #3 (751.0 to 757.7 m).

Depth	Lithologic Description	Stratigraphic Unit
751.0 - 754.1 m (2464 - 2474 ft)	Chert sandstone, black; well indurated (unconfined compressive strengths up to 11,000 psi); dense (bulk density of 2.67 g/cc); fine-grained, argillaceous (clear, subrounded, fine-grained quartz in a black argillaceous matrix); pyritic. White calcite veins 0.25 to 3 mm wide throughout. Distinct calcite veins at: 751.1 m (2464.3 ft), 87° dip; 751.7 m (2466.3 ft), 55° dip; 751.8 m (2466.6 ft), 73° dip; 751.9 m (2467.0 ft), 65° dip; 752.1 m (2467.6 ft), 58° dip; two at 752.5 m (2468.7 ft), 45° and 65° dips; 753.4 m (2471.8 ft), 60° dip; and 753.9 m (2473.4 ft), 25° dip. Core parted along fractures with dis-continous pyrite and calcite coatings at: 751.2 m (2464.7 ft), 78° dip; 751.5 m (2465.4 ft), 80° dip; 752.3 m (2468.3 ft), 57° dip; and 753.2 m (2471.0 ft), 88° dip. The recovered core from this run is well broken. The average core segment is about 0.09 m (0.3 ft) long, with relatively flat ends dipping 3 to 5°. These ends are smoothed, indicating that the core segments have rotated against each other during coring.	Eleana Formation, Unit J (?)
754.1 - 757.7 m (2474 - 2486 ft)	No core recovery.	

Table 24. Description of Core #4 (895.2 - 903.1 m).

Depth	Lithologic Description	Stratigraphic Unit
895.2 - 895.8 m (2937.0-2940.3 ft)	Dolomite: Medium-light-gray to light-gray; finely crystalline; dense; common dark-gray hairline fractures less than 1 mm thick. Fracture at 895.2 m (2937.1 ft) dips 65° with trace of vuggy porosity. Fractures at 895.4 m (2937 ft) dip 35° with 1–mm-thick dark-gray argillaceous fracture fill. Two stylolites at 895.7 m (2938.6 ft), one is offset by fractures and has a dip of 40°. At 855.7 - 895.9 m (2938.8 - 2939.2 ft), stylolites dip 40°; typically filled with similar dark-gray argillaceous material as mentioned above in the hairline fractures.	Lower Simonson Dolomite[1]
895.8 - 896.2 m (2939.0-2940.3 ft)	Dolomite: Medium-light-gray to medium-gray; fine crystalline. Stylolites at 896 m (2939.6 ft) with dark-gray argillaceous material plus discontinuous pyrite; dip is 50°, and separates two shades of gray dolomite.	Lower Simonson Dolomite[1]
896.2 - 897.0 m (2940.3-2943.0 ft)	Dolomite: Medium-dark-gray; finely crystalline; lower contact dips 50°. At 896.2 m (2940.4 ft), a fracture dips 70°; core broke along with this fracture. At 896.5 m (2941.4 ft), tight fractures dip about 80°; macro-fossil fragments including crinoid stems, brachiopod and/or pelecypod. Conspicuous macro-fossils at 896.7 - 897.0 m (2942 - 2943 ft). At 897.0 m (2943 ft) a 1-cm-thick light-gray band dips 20°.	Lower Simonson Dolomite[1]
897.0 - 898.7 m (2943.0-2948.4 ft)	Dolomite: Mottled in appearance, very-light to light-gray and medium-gray to medium-dark-gray; fossiliferous including brachiopods and crinoids. Discontinuous stylolites at 898.2 m (2947 ft). At 898.4 m (2947.5 ft), a fracture with minor displacement dips 70°. At 898.5 m (2947.8 ft), a stylolite dips 55° with several centimeters of offset, appears tight.	Lower Simonson Dolomite[1]
898.7 - 899.9 m (2948.4-2952.5 ft)	Dolomite: Light-gray to medium-light-gray; fine crystalline; common irregular hairline fractures filled with dark-gray argillaceous material; highly fractured area at 899.3 m (2950.4 ft) on one side of core. A fracture at 899.3 m (2950.5 ft) dips 45°. Possible bedding dips 45° and is fractured. Stylolite at 899.6 m (2951.3 ft).	Lower Simonson Dolomite[1]

Table 24. Description of Core #4 (895.2 - 903.1 m) (continued).

Depth	Lithologic Description	Stratigraphic Unit
899.9 - 900.7 m (2952.5-2955.1 ft)	Dolomite: Medium-dark-gray to light-gray; mottled; indistinguishable fossil fragments including a possible rugose coral at 900.2 m (2953.3 ft). Upper contact dips 50°. At 900.4 m (2953.9 ft), the core is broken along a fracture that dips 80°, another fracture healed with 1- to 2-mm thick recrystallized dolomite dips 30° and displays 1- to 4–mm offset due to two other perpendicular fractures. Fracture at 900.5 m (2954.4 ft) dips 50°.	Lower Simonson Dolomite[1]
900.7 - 901.0 m (2955.1-2956.0 ft)	Dolomite: Dark-gray; finely crystalline. At 900.7 m (2954.9 ft) vuggular porosity that range from 2 mm to 1 cm in diameter.	Lower Simonson Dolomite[1]
901.0 - 902.1 m (2956.0-2959.5 ft)	Dolomite: Dark-gray, mottled with very light-gray; increase in brachiopod and other macro-fossil fragments. Secondary vuggy porosity at 901.2 m (2956.6 ft) is about 1 cm long and 0.5 cm wide. At 901. 6 m (2958 ft), the mottled appearance stops and high-angle fractures appear. Fracture at 901.9 m (2959 ft) dips 70°. At 902 m (2959.3 ft), vuggy porosity along irregular fracture.	Lower Simonson Dolomite[1]
902.1 - 903.0 m (2959.5-2962.5 ft)	Dolomite: Dark-gray; very finely crystalline; argillaceous(?); well fractured. Upper contact is possible fault dipping 45°. Several fractures are filled with light-gray recrystallized dolomite less than 1 to 3 mm in width. Fractures are generally healed with no visible porosity. Multiple fracture sets causing 1-mm to 1-cm offset; fracturing increases downward.	Lower Simonson Dolomite[1]
903.0 - 903.1 m (2962.5-2963.0 ft)	No core recovery. (Fractured interval, possible fault)	

[1]Stratigraphic assignment based on paleontological investigations by A.G. Harris, USGS-Reston, VA.

Table 25. Selected Holes that Penetrate the Pre–Tertiary Rocks Surrounding ER–12–1.

Hole Name	Coordinates Meters	Coordinates Feet	Hole TD	Pre–Tertiary Contact (Elevation)	Formation/Lithologies Penetrated
Hagestad #1	N271,094 E192,418	N889,190 E631,132	1687 m (5533 ft)	1109 m (3637 ft)	Precambrian Quartzite
UE12b.07–2 R/C	N272,169 E193,352	N892,715 E634,195	1420 m (4658 ft)	680 m (2232 ft)	Paleozoic Dolomite
UE12n#2	N273,082 E193,195	N895,938 E633,839	542.2 m (1779 ft)	1698.7 m (5572 ft)	Colluvium/alluvium and Stirling Quartzite
UE12n#3	N273,125 E192,804	N896,076 E632,558	429.5 m (1409 ft)	1854.6 m (6083 ft)	Stirling Quartzite
UE12n#8	N272,964 E192,914	N895,550 E632,920	543.8 m (1784 ft)	1763.4 m (5784 ft)	Stirling Quartzite or Wood Canyon Formation
UE12n#9	N272,979 E192,728	N895,600 E632,309	472.4 m (1550 ft)	1807.3 m (5928 ft)	Wood Canyon Formation, Stirling Quartzite
UE12n#10	N273,301 E193,351	N896,656 E634,354	572.7 m (1879 ft)	1707.3 m (5600 ft)	Gold Meadows Stock, Stirling Quartzite
UE12t#5	N273,412 E195,131	N897,020 E640,192	491.0 m (1611 ft)	1691.4 m (5548 ft)	Fractured dolomite, age unknown
Dolomite Hill	N270,270 E194,655	N886,712 E638,632	365.8 m (1200 ft)	1961.9 m (6435 ft)	Upper Sevy Dolomite, Lower Simonson Dolomite
UE12e.M–1	N270,249 E193,101	N886,644 E633,532	457.5 m (1501 ft)	1581 m (5185 ft)	Guilmette Formation or Simonson Dolomite
U12e.06–1 R/C	N269,760 E192,565	N885,187 E631,776	969.3 m (3180 ft)	1581 m (5185 ft)	Guilmette Formation or Simonson Dolomite
U12e.06A	N270,046 E193,204	N885,979 E633,873	304.8 m (1000 ft)	1582.9 m (5192 ft)	Simonson Dolomite (?)
U12e.06B	N269,824 E192,738	N885,249 E632,341	297.2 m (975 ft)	1589.0 m (5212 ft)	Simonson Dolomite (?)
U12s	N275124 E192,457	N902,407 E631,260	1438 m (4718 ft)	1438 m (4718 ft)	Quartz Monzonite

Information from: Schoff and Winograd, 1973; Maldonado et al., 1979; and Emerick and Dickey, 1961; Cole, unpublished data.

Table 26. Rainier Mesa Drill Holes Penetrating Quartz Monzonite (Gold Meadows Stock).

Drill Hole	Collar Elevation MSL	Quartz Monzonite Depth BGL	Quartz Monzonite Elevation MSL	Hole Coordinates Northing	Hole Coordinates Easting
Rainier Mesa	2245.5 m (7367 ft)	1108.3 m (3636 ft)	1137.2 m (3731 ft)	271,911.2 m (892,097 ft)	191,842.3 m (629,404 ft)
UE12p#1	1974.2 m (6477 ft)	602.3 m (1976 ft)	1371.9 m (4501 ft)	276,280.5 m (906,432 ft)	196,543.3 m (644,827 ft)
U12R	2291.2 m (7517 ft)	618.7 m (2030 ft)	1672.4 m (5487 ft)	272,918.2 m (895,401 ft)	196,543.3 m (628,500 ft)
UE12n#10	2250.6 m (7384 ft)	544.1 m (1785 ft)	1706.6 m (5599 ft)	273,300.7 m (896,656 ft)	193,351.1 m (634,354 ft)
UE12n#15A	2246.1 m (7369 ft)	574.9 m (1886 ft)	1671.2 m (5483 ft)	272,719.5 m (894,794 ft)	192,535.5 m (631,678 ft)

MSL - Mean Sea Level
BGL - Below Ground Level
Information from Maldonado et al., 1979; and Townsend, 1991 (verbal communication)

mostly to the dolomite units and the intrusive, except near faults where fracturing usually increases independent of lithology. Bedding in the borehole generally dips in a westerly direction at an angle of 25 - 30°. This orientation is consistent with that measured at the surface in the vicinity of ER-12-1.

Other structural solutions, for the observations made at ER-12-1, may be acceptable. For example, the Tongue Wash Fault can be projected from the surface to the fault zone at 521 to 552 m (1710-1810 ft) at a constant dip of about 45°. This interpretation would imply that it is younger than the faults that shuffle the stratigraphy in the upper part of the hole, which is consistent with the surface observation that the most recent movement on the Tongue Wash Fault was dominantly strike-slip (left-lateral, with a component of reverse slip).

STRATIGRAPHY, STRUCTURE, AND THERMAL HISTORY OF ROCKS PENETRATED BY WELL ER-12-1 BASED UPON MICROSCOPIC OBSERVATIONS

This section describes the results of several related, detailed studies of cuttings from well ER-12-1 and includes certain observations made during field investigations in and around the well site. The cuttings samples that form the basis of these studies were obtained in one-gallon metal cans at each 15.2 m (50-ft) advance of the drill bit, and were collected in addition to the two sets of cuttings

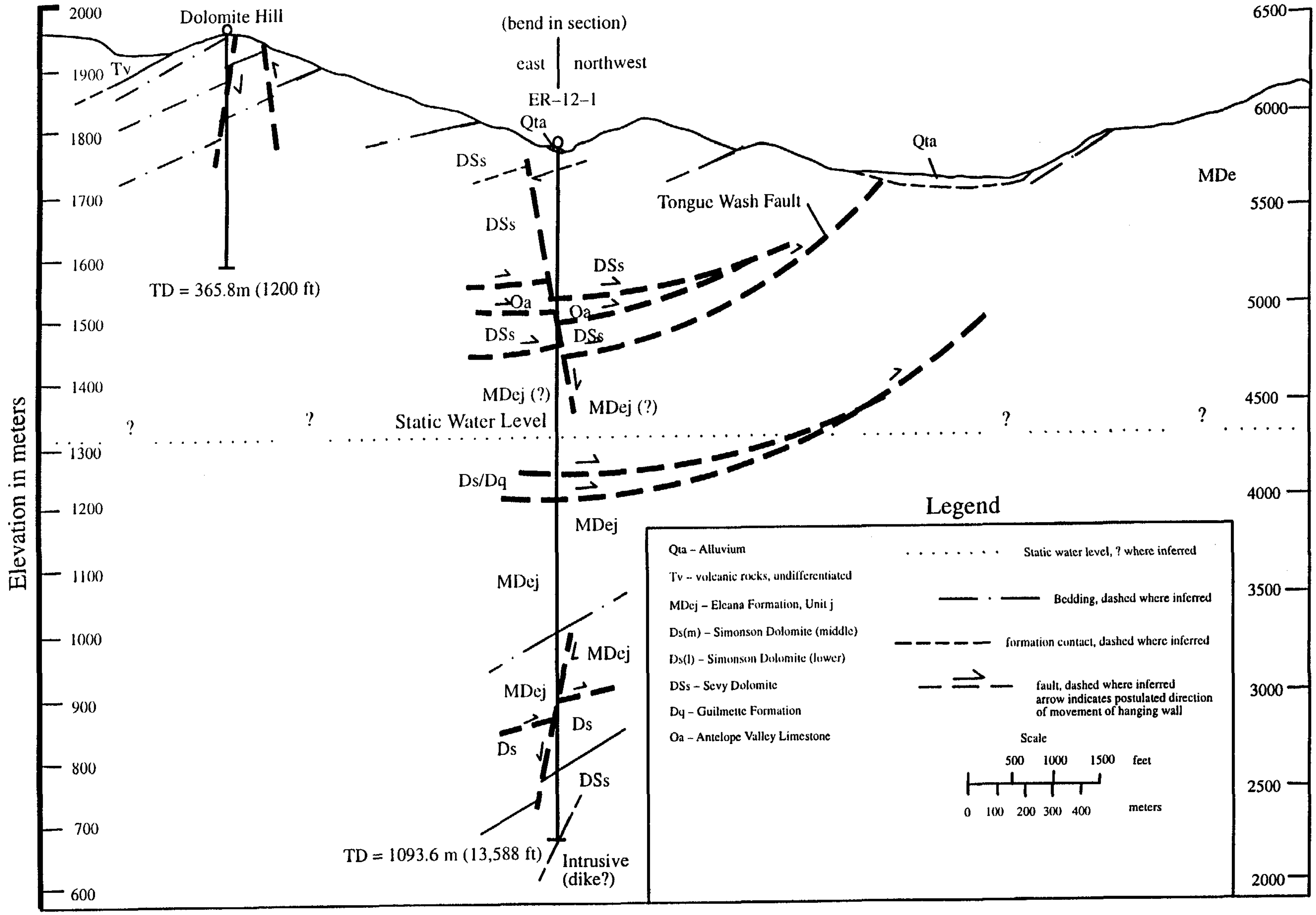


Figure 4. Preliminary west–east geologic cross section for ER–12–1. (Includes recent stratigraphic assignments based on paleontological analysis by A.G. Harris, USGS–Reston, VA.)

Table 27. Probable Faults Intersected in the ER–12–1 Borehole.

Depth		Formations		Lithologies		Strike	Dip	Indicators*
Meters	Feet	Hanging Wall	Footwall	Hanging Wall	Footwall			
237.7	780	Lower Sevy Dolomite	Antelope Valley Limestone	Dolomite	Dolomite	NA	NA	a,b
259.1	850	Antelope Valley Limestone	Antelope Valley Limestone	Dolomite	Dolomite	NA	NA	a, b, c
274.3	900	Antelope Valley Limestone	Lower Sevy Dolomite	Dolomite	Dolomite	NA	NA	a,b
312.4	1025	Sevy Dolomite	Eleana, Unit J	Dolomite	Calcareous Siltstone	NA	NA	a
521.2	1710	Eleana, Unit J(?)	Upper Simonson Dolomite–Lower Guilmette Form.	Siltstone	Dolomite	NA	NA	a, b, c
533.4	1750	Simonson Dolomite	Simonson Dolomite	Dolomite	Dolomite	NA	NA	b, c
543.1	1782	Simonson Dolomite	Simonson Dolomite	Dolomite	Dolomite	NA	NA	b, c
550.8	1807	Simonson Dolomite	Eleana, Unit J	Dolomite	Chert Sandstone	NA	NA	a, b, c
856.8	2811	Eleana, Unit J	Eleana, Unit J(?)	Shale	Calcareous Siltstone	N30°E	78°NW	a, c
874.2	2868	Eleana, Unit J(?)	Lower Simonson Dolomite	Siltstone	Dolomite	NA	NA	a, c
932.7	3060	Lower Simonson Dolomite	Lower Simonson Dolomite	Dolomite	Dolomite	NA	NA	a, c, d
949.4	3115	Lower Simonson Dolomite	Lower Simonson Dolomite	Dolomite	Dolomite	NA	NA	b, c
926.6	3158	Lower Simonson Dolomite	Lower Simonson Dolomite	Dolomite	Dolomite	NA	NA	c, d

a – stratigraphy
b – lithology
c – geophysical logs
d – drilling data
NA – Not available

Table 28. Possible Faults and/or Fractured Intervals Intersected in the ER–12–1 Borehole.

Depth Meters	Depth Feet	Formations	Lithologies	Strike	Dip	Indicators*
104.5	343	Sevy Dolomite	Dolomite	NA	NA	c
185.9 – 192.0	610 – 630	Sevy Dolomite	Dolomite	NA	NA	b
285.3	936	Sevy Dolomite	Dolomite	NA	NA	c
528.2	1733	Upper Simonson Dolomite or Lower Guilmette Fm.	Dolomite	NA	NA	c
591.3	1940	Eleana, Unit J	Chert Sandstone	NA	NA	c
856.8 – 888.8	2811 – 2916	Eleana, Unit J, Lower Simonson Dolomite	Siltstone, dolomite	NA	NA	c
901.0 – 910.1	2956 – 2986	Lower Simonson Dolomite	Dolomite	NA	NA	c
1077.5 – 1083.9	3535 – 3556	Upper Sevy Dolomite	Dolomite	NA	NA	c

* a – stratigraphy
b – lithology
c – geophysical logs
d – drilling data

NA – Not available

(archived and washed samples) obtained for each 3 m (10 ft) advance (Drellack et al., 1991). These cuttings were washed over a 10-mesh sieve to remove drilling mud and excess fines, repackaged, and forwarded to the U.S. Geological Survey offices in Denver, Colorado.

At the USGS in Denver, cuttings (about 20 gm) were selected from each of the sample containers, bagged, and sent to a private contractor to prepare standard glass-covered petrographic microscope thin sections. All of the remaining sample material was shipped to the Reston, Virginia, laboratories of the USGS for evaluation and processing for non-calcareous microfossils. Each container of carbonate rock cuttings (as well as several containers of calcareous siltstone) was digested in warm acetic acid, and conodonts were hand-picked from the insoluble residue for more detailed identification and examination. The results of those analyses are summarized in Table 29 and are discussed in a following section.

LITHOLOGY, STRATIGRAPHY, AND PALEONTOLOGY

The rocks penetrated by the ER-12-1 drillhole are a complex assemblage of Ordovician, Silurian, Devonian, and Mississippian sedimentary rocks that are bounded by numerous faults that show substantial stratigraphic offset. The final 7.3 m (24 ft) of this hole penetrated an unusual intrusive rock of Cretaceous age, as described below. All of these units have been well described in terms of their macroscopic characteristics in the lithologic log prepared by Raytheon Services Nevada (Drellack et al., 1991; Table 21), and so this section of the report only covers additional observations acquired from the prepared thin sections.

The Sevy Dolomite in the upper 237.7 m (780 ft) of the hole consists of generally medium- to coarse-grained recrystallized dolostone with local beds or zones that contain rounded detrital quartz and secondary pyrite. The term "dolostone" is used here due to the pervasive recrystallization textures, the common occurrence of rhombic crystals of dolomite, and prior studies of the Sevy tidal-flat depositional environment (Osmond, 1954). Original shell fragments are only indicated by sparse dolomitized pseudomorphs. Primary porosity (following post-depositional replacement by dolomite) was probably low, but numerous veins of coarse calcite, chalcedony, and quartz traverse these fragments and attest to prior secondary permeability and groundwater activity.

Cuttings collected at 237.7 m (780 ft) and 240.8 m (790 ft) contain numerous fragments of ocher and red-brown dolomite breccia that indicate the presence of a significant fault. Some fragments show slickenside lineations on their broken surfaces. Microscopic examination shows that the breccia formed by brittle shattering and comminution of dolostone with relatively little milling and shearing; recrystallization of the carbonate minerals is also minimal. Veins and replacement patches of quartz are present, and the breccia matrix is irregularly stained with secondary iron-oxide minerals (probably derived from alteration of pyrite).

Between about 240.8 m and 271.3 m (790 ft and 890 ft), cuttings recovered from ER-12-1 consist of heterogeneous, varicolored dolostone and dolomitic limestone and brecciated varieties of both; fragments of quartz-calcite-chalcedony veins are also common. These lithologic

(text continues on page 64)

Table 29. Stratigraphic Log for Groundwater Characterization Project Well ER-12-1 based on Paleontologic and Petrographic Examinations of Cuttings Samples Collected at 15.4 m (50-ft) Intervals [1].

Sample Depth	Formation	Age	Conodont CAI(2)	Lithologic, Stratigraphic, Structural Notes
15–137 m (50-450 ft)	Lower Sevy Dolomite	Early Devonian	4 to 5.5	Medium-gray to gray-brown, fine- to medium-grained dolostone with variable quartz content in silty layers, sparse fossil forms largely replaced by recrystallization; local stylolites; primary voids locally filled with chalcedony and coarse calcite. Equivalent to Unit F and the uppermost part of Unit E of Dolomite of the Spotted Range; late Lockhovian at 15 and 91 m (50 and 300 ft); early Lockhovian at 106–137 m (350-450 ft.) Relatively shallow water, partly restricted marine environment.
152–244 m (500-800 ft)	lower Sevy Dolomite	Late Silurian	5 to 5.5	Mostly medium-brown–gray, medium–grained, variably sandy dolostone (some fragments contain as much as 15% rounded quartz silt in fine layers); brittle breccia fabrics increasingly common downward in this interval, and dolostone breccia is traversed by coarse–grained calcite–quartz veins (veins generally post–date brecciation, but locally show slight strain). Probably equivalent to Unit E of Dolomite of the Spotted Range; relatively shallow water, normal marine environment; sample at 244 m (800 ft) only produced one conodont element of Silurian aspect (may be downhole contaminant).

——— FAULT CONTACT(3) noted in 30 m (10–ft) interval cuttings between 237.8 and 240.8 m (780 ft and 790 ft) ———

Table 29. Stratigraphic Log for Groundwater Characterization Project Well ER-12-1 based on Paleontologic and Petrographic Examinations of Cuttings Samples Collected at 15.4 m (50-ft) Intervals [1] (continued).

Sample Depth	Formation	Age	Conodont CAI(2)	Lithologic, Stratigraphic, Structural Notes
259.1–274.3 m (850-900 ft)	Antelope Valley Limestone (Aysees Peak member)	Middle Ordovician	5 to 5.5	Brown, ocher and red–brown, strongly brecciated dolomitic limestone(?); some fragments show slickensided surfaces; abundant quartz–chalcedony–calcite veins traverse breccia fragments Late early Whiterockian age; conodonts indicate cool water, open–marine depositional environment; sample at 274 m (900 ft) contains some middle Devonian to early Mississippian(?) forms interpreted to have come from tectonically mixed Simonson(?) Dolomite within this fault zone
— FAULT CONTACT noted in 30 m (10–ft) interval cuttings between 271 and 274 m (890 ft and 900 ft) —				
292–320 m (950–1050 ft)	Lower Sevy Dolomite	Late Silurian	5 to 5.5	Dark gray to gray brown, medium– to fine–grained dolostone; calcite veins common in upper part but rocks generally not much deformed; minor shell forms preserved. Probably equivalent to Unit E of Dolomite of the Spotted Range; warm, relatively shallow water, normal marine depositional environment. Sample at 320 m (1050 ft) contains a few indeterminate conodont fragments but abundant siliceous siltstone in the insoluble residue (thus this sample was collected in part below the next major fault contact).
— FAULT CONTACT noted in 3.0 m (10–ft) interval cuttings between 320 and 323 m (1050 ft and 1060 ft) —				

Table 29. Stratigraphic Log for Groundwater Characterization Project Well ER-12-1 based on Paleontologic and Petrographic Examinations of Cuttings Samples Collected at 15.4 m (50-ft) Intervals [1] (continued).

Sample Depth	Formation	Age	Conodont CAI(2)	Lithologic, Stratigraphic, Structural Notes
320–518 m (1050–1700 ft)	Upper Eleana Formation	Late Mississippian	No Data	Dark gray to black, finely laminated carbonaceous, pyritic, fine–grained siltstone with common irregular patches of calcite cement in matrix; local rhombic grains of secondary brown carbonate mineral (ankerite–siderite solid–solution?). Siltstone shows compaction foliation, disruptive silty calcite veins that probably formed during dewatering and lithification, and some conversion of matrix clay to disordered white mica (illite?). Local deformation fabrics include minor crinkling of the compaction foliation and bedding laminations, fine–grained calcite veins parallel to crinkle planes that show synkinematic fibrous crystal growth, small–scale folds with axial–plane shears, and cross–cutting veins of coarsely crystalline calcite and quartz. The shear fabrics and transposition of bedding seem more common between 503 and 518 m (1650 and 1700 ft), and may indicate proximity to a compressional (thrust) fault. Probably equivalent (in part) to Unit J of Eleana Formation. All samples were barren of conodonts with the exception of the collection at 488m (1600 ft) that produced one identifiable Silurian–earliest Devonian element. Thin section from 488 m (1600 ft) shows several fragments of strongly brecciated, veined dolostone in addition to the more common Eleana calcareous siltstone. Possibility of downhole contamination cannot be ruled out; otherwise, a thin tectonic sliver of dolostone is suggested.
——— Complex FAULT ZONE noted in 3 m (10–ft) interval cuttings between 521 and 558 m (1710 and 1830 ft) ———				
533–549 m (1750–1800 ft)	Upper Simonson Dolomite or lower Guilmette Formation	Late Middle to early Late Devonian	5.5 to 6.5	Mixed cuttings of black, pyritic siliceous siltstone (probably from up–hole) with medium gray–brown, coarse–grained dolostone that shows conspicuous breccia fabrics and orange–pink iron–oxide stain; fragments of calcite–quartz vein material common. Abundant diagnostic conodonts recovered from 549 m (1800 ft) sample indicate Givetian–Frasnian age; normal marine depositional environment.
——— FAULT ZONE noted in 30 m (10–ft) interval cuttings at about 558 or 561 m (1830 ft or 1840 ft) ———				
[Cuttings at 561 m (1840 ft) show evidence of contamination from the Baker tank; foreign materials include biotite–bearing zeolitic tuff, scraps of polyethylene, and flakes of epoxy paint]				

Table 29. Stratigraphic Log for Groundwater Characterization Project Well ER-12-1 based on Paleontologic and Petrographic Examinations of Cuttings Samples Collected at 15.4 m (50-ft) Intervals [1] (continued).

Sample Depth	Formation	Age	Conodont CAI(2)	Lithologic, Stratigraphic, Structural Notes
564 – 854 m (1850-2800 ft)	Upper Eleana Formation	Late Mississippian	No Data	Black to dark–gray to variegated gray, fine–grained, siliceous siltstone with irregular carbonate cement and common fresh pyrite; clasts are mostly subrounded and consist of quartz and less common chert and quartz–grain aggregates, and sparse mafic volcanic rock fragments and plagioclase; bedding is inconspicuous and unit is quite uniform over this interval. Cuttings only show compaction foliation and locally common quartz veins and quartz–calcite veins; no fabrics indicative of significant penetrative deformation. Probably equivalent (in part) to Unit J of Eleana Formation. Differs notably from Eleana Unit J at 326 – 518.3 m (1070–1700 ft) as this lower section is uniformly coarser grained, thicker bedded, more heterolithic, and apparently deposited in much deeper water.
——— FAULT ZONE noted in 3.0 m (10–ft) interval cuttings between 875 and 878 m (2870 and 2880 ft) ———				
869–970 m (2850 –3180 ft) (4)	lower Simonson Dolomite	Late Middle to early Late Devonian	5 to 5.5 with some 6.5 to 7	Light–gray to white medium–grained dolostone with common pyrite; gradation to darker gray colors with depth; distinct zone of dark gray, quartz–bearing dolostone at about 927–951 m (3040–3120 ft). No conspicuous deformation fabrics, but some cuttings locally show breccia textures; cannot confirm that breccia cuttings belong to this interval due to obvious downhole contamination with Eleana material and with foreign Tertiary volcanic rock. Latest Emsian to earliest Eifelian age; relatively shallow water, normal marine depositional environment. Variable CAI values and pitted surfaces on conodonts indicate hydrothermal alteration.

Table 29. Stratigraphic Log for Groundwater Characterization Project Well ER-12-1 based on Paleontologic and Petrographic Examinations of Cuttings Samples Collected at 15.4 m (50-ft) Intervals [1] (continued).

Sample Depth	Formation	Age	Conodont CAI(2)	Lithologic, Stratigraphic, Structural Notes
976–1082 m (3200–3550 ft)	Upper Sevy Dolomite	Late Early Devonian to Late Silurian	5 to 7	Uniform medium–gray and brownish–gray, coarse–grained dolostone with some pyrite; few veins, fractures, or breccia textures. Conodonts indicate Emsian and older ages (late Silurian), with no indication of a break or repetition in the sequence; normal marine depositional environment. Variable CAI values and pitted surfaces on conodonts indicate hydrothermal alteration.
——— Apparent INTRUSIVE CONTACT noted in 3 m (10–ft) interval cuttings at 1086 m (3564 ft)(5) ———				
1086–1094 m (3564–3588 ft) (TD)	Biotite Lamprophyre	Cretaceous 102.3 ± 0.5 Ma	No Data	Dark-greenish-gray, altered microporphyritic igneous rock with abundant phenocrysts of plagioclase and biotite; matrix consists of assemblage of secondary chlorite, calcite, white mica, albite, and rutile along with very common accessory magnetite, apatite, and sphene. Overall composition and texture suggest affinity with lamprophyric clan. Age determined by Ar^{40}–Ar^{39} analysis of biotite; see text for details and explanation.

Table 29. Stratigraphic Log for Groundwater Characterization Project Well ER-12-1 based on Paleontologic and Petrographic Examinations of Cuttings Samples Collected at 15.4 m (50-ft) Intervals [1] (continued).

Notes:

(1) Paleontologic investigations supervised by A.G. Harris (USGS Report CRG−92-2, June 4, 1992); petrographic studies by J.C. Cole (USGS, Denver, CO), except for detailed petrographic and microprobe study of 1086−1094 m (3564−3588 ft) by R.G. Warren (LANL, Los Alamos, NM);
geochronologic investigation by M.A. Lamphere (USGS, Menlo Park, CA).

(2) CAI = Color Alteration Index (Epstein et al., 1977) that indicates the maximum temperature to which the conodont sample has been exposed over geologically significant time. CAI values between 4 and 7 indicate exposure temperatures of at least 220°C and locally as much as 450°C.

(3) Identification of faults is based on study of detailed 3 m (10−ft) interval cuttings by J.C. Cole; faults are indicated by major changes in stratigraphic units, by presence of fragments of fault breccia, by oxidation and alteration, and(or) by the presence of cuttings with slickensided surfaces. Depths may differ slightly from those listed in the RSN lithologic log (Drellack et al., 1991), and Table 21, which was also based in part on geophysical logs.

(4) An additional sample was collected between 960−975 m (3150 ft and 3200 ft).

(5) Lithologic contact picked by RSN (Drellack et al., 1991).

characteristics alone are not especially distinctive, but the paleontologic analysis clearly indicates these cuttings belong to the middle Ordovician Antelope Valley Limestone (Aysees Peak member; Table 29). The dolomitic composition of this interval, in contrast to the primary limestone typical of this formation, is attributed to recrystallization and replacement of calcite during early stages of brecciation.

Beginning at 274.3 m (900 ft) and continuing to 312.4 m (1025 ft), ER-12-1 penetrated fairly uniform, medium- to fine-grained dolostone of the lower Sevy Dolomite. Fragments of fault breccia with common quartz-calcite veins are more typical in the upper part of this interval. Otherwise, the dolostone through this interval is rather unremarkable and only contains sparse recrystallized relics of bivalve shells.

At about 312.5 m (1025 ft), the well crosses a major fault boundary and intersects very fine-grained, calcareous, carbonaceous, pyritic, laminated siltstones of the Mississippian Eleana Formation. These rocks are characterized by abundant angular to subrounded grains of detrital quartz and lesser chert, by a non-micaceous matrix that consists of compacted clay minerals (montmorillonite?), and by widespread fine-grained, micritic calcite cement. Irregular veinlets of similar micritic calcite crosscut and disrupt the bedding laminations and probably represent diagenetic expulsion of formation water prior to lithification. Some carbonate veinlets of this same apparent period show an internal fibrous structure perpendicular to vein walls that suggests aragonite was growing during vein dilation. Bedding laminations are marked by size variations of detrital grains and by opaque (carbonaceous?) granules and are generally parallel to the compaction foliation defined by crystallographic alignment of matrix clay minerals.

The high degree of carbonate cement and the widespread occurrence of calcite-bearing veins in the upper part of the Eleana Formation are notable. Previously published lithologic log of ER-12-1 (Drellack et al., 1991) noted that, although the lithologic break between Sevy Dolomite above and Eleana Formation below was abrupt at about 312.4 m (1025 ft), the natural gamma-ray geophysical log showed transitional characteristics between dolostone and siltstone from about 308 to 323 m (1010 ft to 1060 ft) (Pawloski and Carlson, 1992). Microscopic examination of the cuttings through this interval indicates that the gamma log was most likely dampened by the extensive (non-radioactive) carbonate in the upper Eleana siltstones. The high carbonate content in these rocks accounts for their positive reaction to dilute hydrochloric acid and explains the use of the term "limestone" in the earlier lithologic log (Drellack et al., 1991) for this interval, but there is no doubt that these were deposited as clastic sediments.

The primary depositional and diagenetic fabrics are overprinted in some locations by weak to moderate shearing that forms small-scale crenulation folds with axial-planar cleavage. This type of deformation is observed in cuttings fragments from throughout the depth interval from 320 m (1050 ft) to 518 m (1700 ft), although it appears to be especially widespread below 503 m (1650 ft). All deformational fabrics are locally crosscut by variably oriented brittle veins filled with coarse-grained, well-crystallized quartz, calcite, and brown, pleochroic carbonate rhombs (siderite-ankerite?). These youngest veins appear to post-date all significant deformation in the rock.

The depth interval between about 521 m and 558 m (1710 ft and 1830 ft) produced cuttings that are a complex mixture of fine-grained Eleana Formation siltstone and light- to medium-gray dolomite, in part due to hole stability problems encountered at this depth (Drellack et al., 1991). The gamma-ray geophysical log indicates that dolomite was present between about 521 and 549 m (1710 ft and 1800 ft) (Pawloski and Carlson, 1992), and the conodonts recovered from the samples taken at 534 m and 549 m (1750 ft and 1800 ft) contained distinctive fauna from the upper Simonson Dolomite or lower Guilmette Formation (Givetian-Frasnian stages; Table 29). Microscopic study of the dolostone cuttings at 534 m and 549 m (1750 and 1800 ft) show intensely shattered fabrics that are cross-cut by quartz veins. On the basis of all observations, it appears that the 521-558 m (1710-1830 ft) zone represents a shattered slab of Middle to Late Devonian dolostone that is bounded by major faults above and below.

Beginning at about 558 m (1830 ft) and continuing to about 875 m (2870 ft), the ER-12-1 drillhole returned to fine grained-siliceous siltstone of the Mississippian upper Eleana Formation. These siltstones differ considerably from the finer-grained, laminated calcareous siltstones in the higher interval 320 to 521 m (1050 ft to 1710 ft)) in that they contain a higher proportion of detrital framework grains (less matrix), less calcite cement, more clasts of chert and sparse clasts of quartzite and mafic volcanic rock, and some detrital plagioclase and tourmaline. Bedding is generally thicker than the dimension of the cuttings, and the Schlumberger Formation Micro-scanner log suggests that depositional bedsets are on the order of one to three m (several feet to ten feet) thick in this part of the Eleana. The composition, bedding, and textural character of these siltstones indicate they were deposited in deeper water than the fine, calcareous silts above and were transported by more turbulent submarine flow. All features are consistent with the upper Unit "J" of the Eleana Formation, but probably at a lower stratigraphic level than the Eleana encountered higher in the hole.

Deformation in this lower Eleana Formation zone is far less common than higher in the hole. These coarser siltstones show less prominent compaction foliation (because they have less matrix clay), and crosscutting shears and veins are far less common.

At about 875.0 m (2870 ft) [(874.7 m (2869 ft;) Schlumberger Formation Micro-scanner log)], the well penetrated a faulted contact between the Eleana and light-gray dolostone of the Middle Devonian lower Simonson Dolomite (Table 28). This dolostone is fairly uniform down to 1086 m (3564 ft), and shows slight variations in color, grain size, and extent of secondary silica. Breccia fabrics, veins, and other indications of deformation are sparse throughout the interval. Conodonts recovered from this zone indicate an orderly progression to older beds downward, with the top of the Sevy Dolomite placed at about 976 m (3200 ft) (Table 29).

The bottom 7.3 m (24 ft) of well ER-12-1 [1086 to 1094 m (3564 to 3588 ft)] penetrated an altered biotite-rich microporphyritic igneous rock that is interpreted to intrude the Sevy Dolomite. Detailed microscopic study of this rock by R.G. Warren (Los Alamos National Laboratory; written communication, January 1993) indicates that the primary minerals consisted of plagioclase (about 22 percent), biotite (about 20 percent), and accessory magnetite and apatite (about 1 percent each) in a fine-grained matrix. All of the matrix is replaced by chlorite, albite, sphene, and calcite, original calcic plagioclase has all been replaced by albite and calcite, and secondary chlorite, rutile, and sphene occur within the primary biotite. The relict mineralogy and the apparent bulk composition suggest that the original rock was probably a lamprophyre (a class of small volume intrusive igneous rocks characterized by mafic-alkalic compositions, sparse to absent quartz, and abundant mafic minerals).

Generally similar, altered, biotite-rich intrusive rocks have been observed in outcrop in several locations within the Eleana Range and in Banded Mountain in the form of thin, subvertical dikes. In three of five occurrences, the dikes were emplaced in roughly east-west orientations. If the lamprophyric intrusion encountered at the bottom of ER-12-1 is related to these mafic dikes that crop out in the area, then it would not be expected to be voluminous, and that conclusion is supported by the absence of a detectable aeromagnetic anomaly near the drill site.

Biotite was separated from cuttings obtained at the bottom of ER-12-1 and sent to the USGS Geochronology Laboratory in Menlo Park, California, for analysis by M.A. Lanphere. Despite the altered character of this mineral, the incremental-heating ^{40}Ar-^{39}Ar analysis showed that more than 84 percent of the argon produced between 650° C and 1090° C had a very uniform composition that indicates a weighted mean plateau age of 102.3 ± 0.5 Ma. This age (middle Cretaceous) reflects the time of intrusion of the lamprophyre into the Sevy Dolomite (Cole et al., 1993), and is statistically equivalent to the emplacement ages previously determined for the Gold Meadows and Climax granitic stocks (Naeser and Maldonado, 1981).

Thermal History of Rocks at the ER-12-1 Well

Conodonts that were recovered from the carbonate rocks in ER-12-1 were also examined to determine the thermal history of the site. Conodonts systematically change color as they are exposed to increasing temperature, either as a result of sedimentary burial, metamorphism, or intrusion. The Color Alteration Index (CAI) (Epstein et al., 1977) has been calibrated to an absolute temperature scale and can provide a measure of the maximum temperature imposed on the sample over its total history. In addition, the presence of mixed-CAI-value conodonts in an individual sample, indicating exposure to non-equilibrium thermal conditions, has been shown to correlate with hydrothermal alteration and contact metamorphic geologic settings (Epstein et al., 1977).

The CAI values recorded by conodonts at various depths in ER-12-1 are listed in Table 30. The values of 4-4.5 to 5.5 are typical of the Devonian and lower Paleozoic rocks in this part of southern Nevada and probably reflect the combined effects of sedimentary burial, thrusting during the Antler and Sevier orogenies, and regional heating during Cenozoic extension (Harris et al., 1980). Superimposed on this background, however, is the overprint of a non-uniform heating event whose effect is progressively greater toward the bottom of the hole. Numerous samples produced variable conodont CAI values that indicate a local or short-lived heat source, and many conodonts in ER-12-1 show etched and pitted surfaces due to the corrosive effect of hydrothermal fluids (A. Harris, written communication, 1992).

Six samples of the Eleana siltstone from ER-12-1 were also analyzed for hydrocarbon content by C. Barker in the Branch of Petroleum Geology, USGS, Denver. Progressive heating in the

Table 30. Conodont Color Alteration Index (CAI) Values.

Depth m (ft)	CAI Range	Maximum Rock Temperature	Comment
0–137 m (0-450 ft)	4-4.5 some 5.5	>220 °C up to 320	Hydrothermally altered; Sevy Dolomite, early Early Devonian
152–244 m (500-800 ft)	5-5.5	>320 °C	Sevy Dolomite; Late Silurian
259–274 m (850-900 ft)	5-5.5	>320 °C	Antelope Valley Limestone; Middle Ordovician
289–320 m (950-1050 ft)	5-5.5	>320 °C	Sevy Dolomite; Late Silurian
533–549 m (1750-1800 ft)	5.5-6.5	>350-400 °C	Upper Simonson Dolomite or lower Guilmette Formation; late Middle Devonian; maximum temperatures probably somewhat higher than 400 °C
869–945 m (2850-3100 ft)	some 5; 5.5-6.5; some 7	>300 °C up to 450 °C	Hydrothermally altered; uppermost Sevy Dolomite or lowest Simonson Dolomite; late Early Devonian and Middle Devonian
970–1006 m (3180-3300 ft)	some 5; 5.5-6.5; some 7	>300 °C up to 450 °C	Hydrothermally altered; Sevy Dolomite; Early Devonian
1021–1082 m (3350-3550 ft)	mixed 5 through 7	>300 °C up to 450 °C	Hydrothermally altered; Sevy Dolomite; Late Silurian to Early Devonian

(Data from A. G. Harris, USGS, Reston, VA; written communication, 1992) pyrolysis technique produced no volatile hydrocarbons and confirmed that the Eleana has been subjected to maximum temperatures on the same order as those indicated by the CAI values (greater than 350°C).

The combined results of the conodont CAI analyses and the rock pyrolysis analyses indicate that the carbonate rocks in ER-12-1, as well as the intervening sheets of Eleana siltstone, have been thermally overprinted following movement on the faults that separate them. The probable source of heat for this thermal disturbance is the microporphyritic intrusion encountered at the bottom of the hole, and its age establishes that the major fault activity must have occurred prior to 102.3+0.5 Ma (middle Cretaceous).

GEOPHYSICAL LOGS

The logging suite for ER-12-1 was chosen by a committee, consisting of representatives of the Department of Energy, Desert Research Institute, Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), Raytheon Services Nevada, and the United States Geological Survey, during the planning stages of the hole. A broad range of disciplines and interests were represented, e.g., drillers, logging engineers, geophysicists, geologists, hydrologists, and administrators. As a result, the range of logging techniques requested was quite broad.

Many of the logs run in ER–12–1 were experimental to the logging community on the NTS. On-site logging capability (at the time ER–12–1 was drilled) was optimized for logging in very large (2.18 to 3.05 m or 86 to 120 in diameter) holes, in predominantly very porous, yet unsaturated rocks, with the holes filled with either air or water/mud. By comparison, well ER-12-1 had a small radius, so dry-hole logging tools, typically used on the NTS, were too large to fit into the well. Industry-standard logging capabilities, driven by the needs of oil and gas exploration, are optimized for holes slightly smaller (0.10 to 0.30 m or 4 to 12 in diameter) than ER-12-1. However, the response of many of these logs in air-filled holes is undocumented.

Standard logging technology was chosen for ER-12-1 as the best fit for the environment of the 0.31 m (12.25 in) diameter, water-filled portion of the borehole. In addition, many of these logs were available through the former on-site logging subcontractor (Atlas Wireline Services). The following section describes each log, the processing history, special comments on each data type, and provides preliminary correlation with geological and hydrological data.

Geophysical Logging

Downhole geophysical logs were obtained by Atlas Wireline Services, Schlumberger, Westech Engineering (video camera), and LLNL NTS Geotechnical Engineering Group. Table 31 lists all logs acquired in ER-12-1 to date. The LLNL gravimeter was run in the ER–12–1 borehole following the installation of the 0.14 m (5.5 in) completion string, once the drilling rig was no longer present at the surface.

The subcontract under which Atlas Wireline conducted logging at the NTS referred to a manual of logging procedures that described in detail how the work was to be conducted (Atlas,1988). This

Table 31. List of Geophysical Logs Acquired in ER-12-1.

Hole	Log Type	Run #	Date	Logger	Drldep	Logdep	Toplog	Botlog	Watlev
							Meters		
ER-12-1	3-D[1]	1	19-Oct-1991	ATLAS WS	1093.6	1091.5	460.2	1083.3	-
ER-12-1	CALIPER	1	20-Aug-1991	ATLAS WS	520.9	517.6	1.2	515.1	-
ER-12-1	CALIPER	3	26-Oct-1991	ATLAS WS	1093.6	1065.0	433.4	1062.5	-
ER-12-1	CALIPER	4	29-Oct-1991	ATLAS WS	1093.6	633.1	430.7	630.3	-
ER-12-1	CALIPER	5	12-Nov-1991	ATLAS WS	1093.6	549.2	432.8	546.5	-
ER-12-1	CALIPER+	2	18-Oct-1991	ATLAS WS	1093.6	1091.5	435.6	1088.4	-
ER-12-1	CVL[2]	1	19-Oct-1991	ATLAS WS	1093.6	1091.5	460.2	1085.7	-
ER-12-1	DENSITYBC[3]	1	20-Aug-1991	ATLAS WS	520.9	516.0	7.0	515.1	-
ER-12-1	DENSITYBC	+2	19-Oct-1991	ATLAS WS	1093.6	1091.5	435.9	1090.6	-
ER-12-1	DIP MICRO[4]	1	22-Oct-1991	SCLUMBRGR	1093.6	1092.1	449.3	1091.8	-
ER-12-1	DIR SEEK[5]	1	17-Jan-1992	EASTMAN	1093.6	-	7.6	1073.5	-
ER-12-1	ELOG IND[6]	1	21-Aug-1991	ATLAS WS	520.9	516.3	10.7	515.4	-
ER-12-1	ELOG MINI[7]	1	22-Oct-1991	SCLUMBRGR	1093.6	1091.2	449.3	1087.5	-
ER-12-1	ELOGFOCUS+[8]	1	20-Oct-1991	ATLAS WS	1093.6	1091.5	442.0	1088.1	-
ER-12-1	GAMMA SPEC[9]	1	20-Aug-1991	ATLAS WS	520.9	516.3	0.6	515.7	-
ER-12-1	GAMMA SPEC	2	18-Oct-1991	ATLAS WS	1093.6	1091.5	436.5	1091.2	-
ER-12-1	GAMMA+[10]	1	20-Aug-1991	ATLAS WS	520.9	516.3	9.1	511.5	-
ER-12-1	GAMMA+	2	18-Oct-1991	ATLAS WS	1093.6	1091.5	435.6	1088.4	-
ER-12-1	GAMMA+	3	19-Oct-1991	ATLAS WS	1093.6	1091.5	431.0	1090.0	-
ER-12-1	GAMMA+	4	19-Oct-1991	ATLAS WS	1093.6	1091.5	435.9	1090.6	-
ER-12-1	GAMMA+	5	20-Oct-1991	ATLAS WS	1093.6	1091.5	442.0	1088.1	-
ER-12-1	MAGNET BH[11]	1	21-Aug-1991	LLNL-N	520.9	517.2	21.3	517.2	-
ER-12-1	MAGNET BH	2	21-Oct-1991	LLNL-N	1093.6	1092.4	452.0	1092.4	-
ER-12-1	NCTL[12]	1	23-Aug-1991	ATLAS WS	520.9	448.7	0.6	448.4	-
ER-12-1	NEUTRONEP+[13]	1	20-Aug-1991	ATLAS WS	520.9	516.3	9.1	515.1	-
ER-12-1	NEUTRONEP+	2	19-Oct-1991	ATLAS WS	1093.6	1091.5	431.0	1090.0	-
ER-12-1	SEISMIC DN[14]	1	19-Oct-1991	ATLAS WS	1093.6	1088.4	91.4	1088.4	-
ER-12-1	VIDEO	1	21-Aug-1991	WESTECH	520.9	-	0.0	467.0	-
ER-12-1	WL FLD[15]	1	20-Aug-1991	ATLAS WS	520.9	520.6	455.4	490.7	468.8
ER-12-1	WL FLD	2	21-Aug-1991	ATLAS WS	520.9	-	459.3	479.1	468.8
ER-12-1	WL FLD	3	22-Aug-1991	ATLAS WS	520.9	515.7	442.0	475.5	449.9
ER-12-1	WL FLD	4	18-Oct-1991	ATLAS WS	1093.6	-	455.1	476.7	470.9
	TOTAL:	37							

[1]Acoustic fracture log
[2]Compensated velocity
[3]Borehole compensated density
[4]Formation Micro-scanner
[5]Gyroscopic survey
[6]Induction log
[7]Micro-resistivity log
[8]Focused resistivity
[9]Spectral gamma ray
[10]Gamma ray
[11]Borehole magnetometer
[12]Nuclear cement toplog
[13]Epithermal neutron (ENP) or (Neutron EP)
[14]Downhole seismic
[15]Water level

manual was written principally by LLNL, published by RSN, and agreed to by LLNL, LANL, RSN, and Atlas Wireline. Services not expressly described in this manual were run under logging company standard procedures, and supplemented by specific instructions at the well site. This operating procedure applied to the Schlumberger and Westech logging performed at ER-12-1. Specific NTS procedures existed for the epithermal neutron, gamma ray, and temperature (ENP, GR, and TL) logs. The LLNL logging procedures were defined in a separate document (Millet and Felske, 1989), which had been reviewed and accepted by the LLNL Containment Program.

Connection of signal processing elements to the logging cable, the selection of what data was to be presented on film and tape, and the format of that data was controlled by the logging truck computer via utilization of a service table. A service table is defined as a small file of information set up for each log and called up by the computer when that particular log was to be run. Much of the previously discussed NTS procedure consisted of descriptions of the specific service table to be used for each log.

An attempt was made to decrease the time spent logging at ER–12–1 by stacking logging tools. Stacked logging tools consists of connecting several mutually compatible tools end-to-end and recording all data during one run in the borehole. This is a common practice in the logging industry, and Atlas Wireline had copies of the requisite service tables for Gamma Ray (GR)/Compensated Density Log (CDL)/Dual Induction Focused Log (DIFL); Six Arm Caliper Log (CA6)/GR; and ENP/GR stacks. All of the stacks were tried, but most would not work, though much time and effort were applied in the attempt. Sondes and equipment, brought to the location by Atlas Wireline, were apparently different than those used in typical oil field applications. In the dry hole, only the ENP/GR stack worked. Additional work by Atlas Wireline, conducted between August 21, 1991 (when the dry–hole logs were run) and October 18, 1991 (when the wet–hole logs were run) resulted in successful logging of the wet–hole with the ENP/GR, CA6/GR, CDL/GR and Dual Laterolog (DLL)/GR stacks. The stacking of these logs did not result in saved time as all of the logs were also run separately. The stacked logs did, however, provide valuable depth correlation between the runs owing to the multiple gamma ray logs. It should be noted that the GR trace was strongly affected by the CDL source, and to a lesser extent by the ENP source, in the dry hole runs. The gamma ray data from these stacked configurations should be used qualitatively, but not quantitatively.

LLNL personnel and RSN logging engineers were present for the Atlas dry– and wet–hole logging suites conducted at ER-12-1. Their presence provided a technical resource for decisions regarding data quality and initial data interpretation.

Logging tools were required to pass quality control standards prior to being run in well ER–12–1. However, some of the tools did not have calibrations or gap corrections for processing data from the 0.44 m (17-1/2 in) diameter, air-filled environment of the upper portion of ER-12-1. In response, LLNL developed new processing procedures for these logs, and has worked with the DOE in an attempt to correct these deficiencies for future drill holes.

One item needs to be noted; casing depths on all logs appeared to be approximately 2 m (6 ft) shallower than the drilling report. Investigations indicated the logging data were consistent; it is suspected that the pipe count was wrong. Additionally, the video log shows the surface casing base at 15.33 m (50.3 ft), which was consistent with neither logging information (14.02 m or 46 ft) nor drilling information (15.85 m or 52 ft).

Presentation of Data

Figures 5 and 6 summarize data types that were common to the dry and wet logging suites. Processed caliper, bulk density, water content, resistivity, natural gamma, and total magnetic intensity are shown, with stratigraphy supplied by RSN geologists and modified on the basis of paleontological investigations. At the bottom of each log trace is the log name and the date it was run. Water content is displayed as percent volume, which readily equates with porosity.

Table 32 lists processed ER–12–1 data archived by the LLNL Containment Program. The processed data have also been transferred to DRI. The data given to DRI have been smoothed on 0.61 m (2 ft) intervals, and then tabulated on 0.30 m (1 ft) increments. This slightly reduced the large number of data points in each file, while making it easier to display and manipulate the information with CAD software. Data at this sampling rate should be sufficient for other uses, such as modeling.

Strict quality control was employed throughout the processing of the data at LLNL. All codes were documented, and history files were constructed which include information from the actual processing procedure. These history files are part of the QA record, and are archived at LLNL.

Caliper Logs

Five caliper logs were run in ER-12-1. A 6-arm caliper tool was utilized, where each arm represented a radius, and diameters were identified by paired arms, i.e., diameters 1-4, 2-5, and 3-6. Caliper Run 2 was stacked with a gamma tool, and both tools acquired information as they were pulled together up the drill hole. Caliper Run 1 (shown in Figure 5) was run to the intermediate depth of 520.90 m (1709 ft) and obtained information predominantly in the dry portion of the hole (52.12 m or 171 ft of data were obtained below the static water level from this run). Runs 2 through 5 were run in the wet portion of the hole after the total depth of 1093.62 m (3588 ft) was reached. Each caliper log started as close to the bottom of the hole as possible.

Caliper processing included determining the minimum and maximum diameters from the three pairs of arms at all locations, the ratio of the maximum to minimum diameters (called elongation index), and the average of the three diameters at each depth. Tolerances on acquiring data were 6 mm (1/4 in) on each diameter. The accuracy of the average diameter was 4 mm (just under 1/4 in). Average diameter and the individual three measured diameters were archived. The change in bit size at 520.90 m (1709 ft) is visible in the data from Runs 2 through 5 (Figure 7). In general, the hole was relatively in gauge, with exceptions being from 73.15-129.54 m (240-425 ft) and 521.21-550.77 m (1710-1810 ft).

Casing locations indicated by the log trace on all five runs appeared to be about 2 m (6 ft) shallower than the drilling report. The surface casing was reported to be at 15.85 m (52 ft), but actually appeared at 14.02 m (46 ft) on Run 1. The intermediate casing was reported at 450.59 m (1478 ft), but appeared at 448.66 m (1472 ft) on Runs 2-5.

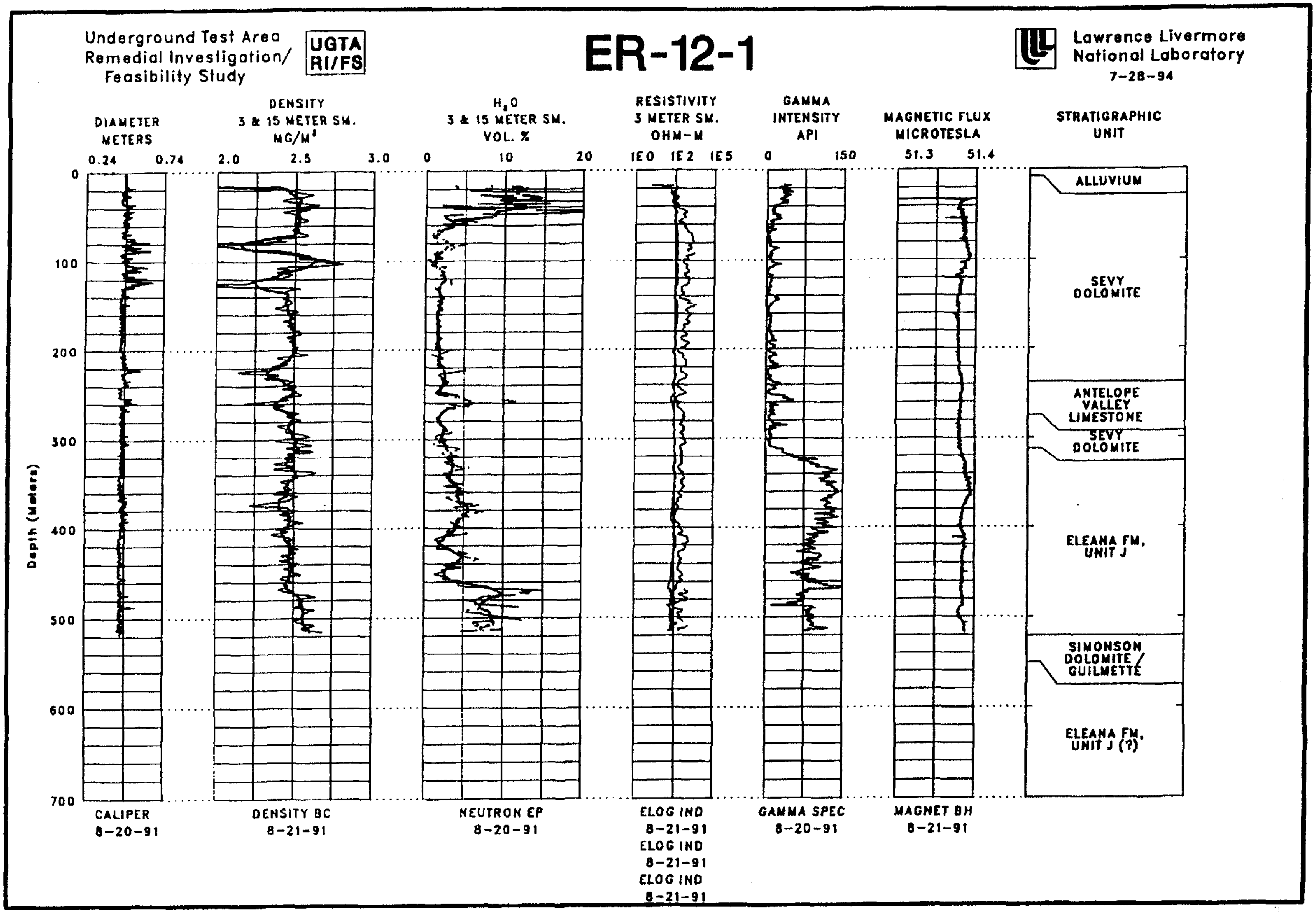


Figure 5. Summary of selected logs from the dry-hole logging suite.

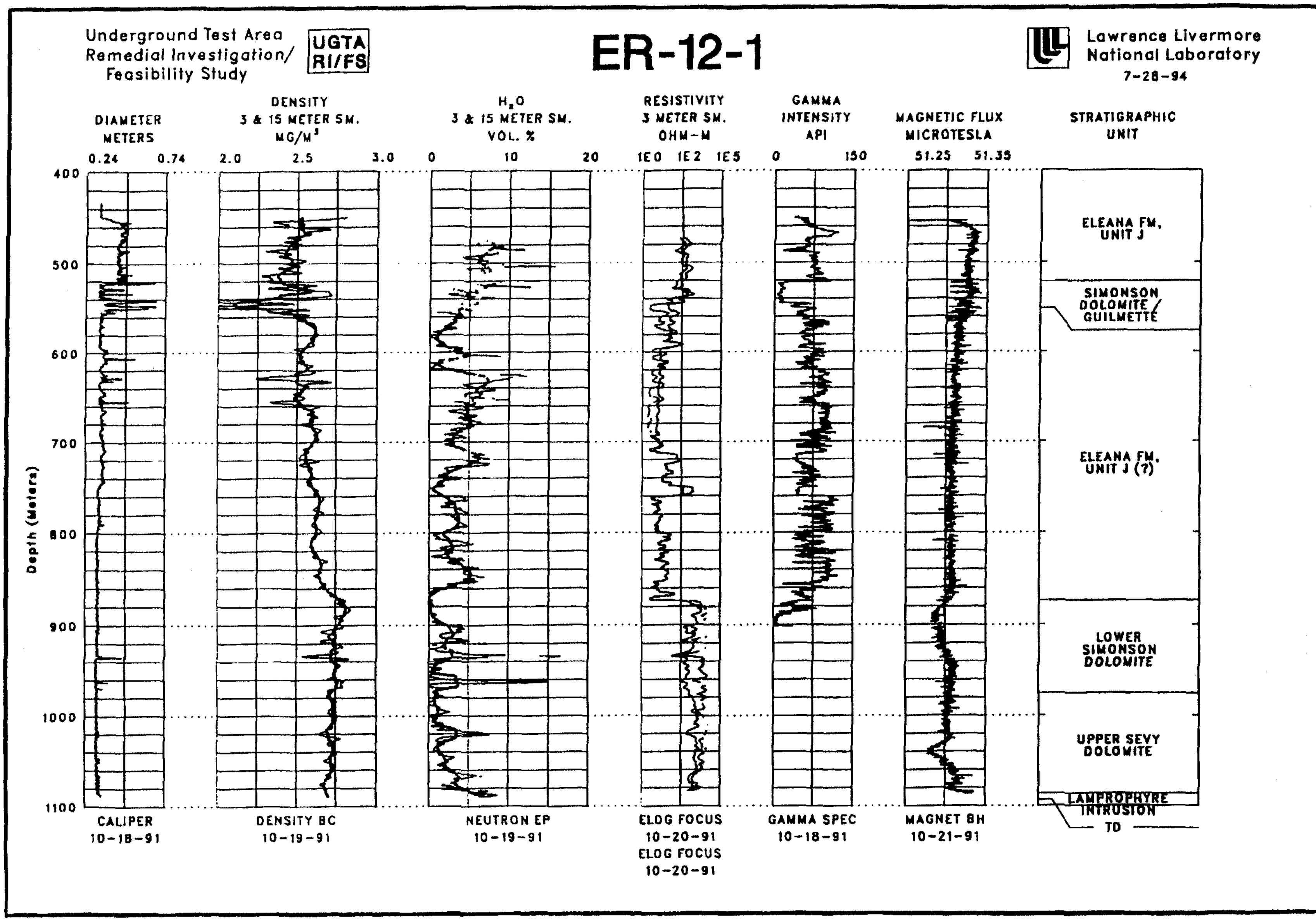


Figure 6. Summary of selected logs from the wet-hole logging suite.

Table 32. Processed Data from ER-12-1 Archived at LLNL.

Hole Name	Log Name	Run #	Log Date	Data Type	Units	Number of Points	Min. Value	Max. Value	Min. Depth	Max. Depth	Archived File Name
ER-12-1	CALIPER	1	20-aug-1991	DIAMETER	INCHES	6816	17.41	26.58	-3.8	1700.0	VO5D10F71
ER-12-1	CALIPER	1	20-aug-1991	DIAMETER 1	INCHES	6816	16.53	29.80	-3.8	1700.0	VO5D10F74
ER-12-1	CALIPER	1	20-aug-1991	DIAMETER 2	INCHES	6816	16.89	28.88	-3.8	1700.0	VO5D10F75
ER-12-1	CALIPER	1	20-aug-1991	DIAMETER 3	INCHES	6816	16.74	33.01	-3.8	1700.0	VO5D10F76
ER-12-1	CALIPER	2	18-oct-1991	DIAMETER	INCHES	8601	11.90	26.94	1421.0	3571.0	VO5D11F13
ER-12-1	CALIPER	2	18-oct-1991	DIAMETER 1	INCHES	8601	11.29	33.08	1421.0	3571.0	VO5D11F14
ER-12-1	CALIPER	2	18-oct-1991	DIAMETER 2	INCHES	8601	11.19	28.29	1421.0	3571.0	VO5D11F15
ER-12-1	CALIPER	2	18-oct-1991	DIAMETER 3	INCHES	8601	11.66	31.16	1421.0	3571.0	VO5D11F16
ER-12-1	CALIPER	3	26-oct-1991	DIAMETER	INCHES	8253	12.18	28.76	1422.0	3485.0	VO5D11F17
ER-12-1	CALIPER	3	26-oct-1991	DIAMETER 1	INCHES	8253	11.95	33.94	1422.0	3485.0	VO5D11F18
ER-12-1	CALIPER	3	26-oct-1991	DIAMETER 2	INCHES	8253	11.50	28.67	1422.0	3485.0	VO5D11F19
ER-12-1	CALIPER	3	26-oct-1991	DIAMETER 3	INCHES	8253	11.87	30.45	1422.0	3485.0	VO5D11F20
ER-12-1	CALIPER	4	29-oct-1991	DIAMETER	INCHES	2593	12.63	30.67	1420.0	2068.0	VO5D11F31
ER-12-1	CALIPER	4	29-oct-1991	DIAMETER 1	INCHES	2593	12.63	33.71	1420.0	2068.0	VO5D11F32
ER-12-1	CALIPER	4	29-oct-1991	DIAMETER 2	INCHES	2593	12.42	28.97	1420.0	2068.0	VO5D11F33
ER-12-1	CALIPER	4	29-oct-1991	DIAMETER 3	INCHES	2593	12.63	30.63	1420.0	2068.0	VO5D11F34
ER-12-1	CALIPER	5	12-nov-1991	DIAMETER	INCHES	1525	12.62	28.21	1412.0	1793.0	VO5D11F35
ER-12-1	CALIPER	5	12-nov-1991	DIAMETER 1	INCHES	1525	12.74	31.86	1412.0	1793.0	VO5D11F36
ER-12-1	CALIPER	5	12-nov-1991	DIAMETER 2	INCHES	1525	12.46	30.21	1412.0	1793.0	VO5D11F37
ER-12-1	CALIPER	5	12-nov-1991	DIAMETER 3	INCHES	1525	12.37	29.72	1412.0	1793.0	VO5D11F38
ER-12-1	CVL	1	19-oct-1991	VELOCITY	FT/SEC	8041	12504.50	24966.19	1550.0	3560.0	VO5D11F39
ER-12-1	DENSITY BC	1	21-aug-1991	DENSITY	GM/CC	6561	1.37	3.02	52.0	1692.0	VO5D11F45
ER-12-1	DENSITY BC	2	19-oct-1991	DENSITY	GM/CC	8405	1.29	3.04	1475.0	3576.0	VO5D11F46
ER-12-1	ELOG FOCUS	1	20-oct-1991	RESISTIVITY	OHM-M	8025	2.09	19933.46	1550.0	3556.0	VO5D11F52
ER-12-1	ELOG FOCUS	1	20-oct-1991	RESISTIVITY	OHM-M	8025	2.00	19647.56	1550.0	3556.0	VO5D11F53
ER-12-1	ELOG FOCUS	1	20-oct-1991	SELF-POTENTIAL	MILLIVOLTS	7885	-249.71	194.00	1550.0	3521.0	VO5D11F54
ER-12-1	ELOG IND	1	21-aug-1991	RESISTIVIVITY	OHM-M	6720	172.80	5904.77	11.3	1691.0	VO5D10F68
ER-12-1	ELOG IND	1	21-aug-1991	RESISTIVIVITY	OHM-M	6720	2.57	9809.16	11.3	1691.0	VO5D10F69
ER-12-1	ELOG IND	1	21-aug-1991	RESISTIVIVITY	OHM-M	6720	5.21	514.54	11.3	1691.0	VO5D10F70
ER-12-1	GAMMA SPEC	1	20-aug-1991	GAMMA	API UNITS	6557	1.02	147.74	52.0	1691.0	VO5D11F21
ER-12-1	GAMMA SPEC	1	20-aug-1991	POTASSIUM	VOL-PERCNT	6557	0.00	4.98	52.0	1691.0	VO5D11F22
ER-12-1	GAMMA SPEC	1	20-aug-1991	URANIUM	PPM	6557	0.41	5.82	52.0	1691.0	VO5D11F23
ER-12-1	GAMMA SPEC	1	20-aug-1991	THORIUM	PPM	6557	0.15	12.94	52.0	1691.0	VO5D11F24
ER-12-1	GAMMA SPEC	2	18-oct-1991	GAMMA	API UNITS	5929	1.52	122.52	1478.0	2960.0	VO5D11F40
ER-12-1	GAMMA SPEC	2	18-oct-1991	POTASSIUM	VOL-PERCNT	5929	-0.01	3.64	1478.0	2960.0	VO5D11F41
ER-12-1	GAMMA SPEC	2	18-oct-1991	URANIUM	PPM	5929	0.25	7.99	1478.0	2960.0	VO5D11F42
ER-12-1	GAMMA SPEC	2	18-oct-1991	THORIUM	PPM	5929	0.66	12.71	1478.0	2960.0	VO5D11F43
ER-12-1	MAGNET BH	1	21-aug-1991	MAGNETIC FLUX DENS	MICROTESLA	1700	51.35	52.69	70.8	1696.3	VO5D11F49
ER-12-1	MAGNET BH	2	21-oct-1991	MAGNETIC FLUX DENS	MICROTESLA	2693	51.25	51.35	1483.0	3584.6	VO5D11F58
ER-12-1	NEUTRON EP	1	20-aug-1991	WATER CONTENT	WT-PERCENT	3276	-0.13	17.69	52.0	1689.5	VO5D11F47
ER-12-1	NEUTRON EP	1	20-aug-1991	WATER CONTENT	VOL-PERCENT	3276	-0.38	45.03	52.0	1689.5	VO5D11F48
ER-12-1	NEUTRON EP	2	19-oct-1991	WATER CONTENT	WT-PERCENT	4063	-0.39	19.80	1544.0	3575.0	VO5D11F29
ER-12-1	NEUTRON EP	2	19-oct-1991	WATER CONTENT	VOL-PERCNT	4063	-1.04	38.90	1544.0	3575.0	VO5D11F30
ER-12-1	SEISMIC DN	1	19-oct-1991	VELOCITY	FT/SEC	47	8285.71	15687.22	0.0	3571.0	VO5D11F25
ER-12-1	SEISMIC DN	1	19-oct-1991	TRAVEL TIME	SEC	47	0.04	0.23	0.0	3571.0	VO5D11F26

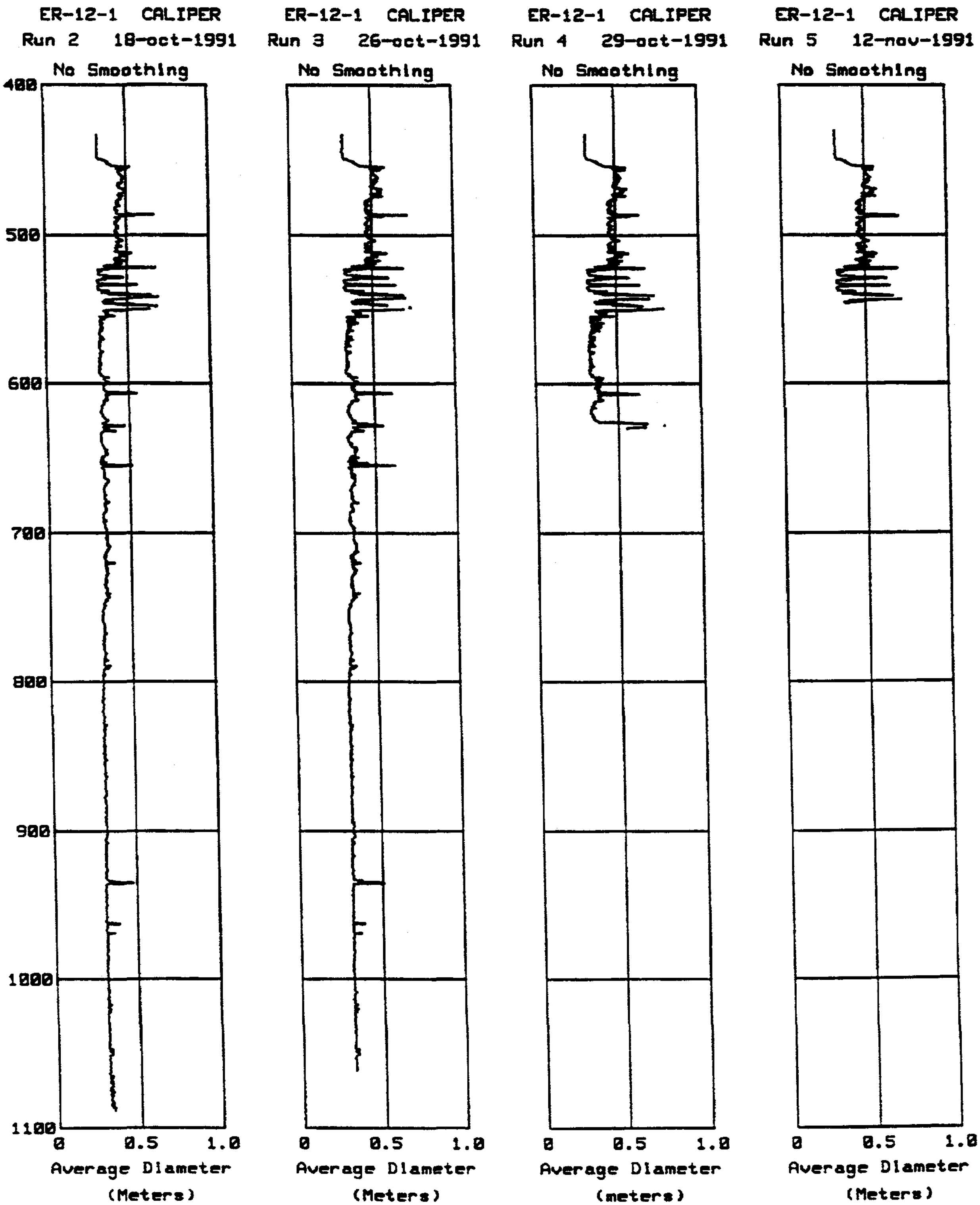


Figure 7. ER–12–1 caliper logs, 400 to 1100 m (1312 to 3608 ft).

Data from Runs 2 and 3 were very repeatable, with both showing the hole being in-gauge for most of the depth, with minor washouts. The repeatability indicated that the hole was fairly stable at this point. Both runs showed a ragged interval between 521.21 to 550.77 m (1710 to 1807 ft) in the Simonson Dolomite. There were five enlarged zones within this interval. Four zones correlated to faults identified in the hole, and the remaining zone correlated to a fractured zone. Total depth of the hole changed between Run 2 (1091.49 m or 3581 ft) and Run 3 (1064.97 m or 3494 ft). Other logs run within days of Caliper Run 2 showed a tagged depth of near 1090 m (3576 ft), indicating sloughing occurred after October 21, 1991 (Magnetometer Run 2) but before October 26, 1991 (Caliper Run 3). Since the data obtained by Caliper Runs 2 and 3 are so similar, the sloughing was probably restricted to the bottom of the hole. Initial well development began sometime after Caliper Run 3, when bentonite drilling fluid was removed from the well and replaced with fresh water. This caused hole instability. Caliper Run 4 on October 29, 1991 tagged fill high in the hole at 633.07 m (2077 ft), indicating that the hole had probably bridged. The rocks at this location were argillaceous bedded units within the Eleana Formation (Unit J). Run 5, on November 12, 1991, showed an even shallower total depth (549.25 m or 1802 ft), indicating hole stability still had not been reestablished.

Faults and fractures identified by RSN geologists using stratigraphy, lithology, geophysical logs, and drilling data were, in general, quite visible on the caliper logs above 603 m (1978 ft). Several sharp breaks in the caliper logs were indicated between 603 to 840 m (1978 to 2756 ft), but none of these were identified by the geologists as faults or fractures. The caliper logs were relatively smooth between 850 to 915 m (2790 to 3000 ft) where faults and fracture have been identified. Between 930 to 965 m (3050-3170 ft) faults and fractures correlated with peaks on the caliper logs.

Density Logs

Two compensated density logs (CDLs), which are two-detector tools, were run in ER-12-1; Run 1 was part of the dry hole suite, and Run 2 was part of the wet suite. Run 2 was stacked with a gamma log. Data from compensated density logs were used to: determine the bulk density of the rock media, assist in lithologic correlation, and calculate physical properties of saturation and porosity.

No calibration data existed for a two-detector tool run in a 0.44 m (17.5 in) diameter air-filled hole. Under water, the tool responded properly to the environment, and data processing was guided by standard procedures. A review of the Atlas Wireline corrected bulk density and the correction factor utilized revealed that the corrected density values appeared to be approximately 0.1-0.2 Mg/m^3 lower than expected for the rock types encountered. In addition, the short-spaced density was higher than the long-spaced density, which is physically impossible for a properly calibrated tool run in a borehole caked with mud having a density less than the formation density. In addition, the automatic correction was negative, which was also not physically possible under these conditions. Atlas Wireline routinely made their compensation correction to the density curve utilizing constants determined in wet environments at their Houston test pits. This configuration was not appropriate for air-filled drill holes at the NTS. LLNL recognized this inconsistency, and subsequently developed methods to resolve the problem.

Below the water level, the tool responded appropriately to the environment (water-filled gaps rather than air-filled gaps), and processing of the data was straightforward. Negative correction was not observed and the short-spaced count was always less than or equal to the long-spaced count. Previous experience in these environments encouraged confidence that the tool was operating correctly. The measured densities were as expected for the given rock type and matched laboratory-measured gravimetric density data. Water levels used in processing data from both runs were obtained from each specific run. A water level of 468.17 m (1536 ft) was used for Run 1 and 470.61 m (1544 ft) was used for processing Run 2.

The density data were processed using the long- and short-spaced count data. First the count rates from the two detectors were converted to density by applying the calibration densities to the counts on the log, which converted the counts from saturated limestone bulk density to electron density in the process. A least squares technique was used in a running window on the two log densities to determine the standoff correction to be applied to the long-spaced density. In the wet hole, this process gave densities that agreed within 0.02 Mg/m^3 with electron densities calculated from the field density curve. In the dry hole, the long-spaced density values were increased and the short-spaced values decreased until the two curves agreed at their high density excursions, and the step in density at the static water level was minimized. The final calibration density values used were 1.756 Mg/m^3 and 2.795 Mg/m^3 for the long-spaced values, and 1.696 Mg/m^3 and 2.625 Mg/m^3 for the short. The unshifted electron density values were 1.628 Mg/m^3 and 2.685 Mg/m^3 for both long and short, so the long-spaced density was shifted by about 0.1 Mg/m^3 and the short-spaced density by about 0.06 Mg/m^3. The step at the SWL was reduced from about 0.2 Mg/m^3 to about 0.05 Mg/m^3.

Two bulk density measurements were made on core samples taken at 754.38 m (2475 ft) (Drellack et al., 1991). The measured values of 2.68 and 2.67 Mg/m^3 compared favorably to the log data from Run 2.

Density data from ER-12-1 are shown in Figures 8 and 9 along with water content and velocity data. The accuracy of the processed data was different (for reasons explained above) for the dry and wet portions of the hole. There was a high level of confidence that the reported density data below the water level were accurate to 0.063 Mg/m^3. A lower level of confidence existed in the data from the dry portion of the hole, and therefore, an accuracy of 0.1 Mg/m^3 was reported for data from 15.85 to 468.26 m (52 to 1536 ft) from Run 1.

Epithermal Neutron Logs

Two epithermal neutron logs (ENP) were run in ER-12-1, both in a stacked configuration with gamma ray tools. Run 1 was part of the dry suite of logs, Run 2 part of the wet suite. Water content was the main data type determined from the measurements, however, the data can also be used with other data to determine porosity, saturation, and lithology. Hydrogen Contact Test Unit (HCTU) calibration data were used for processing data from both runs. The calibration data applied to 0.31 m (12.25 in) diameter holes in both wet and dry conditions. Calibration data for 0.44 m (17.5 in) diameter holes were not available.

Calibrations to determine the multiplier to convert count data (CPS) to API units on Run 1 were not conducted according to standard practice, however, the calibration procedure that was used resulted in a difference of only 0.16 percent, thus the log data were considered acceptable. The repeat section was used as it had better quality data than that in the main run. A fluid level of 467.87 m (1535 ft) was used for processing, taken directly from this log run rather than from a fluid density measurement of 468.78 m (1538 ft) made earlier in the day. Density data from compensated density log Run 1 were used to apply the density correction to the water data. There was a significant increase in water content below the water level, as was expected.

Run 2 was processed using density data from compensated density log Run 2, and a water level of 470.61 m (1544 ft), which was obtained from the trace of the log.

Plots of water content from ER-12-1 are displayed in Figures 8 and 9, along with bulk density and velocity data. The accuracy of the volumetric water content was estimated at ± 8 percent of the value. Since the density correction was small for calculating volumetric water content, the error was assumed to be the same for both the dry and wet sections.

Electric Logs

Four different electric logs were run to obtain lithologic information (altered zones) and physical property information (porosity and saturation). Electric logs do not perform properly in casing, so data from all runs were collected below the cased interval. A dual induction focused log (DIFL) was run as part of the dry hole suite. A Dual Laterolog (DLL), Schlumberger Microlog, and Schlumberger Formation Micro-scanner (FMS) were included as part of the wet hole suite. Each of these logs are discussed below.

Dual Induction Focused Log (Elog Ind)

The dual induction focused log, which was run as part of the dry suite of logs, recorded three types of resistivity information - deep, medium, and focused. The medium and deep data were measured as conductivity, by virtue of the physics of the method. The accuracy of the log was 2 mmho-m. However, at a resistivity of 200 ohm-m (the realm of a fair amount of the data from ER-12-1, after it is converted from conductivity to resistivity), this value resulted in an accuracy of approximately 40% of the value. There were no tool geometry factors available in the logging industry for correcting data run in a 0.44 m (12.5 in) diameter hole, so corrections were not made to these data. Resistivity data from the DIFL were off-scale much of the time, due in part to a small error in conductivity zero. This was corrected during processing by adding a constant to each data trace to prevent conductivity from crossing zero. The medium conductivity trace was corrected by 1.0 mmho/m, deep conductivity was corrected by -0.676 mmho/m, and the focused conductivity trace was corrected by -0.880 mmho/m. Conductivity was then converted to resistivity, and anomalous spikes were stripped out.

Resistivity data from this log are shown in Figure 5, but they are displayed in a clearer form in Figure 10. The deep resistivity trace was lower than the medium resistivity trace as the medium

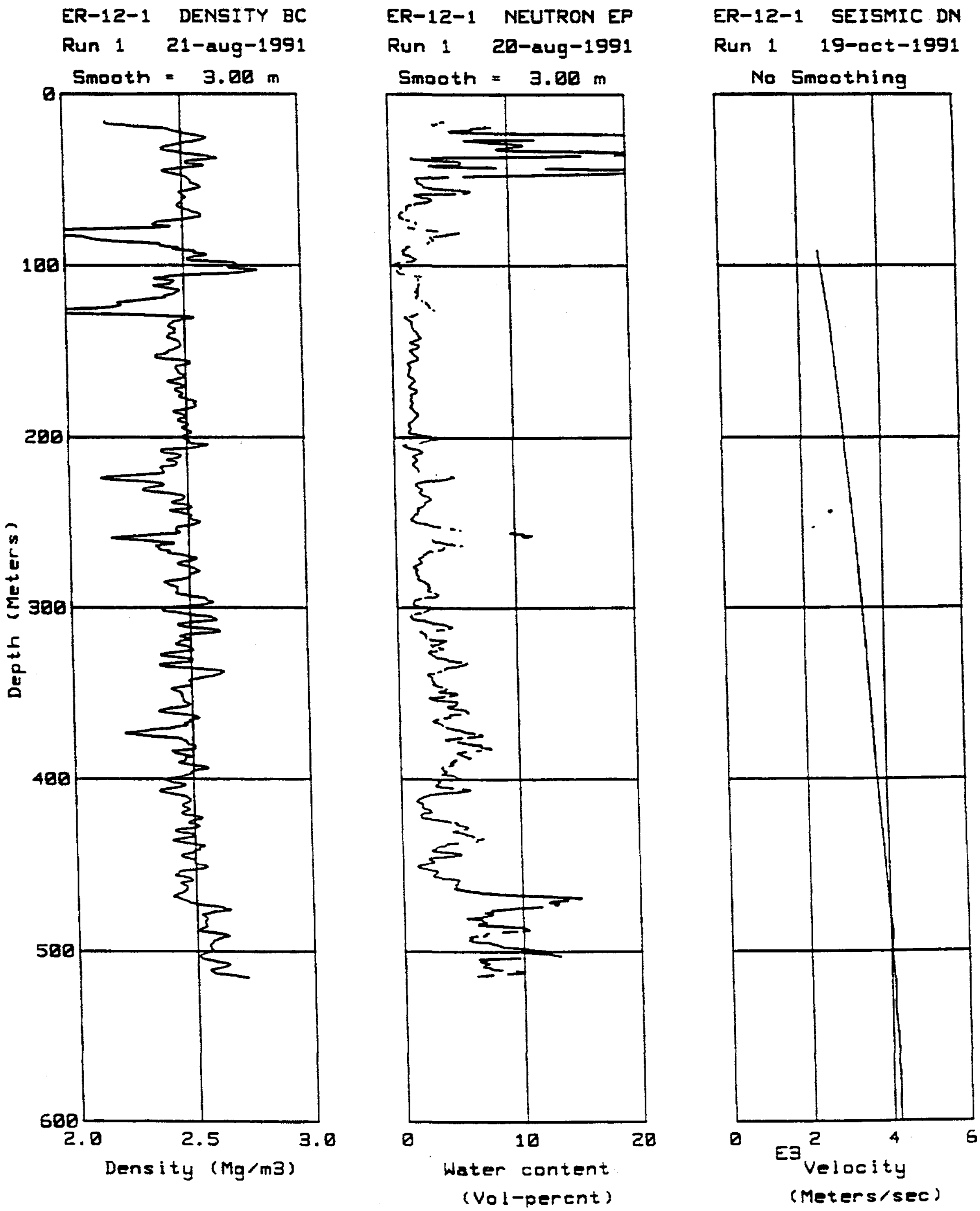


Figure 8. Density, epithermal neutron, and sonic logs from ER–12–1, 0 to 600 m (0 to 1968 ft).

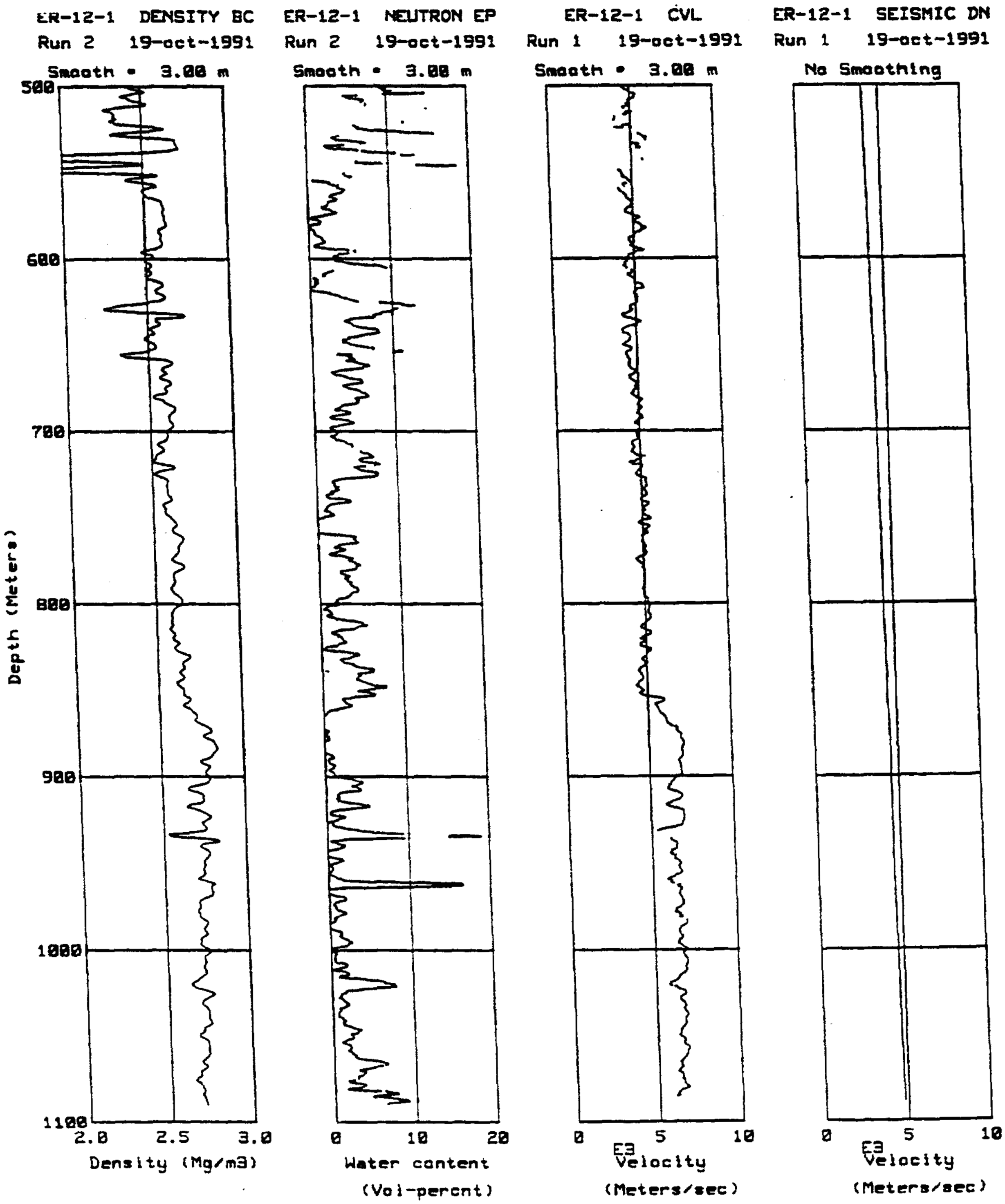


Figure 9. Density, epithermal neutron, continuous velocity and sonic log, 500 to 1100 m (1640 to 3608 ft).

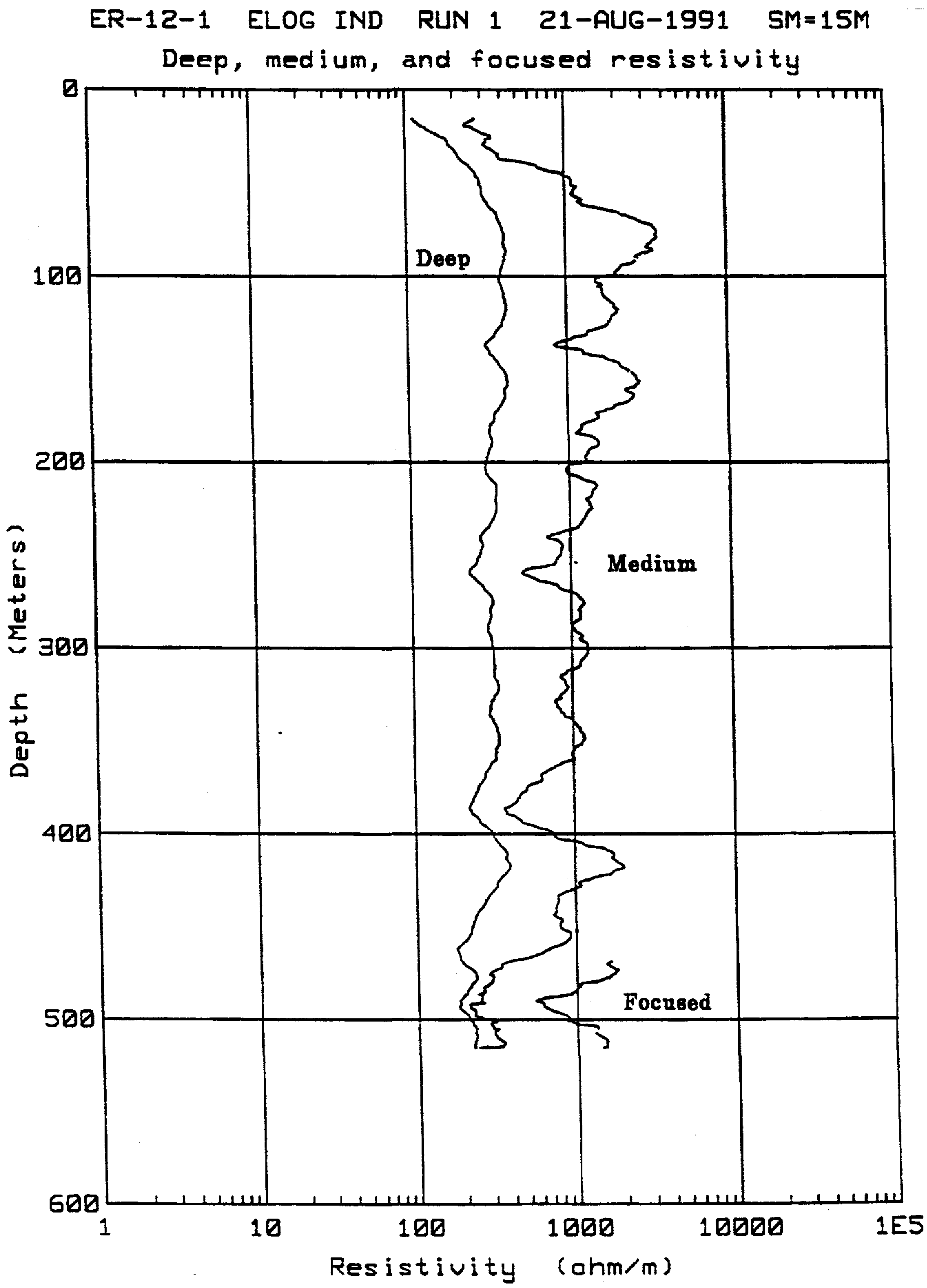


Figure 10. Deep, medium and focused resistivity, 0 to 600 m (0 to 1968 ft).

trace was affected by the air-filled borehole. The two traces were in better agreement below the SWL. The focused data were collected only below the SWL. Values from this trace were higher, falling between the shallow and deep curves of the DLL.

Dual Laterolog (Elog Focus)

The dual laterolog is a wet hole tool that measures deep and shallow resistivity and spontaneous potential (SP). It was run in a stacked configuration with Gamma Run 5. Since the electric log data were acquired in a water-filled hole, tool geometry was not an influential factor. Atlas Wireline Services noted under remarks for this log that spikes on the resistivity curves in high resistivity zones were due to software problems. Processing included removing anomalous spikes from both resistivity files by stripping at limits determined by flat-topped data. Resistivity data are shown in Figures 6 and 11, and spontaneous potential data are presented in Figure 12. It is clear in Figures 6 and 11 that the changes in deep and shallow resistivity with depth were not identical; at times they were far apart, and at times they were coincidental. Separation of the traces usually indicated a zone of lower resistivity near the borehole that has experienced shallow invasion by drilling fluids.

Microlog (Elog Mini)

A Microlog is a wet-hole tool that records diameter, natural gamma, and resistivity, and can be useful in determining mudcake or invaded zone resistivity. Digital data from this log was not obtained from Schlumberger, so no data were processed by LLNL.

Formation Micro-Scanner Log (Dip Micro)

This log is an enhanced dip meter that measures resistivity, natural gamma, hole direction, and two diameters that are displayed as differences. The blueline log trace/printout obtained from Schlumberger displayed eight individual resistivity traces. All of these data were useful in determining geologic structure in the hole, i.e., dips of bedding, fractures, and faults. Large volumes of data were collected. Special processing by the logger and geologic input from the geologist were required to maximize the value of the log. The results of this log were presented in Schlumberger (1992), which is archived at DRI and RSN.

Gamma Logs

Spectralog

This log measures the full spectrum of natural radiation in the drill hole. Data from the log were useful in determining lithology and stratigraphy. The data were recorded digitally as count spectra, and then reprocessed by Atlas in Houston for gain corrections. Typically, four windows of data from the total spectrum were utilized: gamma, K (potassium), U (uranium), and Th (thorium). Gamma data were the total count of the entire spectrum, converted to API units by LLNL using a conversion factor determined in support of the Weapons Program via testing the tool in a calibration facility. K, U, and Th data were converted from counts to the presented units (vol percent, ppm, and ppm, respectively) by Atlas from their standard oil field calibrations. The accuracy of these values were

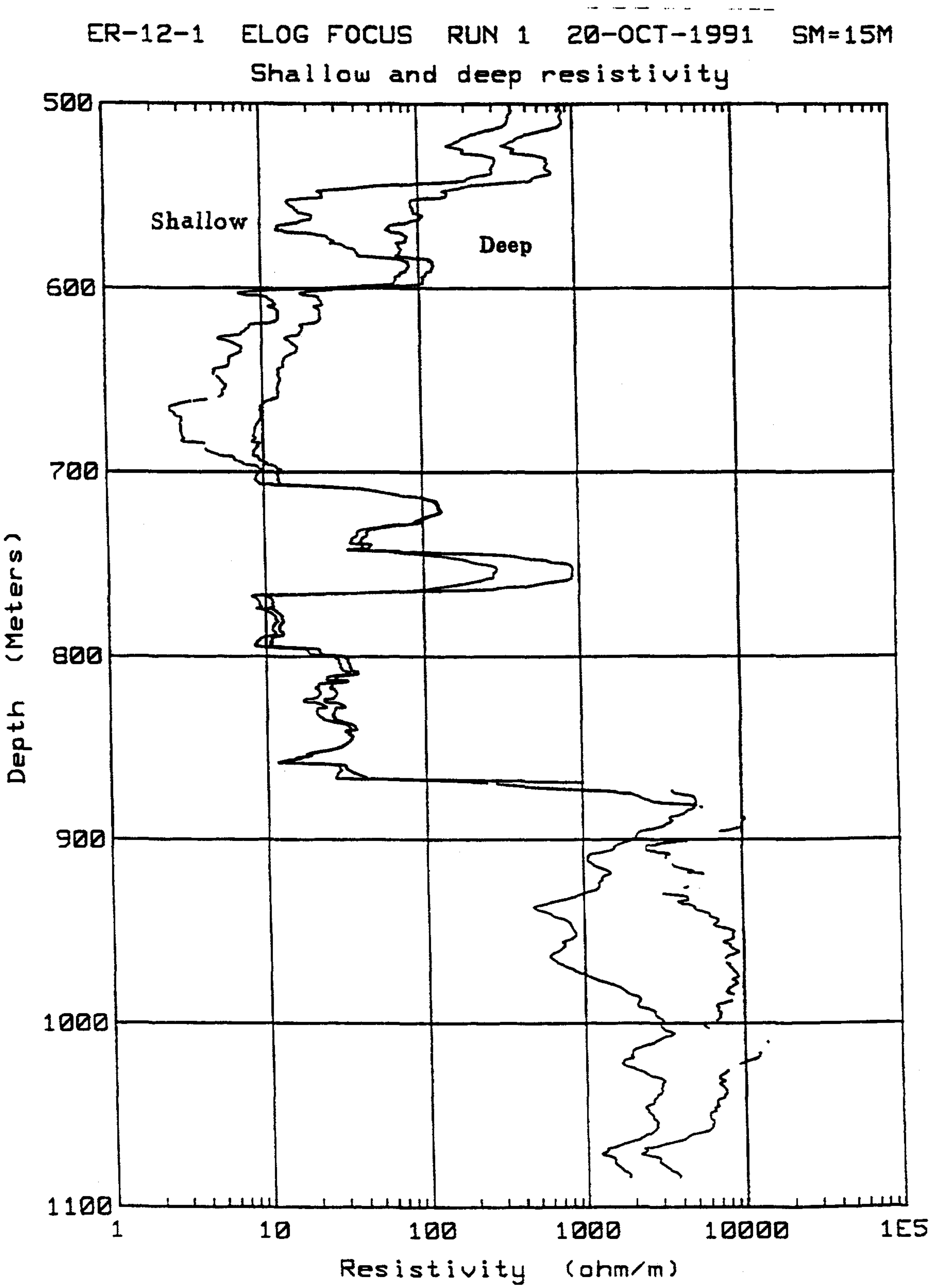


Figure 11. Shallow and deep resistivity, 500 to 1100 m (1640 to 3608 ft).

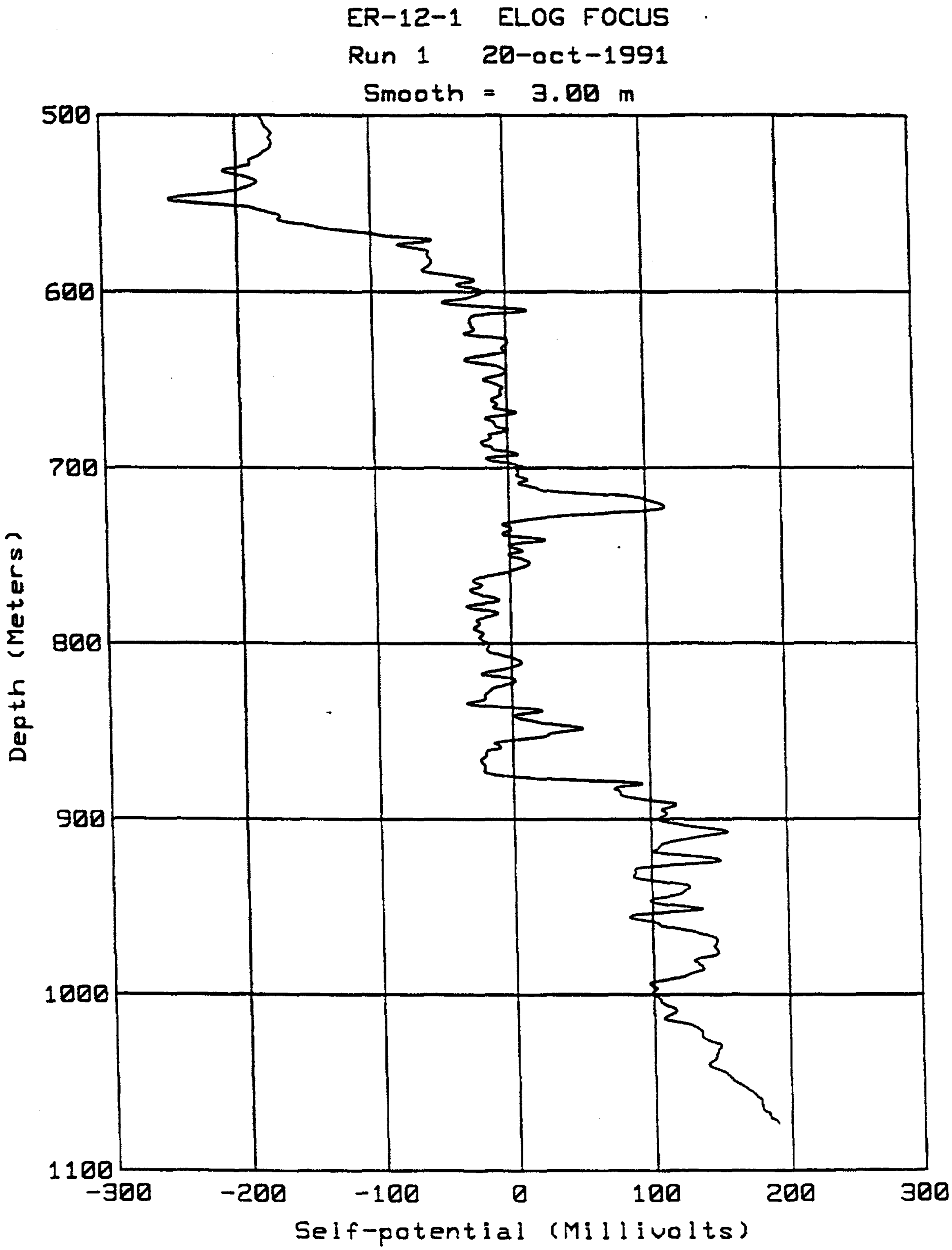


Figure 12. Self potential, 500 to 1100 m (1640 to 3608 ft).

unknown. Frequently, these traces, or combinations of these traces, are used to look for potential zones of swelling clays. RSN geologists did not find correlations between the log and geologic cuttings data. Stratigraphic and lithologic contacts were shown quite well by the gamma traces in Figures 5 and 6. Figures 13 and 14 display gamma, K, U, and Th traces for both spectral gamma runs.

This log does have some deficiencies. The crystal must be warmed before going downhole. Normally, this would occur during preparation for the run, and not impinge on actual logging time. However, if something goes wrong during the warm up procedure, several hours can be added to the waiting time as the crystal correctly comes up to temperature. To obtain statistically accurate, well defined data, the tool is pulled slowly up the hole, at a much slower rate than other logging tools (1 vs 10 m/minute or 3 vs 30 ft/minute). It took eight hours to gather data on Run 1, and nine hours for the second run. However, a significant amount of geologic information was obtained from this log, so it is a valuable tool to run.

Gamma

Five gamma logs were run in ER-12-1. This tool uses a much smaller crystal, and is pulled at a faster rate than the spectral gamma log discussed above. All five gamma logs were stacked with other logs; epithermal neutron run 1, caliper run 2, epithermal neutron run 2, compensated density run 2, and dual laterolog run 1. While the data from the epithermal neutron and compensated density logs cannot be utilized quantitatively because of the interfering radiation sources, the data from all runs can be utilized qualitatively. This provided useful depth and lithology correlation. LLNL relied on the spectral gamma log for natural gamma information from ER-12-1.

Total Intensity Magnetometer Logs

A proton precession magnetometer was run by the LLNL NTS Geotechnical Engineering Group in both the dry and wet portions of the drill hole. Tool response depends on magnetic properties of the rock, e.g., susceptibility, and in the case of volcanic rocks, remnant magnetism frozen in the rock at the time of deposition or cooling. There were some concerns that data obtained from this log, run in the sedimentary rocks at ER-12-1, would not offer much information, since sedimentary rocks usually are not composed of significant amount of magnetic minerals. Thus, this log was run as a test case as part of both dry and wet logging suites.

Processing of the data from magnetometer logs is straightforward as no hole size or environmental (wet/dry) corrections are necessary. For ER-12-1, however, the dry hole was affected in the upper 70 m (about 200 ft) by the drill rig at the surface. The metal in the rig was enough to perturb the down hole signal. Under normal conditions these data would have been discarded. An algorithm was developed to remove the effect of the rig from the upper portion of the data, thus saving about 70 m of data. The same thing happened to data from Run 2 due to the presence of the 450-m-long intermediate casing. The algorithm used to correct data from Run 1 was modified slightly to fit the conditions of Run 2, and the casing signal was also removed. Figures 15 and 16 show the corrected and uncorrected magnetometer data. At depths where the runs overlap, data from Run 2 reads approximately 0.05 microTeslas lower than Run 1. This may be due to the use of different sondes in the different runs.

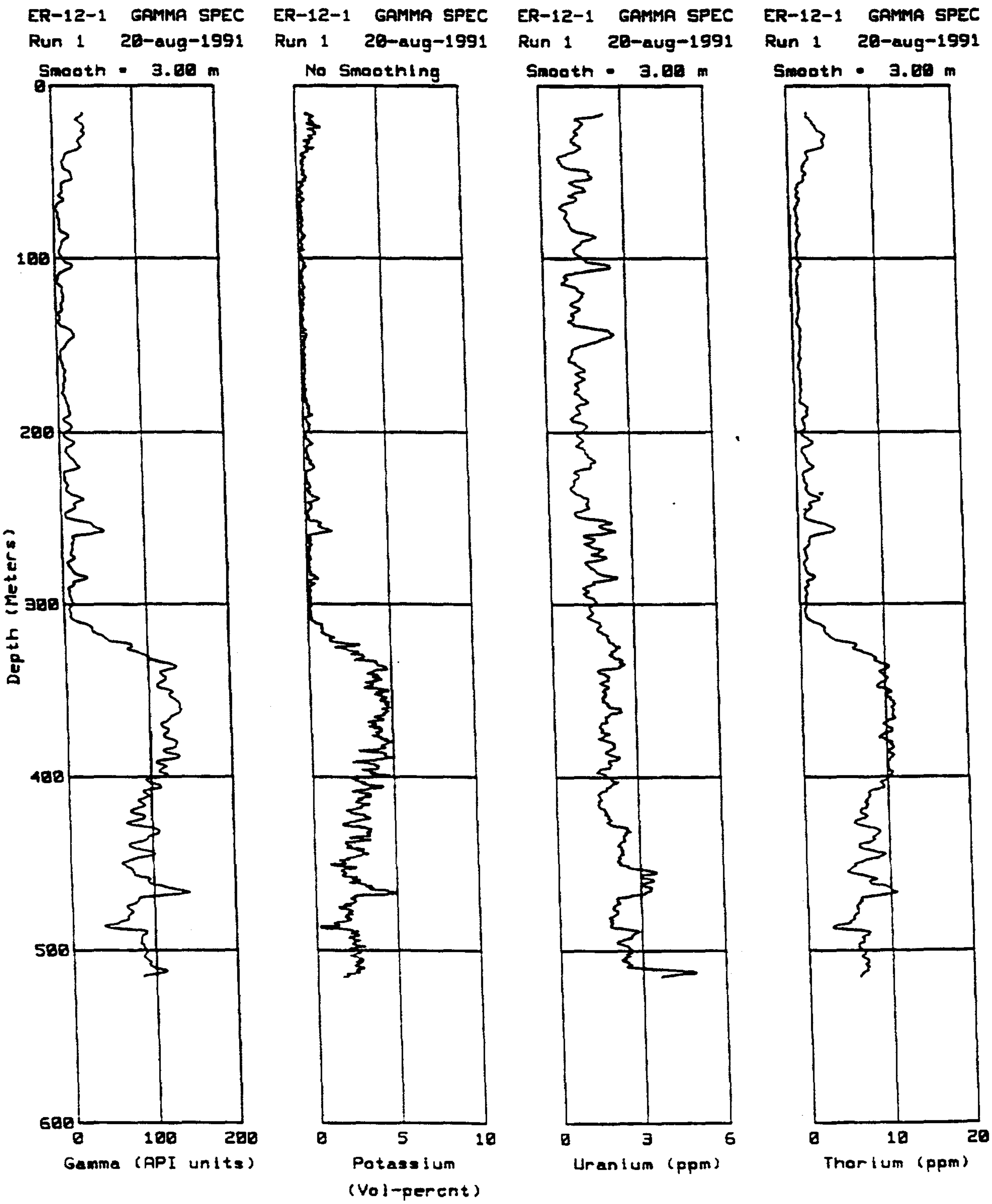


Figure 13. Spectral gamma logs, 0 to 600 m (0 to 1968 ft).

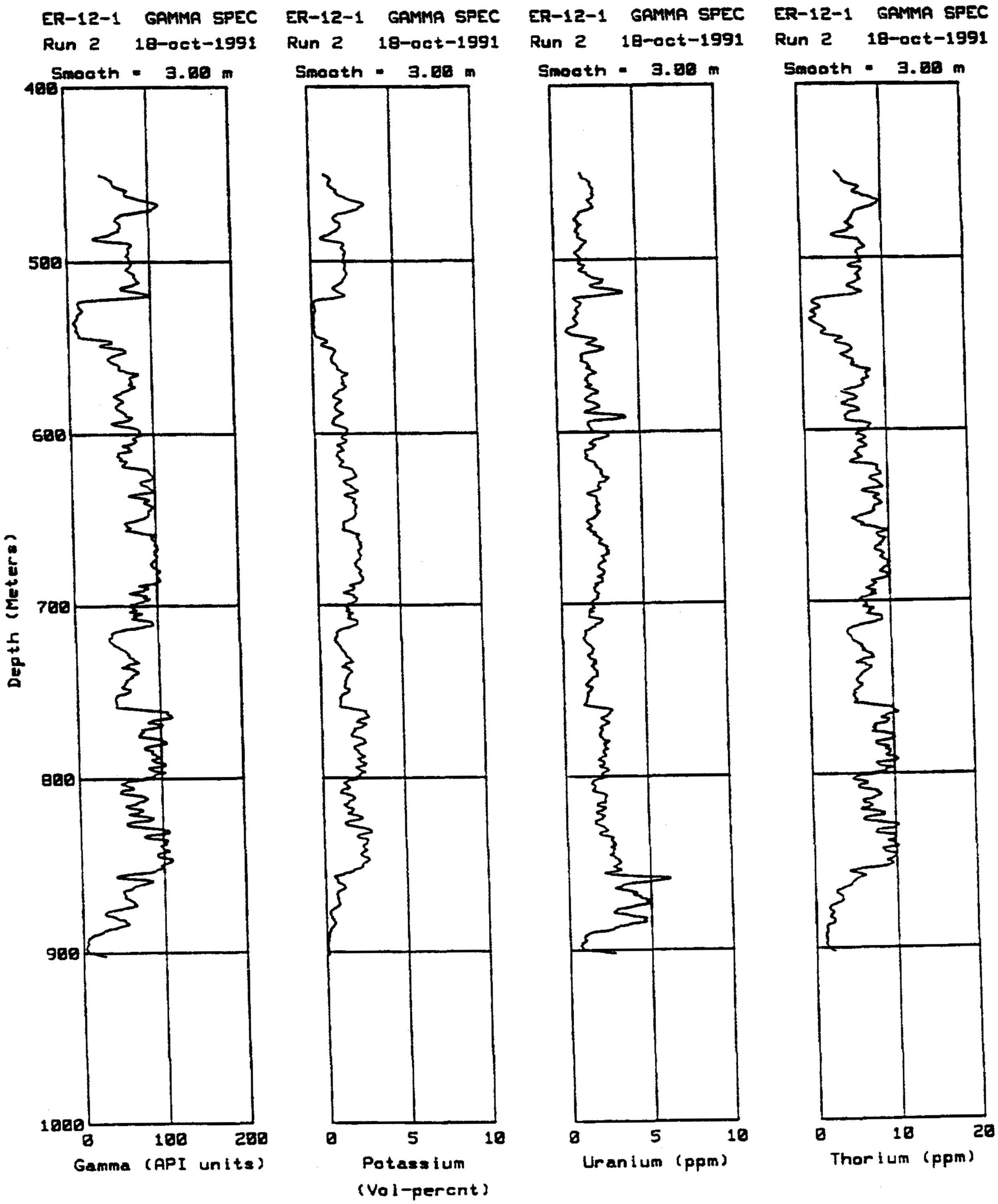


Figure 14. Spectral gamma logs, 400 to 1000 m (1312 to 3280 ft).

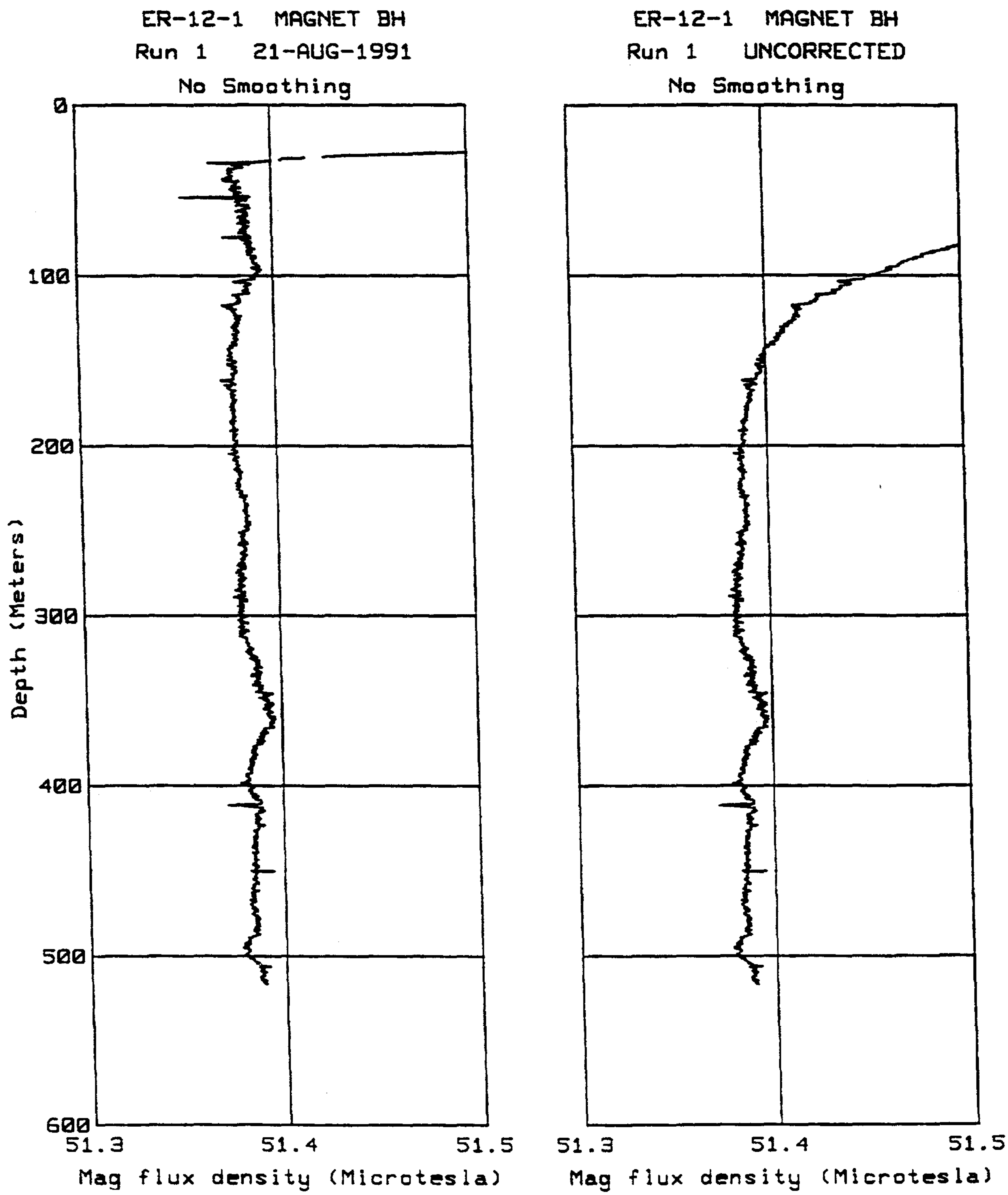


Figure 15. Borehole magnetometer logs, 0 to 600 m (0 to 1968 ft).

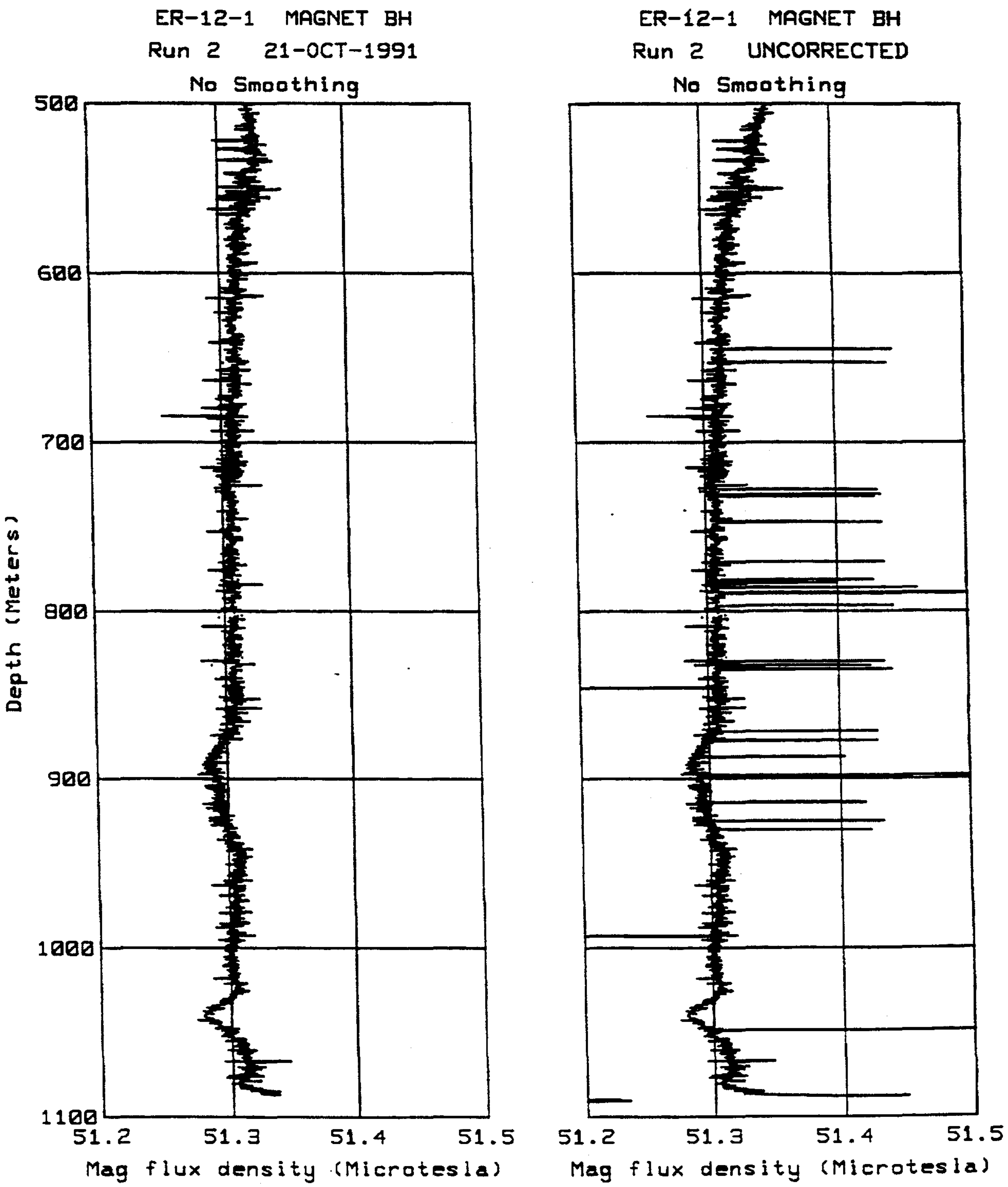


Figure 16. Borehole magnetometer logs, 500 to 1100 m (1640 to 3608 ft).

The magnetic signature from the sedimentary rocks in ER-12-1 were quite subtle. When plotted on a typical scale range for NTS volcanic rock sequences, the data from Run 1 appeared as a straight line. Very little variance in the absolute values were visible. Data from Run 2 were slightly noisier. Some of the noise was due to presence of metal scraps left in the hole during the drilling process.

The accuracy of these data were on the order of 0.05 microTeslas. This level of accuracy was acceptable as these logs are typically used in a qualitative manner to recognize "signatures" of various layers. Studies have not been conducted, as far as is known, to develop characteristic signatures from magnetic logs run in sedimentary rock.

In general, it was difficult to distinguish stratigraphic contacts in hole ER–12–1 based on this log (Figures 5 and 6). A review of the data resulted in the conclusion that the magnetometer log was not an accurate indicator of the stratigraphic or lithologic units at ER–12–1. Useful information will not be gained in future boreholes, drilled into sedimentary rocks, from the total intensity magnetometer log, unless they contain more magnetic material, e.g., magnetite.

Sonic and Seismic Logs

Two sonic logs were run in ER-12-1; a continuous velocity log (commonly called a CVL or ABC) and a full signature sonic log (FRAC log) were run in the wet portion of the hole, while a seismic air-gun survey (SGG) was run on approximately 15 m (50 ft) intervals throughout the drill hole.

During recording of the main run of the CVL, the Atlas logging engineer determined he could improve the triggering stability by manually tracking the signal arrivals. This was done from about 899 m (2950 ft) to the SWL. Since the improvement was substantial, a repeat run was made with manual tracking from total depth to 899 m (2950 ft). This repeat run was combined with the upper part of the main run for data processing and archival. Processing consisted of reading the AC trace in microseconds/foot, reciprocating the data, and changing the units to m/sec. Data accuracy, as indicated by Atlas Wireline references, should be within 6 microseconds/m (2 microseconds/ft) for data with good signal amplitudes. The most obvious feature in the data was the difference between the high velocity Sevy Dolomite and the rest of the hole.

The FRAC log was run with the same sonde as the CVL, however, the entire signal from the two receivers were recorded over a selected time interval at each depth. LLNL instructed Atlas to record data at 4 μs intervals, collecting 1,920 samples per signal at each receiver. This resulted in adequate sampling density, preventing aliasing, and allowed for accurate arrival time picks. The 1.22 m (4 ft) and 1.83 m (6 ft) spaced receivers were recorded. Various playback options were used. To obtain arrival times of p, s, and fluid waves, and to document fractures intersecting the borehole, LLNL chose a scale of 300 to 1800 microseconds for the 1.83 m (6 ft), and 200 to 1200 microseconds for the 1.22 m (4 ft) receivers. An additional display of 0 to 7000 microseconds was chosen for the 1.22 m (4 ft) receiver to document fractures farther from the borehole.

The first arrivals from the seismic air-gun survey appeared to be fairly good, and were modified only slightly to process the data to obtain travel time and velocity data. The accuracy of these data was 0.1 ms.

Velocity data from the CVL and air-gun survey are presented in Figures 8 and 9 with bulk density and water content data. Travel time data from the air-gun survey are presented in Figure 17.

Presentation of Data From Specific Intervals

Screened Intervals

The completion plan specified five screened and gravel-packed intervals within the carbon steel completion string for testing and sampling of the drill hole. These intervals were initially located at the following depths: 518.16 to 554.74 m (1700 to 1820 ft), 585.22 to 597.08 m (1920 to 1960 ft), 765.05 to 789.43 m (2510 to 2590 ft), 914.40 to 963.17 m (3000 to 3160 ft), and 1024.13 to 1048.51 m (3360 to 3400 ft). Figures 18-22 present plots of selected log and stratigraphic data for these intervals.

Cored Intervals

Four conventional cores were cut from ER-12-1, with differing amounts of success. Core 1 was attempted through the depths of 539.19 to 543.76 m (1769 to 1784 ft), and recovered 0.06 m (0.2 ft) of core (1.3%). Core 2 was attempted through the depths of 548.03 to 556.26 m (1798 to 1825 ft), and there was no recovery. Core 3 was attempted through the depths of 751.03 to 757.73 m (2464 to 2486 ft), and recovered 3.0 m (10 ft) of core (45.5%). Core 4 was attempted through the depths of 895.20 to 903.12 m (2937 to 2963 ft), and recovered 7.77 m (25.5 ft) of core (98%). Figures 23-25 present plots of selected logs and stratigraphic data for these intervals.

The scales of Figures 18-25, have been expanded in an attempt to better display the character of the data. Some data at the extreme range may have been clipped on these plots. Referring to Figures 5 and 6, which show the entire data ranges, should provide clarifications.

Lessons Learned

Two things were learned during the conduct of logging and processing the data from ER–12–1: better ways of collecting the data, and better ways to process the data.

Data collection in the field was slower than normal as service tables were not in place for the stacked-tool runs. By the second logging run, several new service tables were developed, however, the tables included a gamma log, which in reality did not speed up the logging process. This deficiency could be corrected by determining which stacked-tool configurations would be necessary to run in future drill holes, and then develop the necessary service tables (if not currently available from the oil and gas industry). The development of standard operating procedures would facilitate the use of these logs in future boreholes.

(text continues on page 101)

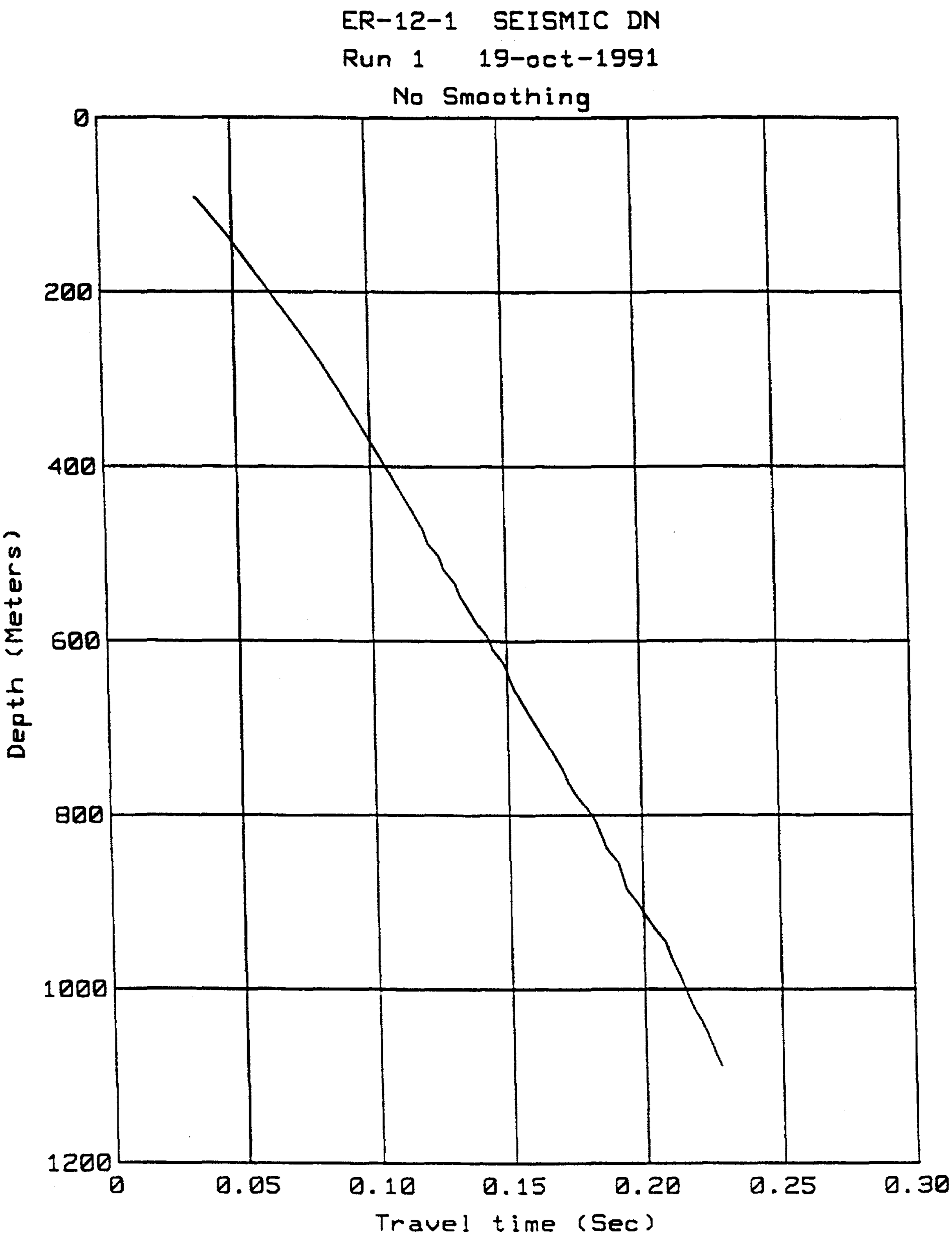


Figure 17. Travel time for the seismic air-gun survey.

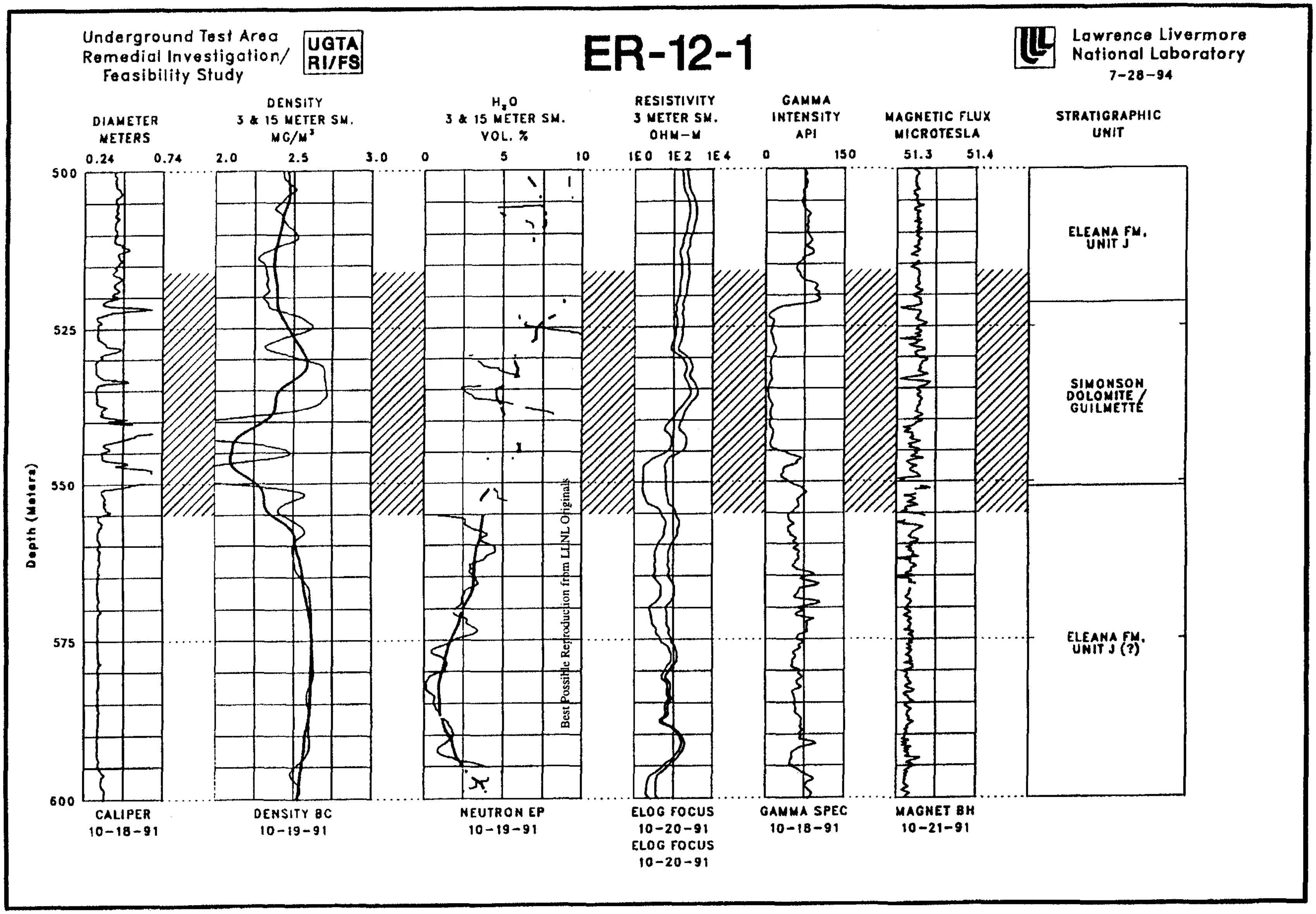


Figure 18. Selected logs for the screened interval of 518 to 554 m (1700 to 1820 ft).

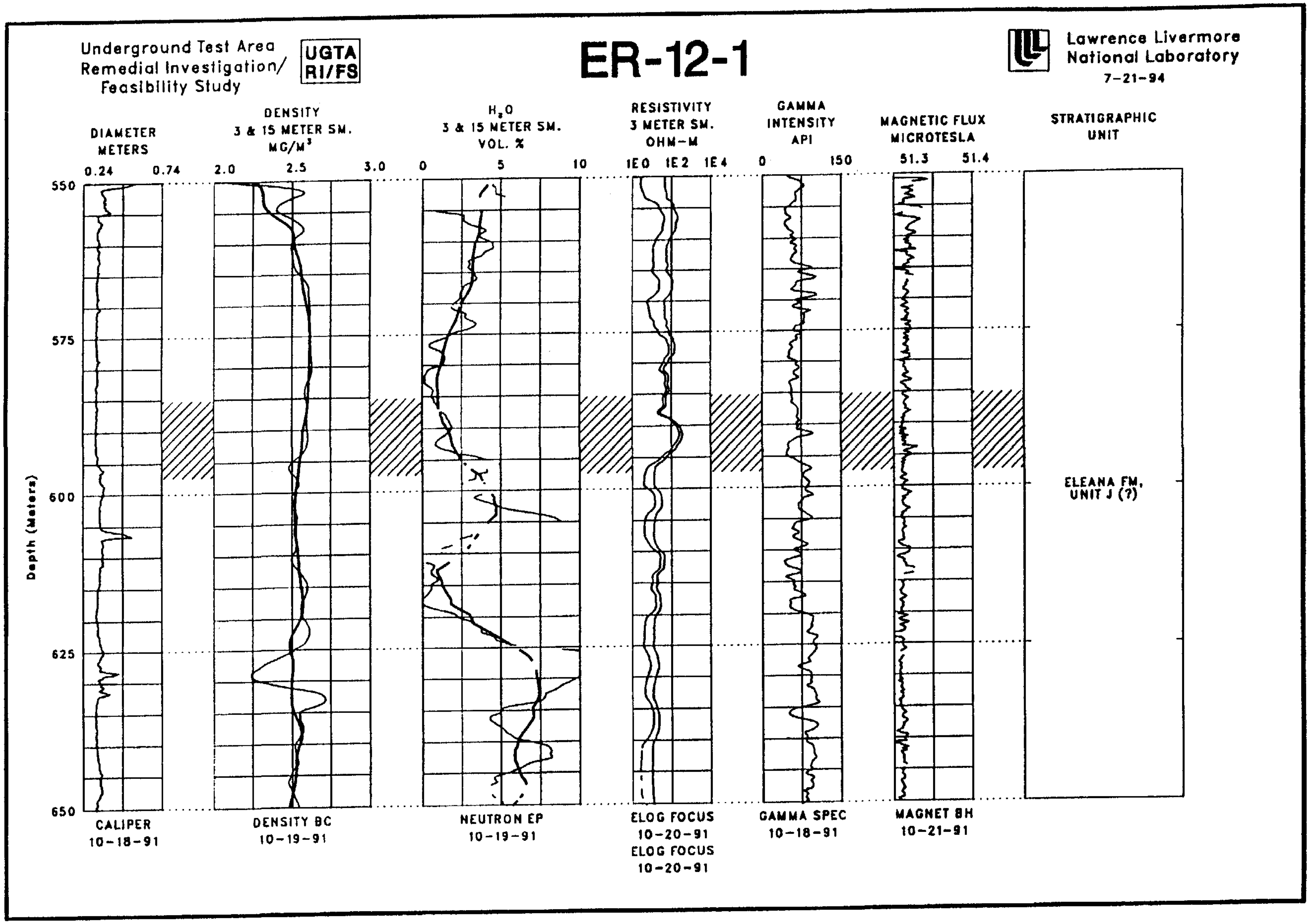


Figure 19. Selected lgos for the screened interval of 585 to 597 m (1920 to 1960 ft).

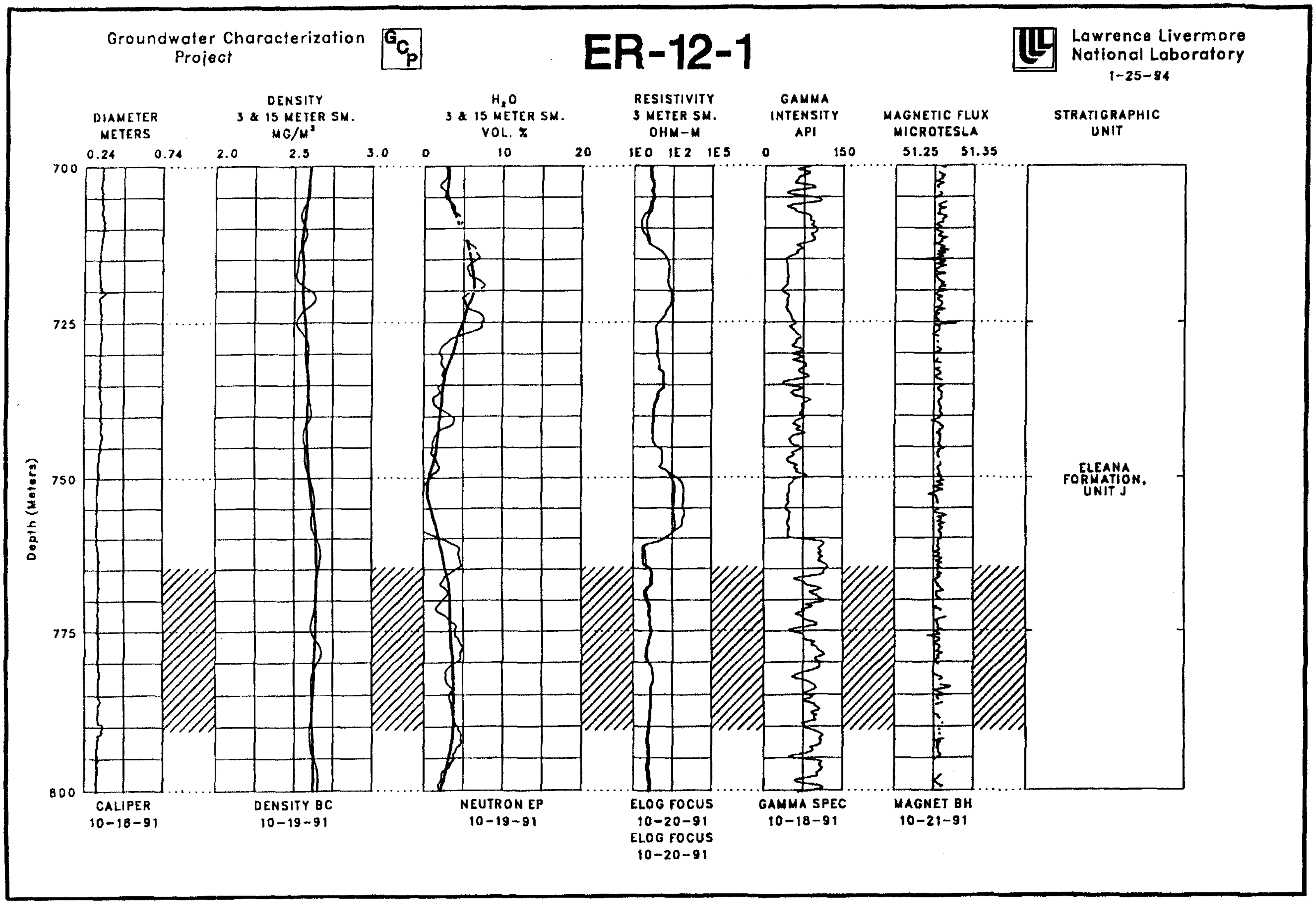


Figure 20. Selected logs for the screened interval of 765 to 789 m (2510 to 2590 ft).

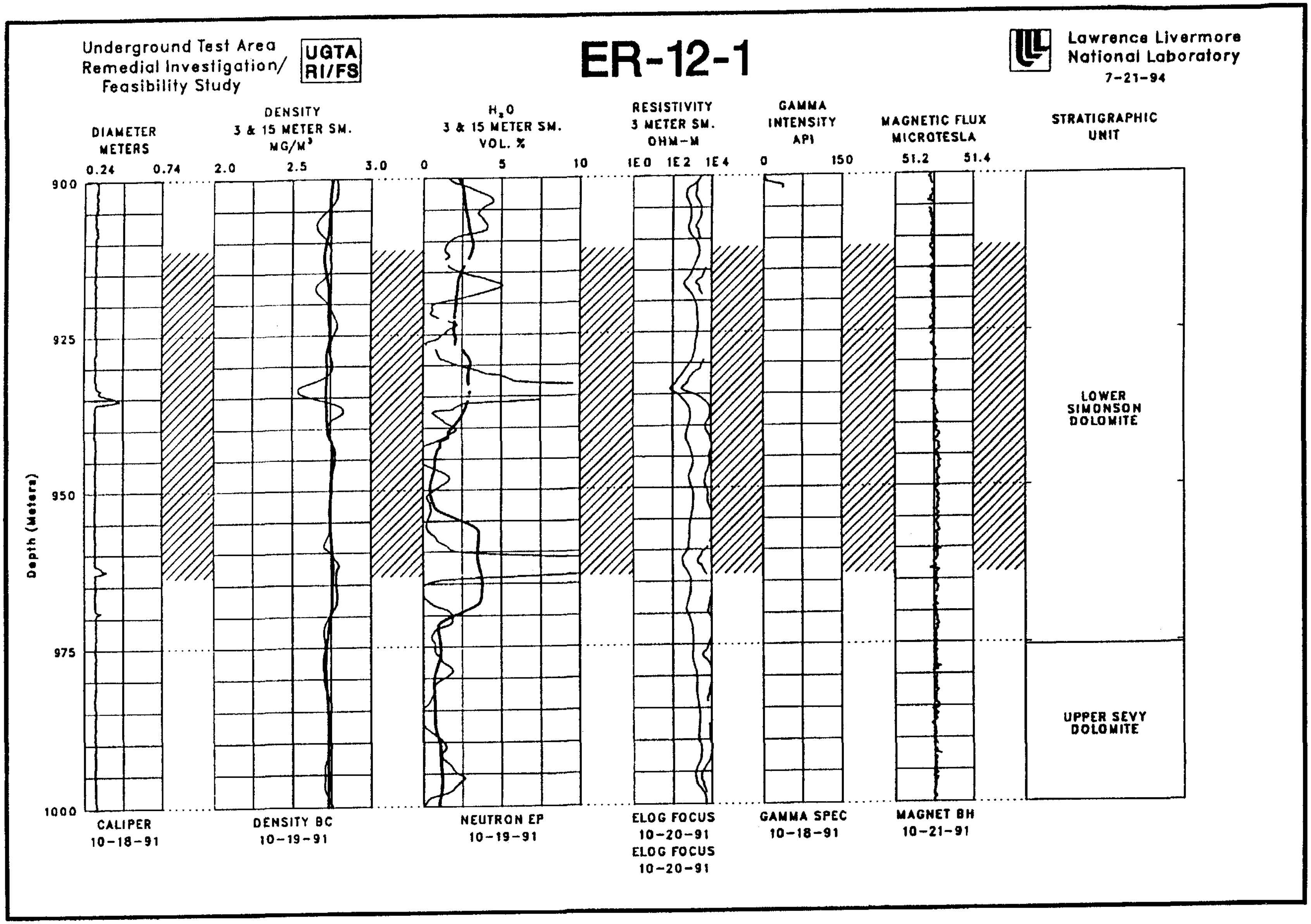


Figure 21. Selected logs for the screened interval of 914 to 963 m (3000 to 3160 ft).

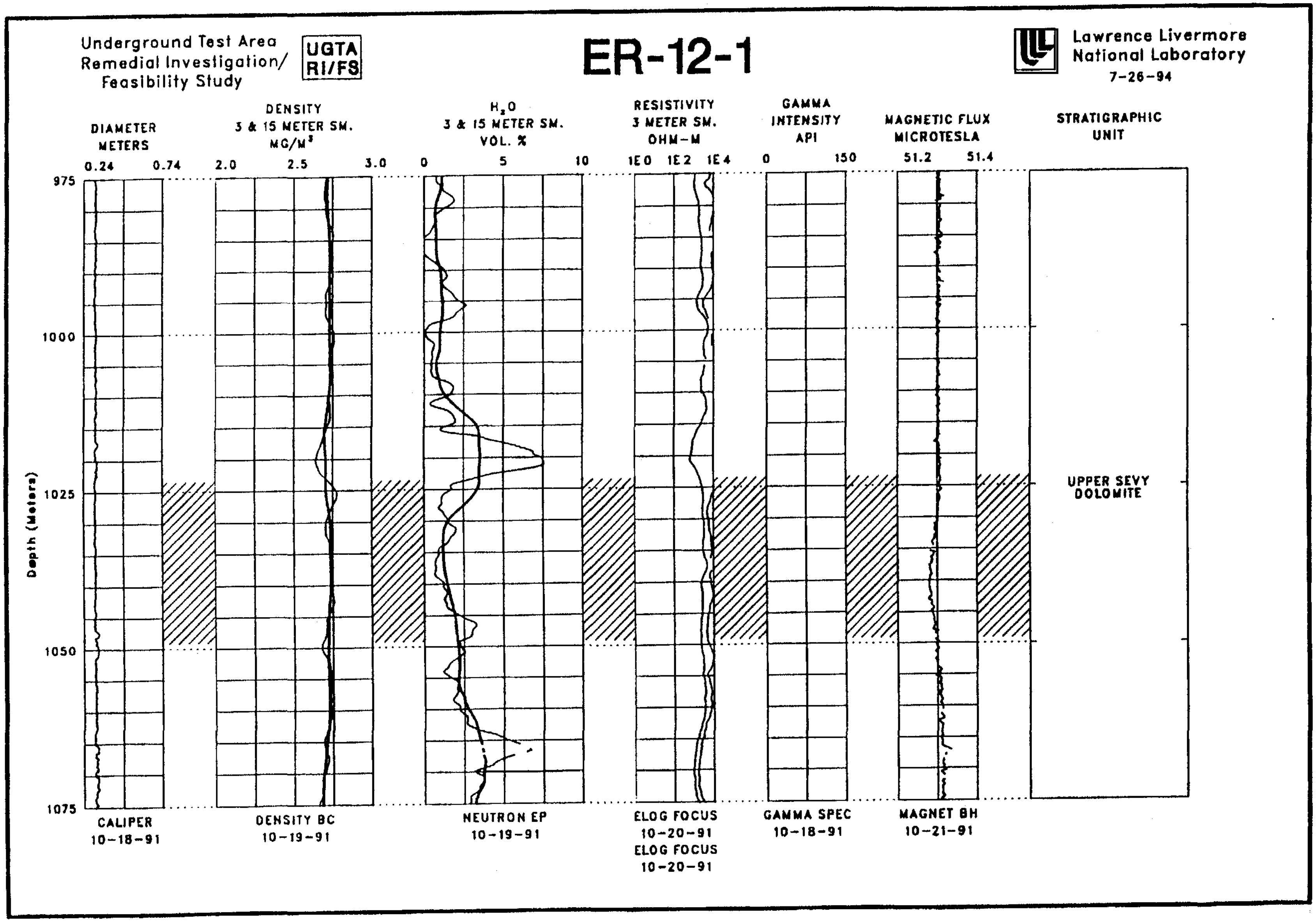


Figure 22. Selected logs for the screened interval of 1024 to 1048 m (3360 to 3440 ft).

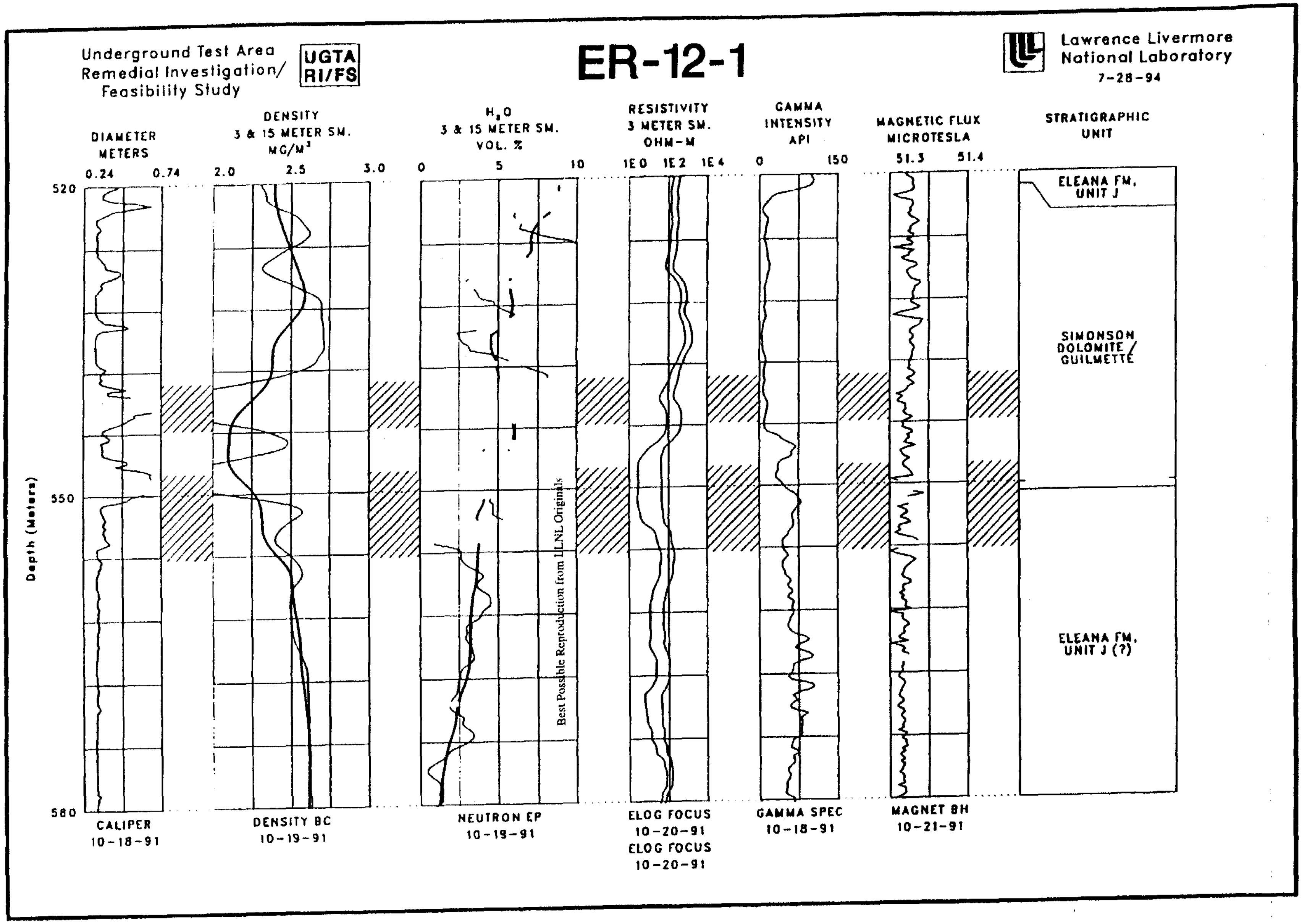


Figure 23. Selected logs for the cored interval of 539 to 543 m (1769 to 1784 ft) and 548 to 556 m (1798 to 1825 ft).

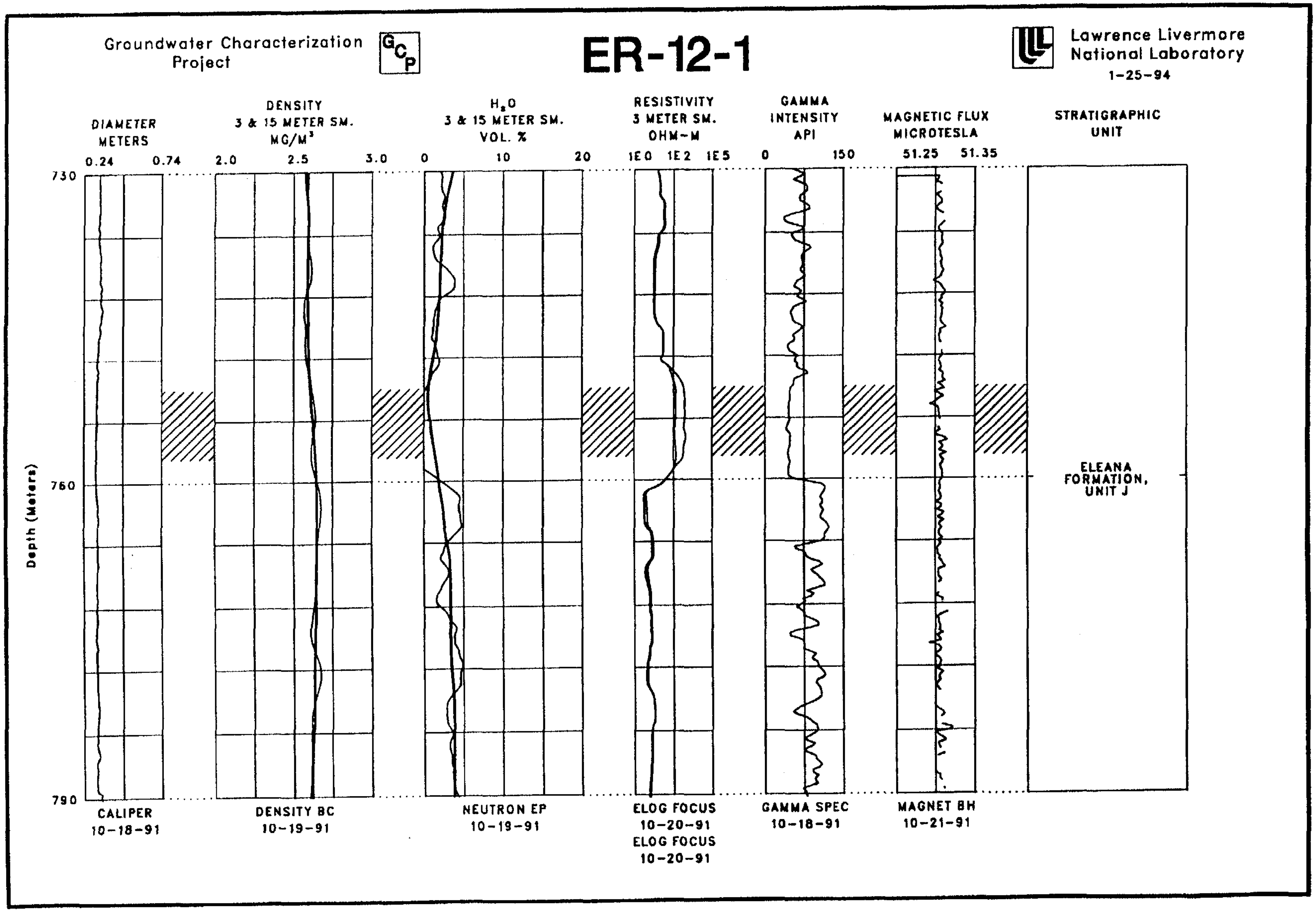


Figure 24. Selected logs for the cored interval of 751 to 757 m (2464 to 2486 ft).

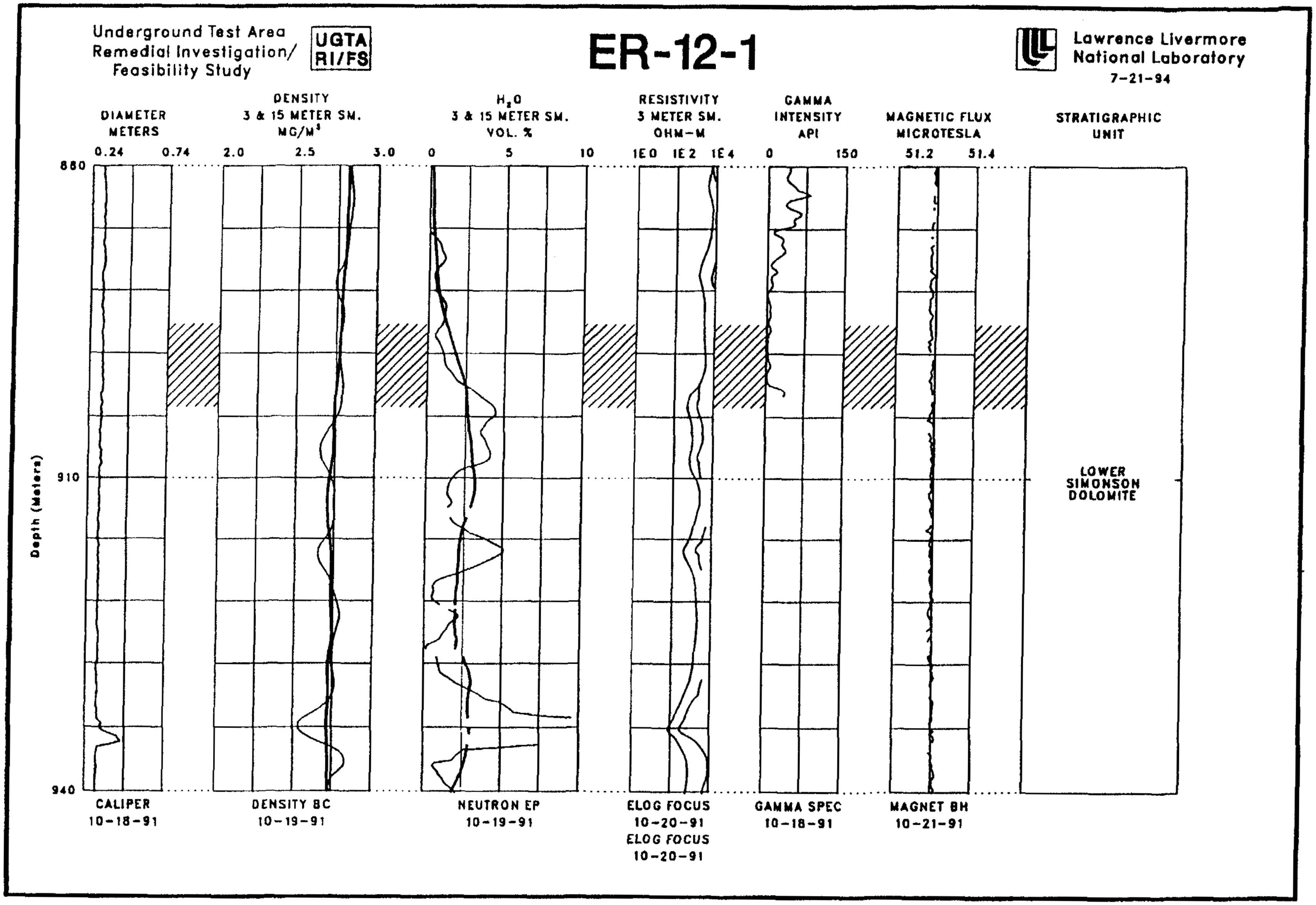


Figure 25. Selected logs for the cored interval of 895 to 903 m (2937 to 2963 ft).

Hydrologic Testing

Water-Level Monitoring

Static water levels at ER-12-1 were measured during drilling, development, aquifer testing, and completion (Table 33). Fluids were initially detected while drilling at a depth of 511.9 m (1679 ft) on August 19, 1991. Subsequent measurements indicated the static water level was approximately 470 m (1540 ft). This measurement represents a composite water level for all of the formations contributing water to the borehole.

Fluid levels were also determined for each of the five screened intervals during drill-stem tests conducted September 25 through October 2, 1992 (Table 34). Fluid levels measured during drill-stem test show similar hydraulic heads for the upper three screened intervals and for the lower two screened intervals. A vertical potentiometric gradient of approximately 3.3 m/m exists through the Eleana Formation and Simonson Dolomite between the depths of 790 m (2592 ft) and 915 m (3000 ft).

Flow Logs

Two flow logs were run in ER-12-1. These logs were originally intended to be run while the borehole was uncased. Borehole instability prevented this until the hole had been cased and screened in five zones. The purpose of the logs was to identify zones within the borehole contributing

Table 33. Depth to Fluid Level and Total Depth Measurements for ER-12-1. (Modified from Drellack et al., 1991)

Date	Depth to Fluid Level	Total Depth	Remarks
08-19-91	"Possible water"	511.8 m (1679 ft)	Drilling
08-19-91	Positive indication	520.9 m (1709 ft)	Drilling
08-20-91	469.4 m (1540 ft)	520.9 m (1709 ft)	USGS Iron Horse
09-04-91	472.1 m (1549 ft)	557 m (1827 ft)	DRI bailer
10-18-91	470.9 m (1545 ft)	1094 m (3588 ft)	AWS DF #4
10-19-91	470.3 m (1543 ft)	1094 m (3588 ft)	AWS WNP #2
10-22-91	470.9 m (1545 ft)	1094 m (3588 ft)	Schlumberger Micro log
10-26-91	471.2 m (1546 ft)	1094 m (3588 ft)	CA6 #2
11-05-91	468.8 m (1538 ft)	627.7 m (1059 ft)	Static hole, hole bridged
11-12-91	470.9 m (1545 ft)	549.2 m (1802 ft)	CA6 #5, hole bridged
04-16-92	469.8 m (1541 ft)	1094 m (3588 ft)	Preparing for thermal flow log
09-19-92	471.3 m (1546 ft)	1044 m (3588 ft)	Developing hole
10-19-92	468.3 m (1536 ft)	1044 m (3588 ft)	Preparing to install sliding sleeves

Table 34. Static Pressures and Heads of Screened Intervals in Well ER-12-1.

Screened Interval Meters (ft)	Static Pressure (psi)	Static Pressure m (ft)	Height of Pressure Gauge Above Measuring Point m (ft)	Depth of Pressure Gauge Below Land Surface m (ft)	Static Fluid Level Above Mean Sea Level m (ft)
518-555 (1692-1820)	131.1	92.1 (302.0)	13.2 (43.4)	531 (1743)	1331±7 (4367±23)
585-597 (1920-1960)	118.3	83.1 (272.6)	47.4 (155.5)	531 (1743)	1322±7 (4337±23)
765-790 (2508-2592)	387.1	271.9 (891.9)	47.4 (155.5)	706 (2316)	1336±7 (4383±23)
915-963 (3000-3160)	37.7	26.5 (86.9)	47.4 (155.5)	871 (2957)	926±7 (3038±23)
1024-1049 (3360-3440)	45.1	31.7 (103.9)	76.8 (251.9)	871 (2857)	931±7 (3055±23)

Notes

±10 psi
1 psi = 2.304 ft of water
Static fluid level = 1540 ft below land surface
Well-head elevation is 5819 ft

groundwater, and quantify the amount, from each zone. The flow logs were also used to delineate ambient circulation patterns within the borehole during equilibrium conditions. The first log, Schlumberger's Oxygen Activation Flow Log, was run on April 6, 1992. This log relies upon a small neutron accelerator (minitron) to activate oxygen within the water molecule to ^{16}N, an unstable isotope of nitrogen that has a half-life of 7.10 seconds. Radioactive decay of the nitrogen isotope is monitored by gamma counters spaced along the length of the tool. The intensity of gamma radiation measured at any given counter is a function of water velocity. The results of the oxygen activation flow log are given in Table 35 and graphically presented in Figure 26. The results from the furthest detector (GR detector), agreed closely with the metered discharge at land surface. The GR detector results indicate all production from this borehole (at 163 l/min or 43 gpm) emanates from the bottom 20 m (64 ft) of the 518 to 555 m (1700 to 1820 ft) screened interval. Minor fluctuations in production below this zone may indicate loss of water to under–pressurized zones, however, variance in production with depth remained within the margin of error of the technique (0.46 m/min or 1.5 ft/min).

The thermal flow log was run on April 24, 1992. This log typically is run in conjunction with a temperature and electrical conductivity log, however, on this run it was not. A thermal flow log operates by emitting a thermal pulse via a grid of heated wires in the center of the tool. The transit time of the thermal pulse up or down the borehole is monitored via fixed thermistors. The transit time is used to calculate a groundwater velocity. The thermal flow log is typically run with a packer to ensure all groundwater passes through the center of the tool. This was not the case at ER-12-1 as

Table 35. Log Depth and Water Velocity from the Oxygen Activation Log.

Minitron Depth	Date - Time	Gamma Ray	Velocity m/min (ft/min) for each Detector Far Detector	Near Detector
504.7 (1655.4)	4/6/92 - 15:16	0.0 (0.0)	0.9 (3.1)	NQ (NQ)
511.6 (1678)	4/6/92 - 15:18	0.0 (0.0)	2.3 (7.7)	0.0 (0.0)
514.6 (1688)	4/6/92 - 20:35	0.0 (0.0)	NQ (NQ)	NQ (NQ)
535.4 (1756)	4/6/92	0.0 (0.0)	2.5 (8.2)	2.6 (8.9)
545.1 (1788)	4/6/92 - 20:54	6.6 (21.7)	5.2 (17.0)	NQ (NQ)
582.3 (1910)	4/6/92	10.8 (35.3)	7.7 (25.4)	NQ (NQ)
591.5 (1940.0)	4/6/92	10.5 (34.5)	7.7 (25.4)	NQ (NQ)
759 (2490)	4/6/92 - 21:14	9.6 (31.6)	7.4 (24.3)	NQ (NQ)
762 (2500.0)	4/6/92	9.2 (30.1)	6.6 (21.8)	NQ (NQ)
777 (2550.0)	4/6/92	9.8 (32.1)	7.0 (23.1)	NQ (NQ)
780.5 (2560)	4/6/92 - 21:34	9.4 (30.8)	7.0 (23.1)	NQ (NQ)
908.5 (2980.0)	4/6/92	9.7 (31.7)	7.8 (25.8)	NQ (NQ)
929.9 (3050.0)	4/6/92	9.8 (32.0)	7.8 (23.6)	NQ (NQ)
948.2 (3110.0)	4/6/92 - 19:15	9.8 (32.3)	8.1 (26.6)	NQ (NQ)
1001.8 (3286)	4/6/92 - 19:40	9.9 (32.6)	7.8 (25.7)	NQ (NQ)

Notes
Effective radius = 0.1894 ft^2
Pump depth = 3333.35 ft
NQ is not quantifiable

the vendor (Desert Research Institute) did not have appropriately sized packers for the 0.29 m (7-3/8 in) diameter borehole. Flow velocities determined by this tool should be qualitative estimates only. The results of the thermal flow log are presented in Table 36 and in Figure 27. The results indicate inflow was occurring at the bottom 12.2 m (40 ft) of the top screen (518 to 555 m; 1700 to 1820 ft) and from the third screen (765 to 790 m; 2510 to 2590 ft) and outflow was occurring through a 6 m (20 ft) section of the fourth screen between the depths of 933 and 939 m (3060 and 3080 ft).

The results of the oxygen activation flow log and the thermal flow log indicate the screened interval between 518 - 555 m (1700 and 1820 ft) has the highest production within the borehole. The thermal flow log indicates that the screened intervals between 585 to 597 m (1920 to 1960 ft) and 765 to 790 m (2510 to 2590 ft) appear to have a similar pressure head as the upper screened zone, while the oxygen activation log indicates these screened intervals have relatively low production

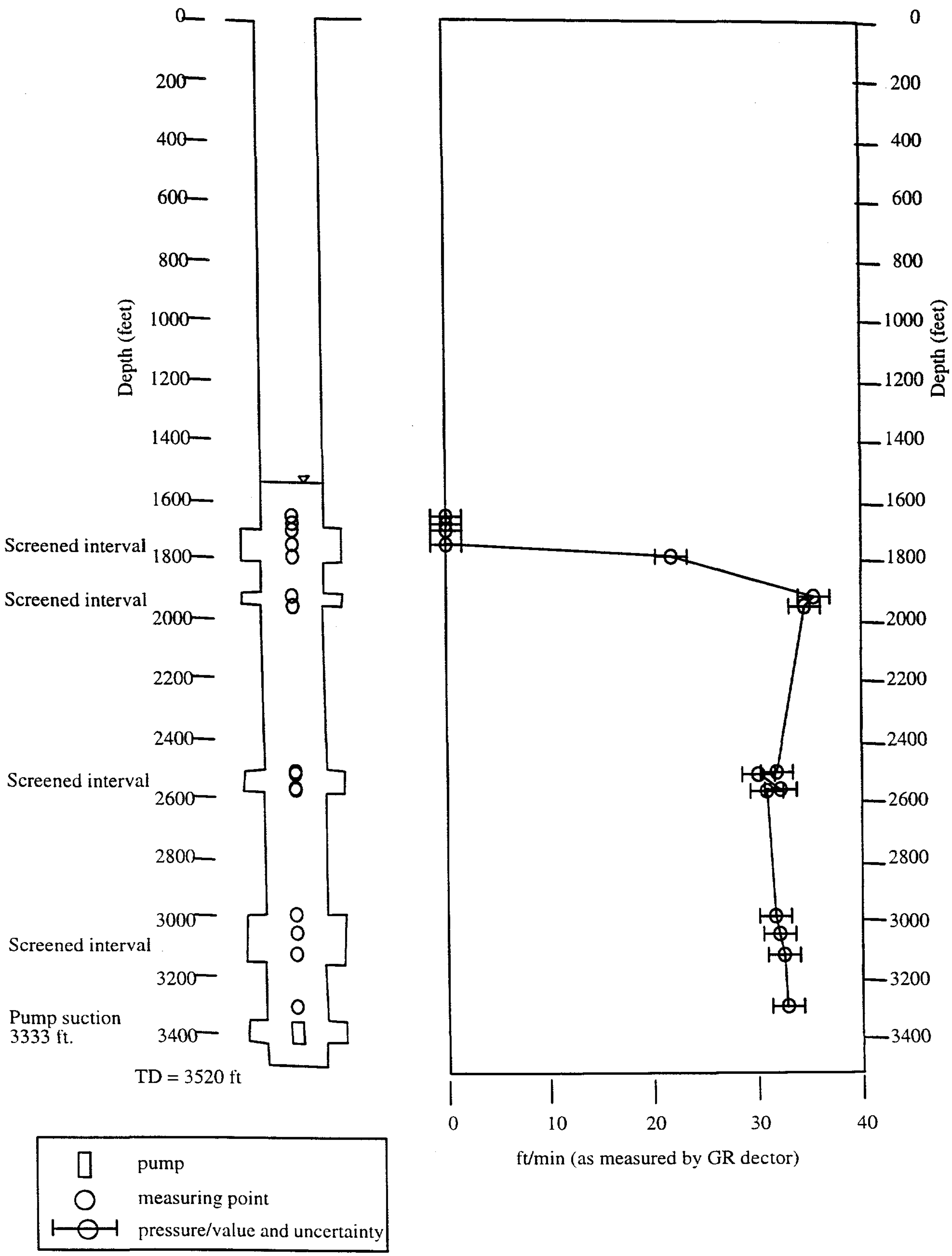


Figure 26. Results of the oxygen activation flow log.

Table 36. Ambient Flow Versus Depth, as Determined by Thermal Flow Log.

Depth m (ft)	Flow l/min (gpm)
473 (1552)	<0.37 (<0.1)
516 (1691)	<0.37 (<0.1)
533 (1750)	<0.37 (<0.1)
541 (1775)	<0.37 (<0.1)
555 (1822)	-3.0 (-0.8)
582 (1910)	-2.27 (-0.6)
600 (1970)	-2.6 (-0.7)
793 (2600)	-4.2 (-1.1)
927 (3170)	-4.2 (<0.1)
933 (3080)	-4.2 (<0.1)
939 (3040)	<0.37 (-1.1)
966 (3060)	<0.37 (-1.1)

Negative values indicate downward flow

rate. The thermal flow log also indicates markedly less formation pressure for the lower two screened intervals relative to the upper three intervals.

<u>Multiple Rate Test</u>

A multiple rate aquifer test was conducted at ER-12-1 on April 4, 1992. The borehole had been drilled, cased, gravel packed and screened at the following depths; 518 to 554 m (1700 to 1820 ft), 585 to 597 m (1920 to 1960 ft), 765 to 790 m (2510 to 2590 ft), 914 to 963 m (3000 to 3160 ft), and 1024 to 1049 m (3360 to 3440 ft). The borehole had been drilled using Davis Mix, bentonite mud, and polymers. Well development was attempted using sodium tetraphosphate and sodium acid pyrophosphate to remove bentonite and break down polymers. A total of 643,000 l (170,000 gal) of water were removed from ER-12-1 during well development, prior to the multiple rate test. Water was removed by air-lifting, swabbing, and pumping; details of well development are presented in Table 10.

Several attempts were made to conduct the multiple rate and step-drawdown aquifer tests on all the intervals in ER-12-1 during March 1992. The first multiple rate aquifer test was conducted using a REDA 205-hp submersible pump, at a depth of 615 m (2020 ft; suction) on 7.3 cm (2–7/8 in) O.D. 8 round tubing with 6.0 cm (2-3/8 in) O.D. hydril tubing strapped to the side to act as an access tube for transducers. The pump size was estimated based on drawdown and production rates during swabbing, as estimated by REECo drillers. The REDA pump was connected to a Varitech Varidrive, which is used to alter the frequency of the power being sent to the pump, controlling the pumping rate. Various pumping rates, ranging from 681 to 113 l/min (180 to 30 gpm), were tried during well

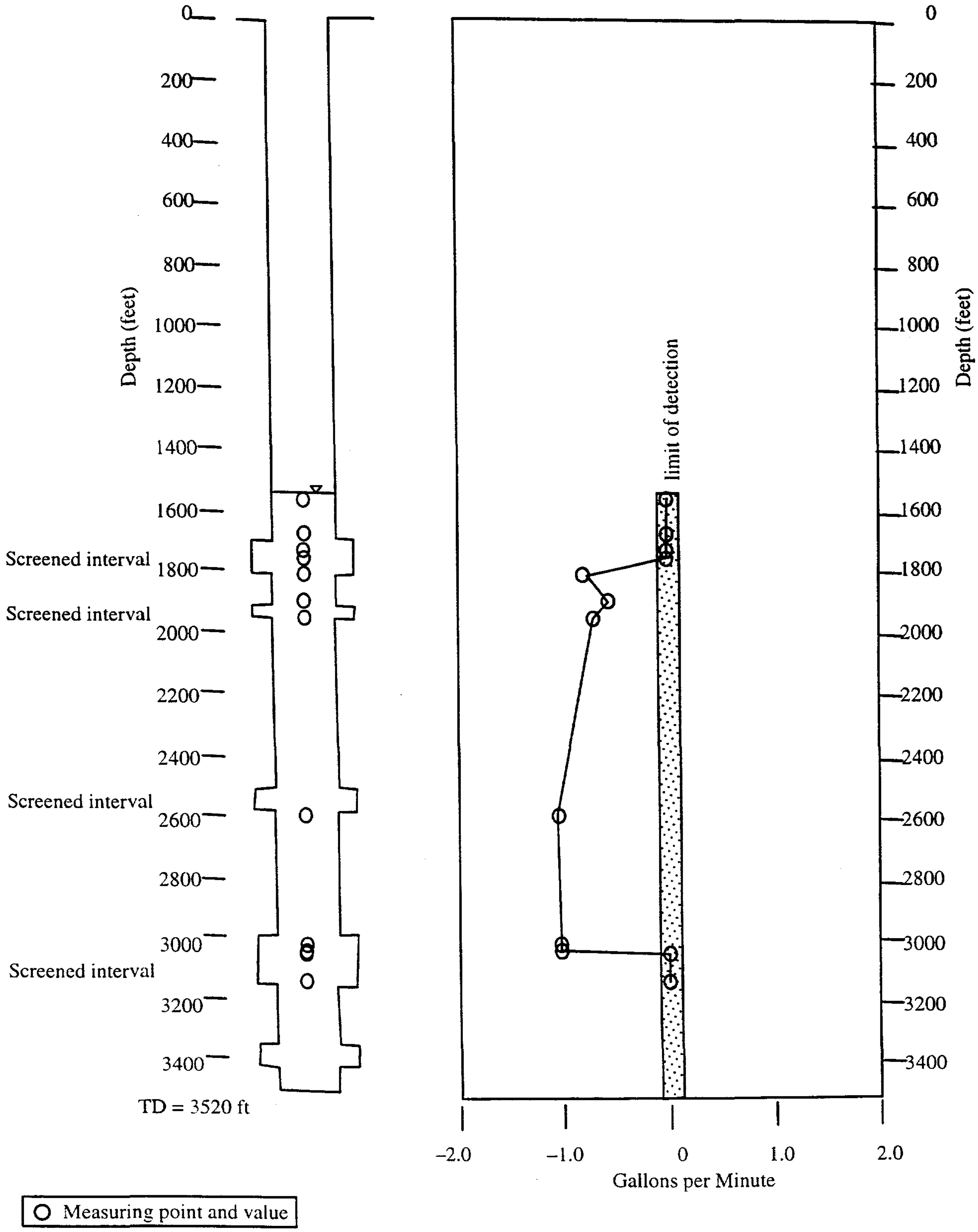


Figure 27. Results of the thermal flow log.

development, testing the electrical system, and initial attempts to start the multiple rate aquifer test. These pumping rates were determined to exceed the production capacity of the well. Development was discontinued on March 6, 1992, until a smaller pump could be installed. A REDA 75-hp pump was installed at a depth of 764 m (2505 ft; suction) on March 12, 1992. The pump was run on 7.3 cm (2-7/8 in) O.D. 8 round tubing with 6.0 cm (2-3/8 in) O.D. hydril tubing attached to the side as a monitoring line. Development continued at approximately 100 l/min (27 gpm) until March 16, 1992, when a 500 psi geokon transducer and wireline were installed in the monitoring tube to a depth of 653 m (2144 ft).

Several problems were encountered with various electronic systems during the operation of the REDA 75-hp pump. The scintillation counter used for tritium monitoring and the geokon transducer were severely affected by signal noise. Tritium analyses and downhole pressure readings were impossible to obtain during operation of the pump, even though the two systems were on entirely separate power supplies. The first multiple rate aquifer test was conducted on March 16, 1992. Transducer signal noise problems caused the test to be aborted. The following two weeks were spent trouble-shooting the cause of the electrical problems. The varidrive was identified as a potential reason for noise in the signal, with proximity of the power cable to the transducer wireline and harmonics within the power supply creating sympathetic voltage fluctuations in the wireline. It was also thought that the wireline may have had a short in it. Atlas Wireline Service was called in and field equipment was modified to use their wireline to conduct the aquifer tests. Resultant pressure data appeared stable, however, temperature data appeared to continue to fluctuate. Examination of the pump power cable, following the multiple rate and long-term aquifer test on April 12, 1992, revealed that it had been sliced open, most likely during installation, and the power cables exposed. The exposed cable was the likeliest reason for signal noise problems during the aquifer tests.

The multiple rate test was conducted to determine the optimal rate for the long-term aquifer test. The multiple rate test was conducted on April 4, 1992. Seven pumping rates, averaging 87, 121, 144, 166, 193, 220 and 242 l/min (23, 32, 38, 44, 51, 58, and 64 gpm) were used, with the duration of each step being 30 minutes long. The test was aborted at 1400 hrs on April 4, 1992, due to excessive drawdown. Recovery was monitored from 1400 hrs until 1730 hrs, at which time the long-term aquifer test was initiated. Logistical constraints prevented a longer recovery period. The downhole pressure data obtained during the multiple rate and long term aquifer tests are given in Figure 28. Total drawdown during the multiple rate test was 78.8 m (258.6 ft) Barometric efficiencies were not calculated due to noise in the downhole pressure signal large enough to mask perturbations due to barometric changes. Barometric pressures recorded during the multiple rate and step drawdown test are presented in Figure 29. Barometric changes during the test were 0.09 m (0.3 ft) or less.

Data collected during the multiple rate aquifer test included time (fractional Julian days), downhole and atmospheric pressure (psi and feet of head), rate of discharge (gpm) and downhole temperature (°C). Data were collected and stored in Campbell CR10 dataloggers and periodically backed up on the hard drive of a field computer. Data conversions in the field include converting

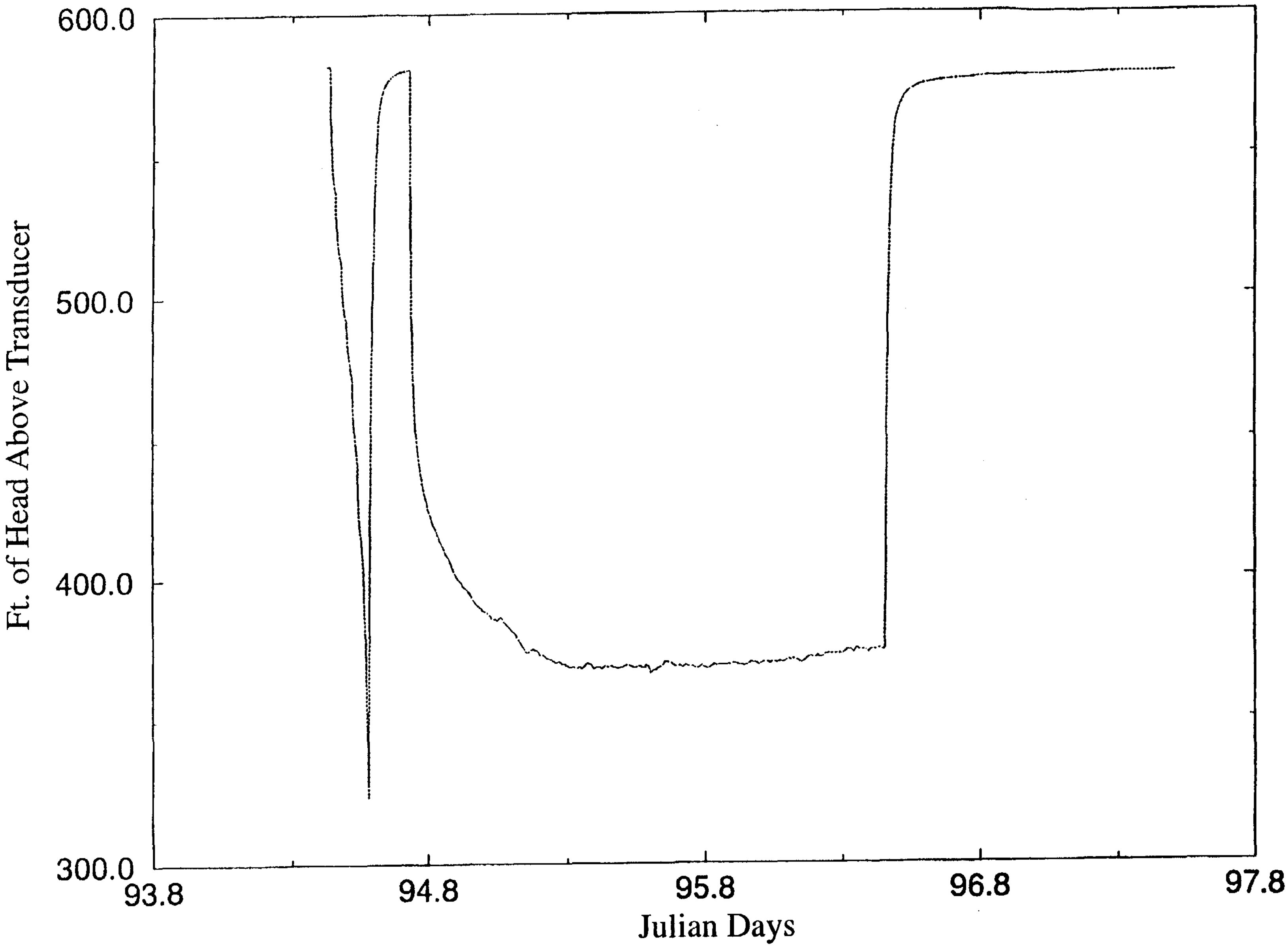


Figure 28. Downhole pressure response during multiple-rate and long-term aquifer test.

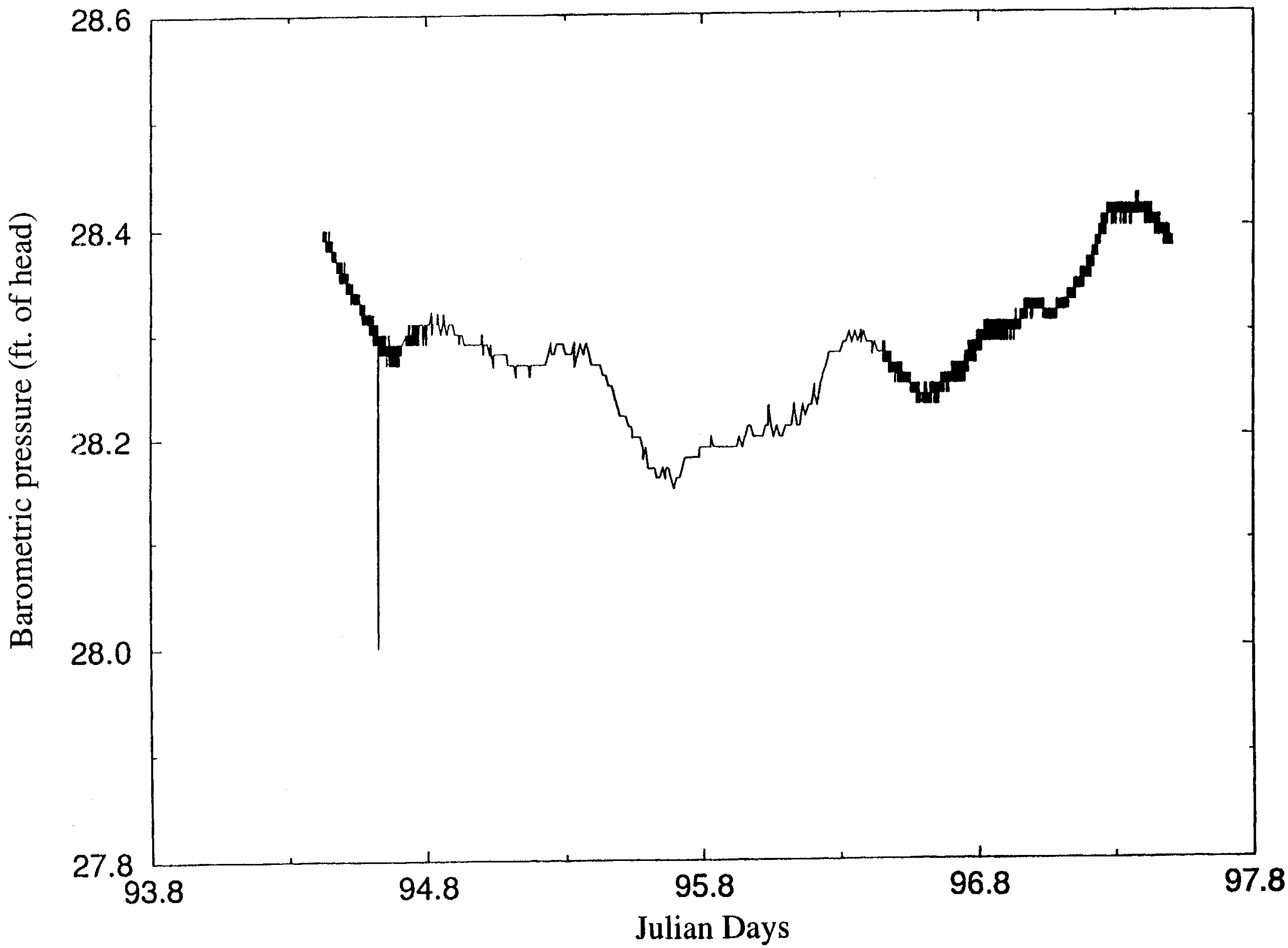


Figure 29. Barometric pressure changes during multiple-rate and the long-term aquifer test.

frequency data collected from vibrating wire transducers into temperature corrected psi (Equation 1) and feet of head (Equation 2) and mv data for temperature into °C (Equation 3).

$$P_{(PSI)}\left((M \cdot kH_2^{\,2}) + 0\right) \cdot T \cdot C \qquad (1)$$

where
$P_{(PSI)}$ = pressure in PSI - temperature corrected
M = multiplier supplied with transducer from factory
O = offset supplied with transducer from factory
kH_2 = frequency response of downhole vibrating wire transducer
T = downhole temperature in °C
C = factory supplied temperature calibration factor

$$P_{(ft)} = P_{(PSI)} \cdot 2.308 \qquad (2)$$

where
$P_{(ft)}$ = pressure in feet - temperature corrected

$$T = 43.089m_v^{\,5} - 240.91m_v^{\,4} + 544.27m_v^{\,3} - 611.59m_v^{\,2} + 378.11m_v - 104.78 \qquad (3)$$

where
T = temperature in °C
m_v = millivolt reading from downhole
polynomial is empirically derived and used for all thermistors

The multiple rate aquifer test suggested that a pumping rate of approximately 151 lpm (40 gpm) would be sustainable for long periods of time at ER-12-1.

Radially Converging Aquifer Test

Well ER-12-1 was allowed to equilibrate for a period of 3.5 hours following the end of the multiple rate aquifer test. The long-term radially converging aquifer test was initiated at 1730 hrs on April 4, 1992, at a rate of 155 l/min (41 gpm) and was continued until 1100 hrs. on April 5, 1992. Recovery was monitored until 1200 hrs on April 6, 1992.

The data collected during the aquifer test are presented in Figure 30. The data were analyzed using interpretive software entitled Well Hydraulics Interpretation Program (WHIP) version 3.22

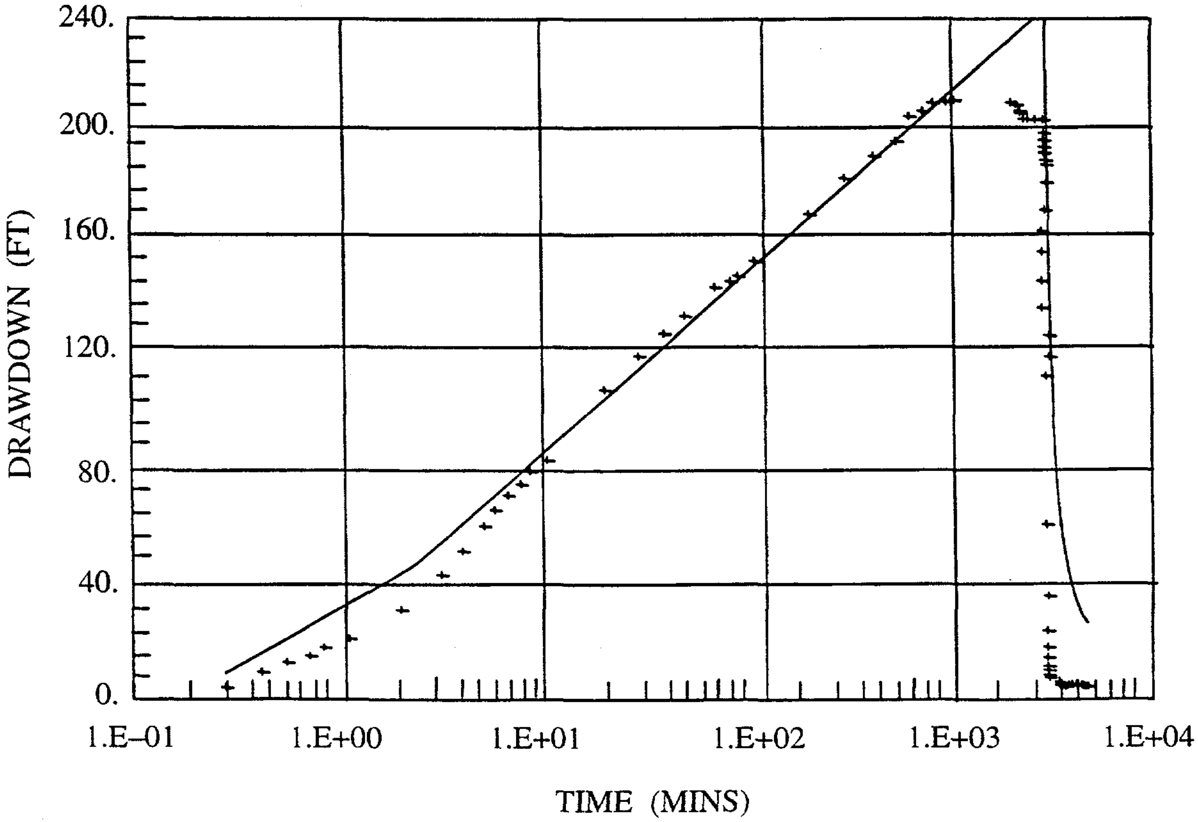


Figure 30. Cooper-Jacob analysis of drawdown data from long-term aquifer test at ER-12-1, April 4, 1992.

by Hydro GeoChem Inc., 1988. The initial analysis entailed plotting the drawdown and recovery data in terms of drawdown below initial fluid level versus the log of total elapsed time and plotting the best fitting straight line through the data according to Cooper and Jacob (1946) while accounting for deviations in early drawdown due to borehole storage. The best fitting line was determined by least squares best fit through the data points obtained during the period of 10 to 800 minutes following the start of the test. The data collected during this time period appeared to be characterized by a straight line with positive slope, indicating pseudo-steady-state radial flow (Kruseman and de Ridder, 1992). The transmissivity and storativity determined by this method were also used to calculate a type curve for the recovery data (Theis, 1935). A comparison of the measured drawdown and recovery to the theoretical drawdown indicates that the early drawdown data from the aquifer test was affected by well bore storage. The latter drawdown data as well as all of the recovery data were affected by either continuing well development or the presence of a zone within the well, with a lower head, that began to contribute additional groundwater only after head within the well declined to a certain point. The Cooper-Jacob (1946) analysis resulted in an estimated transmissivity of 2.4 x 10^{-5} m^2/s and a storativity of 0.15. Storativity estimates derived from drawdown data taken from the pumping well are subject to several types of errors including uncertainties in effective radius of the well. It is likely that this storativity estimate is in error by several orders of magnitude. Alternatively, Moench (1984) reported a storativity value of 0.15 derived from drawdown data taken from UE-25b#1, a well completed in fractured Tertiary volcanics. Moench (1984) attributed the large storativity value to the presence of highly compressible microfissures in the rock matrix. These conditions may exist at ER-12-1 (Table 28).

Theoretical drawdowns were generated using analytical solutions in the laplace transform space to the differential equations representing the response of groundwater flow systems to hydraulic stress tests (Hydro GeoChem, 1988). The solutions are of the general form

$$H(d,z,p) = Q(z) * I(d,z,p) \tag{4}$$

where:

H() = laplace transform of the drawdown
Q() = laplace transform of the pumping history
I() = laplace transform of the aquifer impulse response function
d = dimensionless distance from the center of the pumped well
p = hydraulic parameters of the system
z = laplace transform variable corresponding to dimensionless time.

The impulse response function is based upon Lai and Su (1974). The pumping rate function is based upon a solution developed by Gupta (1985). The drawdowns in the real domain are obtained by numerical laplace inversion using Stehfest (1970).

The analytical solutions were used to generate several theoretical drawdowns that matched the observed data set. Input variables were iteratively altered with the purpose of estimating key hydrologic parameters. The results are presented in Figure 31. Theoretical drawdowns that utilized a transmissivity of 2.4 x 10^{-5} m^2/s and a storativity of 0.11 appeared to create the best fit to the observed data. The theoretical effective radius is smaller than the effective radius (0.229) calculated from the casing minus the pump column, transducer column, and power cable. The discrepency may be due to fluid loss from the upper three zones to the lower three. The fluid loss would decrease effective borehole storage.

The transmissivity and storativity values estimated by this technique are very close to those determined by the Cooper and Jacob (1946) method. Poor fits to the early and late portions of the drawdown curve and the late portion of the recovery curve remained. The early variation of the drawdown curve from the analytical solution may have been due to variations in pumping. Variance

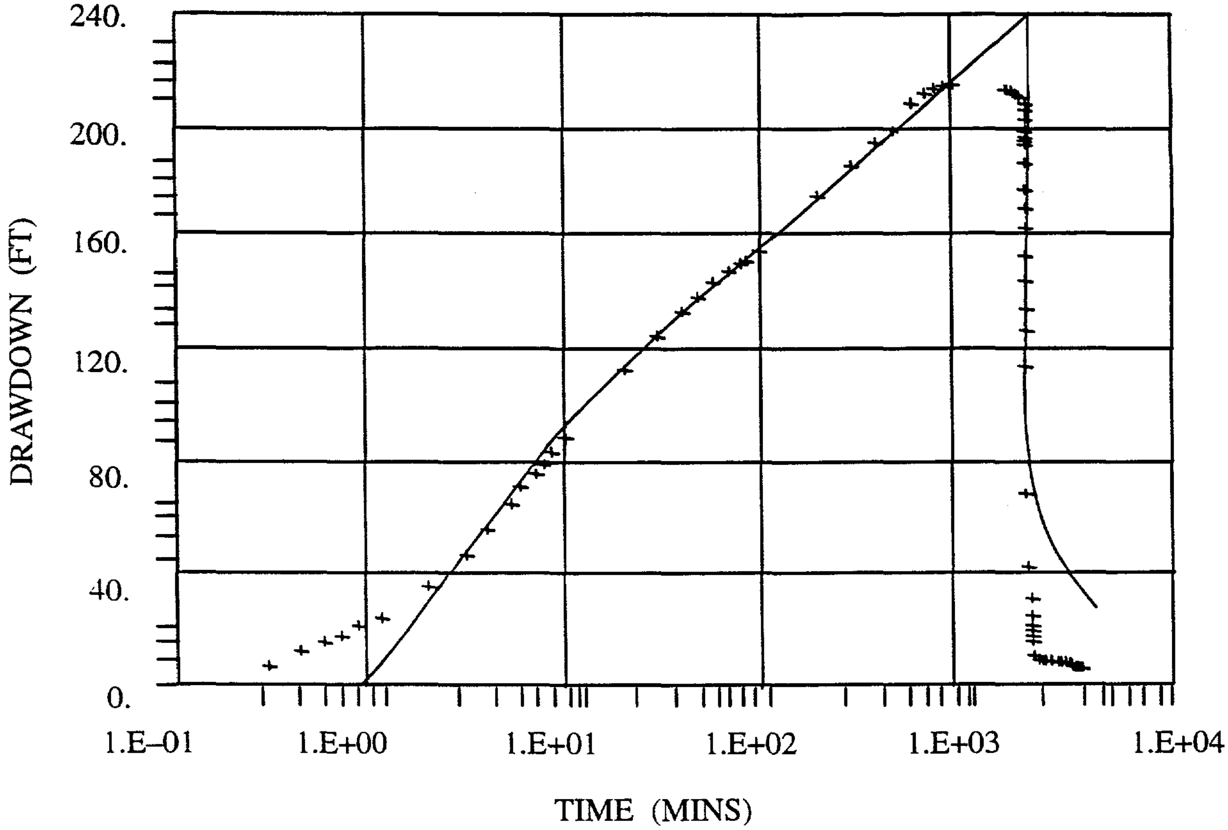


Figure 31. Hydrologic parameter estimation of ER–12–1 aquifer test, April 4, 1992.

from the analytical curve during the latter portion of drawdown may have been due to well development occurring during pumping or to the development of one of the lower zones that are under–pressured (see results of drill-stem tests). Development of one of the lower pressure zones would only occur when fluid pressures within the pumped borehole dropped below the static pressure in the under–pressured zones, stopping potential fluid loss into that zone and allowing fluid production to begin. This process would create a situation where the rate of fluid decline would slow or even possibly reverse. This process would affect recovery by causing a more rapid recovery than expected until pressure in the borehole exceeded that of the under–pressured formation, at which time the rate of recovery would be reduced. The data contained in Figures 30 and 31 appear to fit the proposed explanation, however, this does not rule out other possibilities.

Drill-Stem Tests

Drill-stem tests were conducted on three of the five screened intervals during the period of September 25 through October 2, 1992. These tests were conducted using a Schlumberger drill-stem test tool configured with thermistors and 0 to 15,000 psi pressure transducers above, below, and within the packer interval and an MSRT 104 pressure gauge with real time data collection on the surface and downhole.

The transducers have an accuracy of 10 psi and a repeatability of 0.1 psi. Three drill-stem tests were conducted: the first was conducted on the screened interval of 915 to 963 m (3000 to 3160 ft; lower Simonson Dolomite), the second from 765 to 790 m (2510 to 2590 ft; Upper Eleana Formation), and the third from 585 to 597 m (1920 to 1960 ft; Upper Eleana Formation). The pressure response for each of the three tests are presented in Figures 32 to 34. The first drill-stem test was an injection test where fluid was introduced into the borehole. The two other drill-stem tests were withdrawal tests where fluid was withdrawn from the borehole into an evacuated space within the drill-stem test tool and drill-pipe. Formation pressures were allowed to approach equilibrium prior to starting each drill-stem test. Ambient formation pressures of each of the three screened intervals are given in Table 34. These pressures indicate the two lowermost zones are under–pressured by approximately 396 m (1300 ft), relative to the three uppermost zones; a conclusion in complete agreement with the results of the thermal flow logs and the interpretation of the composite long-term radially converging aquifer test.

Pressures were monitored above and below the packed-off interval during the drill-stem tests. The purpose for collecting these data was to determine if the packers, well annulus, and geologic formations were allowing a detectable quantity of fluid to vertically migrate, from one screened interval to the other, during the test. Table 37 presents the maximum, minimum and duration of hydraulic stresses during the various drill-stem tests. At no time, during any of the drill-stem tests, was a pressure response observed above or below the packed-off interval. Small pressure changes were observed that temporally coincided with the raising or lowering of the drill-stem tool to initiate or end the test. The packers, annular seals, and geologic formations appear to have adequate seals and/or low enough permeability to retard detectable fluid flow at the pressures and test durations recorded in Table 37.

The pressure responses within the packed-off interval were analyzed using Cooper et al., (1967) and Papadopulous et al., (1973). The general form of the solution is :

$$\frac{H}{H_o} = F(\beta, \alpha) \qquad (5)$$

where

β = T_t/r_o^2

α = $r_s^2 S/r_o^2$

r_s = effective radius of the well

r_c = radius of the well casing in the interval over which the head change takes place

T = transmissivity of the well

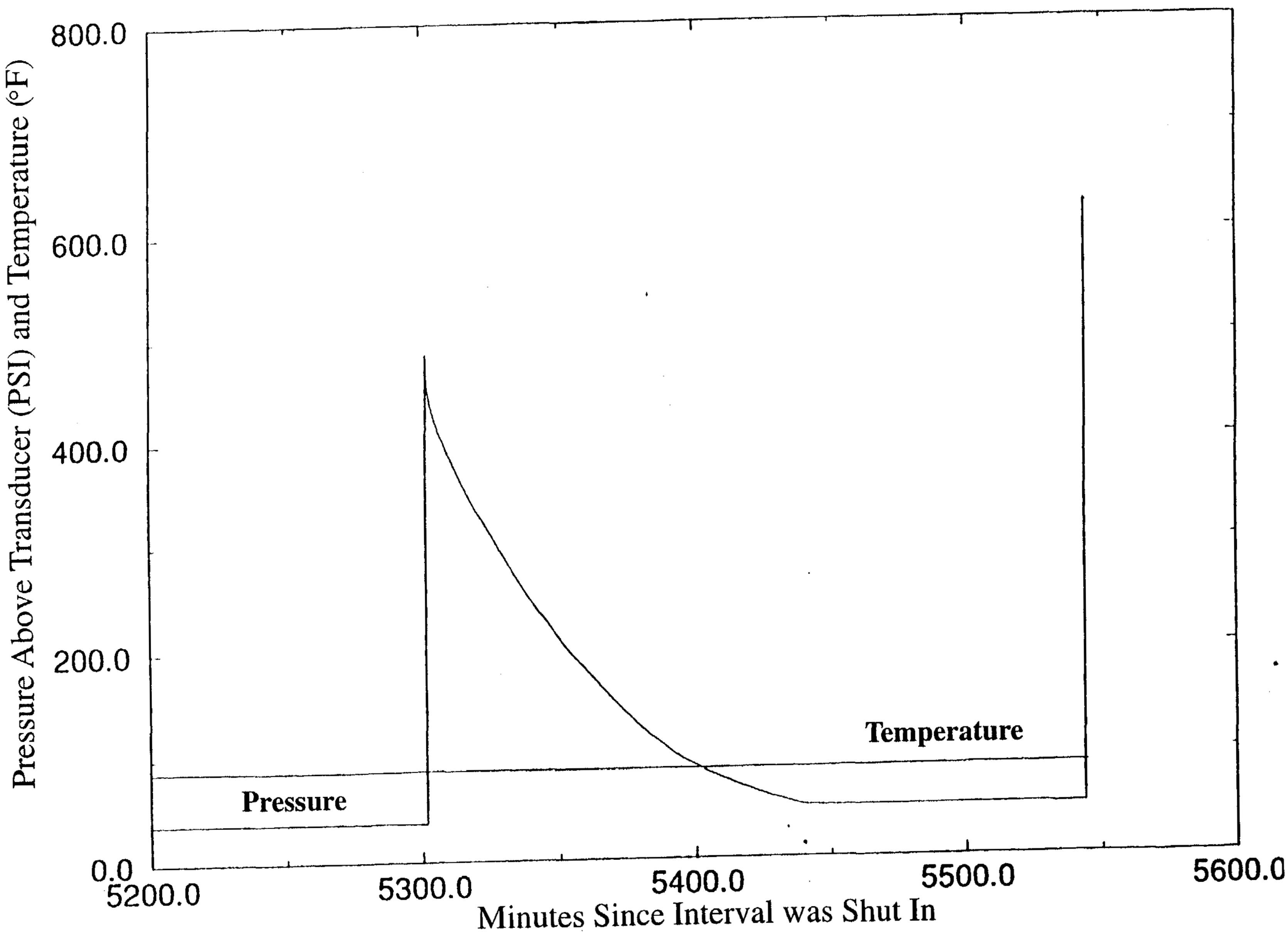


Figure 32. Pressure and temperature results of drill–stem test conducted on 915 to 963 m (3000 to 3160 ft) screened interval.

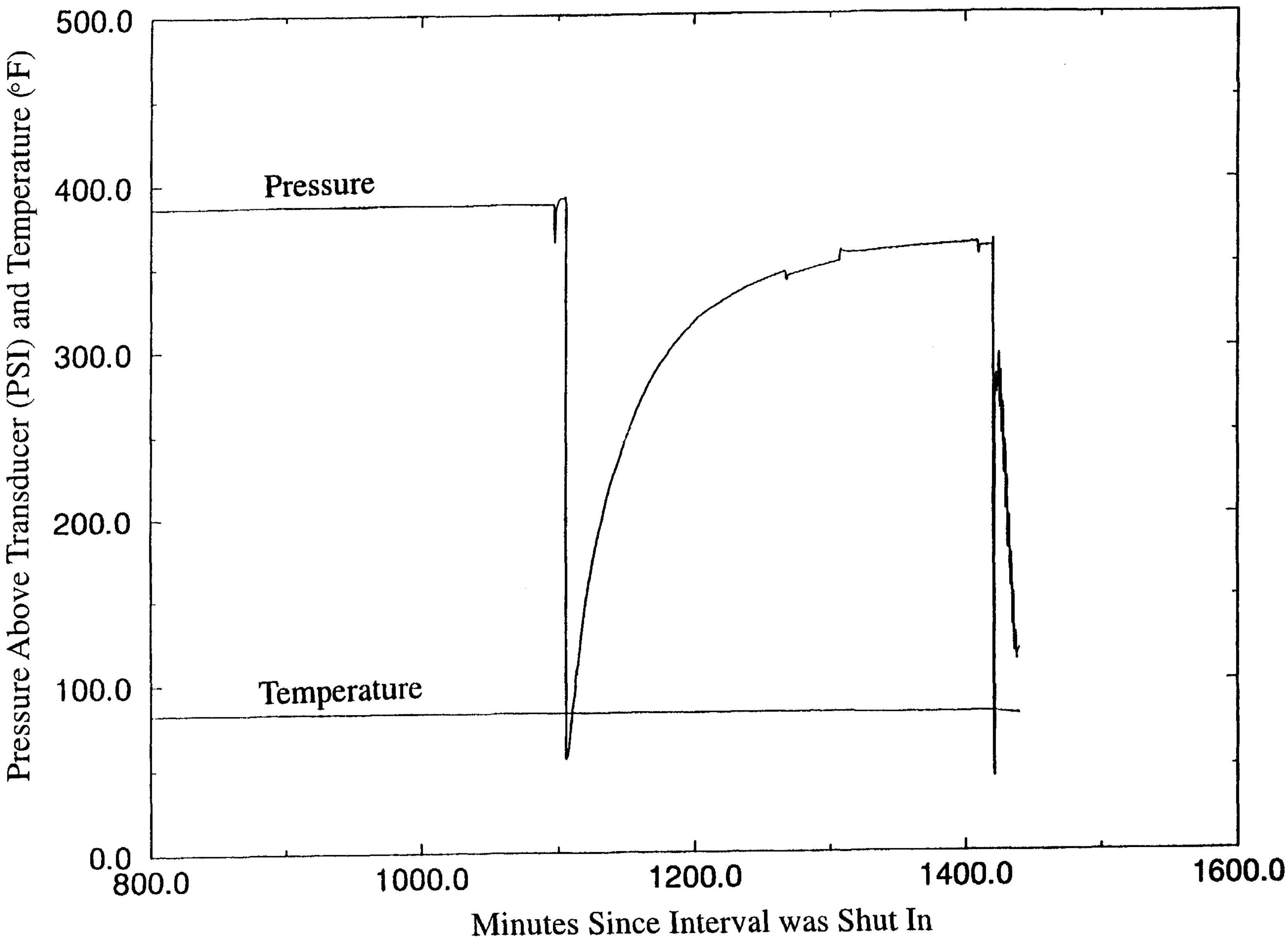


Figure 33. Pressure and temperature results at drill–stem test conducted on 765 to 790 m (2510 to 2550 ft) screened interval.

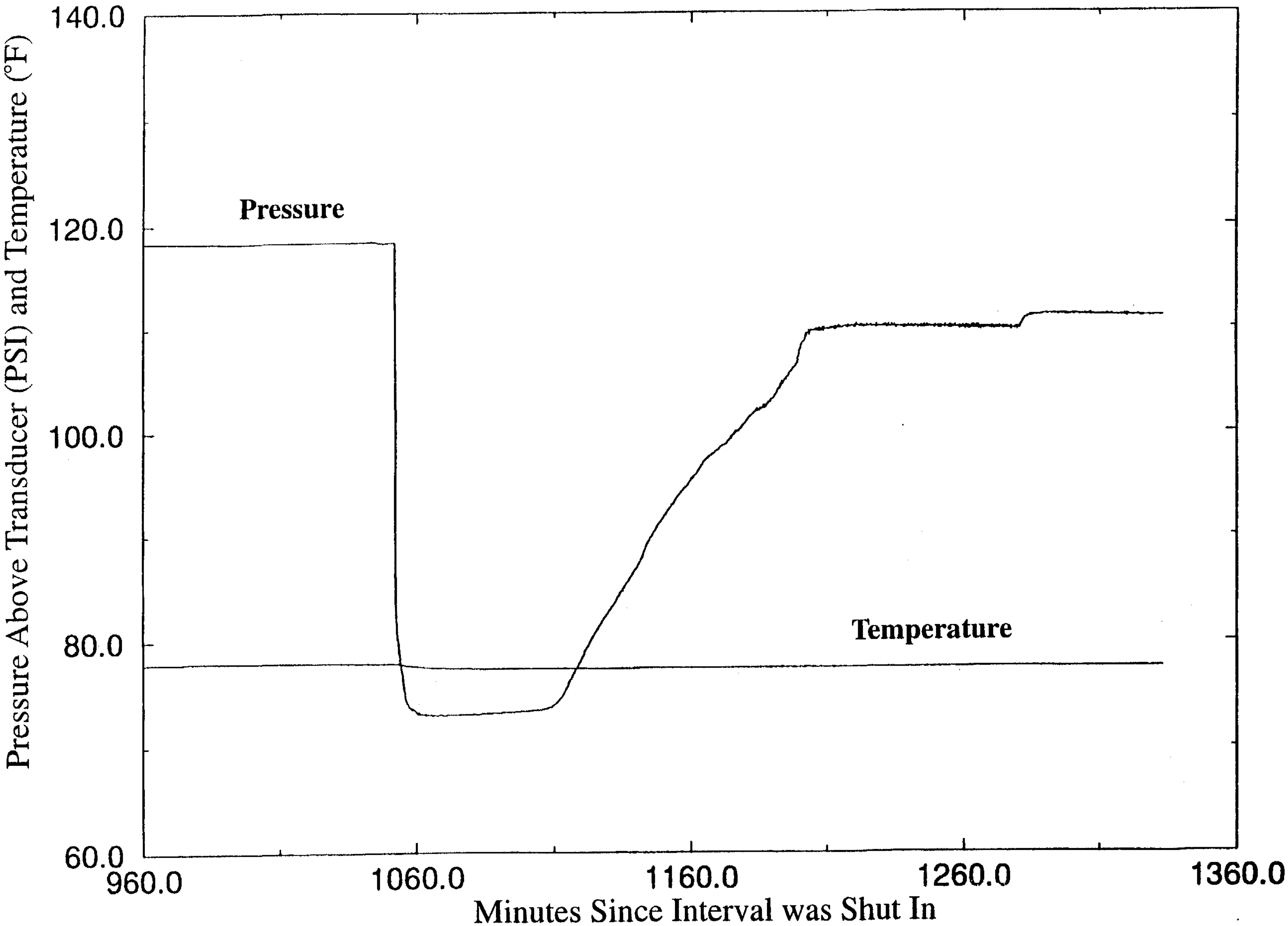


Figure 34. Pressure and temperature results of drill–stem test conducted on 585 to 597 m (1920 to 1960 ft) screened interval

t = time since the instantaneous head change

H = head in the well at time > 0

H_o = instantaneous head change in the well

$F(\beta,\alpha)$= a function of b and a whose tables and graphs are present in Cooper, et al., (1967).

The data and type curves for the drill-stem test conducted on the 915 to 963 m (3000 to 3160 ft; lower Simonson Dolomite) screened interval are presented in Figures 35 and 36. Results of the analysis indicate an estimated transmissivity for this zone ranging from 1 x 10^{-5} to 2 x 10^{-5} m^2/s. Two analyses were conducted on the data owing to the poor fit of the data to the type curves. If the value of α for the relevant type curve is within two orders of magnitude of the actual value, the error in the determined T is less than about 30 % (Papadopulos et al., 1973). The data and type curves for the drill-stem test conducted on the 765 to 790 m (2510 to 2590 ft; Upper Eleana Formation) screened interval are presented in Figure 37. Results of the analysis indicate a transmissivity of 7.5 x 10^{-6} m^2/s for this zone.

The transmissivities determined from all of the drill-stem tests are only representative of materials close to the borehole. Materials potentially impacting the test include the screen, gravel pack, and geologic formations that may have been negatively impacted through the introduction of mud during drilling or positively impacted during subsequent development efforts. In addition, subsurface conditions at ER-12-1 violate several assumptions inherent in Cooper et al., (1967): for example, the conditions of infinite areal extent, homogeneity, isotropy, uniform thickness, full aquifer penetration, and the lack of well-bore storage are not met. The transmissivities estimated by this analysis should be treated, at best, as an order of magnitude estimates. It is interesting to note that the Lower Simonson Dolomite in the screened interval of 915 to 963 m (3000 to 3160 ft) has a transmissivity equal to that determined for the composite borehole and is also under–pressured by

Table 37. Maximum, Minimum, and Duration of Stress during Drill-stem Tests Conducted at ER-12-1.

Zone Tested	Max Stress m (ft)	Min Stress m (ft)	Duration of Stress
585-598 m (1920-1960 ft)	121 m (397 ft)	6.0 m (19.6 ft)	149 min
765-790 m (2510-2590 ft)	310 m (1016 ft)	25.3 m (82.9 ft)	212 min
915-963 m (3000-3160 ft)	381 m (1250 ft)	8.7 m (28.5 ft)	138 min

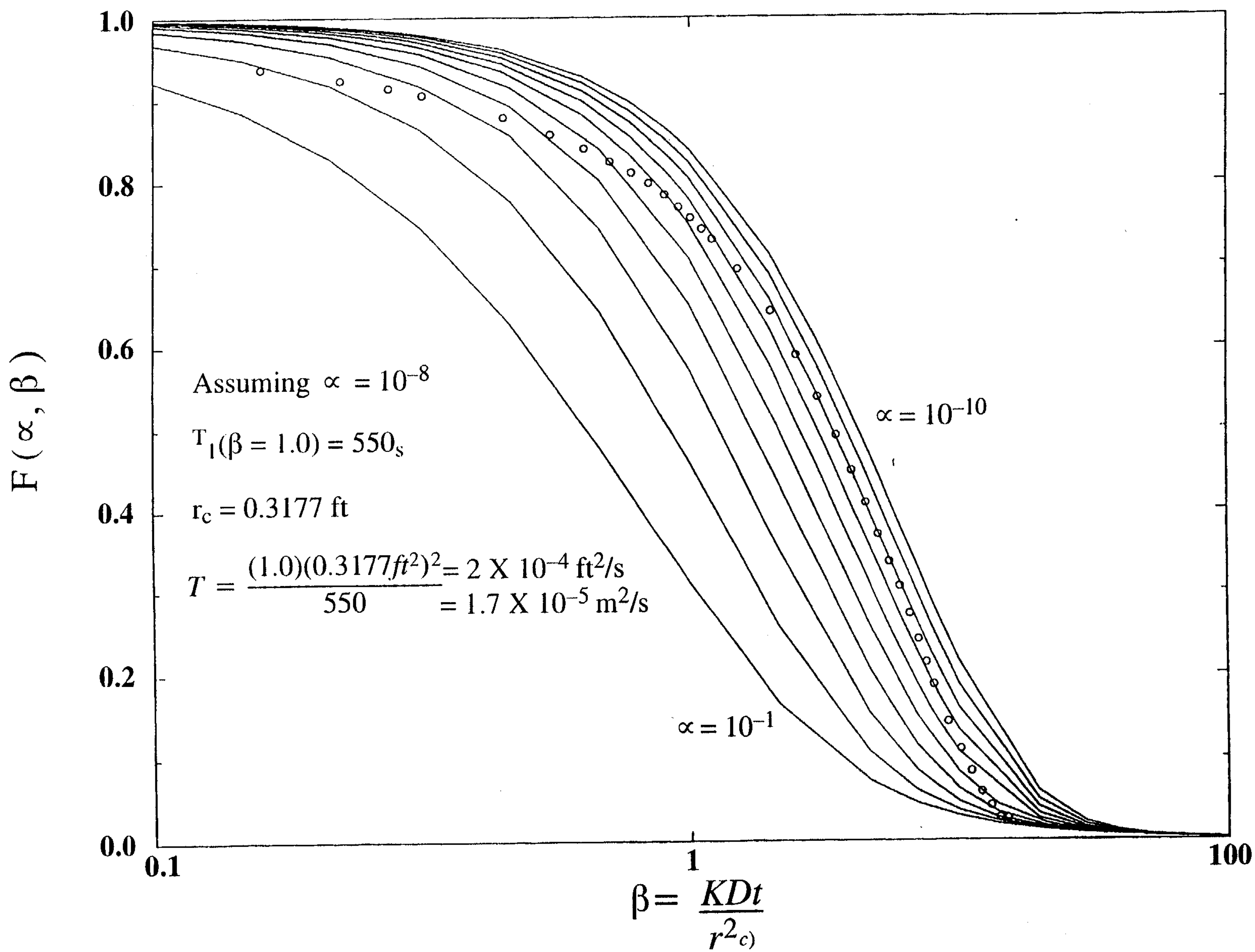


Figure 35. Results of drill–stem test conducted on the screened interval extending from 915 to 963 m (3500 to 3160 ft) using an $\propto = 10^{-8}$.

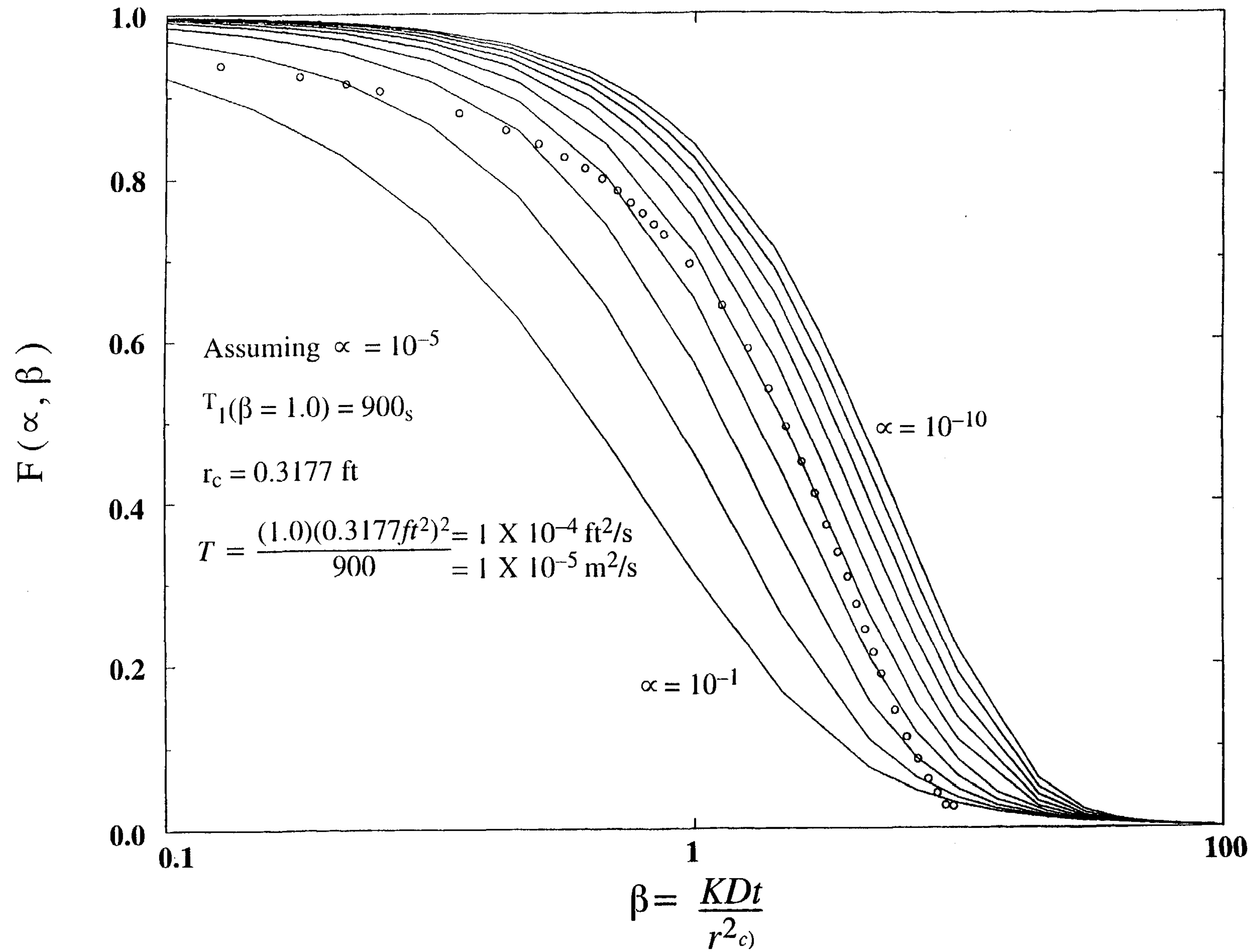


Figure 36. Results of drill–stem test conducted on the screened interval extending from 915 to 963 m (3000 to 3160 ft) using an ∝ = 10^{-5}.

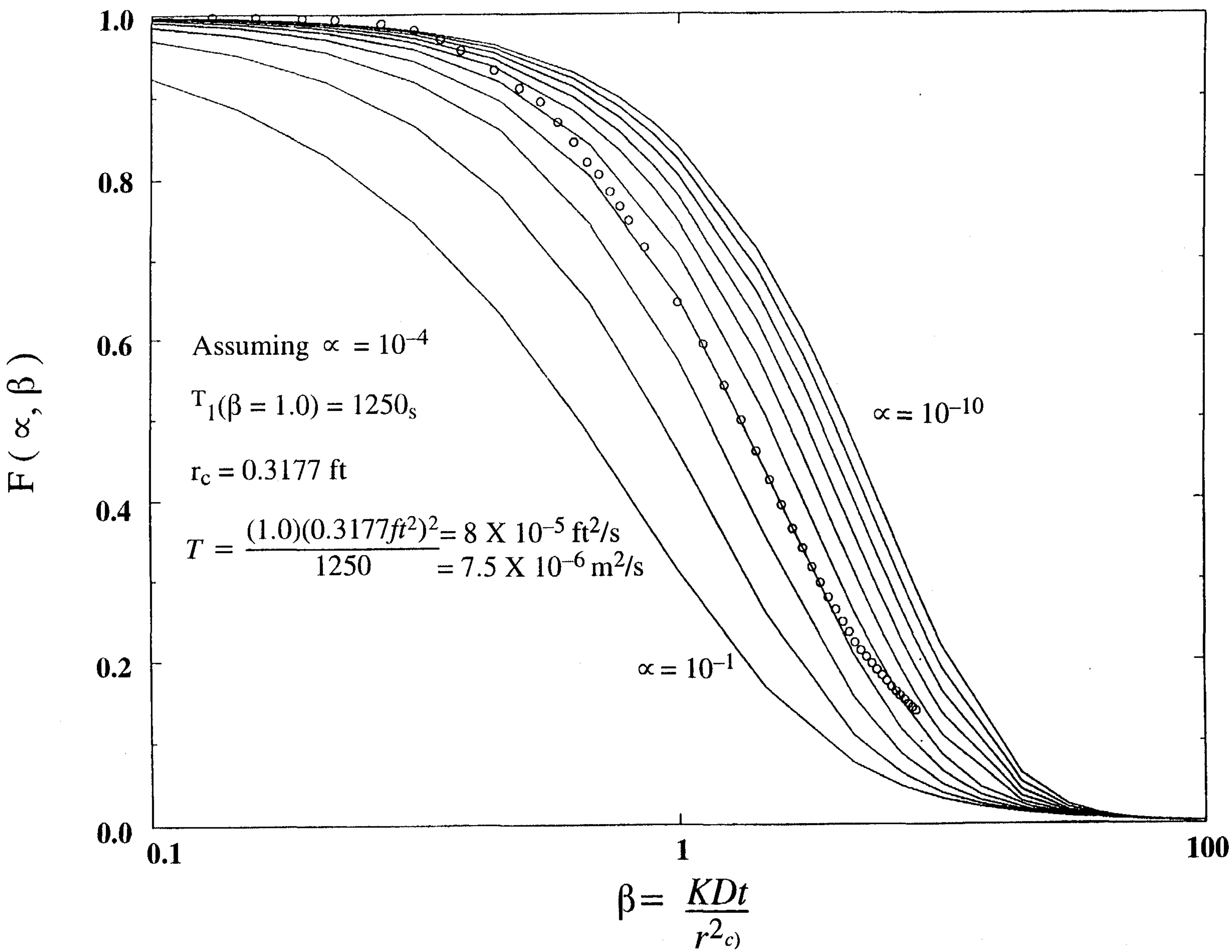


Figure 37. Results of drill–stem test conducted on the screened interval extending from 765 to 790 m (2510 to 2590 ft) using an ∝ = 10^{-4}.

approximately 396 m (1300 ft) relative to the upper zones within the borehole. This evidence supports the interpretation of the long-term aquifer test.

The pressure response following the test conducted on 585 to 597 m (1920 to 1960 ft; Figure 34) was characterized by a rapid drop during depressurization once the drill-stem test tool was opened, followed by a relatively static period of approximately 45 minutes where the pressure response rose approximately 0.3 m (one ft) of head. The relatively static period was followed by a rapid increase in pressure. The static period masked the early pressure response and prevented analysis of these data. Two potential explanations for the period of static pressures are offered; the screened zone between 585 to 597 m (1920 and 1960 ft) was subjected to various types of drilling fluids during well construction, including mud, polymers and air foam, and the drilling fluid may have temporarily plugged fractures during the initial portion of the drill-stem test, causing a slow initial rise in pressure. The sustained 14 m (45 ft) head differential may have eventually forced a channel through the filtrate, allowing a much more rapid response. An alternative explanation is the zone rapidly dewatered during the withdrawal test, exposing the transducer to air. The pressure did not rise until the zone refilled with water.

Radially Converging Aquifer Test of the Upper Zone

A 113 to 227 l/min (30 to 60 gpm) pump was installed in ER-12-1 on January 4, 1993, on a string of 6 cm (2-3/8 in) hydril tubing to a depth of 521 m (1710 ft) in preparation for sampling the 518 to 554 m (1700 to 1820 ft) interval. A transducer was strapped to the pump column at approximately 496 m (1628 feet) below ground surface to monitor pressure during pumping. A 13.94-cm string, with sliding sleeves opposite each screened interval, was emplaced in the borehole. The only sliding sleeve open in the well was the uppermost sleeve. Static water levels were at 470.2 m (1542.5 ft) just prior to the aquifer test. Pumping was initiated on January 5, 1993, at 1028 hrs at a rate of 189 l/min (50 gpm). Pumping was discontinued 13 minutes later at 1041 hrs due to a leaking union in the discharge line. The aquifer test was reinitiated at 1057 hrs. The well was not allowed to re-establish equilibrium conditions as the aquifer test was not the primary purpose for pumping the well. Pumping was discontinued at 1500 hrs on January 5, 1993.

The data collected during the aquifer test are presented in Figure 38. The data were analyzed using interpretive software (WHIP) version 3.22 by Hydro GeoChem Inc. (1988). The initial analysis entailed plotting the drawdown and recovery data in terms of drawdown below initial fluid level versus the log of total elapsed time and plotting the best fitting line through the data according to Cooper and Jacob (1946). The best fitting line was determined by least squares best fit through the data points obtained during the period of 40 to 700 minutes following the start of the test. The data collected during this time period appeared to be characterized by a straight line with positive slope. A comparison of the measured drawdown and recovery to the best fitting line indicates the early drawdown data from the aquifer test were affected by well bore storage, the latter drawdown data may have been affected by a change in aquifer thickness or a decrease in aquifer permeability at a distance, or the presence of a no-flow barrier. The comparison also indicates that the latter portion of the recovery data was affected by residual recovery due to relict drawdown created prior

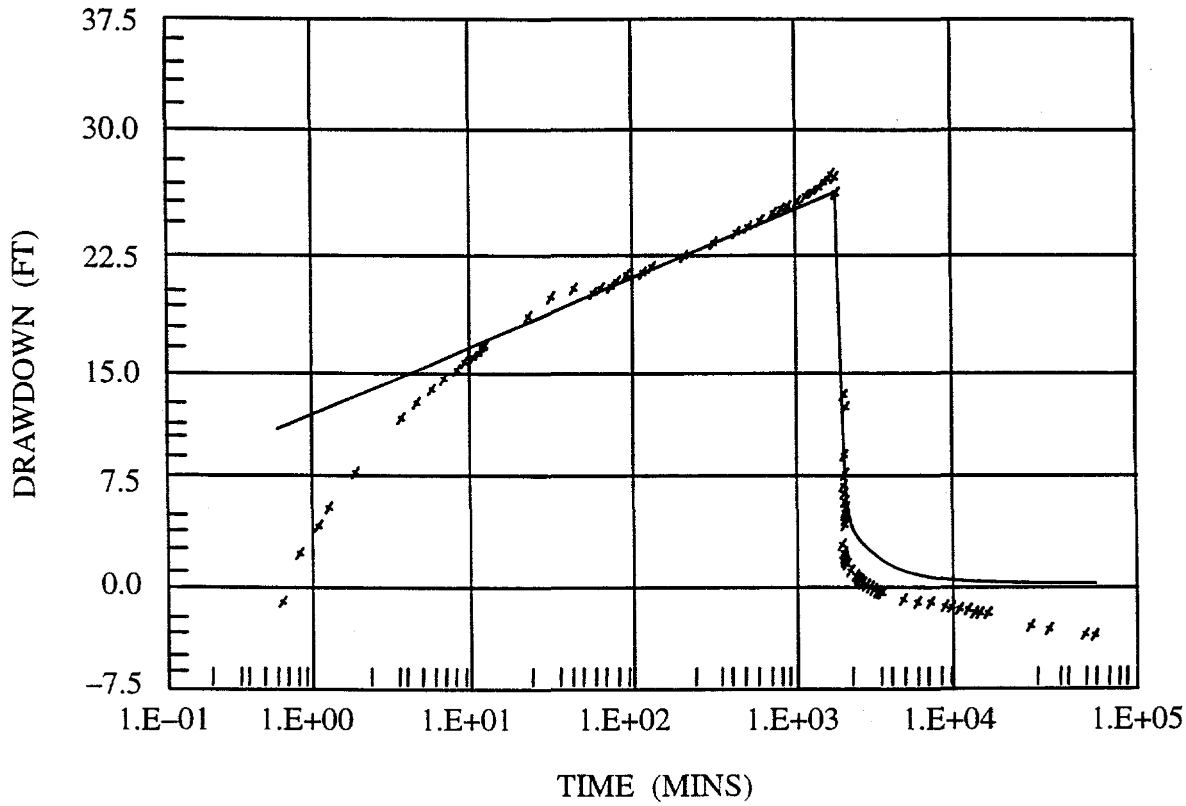


Figure 38. Reduction of ER–12–1 upper zone aquifer test, March 17, 1993.

to the start of the aquifer test. The Cooper and Jacob (1946) analysis resulted in an estimated transmissivity of 4 x 10^{-4} m^2/s and a storativity of 5 x 10^{-3}.

Analytical solutions were used to generate type curves that matched the observed data set. Input variables were iteratively altered with the purpose of estimating key hydrologic parameters. The results are presented in Figure 39. Type curves that utilized a transmissivity of 4.4 x $10^{-4} \pm 2.2$ x 10^{-4} m^2/s, a storativity of 4.0 x 10^{-3} ± 0.05, an effective casing radius (borehole storage) of 0.106 $\pm$ 0.03 m (0.35$\pm$0.1 ft) and a no-flow hydrologic barrier approximately 58 $\pm$ 305 m (190 $\pm$ 1000 ft) distant appeared to create the best fit to the observed data. The results of this analysis agree with the results of the oxygen activation log in that the screened interval between 518 to 554 m (1700 to 1820 ft) was the most transmissive zone within the well.

The transmissivity and storativity values estimated by this technique are very close to those determined by the Cooper and Jacob (1946) method. Washout zones exceeding a diameter of 0.76 m (30 in) in the interval of 518 to 554 m (1700 to 1820 ft), as determined by caliper runs (Figure 18), support an effective casing diameter of 0.21 m (0.70 ft) versus a calculated casing diameter of 0.12 m (0.40 ft), which takes into account the volume of the pump column and monitoring string within the well. The geologic cross section of ER-12-1 (Figure 4 from RSN geologic report) shows

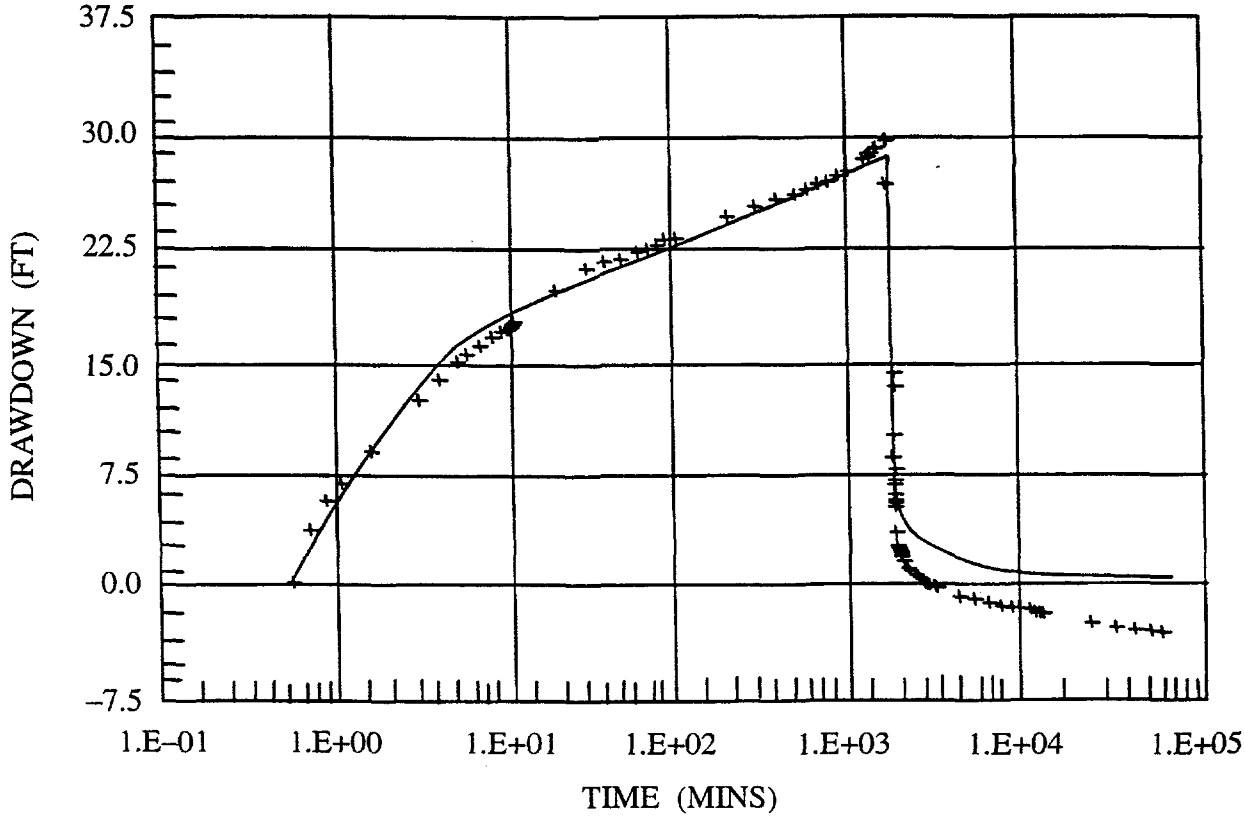


Figure 39. Hydrologic parameter estimation of ER-12-1, upper zone aquifer test, March 17, 1993.

a thin wedge of upper Simonson Dolomite or lower Guilmette Formation occurring in the test interval of 518 to 554 m (1700 to 1820 ft) and pinching out to the southeast. The decrease in thickness may be the reason for the the increase in drawdown during the latter part of the test and may also be a justification for the use of a no-flow barrier in the analytical solution.

The parameters estimated through this technique are to be treated as estimates of values associated with one potential solution to the observed data. Other solutions may also be equally valid.

Hydrochemistry

Routinely monitored samples, collected during drilling, completion, development and testing activities at ER-12-1, consisted of field measurements of geochemical parameters and geochemical samples obtained for laboratory analysis. Field measurements were obtained for tritium, bromine, turbidity, pH, and temperature. Geochemical samples were routinely obtained during drilling and well development for metals and hydrocarbon analysis to asses the quality of fluids introduced to, and removed from, the well. Geochemical characterization samples were obtained at the conclusion of the upper zone aquifer test.

Field Measurements During Drilling

Field measurements for tritium were conducted whenever fluids were introduced into, or removed from, the well. Field tritium measurements prior to September 1992, were made using a 1206 BetaMan liquid scintillation counter. After September 1992, a Packard liquid scintillation counter was used for tritium field measurements. All drilling fluids brought onto location were measured for background tritium levels. Returns from the well during drilling were monitored hourly. Fluids recovered from the well during development and testing activities were also monitored hourly for tritium content. All tritium field measurements obtained at ER-12-1 indicated tritium contents well below the 20,000 pCi/l State of Nevada Safe Drinking Water (SNDW) standard. No detectable trends in tritium concentration were observed (Figure 40).

A concentration of approximately 21 mg/l of lithium bromide was added to all fluids introduced to ER-12-1 during drilling as a hydrologic tracer. Bromine concentrations were monitored in fluids produced from the well to determine the degree to which development had occurred. Bromine measurements were obtained in the field using an Orion 250A meter with an Orion bromine probe and reference cell.

During drilling, bromine field measurements were obtained for drilling fluids held in Baker-tanks prior to use, and for returns from the well (Figure 41). While using air-foam as the circulation medium, there appeared to be a definite dilution in the bromine concentration of returned fluids following penetration of the static water level within the well between 450 and 520 meters (1500 and 1700 ft). However, after converting to mud as the circulation medium, the bromine concentrations in the Baker-tank and in the returns from the well became more consistent. This is expected as the weight of the drilling mud does not allow formation fluids to enter the wellbore. Bromine concentrations within the Baker-tanks and in returns from the well were consistently less than the target concentration of 21 mg/l. Laboratory experiments at DRI determined that bentonite adsorbed bromine until mixed with the detergent component of the air-foam mixture. Depressed concentrations of bromine in the baker tanks were most likely due to inadequate mixing of bentonite and detergent or adsorption to bentonite if drilling mud was being used.

Field Measurements During Well Development and Testing

Tritium field measurements obtained from fluids produced from the well were monitored by DRI personnel. Tritium field measurement results were compared with tritium measurements for UE-16d (essentially tritium-free water) 10,000, 20,000 and 40,000 pCi/l standards (Figure 42). All samples were found to be well below the 20,000 pCi/l SNDW. Temporal trends in the tritium activity of the fluids from ER–12–1 were virtually identical (with one exception) to temporal changes observed in the baseline (UE–16d water) and 20,000 pCi/L standards. The only relative difference in Figure 42 were early tritium measurements (derived from water produced during initial well development) invariably plotted below the UE–16d (dead) water. Once aquifer testing was initiated (625,000 L or 165,000 gallons had been discharged from the well), fluids produced from well ER–12–1 were coincident with UE–16d (dead) water activities. The change in ER–12–1 tritium activity relative to UE–16d water activity may have been due to minor contamination of the UE–16d

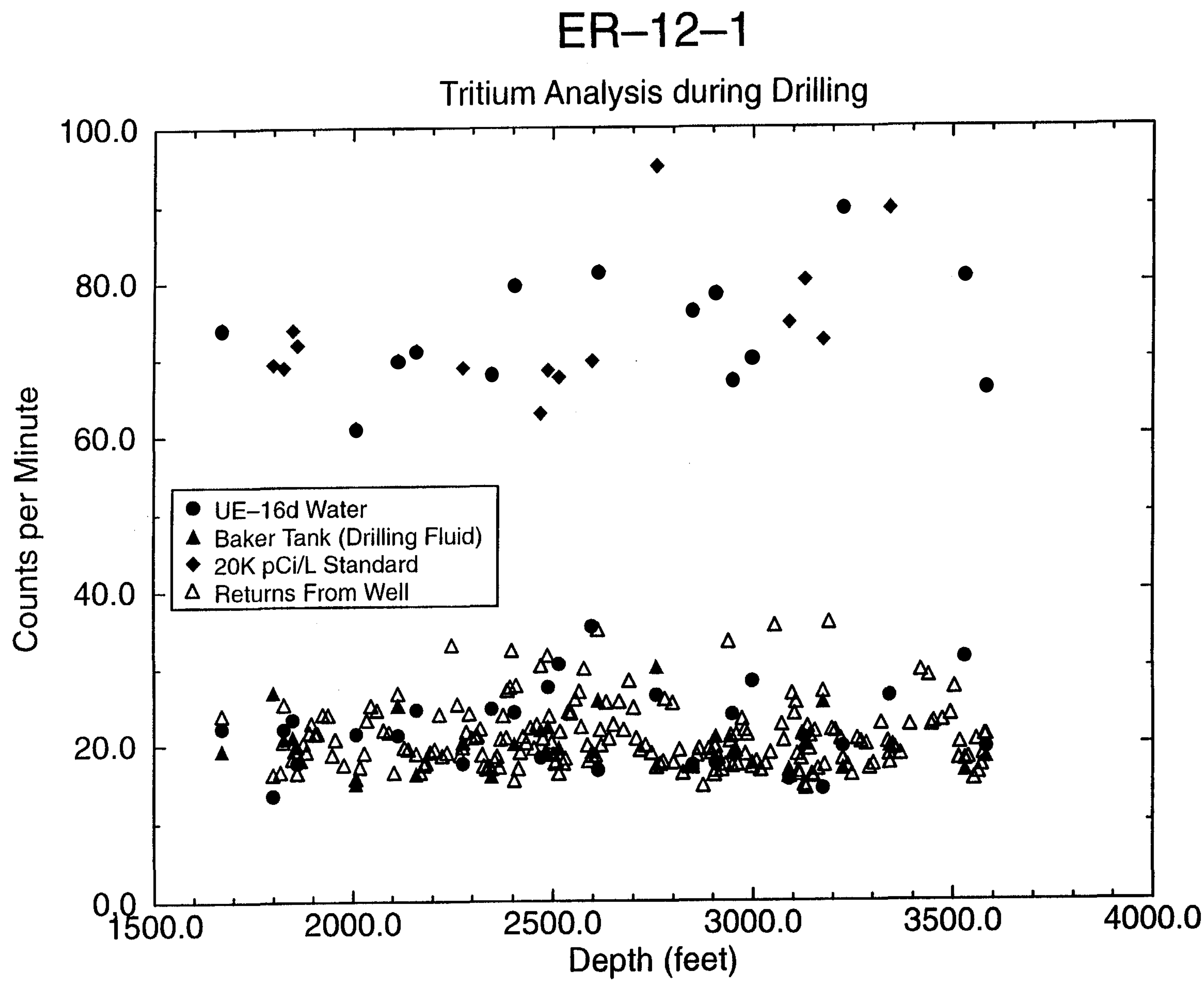


Figure 40. Results of tritium analyses during drilling.

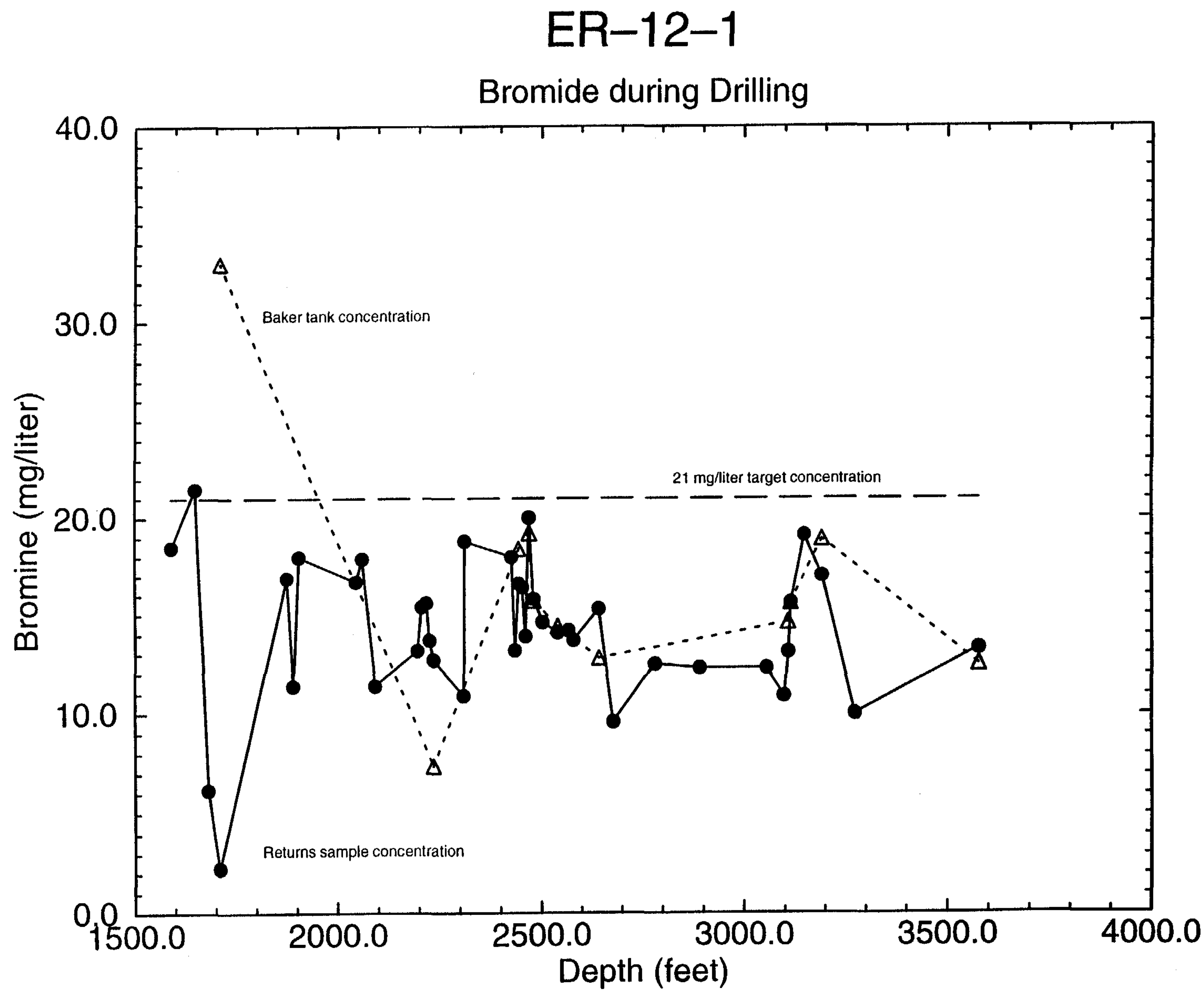


Figure 41. Bromine concentration during drilling.

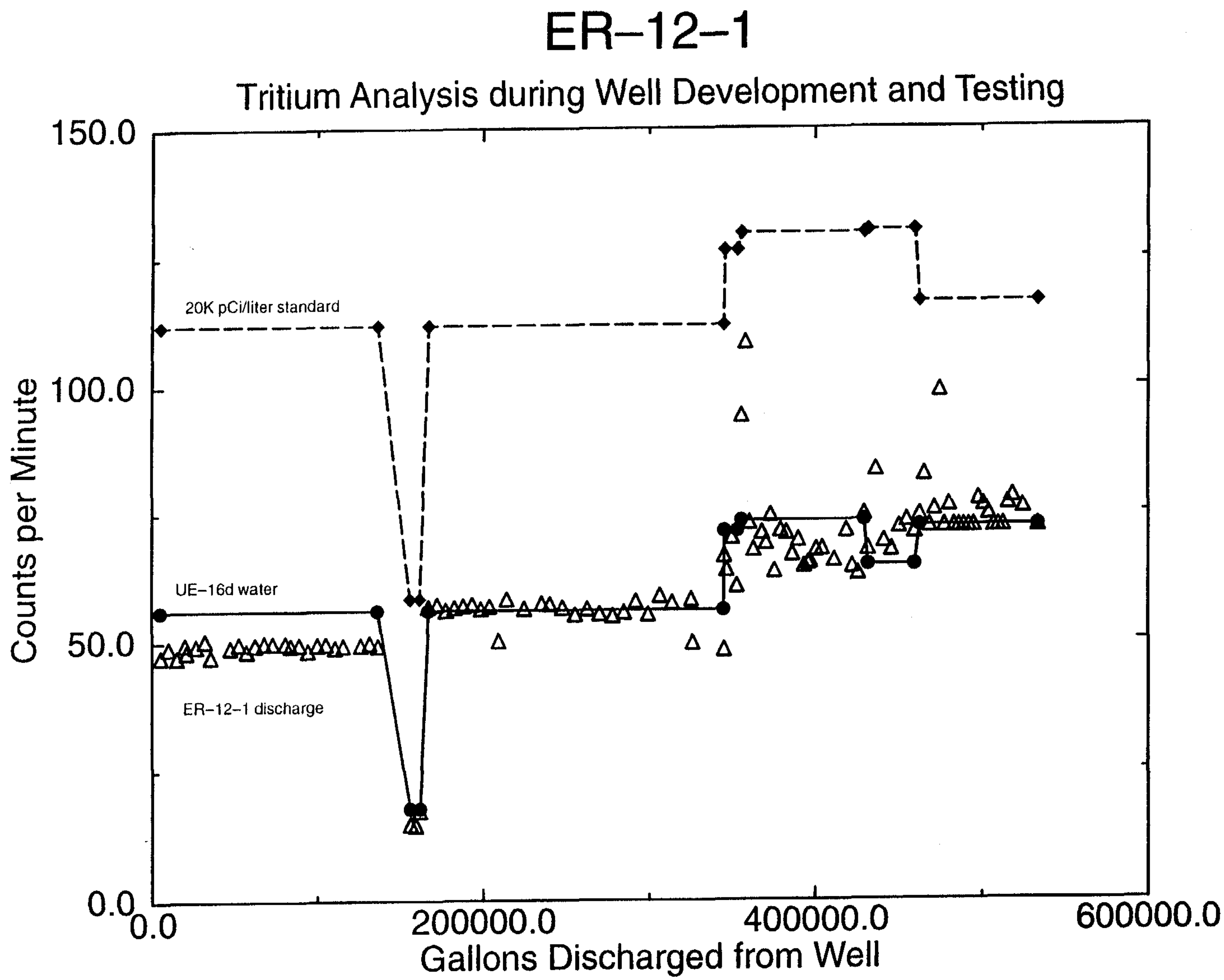


Figure 42. Tritium Analysis during well development and testing.

sample during initial well development, a decrease in the production of drilling fluids injected into the well that may have had a relatively less tritium activity than groundwater surrounding well ER–12–1, or a minor increase in tritium concentrations in the ER–12–1 water during initial aquifer testing due to contaminant migration from tritiated fluids that may have recharged through the nearby U12e tunnel pond sumps (located 450 m to the east of well ER–12–1). Relative temporal variations observed in the baseline (UE-16d water) and the 20,000 pCi/l standard displayed in Figure 42 were due to the use of different scintillation counters, scintillation solutions, and possibly erroneously high sample counts due to failure to sufficiently dark-adapt samples prior to counting. An example is the sharp increase in all standards and samples at 1.26 x 10^6 L discharged (335,000 gallons). This increase is due to the change in field scintillation counters from the 1206 Betaman to the Packard liquid scintillation counter.

Bromine concentrations during well development and testing are displayed in Figure 43. During initial well development, bromine concentrations in recovered fluids displayed a logarithmic decrease from approximately 18 mg/l to between 2.5 and 3 mg/l. Spiking in the bromine concentration of the discharge occurred during the open–hole aquifer test. An abrupt increase, to approximately 20 mg/l, resulted from the introduction of additional fluids to the well during the second phase of well development. Subsequent removal of fluids by air lifting resulted in a reduction of bromide concentration in recovered fluids to approximately 9 mg/l.

Prior to placement of the 0.14 m (5-1/2 in) casing and sliding sleeves, all five completed zones were capable of contributing to the production of fluids removed from the well. Following placement of the 0.14 m (5-1/2 in) casing the lower four sliding sleeves were closed, isolating those zones from the well. The abrupt drop in bromine concentrations from approximately 9 mg/l to about 3 mg/l was due to the change from recovering fluids from all five zones to only the uppermost zone producing the fluids recovered from the well. The upper zone was the most transmissive and had one of the highest heads in the well. A greater amount of water had been produced from this zone than any other; thus, the fluids from this well would tend to have the lowest concentration of bromine.

Field measurements for the pH of the fluids recovered from the well were obtained during pumping of the well using an Orion 250A meter and Orion Triode (pH/temperature/reference cell) probe. pH measurements were not obtained during development of the well by air-lifting due to the potential alteration of the pH by aeration.

pH measurements during initial well development displayed a logarithmic decrease from about 9.2 units to an average of 7.55 units (Figure 44). The pH of recovered fluids again stabilized, during initial aquifer testing, at approximately 7.5 units. Near the end of both stages of pumping, some increased pH values were obtained. These higher pH values may be the result of measurement errors, or possibly result from drawdown in the well allowing contributions from lower pressure zones which would not normally contribute fluid to the well. The pH of recovered fluids averaged approximately 7.3 units during aquifer testing of the upper zone only.

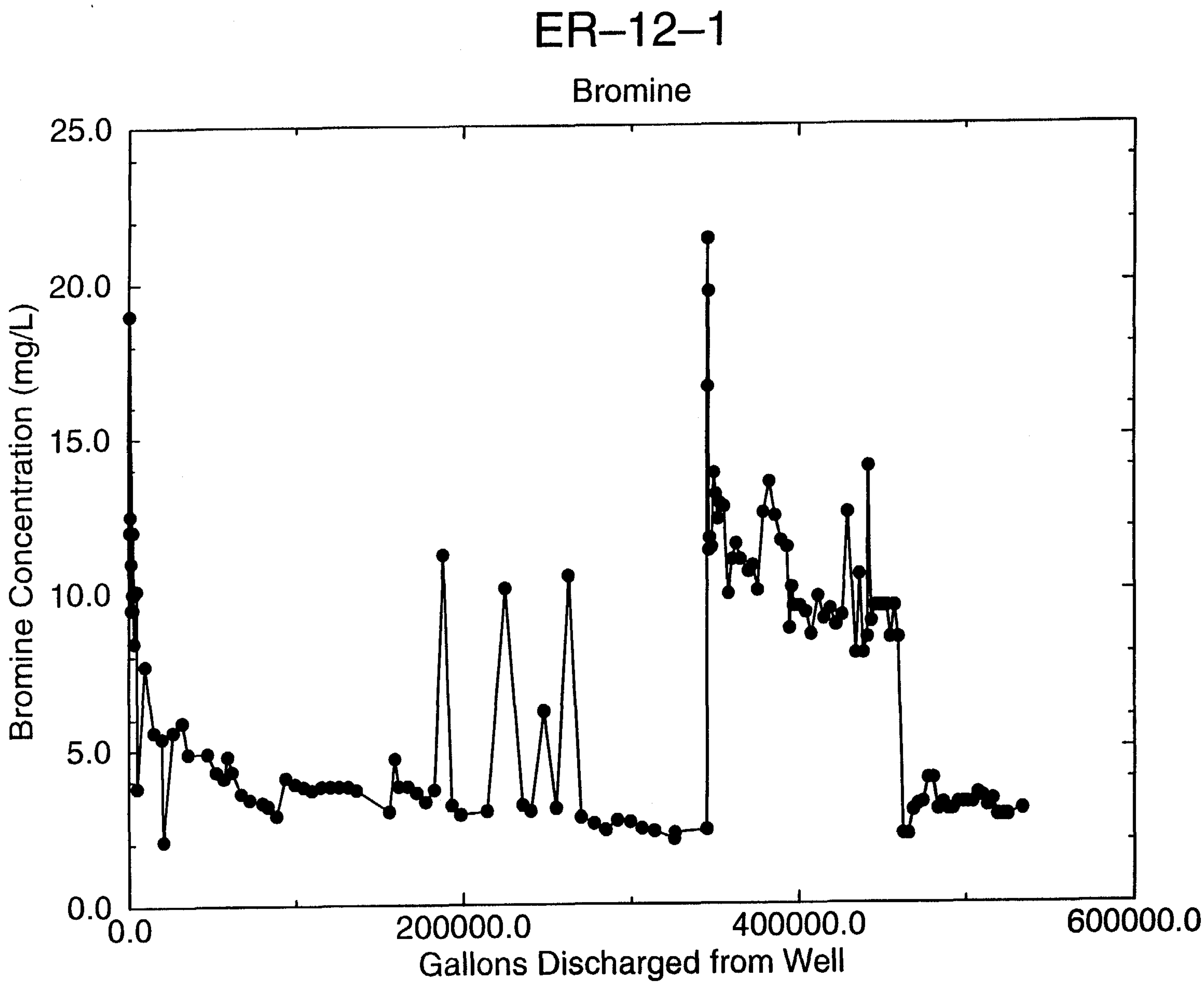


Figure 43. Bromine concentrations during well development and testing.

Temperature measurements, although obtained when pH measurements were taken using the temperature probe included in the Orion 250A meter, should not be considered valid except during the aquifer test of the upper interval. Representative water temperature measurements were difficult to obtain due to the well head configuration during initial well development and aquifer testing. During the aquifer test of the upper interval, a valve was installed in the pump tubing to permit the acquisition of samples for temperature measurements. However, even with this improved system at least four measurements are obviously lower than the actual discharge water temperature (Figure 45).

Turbidity measurements were obtained for fluids produced from the well during development by air-lifting and during aquifer testing of the upper interval (Figure 46). The initial turbidity of fluids recovered during air-lifting exceeded the 200 NTU (Nephelometric Turbidity Unit) capacity of the HF Scientific Turbidity Meter used to obtain turbidity measurements. However, by the completion of development activities, turbidity values had fallen to approximately 40 NTU. During aquifer testing of the upper interval, turbidity values displayed a logarithmic decrease from 17.5 NTU after the first hour of pumping to approximately 3 NTU at the end of the test.

Electrical conductivity measurements were obtained for fluids produced from ER-12-1 only during aquifer testing of the upper interval. A YSI Model-33 conductivity meter was used to obtain fluid conductivity measurements. A marked increase in fluid conductivity was observed for the first five measurements obtained during the aquifer test. Following the initial increase from approximately 1080 μmhos/cc, fluid conductivity averaged about 1160 μmhos/cc for the remainder of the pumping portion of the aquifer test (Figure 47).

Field Measurement Quality Control/Quality Assurance

All field measurements (tritium, bromide, pH, turbidity, etc.) acquired by DRI personnel during drilling, development or testing activities at ER-12-1 were obtained using DRI Standard Operating Procedures and Prompt Sheets. Standard Operating Procedure, governing a particular method, dictated the method for instrument calibration and data acquisition based on manufacturer specifications. Prompt Sheets containing instrument calibration and measurement data were completed in the field. Results of measurements were also recorded in the ER-12-1 Field Activity Logbook. As soon as possible, following completion of individual field measurements, the Prompt Sheets were archived in files maintained at the DRI office in Las Vegas, Nevada.

Geochemical Water-Quality Samples

A total of 12 geochemical samples were obtained in association with activities at ER-12-1. These 12 samples are described in Table 38. Samples 10001 through 10009 were obtained to evaluate the hydrochemical characteristics of fluids introduced to, or removed from, the well during well construction. Sample 10010 was obtained to verify compliance with SNDW standards prior to discharging fluids to land surface during aquifer testing. Sample 10011 was collected at the conclusion of the initial aquifer test as a check of fluids discharged to land surface during testing. Sample 10012 was obtained for geochemical characterization at the conclusion of pumping during

(text continues on page 138)

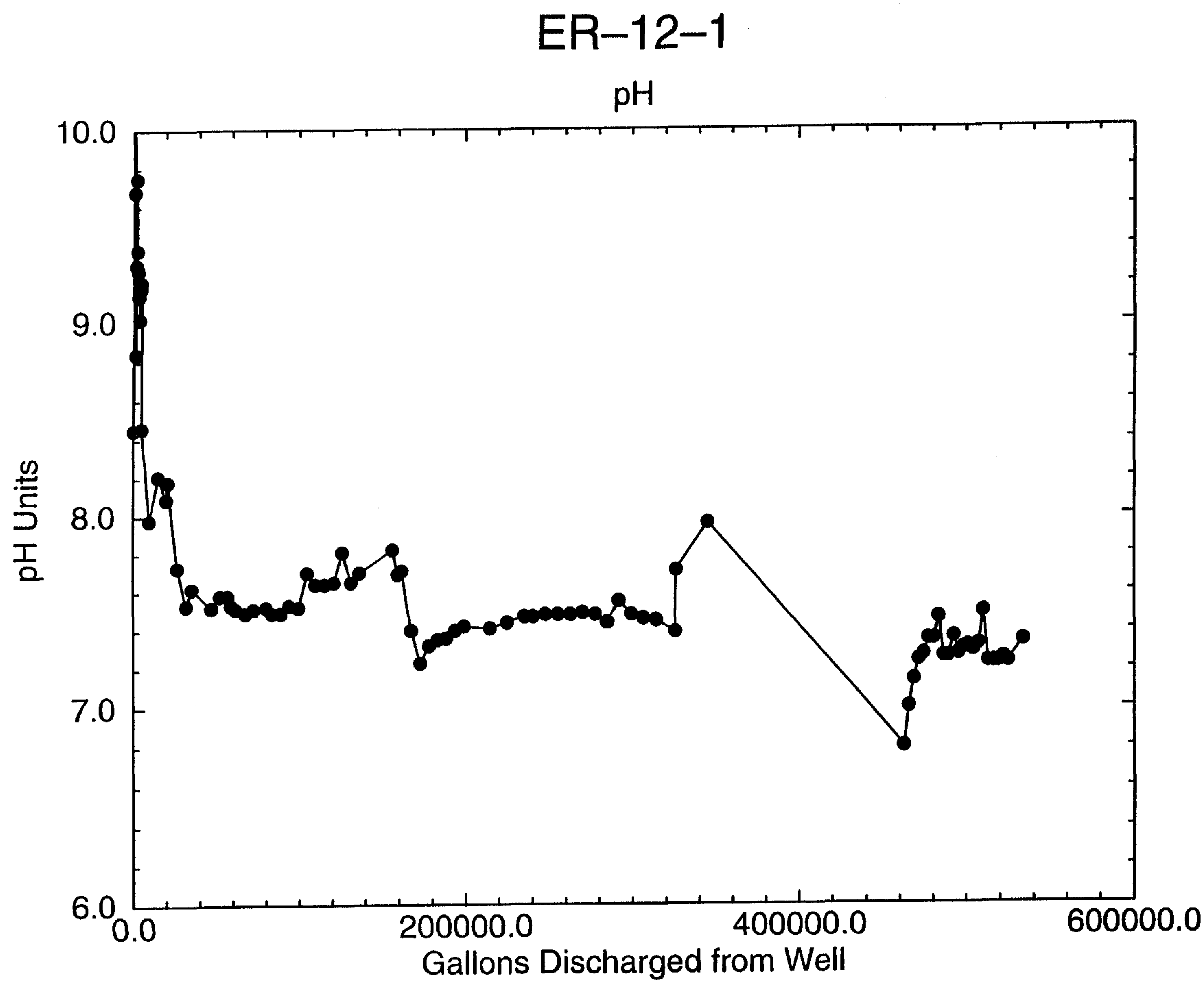


Figure 44. pH of water produced from ER–12–1.

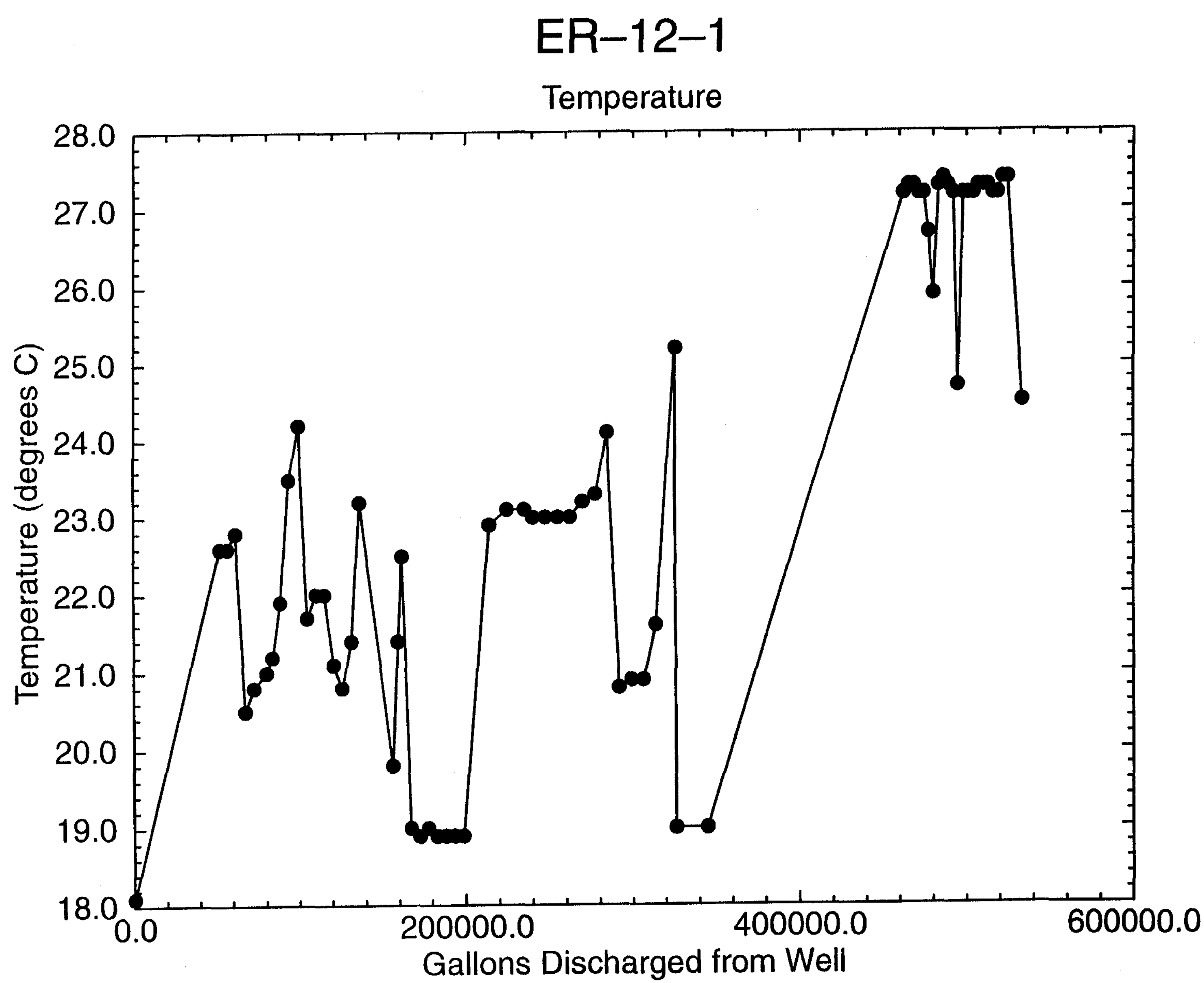


Figure 45. Temperature of water produced from ER–12–1.

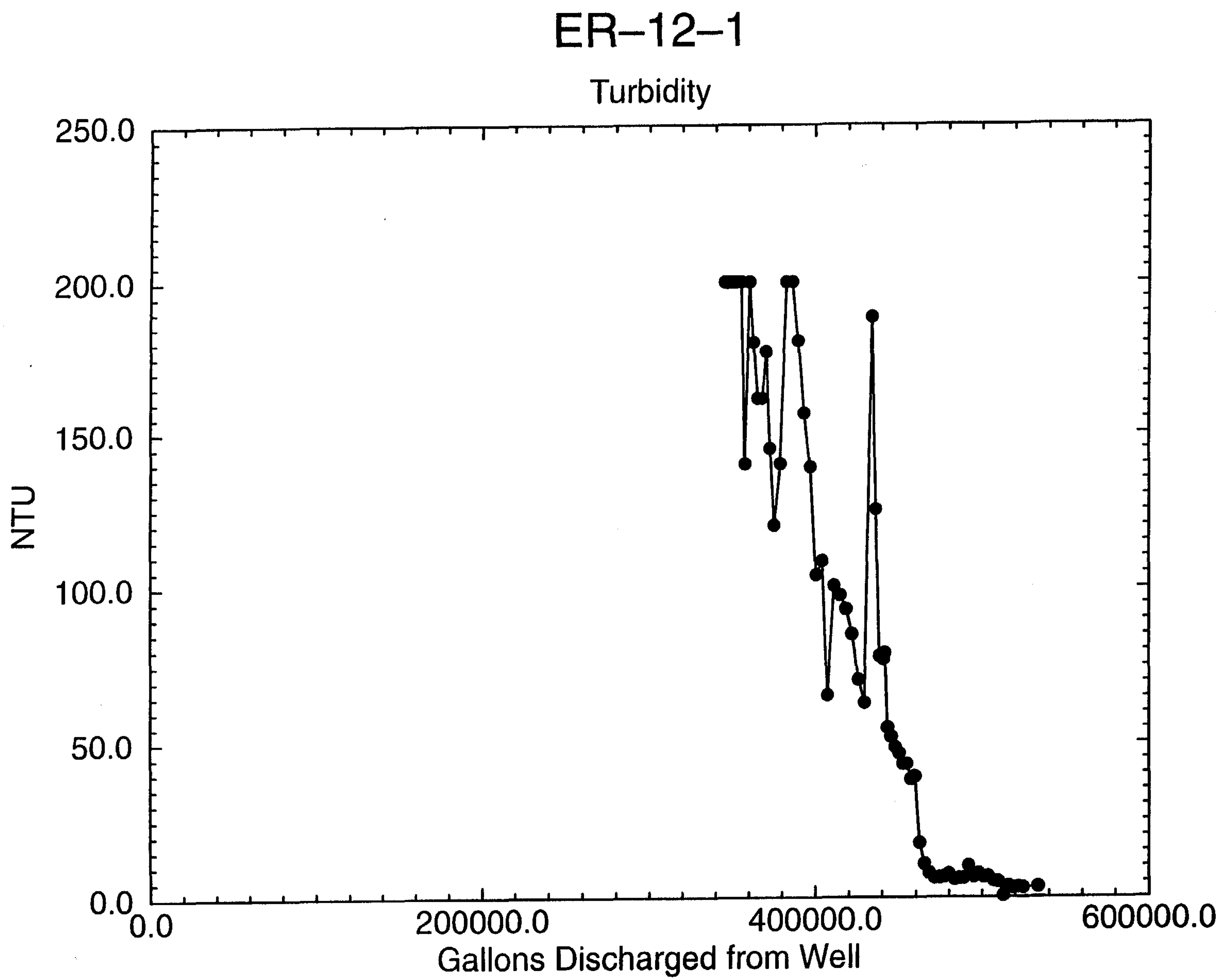


Figure 46. Turbidity of water produced from ER–12–1.

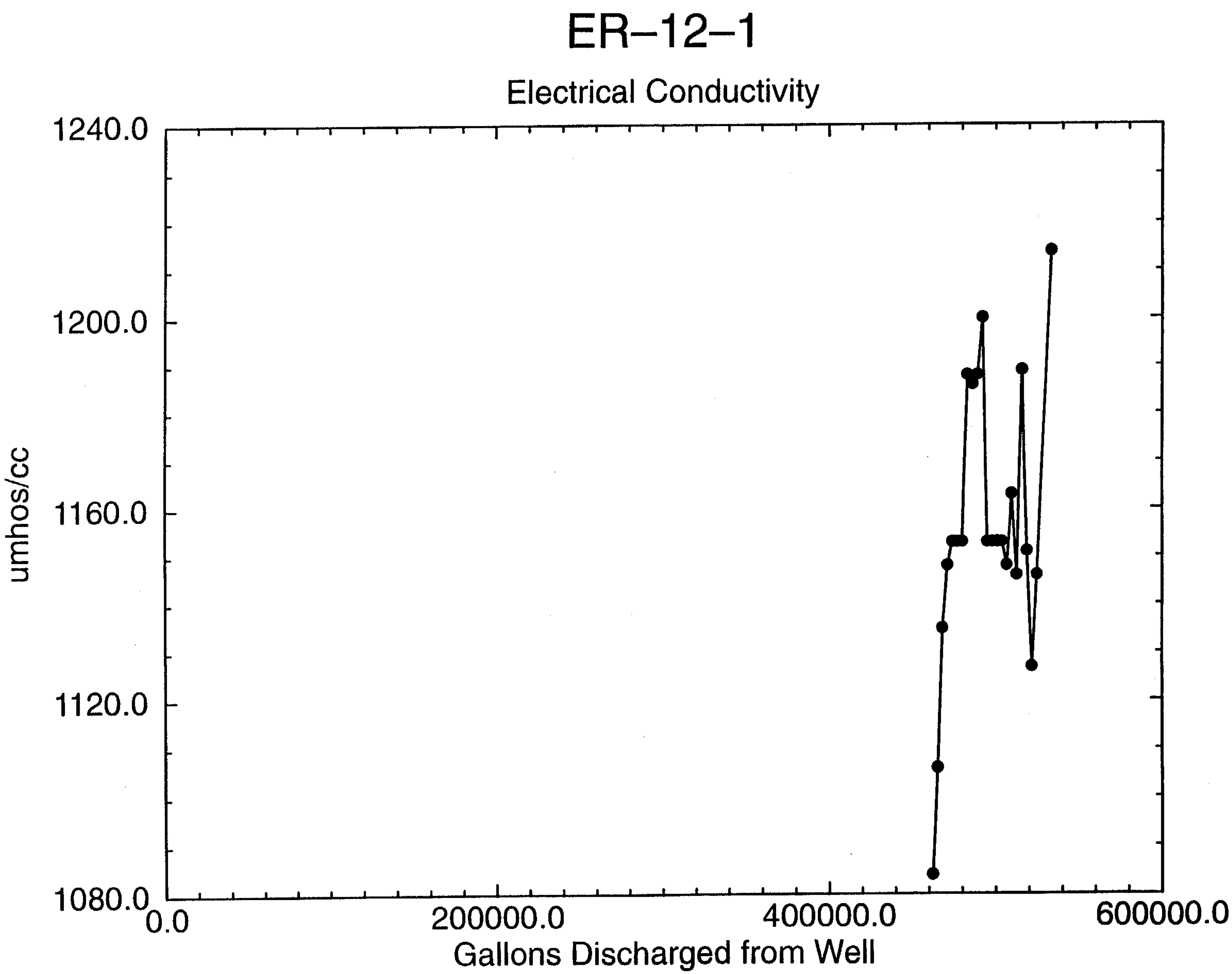


Figure 47. Electrical conductivity of water produced from ER–12–1.

Table 38. Geochemical Samples Acquired from Well ER-12-1.

Sample #:	10001 and 10002
Date:	July 22, 1991
Location:	water truck (10001) and sump (10002) at drill site
Analysis:	voa, s-voa, tph
Comment:	samples lost due to storage cooler breakdown
Sample #:	10003 a,b,c,d
Date:	July 31, 1991
Location:	sump at drill site
Analysis:	voa, s-voa, tph
Comment:	samples collected from sump to replace 10002
Sample #:	10004 a,b,c,d
Date:	July 31, 1991
Location:	water truck
Analysis:	voa, s-voa, tph
Comment:	sample collected from water truck used to deliver water to the drill site; sample collected to replace 10001
Sample #:	10005
Date:	August 12, 1991
Location:	collected from water in sump at Area 3
Analysis:	voa, s-voa, tritium, gross alpha-beta-gamma spect., metals, and anions
Comment:	water in sump at Area 3 (mud plant) used to make drilling fluids used at drill site
Sample #:	10006 a,b,c,d,e,f,g,h,i
Date:	August 27, 1991
Location:	sump at drill site
Analysis:	voa, s-voa, tritium, nutrients, pcbs, gross alpha-beta-gamma spect., metals and anions
Comment:	drilling returns
Sample #:	10007 a,b,c,d,e,f,g,h
Date:	September 4, 1991
Location:	water samples from 509.4m (1671 ft) within well
Analysis:	voa, metals, nitrates, rad nucs, bacteria
Comment:	water sample collected using discrete interval wireline sampler from 509.4 m (1671 ft) (water level at 470 m (1540 ft)); samples collected for sdwa analysis
Sample #:	10008a
Date:	September 27, 1991
Location:	Baker-tank at drill site
Analysis:	metals
Comment:	sample of mud used as drilling fluid, collected to determine source of high Cr content observed in previous returns samples

Table 38. Geochemical Samples Acquired from Well ER-12-1 (continued).

Sample #:	10008b
Date:	September 27, 1991
Location:	Area 3 mud plant
Analysis:	metals
Comment:	sample of foam used as drilling fluid, collected to determine source of high Cr content observed in previous returns samples
Sample #:	10009a
Date:	October 11, 1991
Location:	standpipe at drill rig
Analysis:	total petroleum hydrocarbons
Comment:	sample of drilling mud collected immediately prior to entering well
Sample #:	10009b
Date:	October 11, 1991
Location:	flowline at drill rig
Analysis:	total petroleum hydrocarbons
Comment:	sample of drilling fluids collected immediately after return to surface from well
Sample #:	10010a
Date:	March 15, 1992
Location:	pumped discharge from well
Analysis:	voa, s-voa, nitrates, rad nucs, metals, anions
Comment:	sdwa samples collected at end of well development by pumping
Sample #:	10010b
Date:	March 15, 1992
Location:	as above
Analysis:	as above
Comment:	as above; 10010b collected as duplicate sample for 10010a
Sample #:	10011
Date:	April 1, 1992
Location:	pumped discharge from well
Analysis:	cations, anions, nitrate, rad nucs and Sr
Comment:	samples collected at end of aquifer testing (Sr collected for USGS)
Sample #:	10012
Date:	January 6, 1993
Location:	pumped discharge from well
Analysis:	complete geochemical sample suite
Comment:	samples collected at end of aquifer test on upper zone

the upper-zone aquifer test. All produced fluids were contained in the lined sump at the ER-12-1 well site during aquifer testing of the upper zone.

Samples 10001 and 10002

Samples 10001 and 10002 were collected at 1400 hours on July 21, 1991 to assess the quality of water introduced to, and removed from the well during construction. Sample 10001 was collected from the water truck delivering water to be used in the drilling operation at the drilling location, and taken to the REECo laboratory in Mercury for volatile organic analysis (VOA), semi-volatile organic analysis (SVOA), tritium analysis and gross alpha-beta-gamma spectroscopy. Water Well 8 at the NTS was the source of this water. Sample 10002 was collected from the sump at the drilling location and is comprised of drilling returns from the well. This sample was collected for VOA, SVOA, and total petroleum hydrocarbons (TPH) analysis. Due to the failure of the refrigeration unit at the REECo laboratory, all samples were lost except those collected for tritium and gross alpha-beta-gamma spectroscopy from the water truck (sample 10001).

Tritium concentration in sample 10001 was below the detection limit of the analysis method used, i.e., less than 307 pCi/l. The SNDW standard for tritium is 20,000 pCi/l. Gross alpha radiation was reported to be 2.87E-9 μCi/ml, slightly above the detection limit of 2.15E-9 μCi/ml. This activity is well within the SNDW standard of 15.0E-9 μCi/l. Gross beta activity was below the detection limit of 2.73E-9 μCi/l. The state of Nevada does not set a drinking water standard for beta radiation. Gamma activity was not detected in the sample.

Samples 10003 and 10004

Samples 10003 and 10004 were collected at 1520 hours on July 31, 1991 (replacing samples 10001 and 10002, described above) to determine if organic compounds were entering the circulation system at ER-12-1. Sample 10003 was collected from the sump; sample 10004 was collected from the water truck (construction water from Water Well 8). Volatile organic analyses of samples 10003 and 10004 indicated the presence of methylene chloride at an estimated concentration of 4 μg/l. (Estimated concentrations indicate the presence of a compound that meets the identification criteria, but the result is less than the sample quantification limit of the method used.) An unknown volatile organic compound with a retention time of 1.07 minutes in the gas chromatograph was also detected at an estimated concentration of 140 μg/l in sample 10003 and 28 μg/l in sample 10004 (at a retention time of 1.09 minutes). The methylene chloride was detected in the associated laboratory blank at an estimated concentration of 1.7 μg/l. The unknown volatile organic was not detected in the associated laboratory blank. The detection of methylene chloride in the associated laboratory blank, although at a lower estimated concentration than in the sample, cast doubt on the validity of its detection in the samples. The source and the nature of the unknown volatile organic is not known; however, due to its occurrence at a low concentration it is not considered cause for significant concern. Possible sources for this compound may be materials used in the well, the water truck, bottles used to transport samples, or laboratory contamination.

Semi-volatile organic analysis of sample 10003 indicated the presence of di-n-butylphthalate, butylbenzylphthalate, and bis(2-ethylhexy)phthalate, at estimated concentrations of 0.8, 3.0, and

1.0 μg/l, respectively. Three unknown SVOA compounds with retention times of 8.36 (tentatively identified as 4-methyl-2-pentanon-4-ol), 8.73 and 11.84 minutes and concentrations of 8, 15 and 143 μg/l respectively, were also detected. SVOA analysis of sample 10004 also indicated the presence of di-n-butylphthalate, butylbenzylphthalate, and bis(2-ethylhexy)phthalate at estimated concentrations of 0.7, 1.0, and 2.0 μg/l, respectively. Six unknown VOA compounds with retention times of 8.31 (tentatively identified as 4-methyl-2-pentanon-4-ol), 9.59, 13.54, 13.89, 16.77, and 38.83 minutes at concentrations of 8, 9, 17, 10, 14, and 8 ug/l, respectively, were also detected. All three of the known VOA compounds found in both samples 10003 and 10004 were detected in the associated laboratory blank in concentrations exceeding those detected in the samples. One of the seven unknown SVOA compounds, tentatively identified as 4-methyl-2-pentanon-4-ol, was detected in the laboratory blank at an estimated concentration more than double the concentrations detected in the samples. The extremely low concentrations and detection of the compounds, at a higher concentration, in the laboratory blank, cast doubt on the validity of detection of these compounds in the sample. None of the other six unknown semi-volatile organics were detected in the laboratory blank. The source and nature of these compounds are unknown; however, due to their occurrence in extremely low concentrations, they are not considered cause for significant concern.

Total petroleum hydrocarbon (TPH) analysis for sample 10003 indicated the absence of any petroleum hydrocarbons in the sample.

Sample 10005

In addition to water from Water Well 8, water from the sumps at the area 3 mud plant were used in the construction of ER-12-1. Water in this sump could have been derived from a number of wells on the NTS (Doug Duncan; DOE, personal communication). The origin of the water in the sump at the time of the construction of well ER–12–1 was unknown. Sample 10005 was collected for VOA, SVOA, tritium, gross alpha-beta-gamma spectroscopy, cations and anions analysis to determine the hydrochemical character of water from the area 3 mud plant sump. This sample was collected from the mud plant sump in area 3 at 0800 hours on August 12, 1991, and taken to the REECo laboratory in Mercury for analysis.

Radiological analysis of sample 10005 indicated an estimated tritium concentration of 237 pCi/l, which was slightly above the detection limit. Gross alpha radiation was reported to be 1.44E-8 μCi/ml with a detection limit of 2.04E-9 μCi/ml. Gross beta radiation was reported to be 9.85E-9 μCi/ml with a detection limit of 3.03E-9 μCi/ml. Gamma radiation was not detected in the sample. Radiological analysis of sample 10005 indicated all measured parameters to be well within the SNDW standards.

Volatile organic analysis of sample 10005 indicated the presence of methylene chloride at an estimated concentration of 1 μg/l, and an unknown compound with a retention time of 1.05 minutes at an estimated concentration of 6 μg/l. Neither of these compounds were detected in the associated laboratory blank analysis. The source of these compounds and the nature of the unknown compound are unknown, however, their presence at extremely low concentrations are not considered cause for significant concern.

SVOA analysis of sample 10005 indicated the presence of 4-methyl-2-pentanon-4-ol at a concentration of 31 μg/l. However, the detection of 4-methyl-2-pentanon-4-ol at a concentration of 51 μg/l in the laboratory blank cast considerable doubt on the validity of its detection in the sample. No other known semi-volatile organic compounds were detected.

Inorganic (metals and anions) analyses of sample 10005 were obtained by DRI's Water Analysis Laboratory in Reno, Nevada. All analyzed constituents (magnesium, sulfate, chloride, nitrate, arsenic, iron, manganese, copper, zinc, barium cadmium, chromium, lead, mercury, selenium, silver, and fluoride) were below the SNDW standard.

Sample 10006

Sample 10006 was collected at 2330 hours on August 27, 1991, from the sump at ER-12-1 to determine the hydrochemical characteristics of fluids recovered from the well during the drilling process. The well had not yet penetrated the static water level. Samples were collected for VOA, SVOA, tritium, gross alpha-beta-gamma spectroscopy, metals/anions, and PCB analysis. VOA, SVOA, PCB, and radiological analysis was performed by the REECo laboratory in Mercury. Inorganic analyses (metals/anions) were conducted by DRI's Water Analysis Laboratory in Reno.

Radiological analysis of sample 10006 indicated tritium concentration below background with a detection limit of 285 pCi/l for the method used. Gross alpha radiation was reported to be 1.58E-8 μCi/ml, below the detection limit of 1.78E-8 μCi/ml. Gross beta radiation was reported to be 3.00E-8 μCi/ml with a detection limit of 2.26E-8 μCi/ml. Gamma radiation was not detected in the sample. Radiological analysis of sample 10006 indicated all measured parameters to be well within the SNDW standards.

Initial volatile organic analysis of sample 10006 indicated the presence of acetone and an unknown compound tentatively identified as 2-propanol in excess of the calibration range for the method used. The sample was re-run at a dilution factor of 5. A back-up sample (sample 10006b), collected at the same time, was also run at a dilution factor of 5. Sample 10006, run at a dilution factor of 5, indicated the presence of acetone and methylene chloride at concentrations of 650 and 27 μg/l, respectively. Sample 10006b, also run at a dilution factor of 5, indicated the presence of acetone, methylene chloride and 4-methylene-2-pentanone at concentrations of 800, 11, and 8 μg/l, respectively. Concentration values for methylene chloride and 4-methyl-2-pentanone in sample 10006b are estimated. The unknown compound tentatively identified as 2-propanol in the original undiluted analysis of sample 10006 was not detected in either sample run at a dilution factor of 5. In the associated laboratory blank, run at a dilution factor of 1, methylene chloride was detected at a estimated concentration of 0.8 μg/l. The detection of methylene chloride in the associated laboratory blank, although at a much lower estimated concentration, casts doubt on the validity of its detection in the samples. The acetone detected in both sample 10006 and the back-up sample 10006b may be due to bottle contamination or the presence of the compound within fluids obtained from ER-12-1.

Semi-volatile organic analysis (SVOA) of sample 10006 indicated the presence of 2-chlorophenol, benzoic acid, 2-methylnaphthalene, acenaphthylene, di-n-butylphthalate, and bis

(2-ethylhexyl)phthalate at estimated concentrations of 0.4, 7, 0.3, 6, 0.7, and 2 µg/l, respectively. Twenty-one unknown or tentatively identified SVOA compounds were also detected in sample 10006. The 16 unknown compounds had retention times within the gas chromatograph of 5.61, 6.31, 14.45, 18.26, 21.94, 24.12, 26.66, 28.13, 29.05, 29.45, 30.4, 31.61, 32.8, 33.54, 33.75, and 36.62 minutes, and estimated concentrations of 69, 17, 36, 85, 16, 14, 23, 41, 23, 87, 550, 180, 91, 330, 62, and 36 µg/l, respectively. The five tentatively identified SVOA compounds detected in sample 10006 include heptanoic acid, nonanoic acid, decanedioic acid, dodecanamide, and ethanol, with retention times of 14.22, 18.14, 22.43, 23.16, and 25.64 minutes, at estimated concentrations of 16, 10, 67, 10, and 29 µg/l, respectively. The associated laboratory blank contained di-n-butylphthalate at an estimated concentration of 0.7 µg/l, and three unknown compounds. The three unknown compounds detected in the laboratory blank had retention times of 5.6, 30.27, and 33.53 minutes, with estimated concentration of 94, 17, and 65 µg/l, respectively. The source of these SVOA compounds (and nature of the unknown compounds) is not known.

The origin of the detected VOA and SVOA compounds are not known. It is known, however, that on August 14, 1996, two gallons of oil were put down the hole to lubricate the bit. This oil is a likely source of the VOA and SVOA compounds detected in this sample. This theory is further supported by analysis of levels of waste oil in sample 10009 (fluid being circulated in well ER–12–1) at concentrations of 40 to 47 mg/Kg.

No PCBs were detected in sample 10006. Detection limits for the method used were 2.5 µg/g for oil, 0.866 µg/g for swipe, and 0.05 µg/g for soil.

Inorganic (metals and anions) analyses of sample 10006 were obtained by DRI's Water Analysis Laboratory in Reno, Nevada. All analyzed constituents (magnesium, sulfate, chloride, nitrate, arsenic, iron, manganese, copper, zinc, barium cadmium, chromium, lead, mercury, selenium, silver, and fluoride) were determined to be within SNDW standards.

Sample 10007

Sample 10007 was collected at 1900 hours on September 4, 1991, from 509.3 (1671 ft) below ground level following penetration of the static water level (swl at approximately 470 m (1542 ft) below ground level). The sample was collected by DRI using a discrete interval wireline sampler for safe drinking water analysis by the state of Nevada.

All analyzed inorganic constituents (magnesium, sulfate, chloride, nitrate, arsenic, iron, manganese, copper, zinc, barium cadmium, chromium, lead, mercury, selenium, silver, and fluoride) were determined to be within SNDW standards with the exception of chromium and lead. The SNDW standard for both chromium and lead is 0.05 mg/l. Sample 10007 was determined to contain lead at a concentration of 0.3 mg/l, and chromium at a concentration of 0.69 mg/l. Subsequent sample analysis results and an inventory of the materials used in well construction indicated the most likely source for these elevated concentrations to be the plating used to protect the pipe threads on the drilling string. Repeated threading and unthreading of the drilling string may have resulted in abrasion and solution of the plating material, producing elevated chromium and lead concentrations in the fluid within the wellbore.

Sample 10008

Samples 10008a and 10008b were collected at 1400 hours on September 27, 1991. These samples were collected in an effort to determine the source of the chromium detected in sample 10007. Sample 10008a consisted of drilling foam used in the well construction process at ER-12-1. Sample 10008b was composed of drilling mud from the Baker tank at ER-12-1. Analysis by DRI's Water Analysis Laboratory in Reno indicated a chromium concentration in sample 10008b of 0.01 mg/l, and in sample 10008a of less than 0.01 mg/l.

Sample 10009

Samples 10009a and 10009b were collected at 1240 and 1226 hours, respectively, on October 11, 1991. These samples were collected to determine the total petroleum hydrocarbon (TPH) content of the drilling fluid (60 to 120 vis mud; Table 5) prior to entering the well (sample 10009a) and immediately upon its return to the surface (sample 10009b). Sample 10009a was collected at the standpipe at the drilling rig; sample 10009b was collected at the flowline where drilling fluids were discharged from the well. TPH analysis was conducted by REECo's Industrial Hygiene Laboratory. Gasoline and diesel fuel were not detected in either sample. Waste oil was detected in sample 10009a at a concentration of 47 mg/kg with a detection limit of 10 mg/kg for the method used. Sample 10009b contained waste oil at a concentration of 40 mg/kg with a detection limit of 10 mg/kg.

Sample 10010

This sample was collected for safe drinking water analysis prior to discharging pumped fluid from the well to land surface. Approximately 578,460 liters (152,630 gallons) of fluid were produced from the well by pumping and developing prior to sampling. Samples were collected for cations, anions, nitrate, gross alpha, radium-226 and -228, tritium, and strontium-90 activity. Sample 10010 was collected at 1215 hours on March 15, 1991, and taken to Lockheed Analytical Laboratory in Las Vegas, Nevada, for analysis.

Radiological analysis of sample 10010 indicated a tritium activity of 167 pCi/l with an estimated uncertainty of 51 pCi/l and a detection limit of 66 pCi/l (based upon a counting period of 300 minutes on a Quantulus Liquid scintillation counter; Russ Stimmel, LES Laboratory, formerly Lockheed Analytical Laboratory; personal communication, January 6, 1997). Gross alpha activity was reported to be 21 pCi/l with an estimated uncertainty of 8 pCi/l and a detection limit of 8 pCi/l. Strontium-90 activity was reported to be 0.93 pCi/l with an estimated uncertainty of 0.62 pCi/l and a detection limit of 1.1 pCi/l. Radium-226 activity was reported to be 2.0 pCi/l with an estimated uncertainty of 0.19 pCi/l and a detection limit of 0.04 pCi/l. Radium-228 activity was reported to be 2.6 pCi/l with an estimated uncertainty of 0.8 pCi/l and a detection limit of 1.1 pCi/l.

All analyzed constituents (magnesium, sulfate, chloride, nitrate, arsenic, iron, manganese, copper, zinc, barium cadmium, chromium, lead, mercury, selenium, silver, and fluoride) were determined to be within SNDW standards.

Sample 10011

Sample 10011 was collected at the completion of initial aquifer testing at ER-12-1. The sample was collected at 1240 hours on April 1, 1992 and taken to Lockheed Analytical Laboratory in Las Vegas, Nevada for analysis. Analysis was requested for compliance with applicable SDWA standards (cations, anions, nitrate, and gross alpha-beta-gamma spectroscopy). At the time the sample was collected, approximately 648,600 liters (171,200 gallons) of fluid had been recovered from the well during development and testing activities.

Radiological analysis of sample 10011 reported gross alpha activity to be 22 pCi/l with an estimated uncertainty of 9 pCi/l and a detection limit of 11 pCi/l. Gross beta activity was reported to be 17 pCi/l with an estimated uncertainty of 9 pCi/l and a detection limit of 13 pCi/l. Gamma spectrum analysis reported a total activity of 231 pCi/l. The level of gamma activity observed in the sample was due primarily to high concentrations of lead-214 and bismuth-214. Both lead-214 and bismuth-214 were detected in the sample at concentrations slightly in excess of 100 pCi/l. Lockheed Analytical Laboratory, in their analysis summary, indicated the high concentration of lead-214 and bismuth-214 were probably due to the presence of radon-222 and its daughters. Since the sample was counted two days after collection, much of the radon-222 and its daughters would still have been present in the sample.

All analyzed constituents (magnesium, sulfate, chloride, nitrate, arsenic, iron, manganese, copper, zinc, barium cadmium, chromium, lead, mercury, selenium, silver, and fluoride) were determined to be within SNDW standards with the exception of manganese and iron. Manganese and iron concentrations within sample 10011 were reported at 0.21 and 1.1 mg/l, respectively. SNDW standards set limits of 0.1 for manganese and 0.6 μg/l for iron. The source of the elevated manganese and iron concentrations in sample 10011 is unknown. Sample 10011 was collected immediately prior to the conclusion of pumping during the long-term aquifer test portion of initial aquifer testing at ER-12-1. At that time, approximately 648,600 liters (171,200 gallons) of fluid had been recovered from the well. Sample 10010, collected at the end of well development, after approximately 578,460 liters (152,630 gallons) of fluid had been recovered from the well, contained manganese and iron concentrations well below the SNDW standards. A possible explanation is that by the end of the long-term aquifer test, draw-down within the well was sufficient to allow intervals in the well, which did not normally contribute to discharge from the well, to begin yielding fluids. These fluids would consist, to a large degree, of drilling and development fluids from zones that may not have been purged until this time.

<u>Geochemical Characterization Sample</u>

Sample Number 10012

Sample 10012 was acquired on January 5, 1993, at the end of the long-term aquifer test conducted on the upper zone 518 to 554 m (1700 to 1820 ft). The purpose of this sample was to acquire the ionic and isotopic chemistry of the water and use it to determine the source of the fluid within this zone. Samples were acquired for volatile and semivolatile organic analyses, total petroleum hydrocarbons, ionic chemistry, trace metals, stable and radiogenic isotopes, and total organic carbon. The results of these analyses are presented in Table 39.

Several volatile organic compounds were detected in sample 10012 above the detection limit and were not detected in associated blanks. These consist of chloroform (5.0 μg/l) bromodichloromethane (7.0 μg/l), dibromochloromethane (16 μg/l), bromoform (65 μg/l), and an unknown compound with a retention time of 1.54 minutes (17 μg/l). Two semivoloatile organic compounds were identified in the well water. These consisted of an unknown compound with a retention time of 5.75 minutes with an estimated concentration of 9 μg/l and a second compound, tentatively identified as Phenol, 4,4'-(1-methylethyli), with a concentration of 10 μg/l. No petroleum hydrocarbons were detected in the water.

The ionic chemistry of sample 10012, and that of samples previously taken from carbonate wells, volcanic wells, and wells completed in the Eleana, are presented in Figure 48. The results indicate that sample 10012 had anomalous calcium, chloride, magnesium, and sulfate values concentrations relative to similar wells on the NTS. These elevated concentrations were also detected in sample 10007 and 10010. Examination of the bromide concentration in sample 10012 indicates that drilling fluids compose approximately 20 to 25 percent of the fluid in this sample. Elevated concentrations of calcium and chloride may be due to calcium chloride used in the well as a cement accelerator. Elevated levels of sulfate may be due to the use of bentonite mud in the borehole. In either case, it is highly probable that analysis of sample 10012 is not representative of formation water.

Results of the radiochemical analysis from LLNL are also presented in Table 39. Portions of the following discussion are excerpted from LLNL (1993). All radionuclides measured in the ground water from ER–12–1 were found to be at or below detection limits, with the exception of tritium. Tritium was measured at 361 pCi/L (113 TU) or approximately 50 times less than the drinking water standard (20,000 pCi/L). The source of the tritium was speculated to have originated from the drilling fluids (LLNL, 1993).

It is estimated that a total of 8.4 x 10^6 liters (2.2 x 10^6 gallons) of drilling and development fluid were circulated through well ER–12–1. Approximately 6.2 x 10^6 liters (1.6 x 10^6 gallons) were trucked away from the well and 0.6 x 10^6 liters (0.16 x 10^6 gallons) were discharged to land surface and 0.32 x 10^6 liters (0.084 x 10^6 gallons) were left in the sump at ER–12–1. These calculations result in approximately 1.2 x 10^6 liters (0.32 x 10^6 gallons) of drilling fluid remaining in well ER–12–1. This quantity of fluid has been partially purged by the approximately 1.2 x 10^6 liters (0.32 x 10^6 gallons) that drained from the upper zone into the three lower zones (during the period of April 24 to October 23, 1992) while the borehole remained open. Sample 10005 (fluid from the mud plant sump) had a tritium activity of 237 pCi/L. It is highly probable, assuming there was some dilution of the drilling fluid with the formation water, that some fraction of the drilling fluid remained in the upper zone in well ER–12–1 (as indicated by the elevated levels of bromide in the sample; 4.9 mg/L), and potentially contributed to a portion of the tritium activity detected in sample 10012. The maximum activity, based on the aforementioned data, that could be potentially contributed by

Table 39. Geochemical Results from the Upper Zone, 518 to 555 m (1700 to 1820 ft), of Well ER-12-1

.

Volatile Organic Analysis

Compound	Concentration Units µg/l	Qualifier
Chloromethane	2.0	U
Bromomethane	2.0	U
Vinyl Chloride	2.0	U
Chloroethane	2.0	U
Methylene Chloride	1.0	U
Acetone	1.0	BJ
Carbon Disulfide	1.0	U
1,1-Dichloroethene	1.0	U
1,1-Dichloroethane	1.0	U
1,2-Dichloroethane (total)	1.0	U
Chloroform	5.0	
1,2-Dichloroethane	1.0	U
2-Butanone	2.0	U
1,1,1-Trichloroethane	1.0	U
Carbon Tetrachloride	1.0	U
Vinyl Acetate	2.0	U
Bromodichloromethane	7.0	
1,2-Dichloropropane	1.0	U
cis-1,3-Dichloropropene	1.0	U
Trichloroethene	1.0	U
Dibromochloromethane	16.	
11,1,2-Trichloroethane	1.0	U
Benzene	1.0	U
trans-1,3-Dichloropropene	1.0	U
Bromoform	65.	E
4-Methyl-2-Pentanone	2.0	U
2-Hexanone	2.0	U
Tetrachloroethehe	1.0	U
1,1,2,2-Tetrachloroethane	1.0	U
Toluene	1.0	U
Chlorobenzene	1.0	U
Ethylbenzene	1.0	U
Styrene	1.0	U
Xylene (total)	1.0	U

Compound	Return Time	Est. Conc.	Qualifier
Unknown	1.54	17.00	J

Table 39. Geochemical Results from the Upper Zone, 518 to 555 m (1700 to 1820 ft), of Well ER-12-1 (continued).

Semivolatile Organics Analysis

Compound	Concentration Units µg/l	Qualifier
Phenol	10	U
bis (2-Chloroethyl) ether	10	U
2-Chlorophenol	10	U
1,3-Dichlorobenzene	10	U
1,4-Dichlorobenzene	10	U
Benzyl alcohol	10	U
1,2-Dichlorobenzene	10	U
2-Methylphenol	10	U
bis (2-chlorolisopropyl) ether	10	U
4-Methylphenol	10	U
N-Nitroso-Di-n-propylamine	10	U
Hexachloroethane	10	U
Nitrobenzene	10	U
Isophorone	10	U
2-Nitrophenol	10	U
2,4-Dimethylphenol	10	U
Benzoic acid	50	U
bis (2-Chloroethoxy) methane	10	U
2,4-Dichlorophenol	10	U
1,2,4-Trichlorobenzene	10	U
Naphthalene	10	U
4-Chloroaniline	10	U
Hexachlorobutadiene	10	U
4-Chloro-3-methylphenol	10	U
2-Methylnaphthalene	10	U
Hexachlorocyclopentadiene	10	U
2,4,6-Trichlorophenol	10	U
2,4,5-Trichlorophenol	50	U
2-Chloronaphthalene	10	U
2-Nitroaniline	50	U
Dimethylphthalate	10	U
Acenaphthylene	10	U
2,6-Dinitrotoluene	10	U
3-Nitroaniline	50	U
Acenaphthene	10	U
2,4-Dinitrophenol	50	U
4-Nitrophenol	50	U
Dibenzofuran	10	U

Table 39. Geochemical Results from the Upper Zone, 518 to 555 m (1700 to 1820 ft), of Well ER-12-1 (continued).

Semivolatile Organic Analysis

Compound	Concentration Units µg/l	Qualifier
2,4-Dinitrotoluene	10	U
Diethylphthalate	10	U
4-Chlorophenyl-phenylether	10	U
Fluorene	10	U
4-Nitroaniline	50	U
4,6-Dinitro-2-methylphenol	50	U
N-Nitrosodiphenylamine (1)	10	U
4-Bromophenyl-phenylether	10	U
Hexachlorobenzene	10	U
Pentachlorophenol	50	U
Phenanthrene	10	U
Anthracene	10	U
Di-n-butylphthalate	10	U
Fluoranthene	10	U
Pyrene	10	U
Butylbenzylphthalate	10	U
3,3'-Dichlorobenzidine	20	U
Benzo (a) anthracene	10	U
Chrysene	10	U
bis (2-Ethylhexyl) phthalate	10	U
Di-n-octylphthalate	10	U
Benzo (b) fluoranthene	10	U
Benzo (k) fluoranthene	10	U
Benzo (a) pyrene	10	U
Indeno (1,2,3-cd) pyrene	10	U
Dibenz (a,h) anthracene	10	U
Benzo (g,h,i) perylene	10	U

Compound	Return Time	Est. Conc.	Qualifier
Unknown	5.75	9.00	J
Phenol, 4,4'-(1-methylethyli)	31.39	10.00	J

Total Petroleum Hydrocarbons

Constituent	Result	Units	Minimum Detection
Diesel	<0.5	mg/l	0.5
Oil	<0.5	mg/l	0.5
Gasoline	<5.0	mg/l	5.0

Table 39. Geochemical Results from the Upper Zone, 518 to 555 m (1700 to 1820 ft), of Well ER-12-1 (continued).

Results of Ionic Analyses

Constituent	mg/l
HCO3	319
Cl	46.7
SO4	357
NO3	1.64
Na	74.2
K	5.10
Ca	96.8
Mg	64.8
NO3 as N	0.37
TDS	876
Br	4.9
F	0.33
TKN	<0.1
NH4	.01
NO2	0.02
TPO4	8.59
Al	<0.02
Sb	0.026
As	0.48
Ba	0.011
Be	<0.001
Cd	<0.001
Cr	<0.01
Co	<0.01
Cu	0.008
Fe	0.51
Pb	0.017
Li	1.37
Mn	0.05
Hg	<0.0002
Ni	<0.01
Se	0.006
Ag	<0.005
Tl	<0.001
V	<0.02
Zn	<0.005
TOC	<0.1
Fe2	<0.05
Fe3	0.51

Table 39. Geochemical Results from the Upper Zone, 518 to 555 m (1700 to 1820 ft), of Well ER-12-1 (continued).

Stable Isotopes

Constituent	Per Mil	Standard
$\delta\ ^{18}O$	-12.4	VSMOW
δ D	-94	VSMOW
$\delta\ ^{13}C$	-10.0	PDW

Radioisotopes

Constituent	Activity	Estimated Uncertainty	MDA	Units
Radon-222	403	17.	2.3	pCi/L

Constituent	Activity	Estimated Uncertainty	Units
Gr-Alpha	4.95 E-09	30.3%	µCi/ml
Gr-Beta	2.40E-09	33.3%	µCi/ml
Gamma	no radionuclide detected	N/A	N/A

Constituent	Activity	Estimated Uncertainty	Units
Carbon-14	10.9	1.0	Percent activity at 1950 C-14 activity
	17,800	665	Years BP (^{13}C corrected) Note $\delta\ ^{13}C_{pDB} = 12.2$ per mil
Tritium (DRI)	311	11	pCi/L

Constituent	Activity	Estimated Uncertainty	MDA	Units
Radium-226	0.28	0.37	0.62	pCi/l
Radium-228	1.91	0.79	1.5	pCi/l
Uranium	2.042	0.051	0.10	µg/l

Table 39. Geochemical Results from the Upper Zone, 518 to 555 m (1700 to 1820 ft), of Well ER-12-1 (continued).

LLNL Radiochemistry

Radioisotopes				
Constituent	Activity	Estimated Uncertainty	MDA	Units
$^{3}H–^{3}He$	361	34.	6.4	pCi/L
^{60}Co	≤0.27		0.27	pCi/L
^{85}Kr	≤30		30	pCi/L
^{90}Sr	≤0.5		0.5	pCi/L
^{99}Tc	≤4.5		4.5	pCi/L
^{125}Sb	≤0.74		0.74	pCi/L
^{137}Cs	≤0.28		0.28	pCi/L
^{234}U	7.93			pCi/L
^{235}U	0.073			pCi/L
^{238}U	1.59			pCi/L
^{36}Cl	0.0071			pCi/L
^{14}C	0.1069			pmc
^{13}C	–9.2			per mil
$^{36}Cl/Cl$	$5.06 \times 10^{-12} \pm 5.9 \times 10^{-14}$			
^{36}Cl	360×10^{7}			atoms/L
$^{87}Sr/^{86}Sr$	0.71175 ± 0.00002			
$\delta^{87}Sr$	3.60			
$^{234}U/^{238}U$	0.000275 ± 0.0000003			
$^{234}U/^{235}U$	0.03794			
$^{234}U/^{238}U$	4.99			activity ratio
^{4}He	4.89×10^{12}	2 %		atoms/ml
^{20}Ne	2.55×10^{13}	2 %		atoms/ml
^{36}Ar	8.78×10^{13}	2 %		atoms/ml
^{82}Kr	5.17×10^{11}	2 %		atoms/ml
^{129}Xe	1.36×10^{11}	2 %		atoms/ml
^{3}He	7.38×10^{6}	2 %		atoms/ml

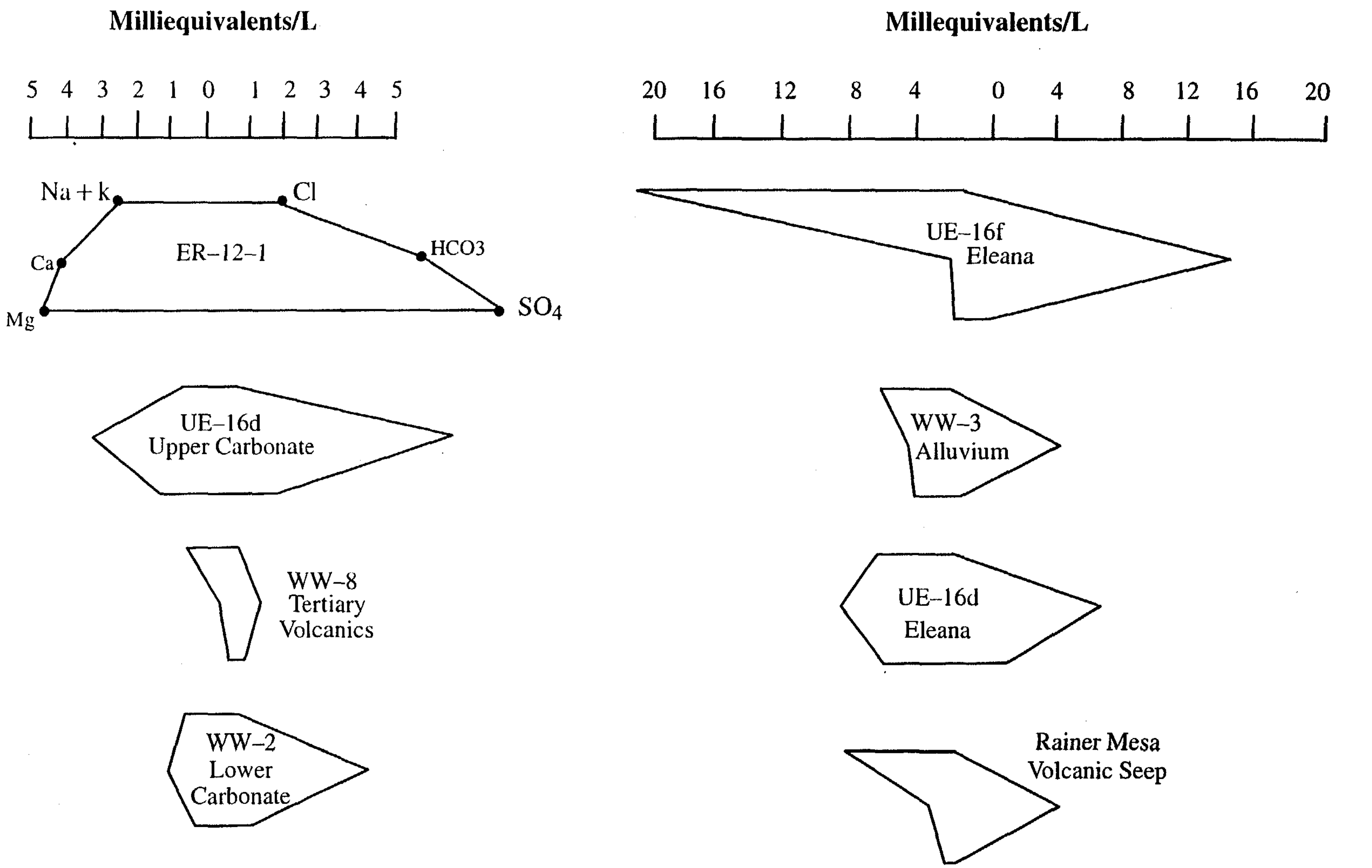


Figure 48. Stiff diagrams for carbonate, Eleana, and volcanic wells.

drilling fluid to sample 10012 is estimated to be 60 pCi/L. An alternative hypothesis is the source of the tritium found in well ER–12–1 (which is 1.5 times greater than the tritium activity found in sample 10005) was the U12e infiltration ponds located 460 m (1500 ft) to the east of well ER–12–1. These sumps have been receiving tritiated effluent with activities of 2.4 x 10^6 pCi/L for over two decades (Russell *et al.*, 1993). The sumps are composed of a thin veneer of alluvium overlying fractured dolomite. A third potential source for the tritium found in the upper zone of ER–12–1 is the underground nuclear tests conducted in Rainier Mesa, located approximately 2.1 km (1.3 miles) to the east of the well site. These detonations, in addition to being more distant than the tritium ponds, were conducted in zeolitized tuffs, which have some of the lowest hydraulic conductivities measured on the NTS (Thordarson, 1965). The underground tests are a less likely source of tritium, owing to their greater distance and an expected lower permeability of the surrounding geologic matrix, relative to the tunnel ponds. The existing data, however, do not differentiate or negate any of the aforementioned hypotheses. Time series sampling, at a pump rate of 190 l/min (50 gpm), in the upper zone is recommended if the source of tritium in ER–12–1 needs to be resolved. If the source of tritium was drilling fluids, the concentrations will dilute with additional pumping and decrease. If the tritium was from the ponds or from underground nuclear tests, then pumping will cause further migration of the tritium to the well, increasing concentrations.

The ^{14}C content of the groundwater from ER–12–1 was much lower than natural atmospheric ^{14}C and indicated that the groundwater had an apparent age of 18,500 years. The $\delta^{13}C$ signature of the groundwater (–9.2 per mil) reflected natural values and was indicative of dissolved carbon derived from the unsaturated zone. This suggested an insignificant amount of Paleozoic carbonate ($\delta^{13}C \sim 0$ per mil) dissolution had occurred. This conclusion was highly uncertain due to the probable influence of the water added down–hole during drilling. Therefore, the low ^{14}C content of the water sampled at ER–12–1 may have been derived from the naturally occurring groundwater in the aquifer, or a mixture of drilling fluids and the aquifer water (LLNL, 1993).

The $^{36}Cl/Cl$ ratio measurement for groundwater from ER–12–1 had an environmental level, but was an order of magnitude higher than naturally occurring groundwater at the NTS from similar depths. This suggested that an anthropogenic chloride component had been introduced into the water, which was consistent with the higher than normal chloride concentration (46.7 mg/L). The drilling fluids, Li/Br, or the cement accelerators were likely sources (LLNL, 1993).

Dissolved noble gas measurements in the groundwater sampled from ER–12–1 indicated that a component of modern injected air was introduced in the groundwater. This was best seen in the abundance of ^{20}Ne, which was a factor of three to six higher than had been found in other UGTA well waters to date. The ^{20}Ne abundance in modern air is high relative to the other dissolved noble gases. It is probable that the noble gas pattern in ER–12–1 was disturbed by atmospheric introduction during well development (LLNL, 1993).

The $^{87}Sr/^{86}Sr$ ratio (0.7118) in the groundwater from ER–12–1 was at a natural level. The ^{235}U concentration was also at an environmental level, as was the $^{234}U/^{238}U$ ratio, which had an activity ratio greater than one, suggesting some natural disequilibria between the solubility of the two isotopes in the crystal lattice structure of the aquifer matrix. Uncertainties in the effects of well development render inconclusive the interpretations based on the strontium and uranium isotopes (LLNL, 1993).

The stable isotopic signature of sample 10012 is plotted in Figure 49. This plot also contains representative isotopic signatures of Rainier Mesa seeps and wells on the NTS completed in various formations. The data for these other wells are presented in Table 40. The plot indicates that the water sampled from the upper zone of well ER-12-1 was intermediate isotopically to the water found in seeps in Rainier Mesa and water from Well 8. If the water from ER-12-1 was contaminated 20 to 25 percent with isotopically depleted water from Water Well 8 and Wells C and C-1 (which feed the sump at the Area 3 mud plant), then the true signature was even more enriched than that shown in Figure 48. The one conclusion that can be drawn from this plot is formation water in Well ER-12-1 was isotopically similar to water that originated as precipitation on Rainier Mesa.

SUMMARY

The objective of well ER-12-1, N886,640.26 E640,538.85 Nevada Central Coordinates, was to determine the hydrogeology of Paleozoic carbonate rocks and of the Eleana Formation, a regional aquitard, in an area potentially down–gradient from underground nuclear testing conducted in nearby Rainier Mesa. Drilling of the 1094 m (3588 ft) well began on July 19, 1991, and reached TD on October 17, 1991. Drilling problems included hole deviation and hole instability that prevented the timely completion of this borehole. Drilling methods used include rotary tri-cone and rotary hammer drilling with conventional and reverse circulation using air/water, air/foam (Davis mix), and bentonite mud.

Geologic cuttings and geophysical logs were obtained from the well. The rocks penetrated by the ER-12-1 drillhole are a complex assemblage of Ordovician, Silurian, Devonian, and Mississippian sedimentary rocks that are bounded by numerous faults that show substantial stratigraphic offset. The final 7.3 m (24 ft) of this hole penetrated an unusual intrusive rock of Cretaceous age. The geology of this borehole was substantially different from that expected, with the Tongue Wash Fault encountered at a much shallower depth, Paleozoic rocks shuffled out of stratigraphic sequence, and the presence of an altered biotite-rich lamprophyre rock at the bottom of the borehole.

Conodont CAI analyses and rock pyrolysis analyses indicate that the carbonate rocks in ER-12-1, as well as the intervening sheets of Eleana siltstone, have been thermally overprinted following movement on the faults that separate them. The probable source of heat for this thermal disturbance is the lamprophyre intrusion encountered at the bottom of the hole, and its age establishes that the major fault activity must have occurred prior to 102.3+0.5 Ma (middle Cretaceous).

Geophysical logs run in the saturated and unsaturated sections of the borehole were invaluable for interpretation of stratigraphy and structure. Problems encountered during logging were lack of

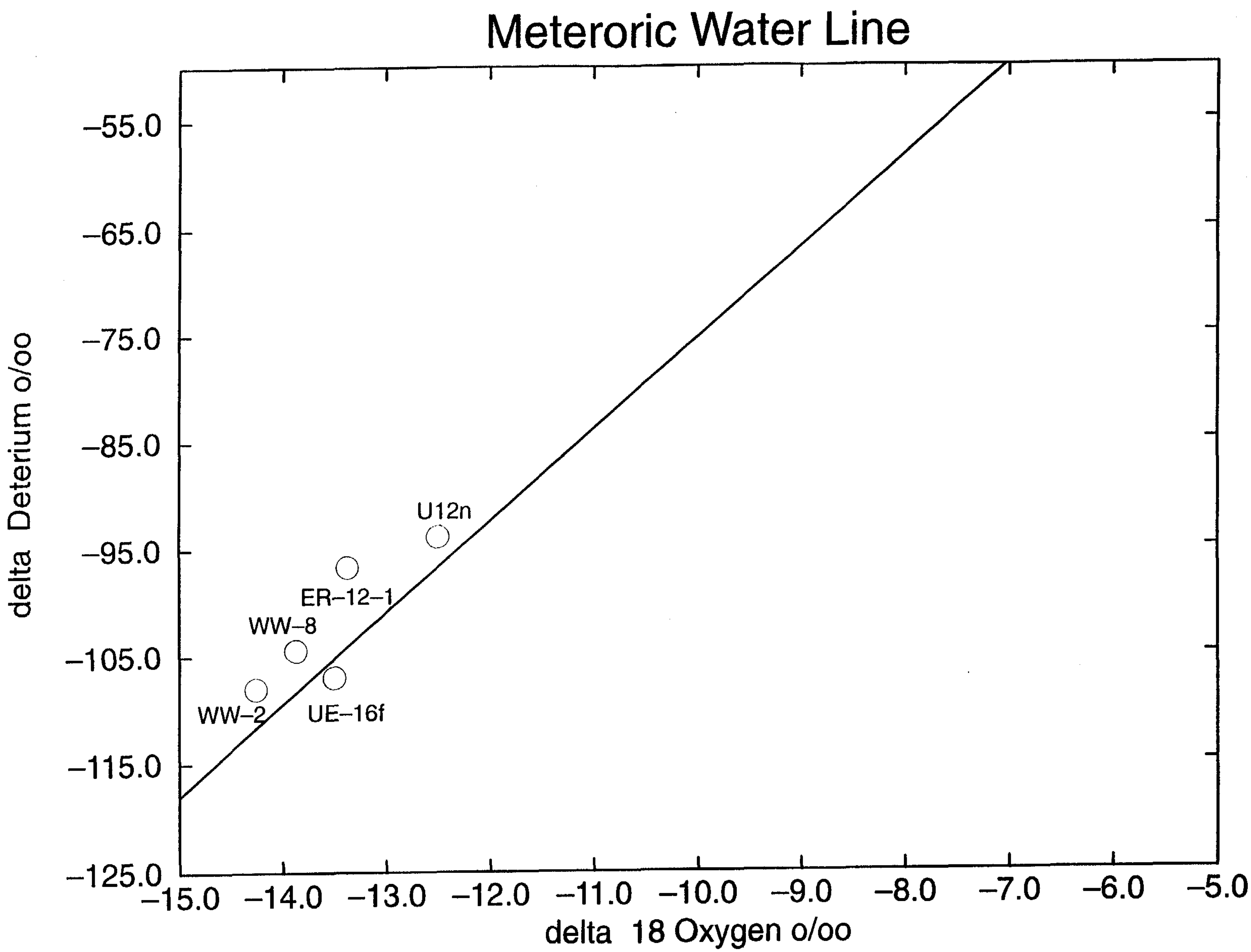


Figure 49. Stable isotopic signature of sample 10012 verses samples from Rainier Mesa seeps, carbonate wells and volcanic wells.

Table 40. Stable Isotopic Signature of Wells and Seeps on the NTS.

Well	$\delta^{18}O$	δD
Carbonate Wells		
UE1q	-14.6	-109
UE-1b	-13.8	-105
Well C-1	-14.4	-109
Well C	-14.4	-109
Test Well-1	-15.3	-110
HTH-3	-14.2	-104
Well 2	-14.2	-103
UE-15d	-14.2	108
UE1c	-13.9	-104
UE16f	-13.5	-107
Volcanic Wells		
U20n	-14.9	-113
UE-18r	-15.0	-110
UE-18t	-13.8	-105
PM3	-14.8	-115
Water Well 20	-15.5	-111
Well 8	-14.0	-104
UE-19c	-15.4	-111
U19ba	-14.0	-104
UE-4t	-13.8	-101
Well ER-12-1		
ER-12-1	-12.4	-94
Alluvial Wells		
Test Well B	-14.1	-105
Rainier Mesa Volcanic Seeps		
U12n.03	-13.3	-97
U12n.03	-12.4	-92
U12n.03	-13.4	-99
U12n.03	-13.5	-95
U12n.03	-13.4	-97
U12n.05	-12.9	-94
U12n.05	-13.0	-93
U12n.05	-13.0	-95
U12n.05	-13.0	-94
U12n.05	-12.8	-93

service tables for stacked logs, lack of calibration tables for the 0.445m (17-1/2in) diameter borehole, and lack of written procedures for running these logs in the field.

Hydrologic investigations consisted of water level monitoring, flow logging, aquifer tests, and drill-stem tests. The results indicated that the static composite fluid level in well ER-12-1 is 469 m (1540 ft) below land surface. Drill-stem tests and flow logs determined that the lower two intervals in the well were under–pressured relative to the upper zones by approximately 396 m (1300 ft). Aquifer tests, drill-stem tests, and flow logs determined that the transmissivity of the well ranged from 7×10^{-6} to 4×10^{-4} m^2/s, with the most transmissive zone being 518 to 554 m (1700 to 1820 ft) below land surface followed by the 914 to 963 m (3000 to 3160 ft) interval. The pressure differential between these zones allowed for substantial cross–flow to occur while the well was open.

Two types of geochemical samples were acquired from this well. Water quality samples taken during drilling and testing indicated very few problems associated with the well. Those identified consisted of elevated concentrations of volatile and semivolatile organics and metals associated with the drilling process. Geochemical characterization samples were taken only from the uppermost zone, 518 to 554 m (1700 to 1820 ft). The results from this sample indicated anomalous chemistry, which is most likely due to residual drilling fluids remaining in the borehole. Trace levels of tritium detected in the upper borehole may be attributed to contamination by drilling fluid, water recharging via the nearby U12e tunnel ponds, or water flowing from the underground nuclear tests conducted in Rainier Mesa.

REFERENCES

Atlas Wireline Services, 1985, "Log Interpretation Charts," Atlas Wireline Services report.

Atlas Wireline Services, 1988, "Logging Procedures Manual for NTS" (Per Contract SC-TS-84-197) Atlas Wireline Services internal report.

Cole, J.C., A.G. Harris, M.A. Lanphere, C.E. Barker and R.G.Warren, 1993, The case for pre-middle Cretaceous extensional faulting in northern Yucca Flat, southwestern Nevada, Geological Society of America Abstracts with Programs, Vol. 25, no. 5, p. 22.

Cole, J.C., 1991 unpublished, "Pre-drilling Geologic Summary for Characterization Well E-Tunnel Access' (ER-12-1)," U.S. Geological Survey Unpublished Report, 7 p.

Cooper, H.H, J.D. Bredehoeft and I.S. Papadopulos, 1967, Response of a finite-diameter well to an instantaneous charge of water, Water Resources Res., Vol. 3, p 263-269.

Cooper, H.H. Jr. and C.E. Jacob, 1946, A generalized graphical method for evaluating formation constants and summarizing well-field history, American Geophysical Union Transactions, 27, No. 4, p 526-534.

Desert Research Institute, 1990, Cultural Resources Reconnaissance Short Report SR081090-1, Quaternary Sciences Center, Desert Research Institute, Las Vegas and Reno, NV.

Dickey, D.D. and F.A. McKeown, 1959, Geology of Dolomite Hill, Nevada Test Site, Nye County, Nevada, U.S. Geological Survey Trace Elements Investigations Report TEI-755, 64 p.

Drellack, S.L., Jr., L.B. Prothro, P.H. Thompson and R.L. McCall, 1991, "Preliminary Geology and Drill Hole Data Report for Groundwater Characterization Well ER-12-1, Nevada Test Site, Nye County, Nevada," Raytheon Services Nevada report, 77 p.

Epstein, A.G., J.B. Epstein and L.D. Harris, 1977, Conodont color alteration - an index to organic metamorphism, U.S. Geological Survey Professional Paper 995, 27 p.

Gibbons, A.B., E.N. Hinrichs, W.R. Hansen and R.W. Lemke, 1963, Geology of the Rainier Mesa Quadrangle, Nye County, Nevada, U.S. Geological Survey Geological Quadrangle Map GQ-215.

Gupta, V.K. and G.R. Walter, (1985) unpublished, Accounting for time variable pumping in analysis of pumping tests, Hydro Geo Chem Inc., 1430 N. 6th Ave, Tucson, AZ.

Harris, A.G., B.R. Wardlaw, C.C. Rust and G.K. Merrill, 1980, Maps for assessing thermal maturity (conodont color alteration index maps) in Ordovician through Triassic rocks in Nevada and Utah and adjacent parts of Idaho and California, U.S. Geological Survey Miscellaneous Investigations Map I-1249, scale 1:2,500,000.

Lai, R.Y. and C. Su, 1974, Non-steady flow to a large well in a leaky aquifer, Journal of Hydrology, Vol. 22, p 333-345.

Lawrence Livermore National Laboratory, 1993, Isotopic Analysis of Groundwater from Monitoring Well Er–12–1. Letter Report to Steve Lawrence DOE/ERP Technical Program Officer of UGTA RI/FS, Dec. 15, 1993.

Kruseman, G.P. and N.A. de Ridder, 1992, Analysis and Evaluation of Pumping Test Data, International Institute for Land Reclamation and Improvement Pub. 47, Wageningen, the Netherlands, 365 p.

Maldonado, F., S.G. Steele and D.R. Townsend, Supplementary Lithologic Logs of Selected Vertical Drill Holes in Area 12, Nevada Test Site, U.S. Geological Survey.

Miller, D.R., 1970, Lithologic logs and stratigraphic identification for vertical drill holes in Area 12, Nevada Test Site, U.S. Geological Survey Report Area 12-27, 34 p.

Millet, M.R. and D.J. Felske, 1989, LLNL NTOD Geophysics Logging Procedures, GEO-89-01.

Moench, A.F., 1984, Double-porosity models for a fissured groundwater reservoir with fracture skin, Water Resources Research, Vol. 20, p. 831-846.

Naeser, C.W. and F. Maldonado, 1981, Fission-track dating of the Climax and Gold Meadows stocks, Nye County, Nevada, In Short Contributions to Geochronology, U.S. Geological Survey Professional Paper 1199-E, p. 45-47.

Osmond, J.C., 1954, Dolomites in Silurian and Devonian of east-central Nevada, Bulletin of the American Association of Petroleum Geologists, Vol. 38, No. 8, p. 1911-1956.

Pawloski, G.A. and R.C. Carlson, 1992, Preliminary geophysical logging data report for Ground Water Characterization well ER-12-1, Nye County, Nevada Test Site, Lawrence Livermore National Laboratory Report, February 1992, 69 p.

Papadopulos, S.S., J.D. Bredehoeft and H.H. Cooper, 1973, On the analysis of slug test data: Water Resources Res., Vol. 9, p. 1087-1089.

Russell, C.E., 1991 unpublished, "Hydrogeologic Summary for Groundwater Characterization Well ER-12-1 (U12e Tunnel Access)", Desert Research Institute unpublished report, Reno and Las Vegas, NV, 14 p.

Russell, C.E., L. Gillespie, D. Gillespie, 1993, Geochemical and hydrologic characterization of the effluent draining from U12e, U12n, and U12t tunnels, Area 12, Nevada Test Site. Desert Research Institute Publication 45105, Reno and Las Vegas, NV, p 24.

Schlumberger Well Services, 1992, Formation MicroScanner Report for ER-12-1, Shlumberger Well Services, 5000 Gulf Freeway, P.O. Box 2175, Houston, Texas 77001.

Schoff, S.L. and I.J. Winograd, 1961, Hydrologic significance of six core holes in carbonate rocks of the Nevada Test Site, U.S. Geological Survey Trace Elements Investigations Report TEI-787, 97 p.

Stehfest, H., 1970, Numerical inversion of Laplace transform, Communications of ACM, Vol. 13, No. 1, p 47-49.

Theis, C.V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage, Trans. Amer. Geophys. Union, Vol. 16, p 519-524.

Thordarson, W., 1965, Perched groundwater in zeolitized-bedded tuff, Rainier Mesa and vicinity, Nevada Test Site, Nevada, U.S. Geological Survey Trace Elements Investigation Report TEI-862, 89 p.

Waddell, R.K., J.H. Robison and R.K. Blankennagel, 1984, Hydrology of Yucca Mountain and vicinity, Nevada-California: Investigative Results through mid-1983, U.S. Geological Survey Water-Resources Investigations Report 84-4267, 40 p.

Winograd, I.J. and W. Thordarson, 1975, Hydrogeologic and Hydrochemical Framework, South-Central Great Basin, Nevada-California, with Special Reference to the Nevada Test Site, U.S. Geological Survey Professional Paper 712-C, 119 p.

APPENDIX A

GEOLOGIC PREDICTION REPORT

DOE ENVIRONMENTAL RESTORATION PROGRAM
GROUND WATER CHARACTERIZATION
DRILLING PROGRAM

PRE-DRILLING GEOLOGIC SUMMARY
FOR CHARACTERIZATION WELL

"E-TUNNEL ACCESS" (ER12-1)

James C. Cole
U.S. Geological Survey
Denver, Colorado

4 May, 1991

Introduction

The first ground water characterization well is proposed to be drilled on the east slope of Rainier Mesa in south-central Area 12 of the Nevada Test Site. The site is about 400 feet south of the paved access road to the (inactive) E-tunnel complex and adjacent to an unimproved jeep trail in the bottom of a small northeast-trending draw.

Hole Name:	E-Tunnel access
Hole Designation:	ER12-1
Site Coordinates:	N. 886,650; E. 640,600
Surface Elevation:	5810 feet
Design Depth:	3500 feet
Water Table Depth:	± 1600 feet (est.)
Surface Geology:	Simonson Dolomite

The coordinates listed above are about 500 feet northeast of those (N. 886,400; E. 640,200) listed in the memorandum of 10 January 1991 ("Well Site Review and Geology Meeting") issued prior to the first meeting of the ground water characterization planning group on 16 January 1991. These coordinates were scaled from the 1:12,000-scale USGS topographic map (Rainier Mesa SW) based on the location identified by flagged lath stakes that were present when the site was visited on 29 March 1991.

This location was selected by DRI and USGS (various correspondence in 1990) to explore the geologic and hydrologic conditions of Paleozoic carbonate rocks in a down-gradient position from expended underground test sites within the Rainier Mesa complex. The collar position was chosen to allow penetration of dolomite through the unsaturated zone and for several hundred feet below the water table, and to reach the footwall of the Tongue Wash fault (most likely Eleana Formation clastic rocks) within the 3500 foot design depth.

Background

Systematic geologic mapping of the area around the E-Tunnel complex east of Rainier Mesa was completed in the late 1950's and published at 1:24,000-scale for the Rainier Mesa quadrangle (Gibbons and others, 1963). The hillslope immediately west of the ER12-1 site was more closely investigated in conjunction with drilling of the "Dolomite Hill" core hole in 1959. This hole penetrated 1200 feet of unsaturated dolomite; core recovery ranged from fair to poor, and approximately 27 boxes of NX core are cataloged at the USGS Core Library facility in Mercury (presently stored in Area 25 at the RMAD building). A detailed geologic map of the area and a detailed lithologic log for that hole were reported by Dickey and McKeown (1960). An interpretation of geophysical logs for the Dolomite Hill hole and the results of limited mineralogical and chemical analyses were presented by Roach and others (1960?).

An exploratory core hole designated U12e.M-1 was also drilled in 1959 from an alcove at elevation 6158 within the E-Tunnel complex. Good to excellent core recovery was obtained by the continuous wireline method, but current records do not indicate where these materials presently reside. No geophysical logs were run. A lithologic log for U12e.M-1 is reported by Schoff and Winograd (1961), along with the results of water level measurements, bailing and pumping tests, and related hydrologic investigations for this and the Dolomite Hill hole. Thordarson (1965) summarized the hydrologic observations for these holes that penetrated Paleozoic rocks as part of a comprehensive report on perched ground water in the Rainier Mesa environs.

Drill holes U12e.06 A and U12e.06 B entered Paleozoic dolomite but did not penetrate more than 100 feet. Hole U12e.06-1 R/C, however, penetrated 755 feet of dolomite (McArthur and Skrove, 1962; Miller, 1970); the existence of geophysical logs and core samples is unknown.

Stratigraphy

Stratigraphic relationships and nomenclature for the Paleozoic rocks exposed along the western margin of the Yucca Flat basin have been the subject of renewed investigation in recent years (Peter Guth, written communication, 1988; Alan Titus, written communication, 1989; Caskey and Schweickert, 1989; Cole and others, 1990, and unpublished mapping). For the Devonian and Mississippian units of interest surrounding the ER12-1 site, the following table summarizes current usage for named stratigraphic units:

CURRENT STRATIGRAPHIC UNITS	PRIOR STRAT UNITS
MDe Eleana Fm (units A-J)	MDe Eleana Fm (units A-J)
[not in stratigraphic contact in this area]	
Dg Guilmette Fm	Dld or Dd Devils Gate Limestone
Ds Simonson Dolomite	Dnu or Dn Nevada Fm (upper)
Dsca "cherty-argil. unit"	Dnl (part) Nevada Fm (lower)
DSs Sevy Dolomite	DSOl Dolomite and limestone; also, Spotted Range dolomite units D-F)
Sl Laketown Dolomite	Sl Laketown Dolomite

The dolomitic rocks mapped at the surface on the east side of Rainier Mesa by Dickey and McKeown (1960) and by Gibbons and others (1963) correspond to the Simonson Dolomite, the "cherty-argillaceous unit", and (possibly) the Sevy Dolomite. The three subunits of the Nevada Fm shown on the Rainier Mesa quadrangle map (Dda, Ddb, and Ddc) correspond most closely with the middle and upper parts of the regionally defined Simonson Dolomite (Osmond, 1954). Osmond's lowermost unit of "tan, coarse dolomite" and the "brown, cliff-forming biostromal dolomite" do not appear to be mappable entities in the NTS area.

Devonian rocks crop out at several widely separated localities at NTS and physical correlation between sections is not possible. No systematic study has been conducted in these rocks to determine internal stratigraphic relations, fossil contents, or depositional environments, and thus the structural and(or) hydrologic connections between the individual outcrop blocks are not determined. In general, however, there is overall similarity in terms of internal lithology, thickness, and fossil content between the exposed sections: 1) North of Oak Canyon; 2) East of Rainier Mesa; 3) Mine Mountain; 4) Shoshone Mountain; and 5) at Mercury Ridge. (NOTE: As pointed out by Rogers and Noble, 1969, two dissimilar Devonian sequences in the Oak Spring Butte quadrangle suggest that a major pre-Tertiary structure is present between the limestone-rich section along Carbonate Wash beneath the basal Eleana Formation and the more typical dolomite-rich section north of Oak Canyon). In summary, the typical Devonian units are:

Guilmette Limestone

about 1000 feet thick; thick, alternating beds of medium-gray limestone and sandy limestone, with local thin beds of brownish quartz sand and limy quartzite; dolomite beds interfinger near base and also dominate in a 200-foot thick zone below the uppermost quartzite beds at Shoshone Mountain; corals, crinoids, and some brachiopods and algal fossils are typical but not common

Simonson Dolomite

thickness appears to range between about 935 feet (Mercury Ridge) and more than 2000 feet (east of Rainier Mesa); chiefly consists of well bedded dolomite of various shades of gray; limestone is untypical and sandy beds are generally sparse except near the base and in the middle; dolomitized fossil brachiopods, stromatoperoid algal masses, crinoids, and tubular forms (described as "spaghetti coral") are common and form substantial concentrations in biostromal beds, particularly in the middle and upper parts of the formation; the distinctive and time-restricted Stringocephalus brachiopod is exceptionally abundant in thin beds near the top of the formation at Mercury Ridge, Shoshone Mountain, and in Carbonate Wash. A general three-fold subdivision seems to be recognizable:

- Upper variegated dolomite (400 to 600 feet thick, but as thick as 1500 feet at Dolomite Hill); well-bedded, generally dark-gray in aspect, fossil-rich
- Middle tan-gray dolomite (250 to 300 feet thick); thick-bedded with platy internal laminations, more uniform in overall color than units above and below; somewhat sandy or silty, especially near base; fossils less common
- Lower variegated dolomite (180 to about 600 feet thick); well bedded; light to medium gray with discrete dark-gray dolomite beds; sandy and brownish in lower part

"Cherty-argillaceous unit"

about 40 to 120 feet thick; brownish sandy, silty, and chert-bearing thin-bedded dolomite; chert nodules are red, brown, or black and irregularly shaped; silty dolomite is olive-drab on fresh surfaces but weathers yellow-gray

Sevy Dolomite

about 900 feet thick; typically poorly bedded and homogeneous, light mouse-gray, coarse-grained; commonly brecciated; fossils extremely rare and generally consist of dolomitized ghosts of corals(?) and brachiopods; the middle third of the Sevy tends to be a bit darker and indistinctly banded, but this feature is most apparent from a distance

Presence of the Early Devonian Sevy Dolomite in the E-Tunnel area is uncertain. Previous investigators (Dickey and McKeown, 1960; Gibbons and others, 1963) have tentatively identified the light-gray, indistinctly bedded dolomites in the lower hanging wall of the Tongue Wash fault with similar-looking dolomites around NTS that are approximately Sevy-age or older ("DSOl"). However, examination of these rocks on 29 March 1991 shows that some of the indistinct bedding is the result of fault-induced brecciation, and that dark-gray dolomites and sparse fossil crinoid fragments are present (both are atypical of the Sevy). The brown-weathering silty and cherty beds at the bottom of the exposed section next to the Tongue Wash fault are most like the "cherty-argillaceous unit" Dsca that marks the faint regional unconformity between the Sevy and Simonson dolomites (Osmond, 1954), and so it is likely that the hillslope above is lower Simonson rather than Sevy. This interpretation is also more consistent with structural relations described in the next section.

The Mississippian Eleana Formation exposed in the Eleana Range east of Rainier Mesa is expected to be encountered at depth in ER12-1 in the footwall of the Tongue Wash fault. Because of structural complications described below, it is difficult to predict which subunits of the Eleana will be penetrated with great certainty. However, the gross anticlinal structure of the Eleana Range indicates that the middle and lower parts of the formation are most likely (units D and lower), and so laminated fine-grained quartzite, siltstone, and thin chert-pebble conglomerate beds are expected (Poole and others, 1961). In this regard, I differ with the interpretation of Gibbons and others (1963) that the west-dipping beds of the Eleana east of Tongue Wash are overturned; examination of conglomerate beds in this area are inconclusive about the sense of stratigraphic facing, but several instances of graded bedding suggest that the section is right-side-up.

Structure

Most of the structural geology on the east side of Rainier Mesa that is relevant to expected conditions beneath the ER12-1 site pertains to the configuration of the Paleozoic rocks. These are exposed along the Tongue Wash valley, in the Eleana Range, and west of the drill site up to Dolomite Hill, but these outcrops lack lateral continuity to the southwest and northeast. Faulting, bedding, and related features must be inferred at depth because they cannot be confidently projected downward from the surface. Uncertainty about some of the Devonian rocks, and lack of reliable stratigraphic indicators in the Eleana Formation on the west flank of the Eleana Range also add to the uncertainty about structural configurations.

The Tertiary volcanic rocks are largely draped over the pre-existing topographic surface formed by the Paleozoic rocks. This area of the Nevada Test Site has been tectonically stable, for the most part, since the onset of major volcanic activity about 15 million years ago (Sawyer and others, 1990). Stability is indicated by the gentle dips of volcanic layering, by the nearly uninterrupted deposition of volcanic ash in the Rainier Mesa area in the period 15 Ma to 11 Ma, and by paleomagnetic investigations by Hudson (1990). Structural warps and high-angle faults do affect the Tertiary section in this area, but the magnitude of deformation is small in comparison to that recorded in the Paleozoic rocks (Minor, 1990).

The west-dipping fault that is exposed on the west side of Tongue Wash and juxtaposes footwall Mississippian Eleana Formation with hangingwall Devonian carbonate rocks has long been interpreted as a thrust (for example, Gibbons and others, 1963) and inferred to have formed during the Mesozoic Sevier orogeny. This "CP thrust" of Carr (1974) and others does not appear to be supported by outcrop evidence. Examination of the fault zone shows numerous grooved slip surfaces in both wallrocks that dip westward between 42° and 48°. Slickenlines consistently plunge toward the northeast at shallow inclinations (four measured values between 14° and 20°; fig. 1), and subtle asymmetries on these surfaces suggest the sense of movement was sinistral-reverse (M. Hudson, oral commun., 1989). At the outcrops north of the E-Tunnel access road just west of the Stockade Wash Road (fig. 1), the silicified fault zone is notably sinuous as it is exposed to the north in a manner that suggests large-scale, northeast-plunging grooves and swales.

The Eleana quartz sandstones, siltstones, and chert-pebble conglomerates adjacent to the fault are relatively unsheared, but the dolomites of the hangingwall tend to be shattered, veined with silica and calcite, and locally stained with iron oxides. These types of features are inconsistent with observations along well-known thrust faults of the Sevier system (Cole and others, 1990).

Additional surface reconnaissance east of the ER12-1 site indicates that the northeast-trending fault shown on the Rainier Mesa quadrangle map (Gibbons and others, 1963) is not a large-displacement high-angle structure. As shown on Fig. 1, and in section on Fig. 2, this fault dips moderately east and is marked by a distinctive, 3-foot-thick breccia zone of gray dolomite fragments and yellow-weathering silica veins; talus blocks of this material litter the east-facing slope of the small ridge, which must approximately coincide with the original fault surface. In addition, the argument given above for identification of the hangingwall rocks in this block as lower Simonson Dolomite (rather than Sevy-equivalent; Gibbons and others, 1963) implies that the amount of offset is small (less than about 200 feet; fig. 2). As shown on fig. 1, slip on this fault appears to diminish to the southwest and die out. Similar relations in minor faults within the dolomites were mapped in detail by Dickey and McKeown (1959).

In summary, the Tongue Wash fault is interpreted as a pre-volcanic structure whose last major movement was dominantly strike-slip, although the orientation of the fault surface at the time of slip is not known. The asymmetric anticlinal form of the Eleana in the footwall may have formed simultaneously or later and may preserve a footwall fold related to mid-Tertiary extension (as perhaps with the Eleana anticline in the Mine Mountains; Cole and others, 1990; see also Guth, 1990). Pre-volcanic Tertiary extension is clearly indicated in this area on the basis of the low-angle fault structures defined at Mine Mountain by Cole and others (1990), by the subsurface detection of stacked structural plates of shattered Devonian(?) dolomite and Eleana siltstone around the Baneberry site (Area 8; U.S. Geological Survey, 1974), and by the presence of out-of-structure fault blocks of Ordovician limestone south of the Area 12 Camp site (Gibbons and others, 1963).

I infer that the Devonian dolomites west of the Tongue Wash fault are dismembered at depth and disconnected from any regional carbonate stratum. Gravity data (Healey and others, 1987) indicate that high-density "basement" rocks are continuous westward beneath Rainier Mesa for about 4 miles where they are probably truncated by the structural wall of the Timber Mountain caldera. These inferred carbonate rocks are probably also truncated toward the south by similar structures at the southwest end of the Eleana Range.

Expected Conditions

Prior experience with drilling, coring, and hydrologic testing in carbonate rocks at the Nevada Test Site has been mixed. In the particular cases of the Dolomite Hill hole, U12e.06-1 R/C, and U12e.M-1 (all of which were continuously sampled by the wireline method; NX core), recovery was moderate to excellent except where brecciation was widespread. This condition was particularly troublesome at Dolomite Hill, which is substantially closer to the Tongue Wash fault than the E-Tunnel holes, where recovery was less than 30% for almost 60% of the hole (Dickey and McKeown, 1959; Schoff and Winograd, 1961). Widespread rock fracturing in U12e.M-1 and Dolomite Hill also led to loss of circulation in several long intervals; large quantities of bentonite was added to the drilling fluid to maintain circulation, and hydrologic test results were compromised (Schoff and Winograd, 1961).

Many breccia zones described from the core had open, vuggy channels and permeable fractures, but other breccias were sealed with calcite cement. In Dolomite Hill, core from the upper and lower thirds of the hole seemed to have open fractures and greater inferred permeability than the middle third where calcite fillings were more pervasive, but no interpretation was given. Nonetheless, the various hydrologic tests that were made in Dolomite Hill and U12e.M-1 clearly indicate that rock permeability is controlled by fractures and not by interstitial flow. Even with the uncertain effect of residual bentonite in fractures, fluid levels declined in these holes at rates that imply total formation permeabilities an order of magnitude greater than lab-measured interstitial permeability (Schoff and Winograd, 1961). In order to establish the effect of fracture conditions on ground water behavior, cuttings alone are inadequate to establish what kinds of fractures and fracture fillings are present. Adequate samples from continuous core must be obtained.

Drilling in the Eleana Formation should not produce unexpected difficulties, even though it is thin-bedded, closely fractured at the surface, and has exhibited some squeezing behavior. More than 96% core recovery (NX size) was obtained in UE17e in a 3000 foot hole (Hodson and Hoover, 1979) and UE25a-3 showed similar recovery over 2500 feet at Calico Hills (Maldonado and others, 1979). UE16d and UE16f both experienced problems in some intervals with caving and hole erosion during rotary drilling (3000 feet and 1500 feet, respectively), but hydraulic tests were successfully completed in both holes (Dinwiddie and Weir, 1979).

Expected Geology

On the basis of surface geology and geometric projections to depth, the following rock units and structures are anticipated to be penetrated during drilling of ER12-1:

DEPTH, in feet	GEOLOGIC FEATURE
320 ± 20	Base of middle Simonson unit
740 ± 40	Base of Simonson Dolomite
790 ± 40	Base of "cherty-argill" unit
1000 ± 100	Intersection with minor east-dipping fault
1650 ± 200	Potentiometric surface
2070 ± 180	Faulted base of Sevy Dolomite top of Eleana Formation Piercement of Tongue Wash fault
3500	Bottom of hole: lower Eleana Fm.

References Cited

Carr, W.J., 1974, Summary of tectonic and structural evidence for stress orientation at the Nevada Test Site: U.S. Geological Survey Open-File Report 74-176, 48 p., map at 1:48,000 scale.

Caskey, S.J., and Schweickert, R.A., Mesozoic west-vergent thrust in the CP Hills, Nevada Test Site, Nye County, Nevada: Geological Society of America Abstracts with Programs, vol. 21, no. 5, p. 64.

Cole, J.C., Wahl, R.R., and Hudson, M.R., 1990, Structural relations within the Paleozoic basement of the Mine Mountain block; Implications for interpretation of gravity data in Yucca Flat, Nevada Test Site: Proceedings of the Fifth Symposium on the Containment of Underground Nuclear Explosions, Santa Barbara; vol. 2, p. 431-456

Dickey, D.D., and McKeown, F.A., 1959, Geology of Dolomite Hill, Nevada Test Site, Nye County, Nevada: U.S. Geological Survey Trace Elements Investigations Report TEI-755, 64 p.

Dinwiddie, G.A., and Weir, J.E., Jr., 1979, Summary of hydraulic tests and hydrologic data for holes UE16d and UE16f, Syncline Ridge area, Nevada Test Site: U.S. Geological Survey Report USGS-1543-3, 21 p.

Gibbons, A.B., Hinrichs, E.N., Hansen, W.R., and Lemke, R.W., 1963, Geology of the Rainier Mesa Quadrangle, Nye County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-215, scale 1:24,000

Guth, P.L., 1990, Bedrock geologic map of the Indian Springs 1:100,000-scale quadrangle, Nevada: U.S. Geological Survey Open-File Report 90-???, 32 p., scale 1:100,000.

Hodson, J.N., and Hoover, D.L., 1979, Geology of the UE17e drill hole, Area 17, Nevada Test Site: U.S. Geological Survey Report USGS-1543-2, 36 p.

Hudson. M.R., 1990, Paleomagnetic evaluation of the Yucca-Frenchman flexure, southern Nevada: Proceedings of the Fifth Symposium on the Containment of Underground Nuclear Explosions, Santa Barbara; vol. 2, p. 417-430.

Maldonado, F., Muller, D.C., and Morrison, J.N., 1979, Preliminary geologic data of the UE25a-3 exploratory drill hole, Nevada Test Site, Nevada: U.S. Geological Survey Report USGS-1543-6, 43 p.

McArthur, R.D., and Skrove, J.W., 1962, ...: Lawrence Radiation Laboratory report CN-1-62.

Miller, D.R., 1970, Lithologic logs and stratigraphic identification for vertical drill holes in Area 12, Nevada Test Site: U.S. Geological Survey Report Area 12-27, 34 p.

Minor, S.A., 1990, Paleostress investigation near Rainier Mesa, Nevada Test Site: Proceedings of the Fifth Symposium on the Containment of Underground Nuclear Explosions, Santa Barbara; vol. 2, p. 457-482.

Osmond, J.C., 1954, Dolomites in Silurian and Devonian of east-central Nevada: Bulletin of the American Association of Petroleum Geologists, vol. 38, p. 1911-1956.

Poole, F.G., Houser, F.N., and Orkild, P.P., 1961, Eleana Formation of Nevada Test Site and vicinity, Nye County, Nevada: U.S. Geological Survey Professional Paper 424-D, p. D104-D111.

Roach, C.H., Izett, G.A., and Roller, J.C., 1959, Interpretation of geophysical logs of the Granite U-15A, Dolomite Hill No. 1, and Marble No. ME-2 drill holes, Nevada Test Site, Nye County, Nevada: U.S. Geological Survey Trace Elements Investigations Report TEI-???, ? p.

Rogers, C.L., and Noble, D.C., 1969, Geology of the Oak Spring Butte quadrangle, Nye County, Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-822, scale 1:24,000.

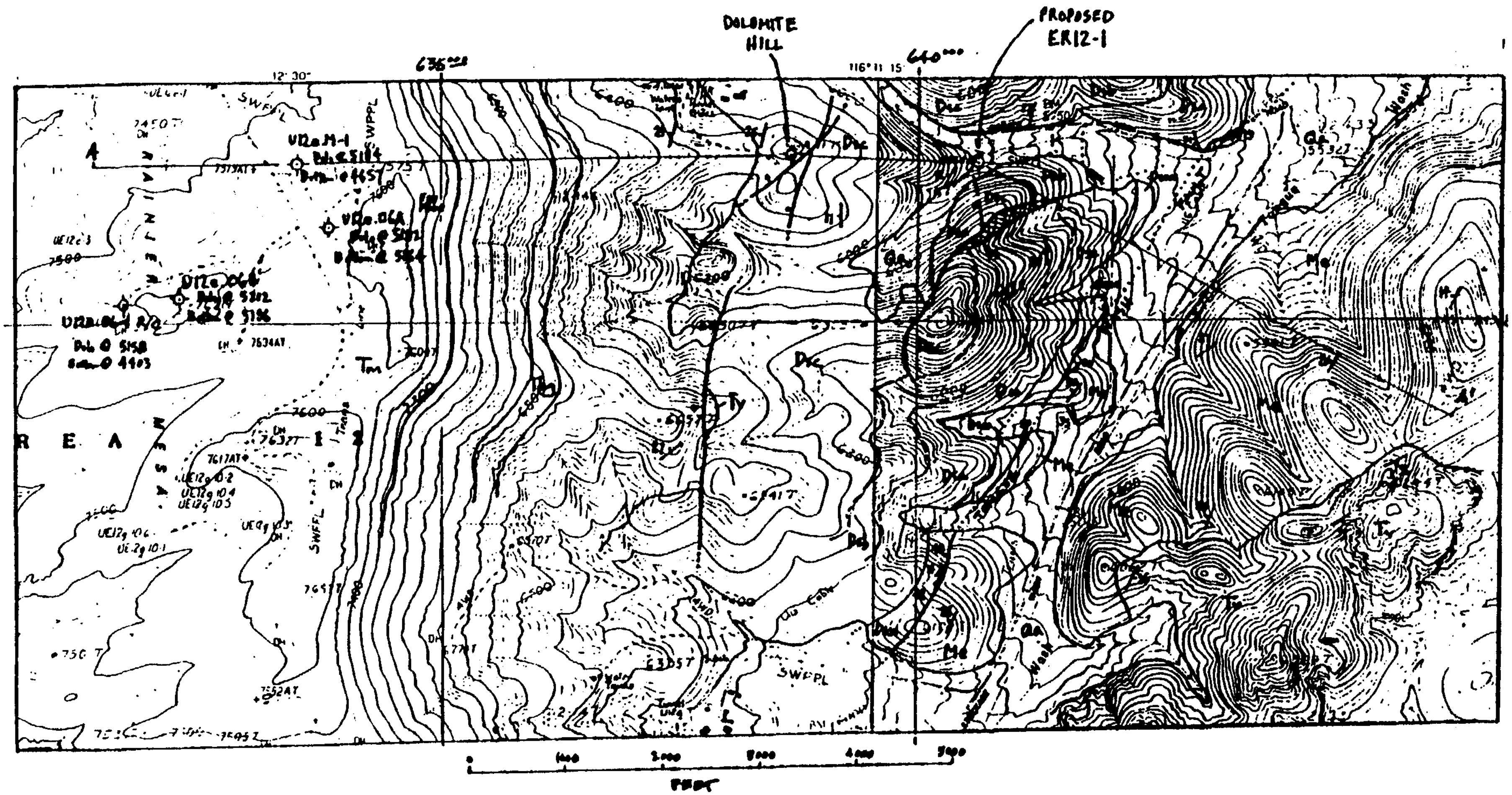
Sawyer, D.A., Fleck, R.J., Lanphere, M.A., Warren, R.G., and Broxton, D.E., 1990, Episodic volcanism in the southwest Nevada volcanic field: new $^{40}Ar/^{39}Ar$ geochronologic results: Transactions of the American Geophysical Union (EOS), vol. 71, p. 1296.

Schoff, S.L., and Winograd, I.J., 1961, Hydrologic significance of six core holes in carbonate rocks of the Nevada Test Site: U.S. Geological Survey Trace Elements Investigations Report TEI-787, 97 p.

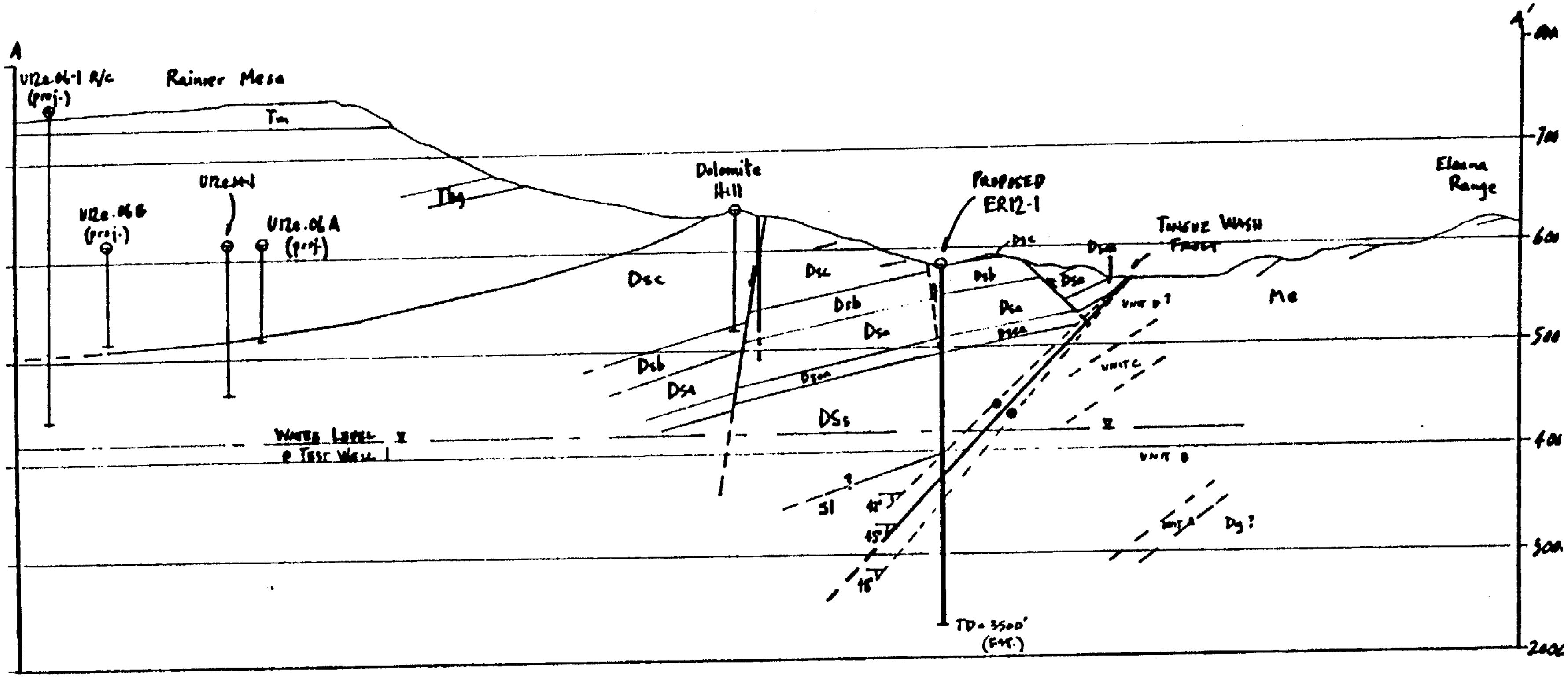
Thordarson, W., 1965, Perched ground water in zeolitized-bedded tuff, Rainier Mesa and vicinity, Nevada Test Site, Nevada: U.S. Geological Survey Trace Elements Investigations Report TEI-862, 90 p.

U.S. Geological Survey, 1974, Results of exploration of Baneberry site, early 1971: U.S. Geological Survey Report 474-145, 94 p.

Weir, J.E., Jr., and Hodson, J.N., 1979, Geohydrology of hole UE17a, Syncline Ridge area, Nevada Test Site: U.S. Geological Survey Report USGS-1543-4, 21 p.



DOLOMITE HILL
PROPOSED ER12-1
636000
660000
116°11'15"
12'30"
RAINIER MESA
0 1000 2000 3000 4000 5000
FEET



A
A'
Rainier Mesa
Tm
Thg
Dolomite Hill
PROPOSED ER12-1
TONGUE WASH FAULT
Eleana Range
Dsc
Dsb
Dsa
Ds
Me
UNIT C
UNIT B
UNIT A
Dg ?
TD = 3500' (EST.)
WATER LEVEL @ TEST WELL 1
800
700
600
500
400
300
2000

APPENDIX B

HYDROLOGIC PREDICTION REPORT

HYDROGEOLOGIC SUMMARY FOR GROUNDWATER CHARACTERIZATION WELL ER-12-1 (U12E TUNNEL ACCESS)

by
Desert Research Institute
University of Nevada System

prepared for
Environmental Restoration and Waste Management Division
U.S. Department of Energy
Field Office, Nevada
Las Vegas, Nevada

August 1991

CONTENTS

FIGURES

TABLES

HYDROGEOLOGIC SUMMARY FOR GROUNDWATER CHARACTERIZATION WELL ER-12-1 (U12E TUNNEL ACCESS)

PURPOSE AND SCOPE

This document summarizes pertinent hydrogeologic, hydraulic and geochemical data from wells relatively close and hydrogeologically similar to the ER-12-1 drill site. It also serves as a predictive report of the most probable hydrogeologic conditions that may be encountered, and is intended to be used as a guide for well design and field sample planning. In addition, this report will act as a baseline for updating the conceptual hydrogeologic model of Rainier Mesa, utilizing data gathered from the ER-12-1 borehole.

OBJECTIVE AND RATIONALE FOR THE ER-12-1 DRILLHOLE

The location of ER-12-1 was chosen to explore the hydrogeology of Paleozoic carbonates potentially downgradient from underground nuclear tests conducted within Rainier Mesa. This location is also ideal to evaluate the effect of infiltration/evaporation ponds on the regional groundwater flow system.

The drillhole was located and designed to intersect approximately 2100 ft of unsaturated and saturated Devonian dolomites, the Tongue Wash Fault, at a depth of approximately 2100 ft, and 1400 ft of underlying Eleana Formation. Hydrogeologic data from the Eleana Formation will help to evaluate the effectiveness of this unit as a groundwater flow boundary.

LOCATION AND SETTING

The ER-12-1 drill site is located at Nevada Central Coordinates N886,666 E640,512 (as built) ± 100 ft in Area 12 (Figure 1) near the base of the eastern slope of Rainier Mesa along the U12e tunnel access road where it passes close to the base of Dolomite Hill. The drill site is at an approximate elevation of 5810 ft and is collared in a very thin veneer of alluvium that overlies the Devonian Simonson Dolomite. It is approximately 2000 ft northwest of the surficial expression of the Tongue Wash Fault, a northeast-trending sinistral-reverse fault that dips approximately 45 degrees to the west. The fault brings into conjunction Devonian dolomites in the hanging wall with the Mississippian Eleana Formation in the footwall.

Surface water in the ER-12-1 site locale drains into Tongue Wash, which eventually flows into other ephemeral channels draining east into Yucca Flat, a closed hydrographic basin.

The drill site of ER-12-1 is within the Ash Meadows groundwater subbasin defined by Winograd and Thordarson (1975) and Waddell *et al.* (1984). Near Rainier Mesa, the boundary between the Ash Meadows and Alkali Flat/Furnace Creek subbasins (Figure 2) has been

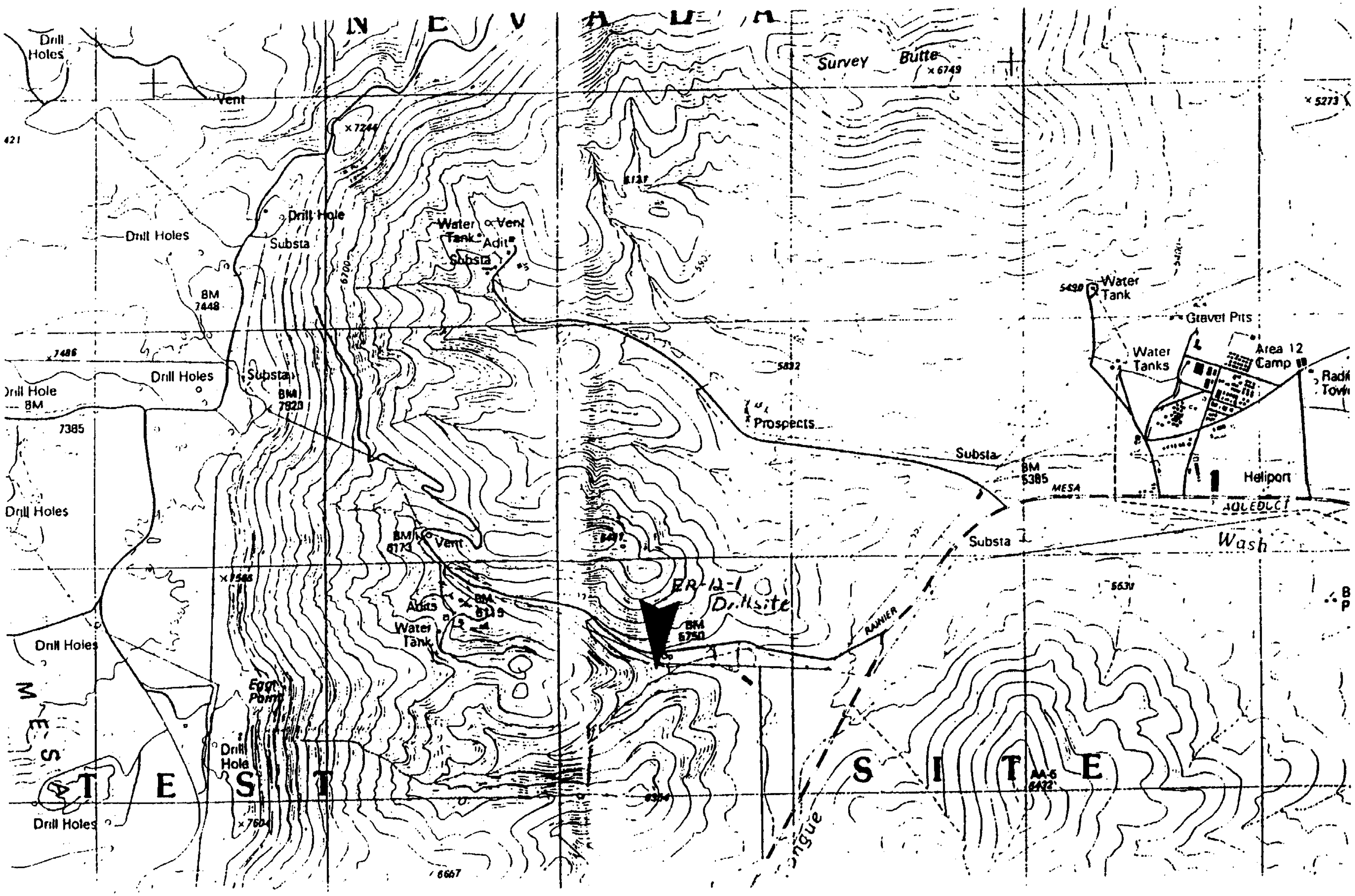


Figure 1. Location of ER-12-1 drill site.

located on the basis of hydrography. It is unlikely that this groundwater subbasin boundary coincides with the hydrographic divide. A more realistic scenario is the groundwater subbasin boundary is defined by the relatively impermeable Eleana Formation (Winograd and Thordarson, 1975). If true, groundwater beneath the ER-12-1 drill site may be draining into the Alkali Flat/Furnace Creek subbasin (via Timber Mountain) with flow ultimately discharging in Alkali Flat and Furnace Creek in Death Valley. If the current boundary, as defined by Winograd and Thordarson (1975) and Waddell *et al.* (1984), is correct, then the ultimate discharge area for groundwater flow originating near ER-12-1 would be the springs at Ash Meadows and perhaps Death Valley (via Yucca and Frenchman Flats).

The drill site for ER-12-1 is located approximately 1.3 miles southeast and east of underground nuclear tests conducted beneath the caprock of Rainier Mesa. Most of these tests are situated in a saturated groundwater lens whose top is perched approximately 2000 ft above the estimated regional groundwater table (Thordarson, 1965). In addition, the drill site is located 1500 ft east of the inactive U12e tunnel effluent ponds. These ponds contained

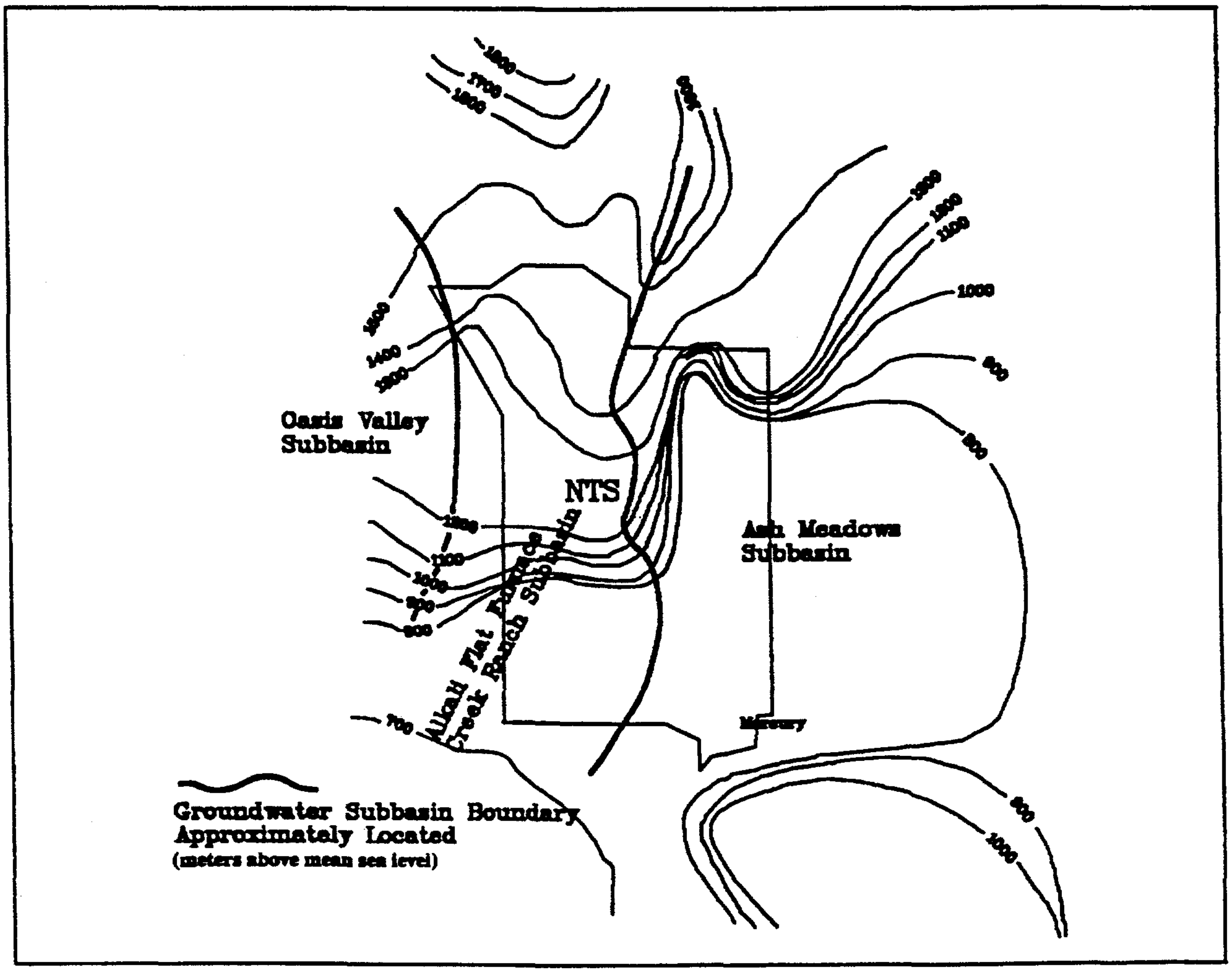


Figure 2. Composite potentiometric surface for the Nevada Test Site and subbasin boundaries (Waddell, Robison, and Blankennagel, 1984).

tritiated effluent while the tunnel was active and may have introduced contamination into the Paleozoic carbonate rocks locally.

HYDROGEOLOGY

Pre-existing hydrogeologic data in the vicinity of ER-12-1 are extremely sparse. Hydrogeologic interpolations are dependent upon incomplete data gathered from wells almost three miles distant. Interpolations of hydrogeologic information from these wells are tentative and will probably be revised as drilling and testing at ER-12-1 proceed.

Geology

A generalized interpretation of the geologic units expected to be encountered in ER-12-1 drillhole is presented in Table 1, based upon written communication (Jim Cole, USGS, Denver, Colorado, 5/4/91). ER-12-1 is collared in a thin veneer of alluvium overlying the Simonson Dolomite (Figure 3). The Simonson Dolomite is an approximately 2000 ft thick, well-bedded, fossiliferous dolomite that has been divided into upper, middle and lower subdivisions. The drillhole is anticipated to encounter approximately 740 ft of the Simonson Dolomite.

TABLE 1. ANTICIPATED GEOLOGY

Depth Interval (feet)	Geologic Unit
0–740	Simonson Dolomite
740–790	Cherty Argillaceous
790–2070	Sevy Dolomite
2070–3500	Lower Eleana Formation

(after Jim Cole, USGS, written communication, 5/4/91)

Underlying the Simonson Dolomite is a thin (40 to 120 ft thick) "cherty-argillaceous unit," consisting of a brownish sandy, silty, chert-bearing, thin-bedded dolomite. Approximately 50 ft of this unit is expected to be encountered within the ER-12-1 drillhole.

Underlying the "cherty-argillaceous unit" is the Sevy Dolomite. This dolomite is approximately 900 ft thick and is coarse grained, poorly bedded and homogeneous. The entire section of the Sevy Dolomite is expected to be encountered within the drillhole. A thin section of the Laketown Dolomite may be encountered immediately below the Sevy Dolomite. It is expected that the Tongue Wash Fault will be encountered at the base of the Sevy Dolomite. If true, the lower portion of the Sevy Dolomite and/or the Laketown Dolomite is expected to compose the hanging wall of the Tongue Wash Fault.

The footwall of the Tongue Wash Fault probably consists of the lower members (units D, C, and potentially B) of the Eleana Formation. These lower units consist of laminated, fine-grained quartzite and siltstone with thin chert-pebble conglomerate beds.

Figure 3. Drill site surface structure and geology.

Hydrology

Fluid Levels

Fluid levels have been measured in several holes in the vicinity of the ER–12–1 drill site: Test Well 1, Hagestad–1, U12e.06–1, U12e.03–1, Dolomite Hill Hole, and U12e.M1 (Figure 4). All of these boreholes were drilled through the Tertiary volcanics into the underlying Devonian dolomites, with the exception of Hagestad–1, which was drilled entirely within Tertiary volcanics. Construction, generalized stratigraphy data, and fluid levels for each hole are presented in Table 2. Fluid levels were declining during fluid–level measurements for all wells except Test Well 1. Fluid levels within Hagestad–1 were representative of perched water lenses found within confining layers created by Tertiary volcanics. Declining fluid levels within Hagestad–1 were attributed to perched groundwater and residual drilling fluids draining from the formations into a mined cavity beneath the borehole (Thordarson, 1965). Declining fluid levels within Dolomite Hill Hole, U12e.06–1, U12e.M1 and U12e.03–1 were attributed to perched groundwater and/or drilling fluids slowly draining into the underlying unsaturated dolomites. Fluid levels in the boreholes were not representative of static water levels within the Tertiary volcanics nor the Devonian dolomites.

Composite water levels have been measured over time in Test Well 1. Composite water levels are a vertically integrated average of potentiometric heads within both the Devonian dolomites and the Tertiary volcanics. These composite water levels have declined 24 feet over 28 years and have remained relatively stable for at least four years (Table 2). The potentiometric surface for dolomites within Test Well 1 was measured at 4,189 ft. This potentiometric surface is probably representative of carbonate rocks underlying Rainier Mesa and outcrops exposed to the east (Thordarson, 1965). Based upon the generalized geology of the site and fluid levels measured within Test Well 1, it is anticipated that the water table will be encountered at a depth of approximately 1600 ± 100 ft.

Transmissivities

Very few aquifer tests have been conducted within units in the vicinity of ER–12–1. The limited test data are presented along with qualitative observations to generate a reasonable estimation of conditions that may be encountered within the ER–12–1 drillhole. Aquifer tests conducted on 498 ft of dolomites found within Test Well 1 indicate a transmissivity of 3500 gal/day/ft (Figure 5). The units tested were either the Simonson Dolomite or the overlying Guilmette Formation (missing in the geologic section at the ER–12–1 drill site). In addition, the retention of 84 ft of elevated head (drilling fluid) for over seven months within the Dolomite Hill Hole is a qualitative indication of a relatively low transmissivity for the Simonson Dolomite (Schoff and Winograd, 1961). However, in the same drillhole, circulation was lost six times. The most serious loss of circulation occurred in a 15–ft–thick section of the Simonson Dolomite, where a maximum of 5,000 gallons of drilling fluid were lost. The loss of drilling fluid is an indication of the presence of relatively permeable sections. Several

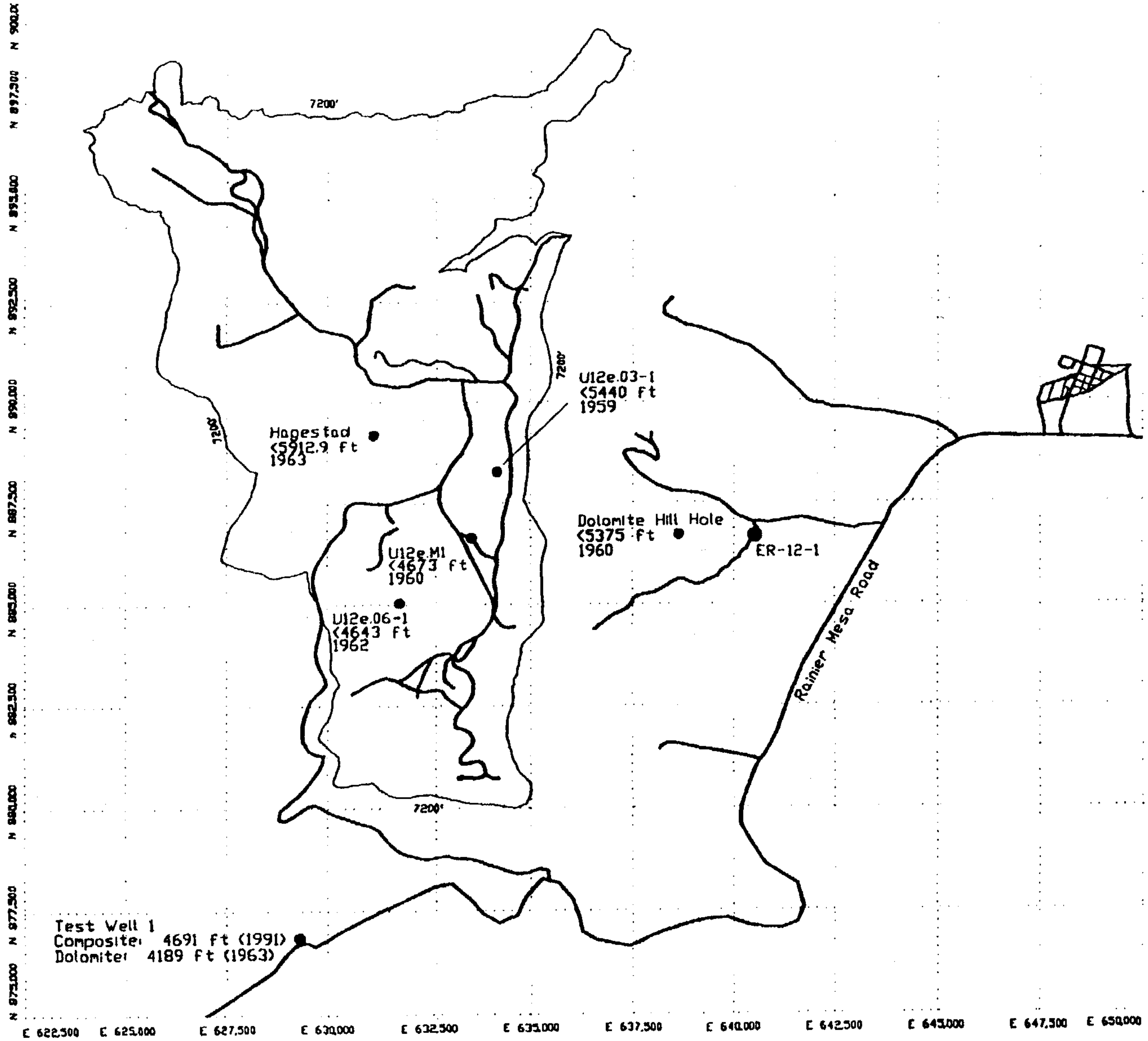


Figure 4. Drillhole locations and water-level elevations.

TABLE 2. WELL CONSTRUCTION AND STATIC WATER-LEVEL DATA											
Well	Coordinates	Year Completed	Depth of Well	Casing Size	Casing Interval	Perforated Zones	Formations Present	Altitude of Land Surface	Static Water Elevation	Date Measured
Hagestad-1	N889,190 E631,132	1957	1941	5 1/2"	0-1941	675-685 990-1000 1600-1620 1750-1770 1885-1895 1905-1915	Tertiary Volcanics Undivided	7485.3	< 5912.9	1963
Test Well 1	N876,855 E629,310	1961	4198	11 3/4" 8 5/8"	0-1615 1563-3700	1910-1950 2030-2050 2100-2160 2230-2270 2370-2430	Tertiary Volcanics Undivided Devonian Dolomite	6156	4715 4691 4691 4189	1963 1987+ 1991* 1963 for Dolomite
U12e.03-1	N888,264 E634,169	1959	855	6" 4" 3"	0-5 0-509 0-702	None	Tertiary Volcanics Undivided Devonian Dolomites	6150	< 5440	1959
U12e.M1	N886,644 E633,532	1960	1501 (spud within U12e tunnel)	3 3/8"	0-854	None	Tertiary Volcanics Undivided Devonian Dolomites	6158	< 4673	1960
Dolomite Hill Hole	N886,712 E638,632	1959	1200	6"	0-40	None	Devonian Dolomites	6399	< 5375	1960
U12e.06-1	N885,038 E631,776	1962	3180	2 7/8"	0-3179	0-3114	Tertiary Volcanics Undivided Devonian Dolomites	7573	< 4643	1962

(Source: Thordarson et al., 1967)
< Indicates fluid level still declining at time of measurement
(All measurements in feet)

+DRI Data
**Bill Scott, USGS, written communication, preliminary data, 3/4/91*

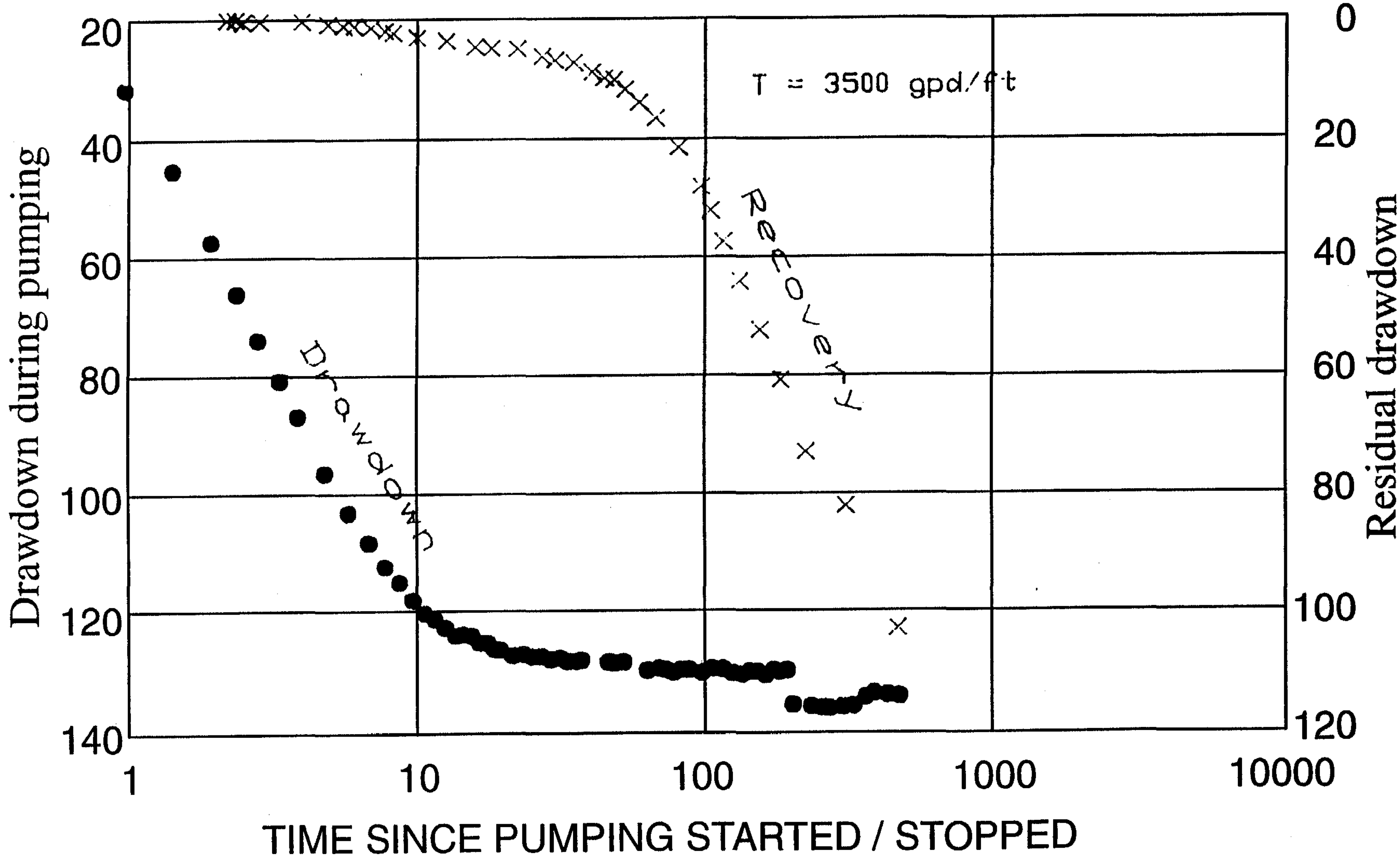


Figure 5. Aquifer test in dolomite in TW–1 (afterr Winograd and Thordarson, 1975)

bailing tests of the drilling fluid stored within the Simonson Dolomite in the Dolomite Hill Hole indicated that fluid levels recovered very slowly (0.5 ft/min to 1 ft /hour). The relatively slow recovery rates are another qualitative indication of relatively low transmissivities for the Simonson Dolomite.

A series of slug tests were performed on a 646-foot section of open drillhole in U12e.M1. One hundred twenty ft of the open hole consisted of Tertiary tuffs and 527 ft consisted of the Guilmette Formation and/or the Simonson Dolomite undivided. The results indicated a transmissivity of 1 to 2 gal/day/ft. These values were calculated from a slug test conducted in an undeveloped well and marred by inaccurate injection volumes. The values obtained were deemed suspect by Schoff and Winograd (1961) owing to the unknown effect of bentonite mud previously lost in the borehole, and should be used only in a qualitative sense.

Winograd and Thordarson (1975) report transmissivities measured within the Lower Carbonate Aquifer at different areas around the Nevada Test Site (which includes the carbonate units that may be encountered at the ER–12–1 drill site) between 1300 to 86,000 gal/day/ft. If the data gathered from Test Well 1, Dolomite Hill Hole and U12e.M1 are representative of conditions at the ER–12–1 drill site, then the transmissivities measured within ER–12–1 should fall toward the lower end of these values.

Examinations of cores from U12e.06–1, U12b.07–1, and Dolomite Hill Hole indicate that the effective porosity ranges from 0.6 to 1.1 percent and the interstitial permeability ranges from 0.0002 to 0.00007 gal/day/sq. ft (Thordarson, 1965). These data, in conjunction with the aquifer–test data, suggest that secondary porosity is the primary fluid transport pathway within the Devonian dolomites. If true, the transmissivities of the units are controlled by the frequency, aperature, and continuity of fractures and faults.

The Eleana Formation has been hydraulically tested south of the ER–12–1 drill site using wells UE–16d (N844 878 E646 567) and UE–16f (N832 355 E648 843). Aquifer tests conducted within unit J of the Eleana Formation yielded transmissivities of 8 and 370 gal/day/ft (Figures 6 and 7). The ER–12–1 drillhole may encounter units D and lower of the Eleana Formation. Transmissivities in these units may be similar to those measured in unit J at UE–16d and UE–16f. If this is correct, the permeability of the Eleana Formation (as measured at the ER–12–1) may be an order of magnitude less than that of the Devonian dolomites. The large distance (8 miles) between the drill site and wells UE–16d and UE–16f, and the different structural and depositional histories of the two sites, makes this interpolation tentative.

Vertical Gradients

Large vertical gradients exist between the Tertiary volcanics and the Devonian dolomite units at Test Well 1 (Table 2), indicating vertical flow from the tuffs to the dolomites. A recent flow survey conducted by the USGS and DRI on Test Well 1 within the Tertiary volcanics

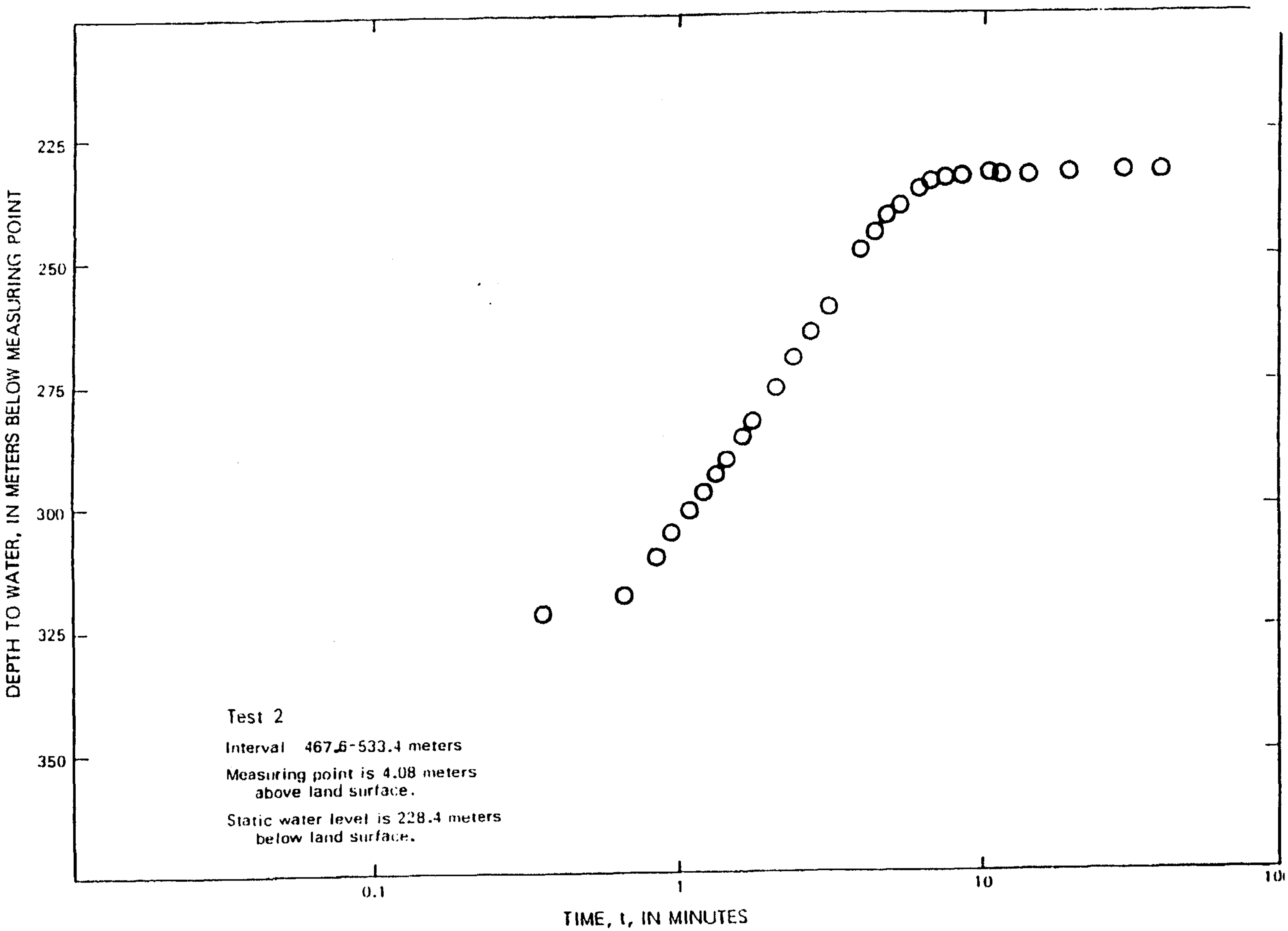


Figure 6. Recovery of water level after slug removal in UE-16d, Eleana Formation (T = 370 gpd/ft).

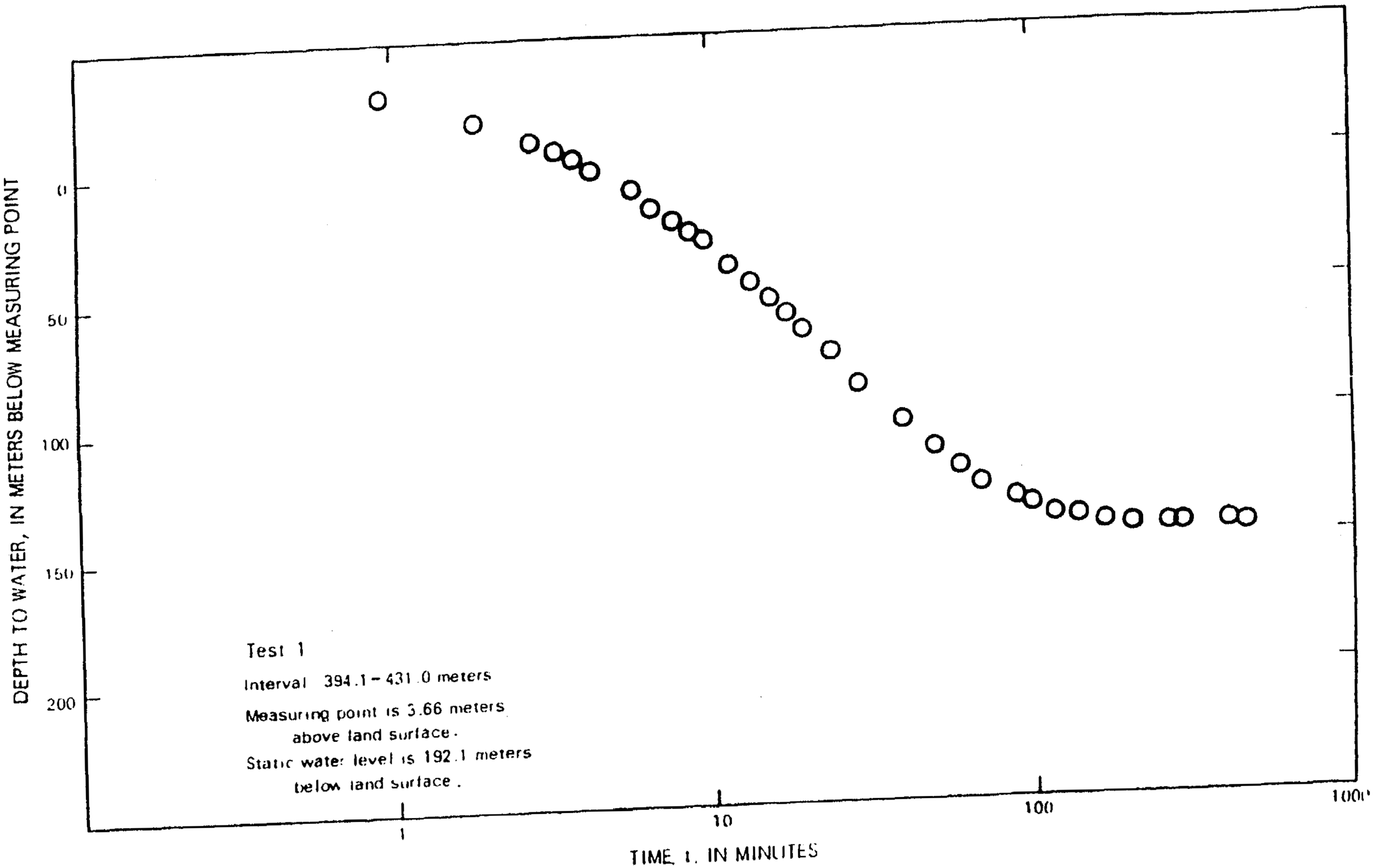


Figure 7. Recovery of water level after slug injection, Eleana Formation at UE-16f (T = 0.1 gpd/ft), Dinwiddie and Wier, 1979.

indicated upward flow occurring between 4691 and 4206 ft elevation and downward flow between 4126 and 3726 ft. Vertical flow may occur in the dolomites as well. Rainier Mesa is a recharge area (Clebsch, 1961; Thordarson, 1965; and Russell, 1988), and as such, decreasing heads with depth may exist within the carbonates for most of the area, including the ER-12-1 drill site, indicating the presence of vertical flow.

Vertical gradients have not been measured within the Eleana Formation in the vicinity of Rainier Mesa. Hydraulic-head measurements from wells UE-16d and UE-16f increase with depth (Dinwiddie and Wier, 1979). This phenomenon may be related to the Eleana Formation acting as a groundwater-flow barrier between the Alkali Flat/Furnace Creek subbasin to the west and the Ash Meadows subbasin to the east. Gradients for upward flow may or may not exist in the Eleana Formation at the ER-12-1 drill site, depending upon local hydrodynamics.

Geochemistry

Geochemical samples were collected on two occasions from Test Well 1. These data are presented in Table 3. Samples were collected 70 ft below the volcanic/dolomite contact and are typical of samples taken from tuffaceous rocks (Na-HCO_3 water type). The geochemistry and sample environment suggest that the groundwater within the dolomites originates from or mixes with groundwater from the overlying tuffaceous sediments. Low tritium values indicate that the water within Test Well 1 recharged prior to atmospheric testing which was conducted during the 1950s and early 1960s. Groundwater at the ER-12-1 drill site will probably be a Na-Ca-HCO_3 water type which is characteristic of water that has reacted or mixed with water from both the tuffs and carbonate rocks. Elevated levels of tritium may be found within groundwater at the ER-12-1 drill site because of the drill site's proximity to the U12e tunnel effluent ponds. A slight potential exists for groundwater to exceed national primary drinking water regulations, maximum contaminant levels (40 CFR, Chapter 1, Part 141, subpart B) for tritium (>20,000 pCi/L).

TABLE 3. AQUEOUS GEOCHEMISTRY FOR TEST WELL 1.

Sample Date	$^3H^+$ pCi/ml	EC (S)	pH	Ca (mg/L)	Na (mg/L)	SiO_2 (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	Cl (mg/L)	SO_4 (mg/L)
7/28/87	15	220	8	2	48	3	117	6	3	1
9/26/90	10	225	9	2	51	2	93	18	3	-

SUMMARY

The ER-12-1 drill site is potentially downgradient from Rainier Mesa where underground nuclear tests have been conducted and tunnel effluent ponds have been in use. Saturated hydrologic units expected to be encountered at this drill site include the Simonson Dolomite, the "cherty-argillaceous unit," the Sevy Dolomite, and the Eleana Formation.

These units correspond to Winograd and Thordarson's (1975) lower carbonate aquifer and the upper clastic aquitard. The water table should be encountered within the Simonson Dolomite at an approximate altitude of 4200 ± 100 ft. Decreasing hydraulic heads with depth may be encountered. The dolomites encountered within ER-12-1 should exhibit a wide range of transmissivities depending upon the degree and continuity of fractures and faults. However, the transmissivities should be similar to those measured in Test Well 1 (3500 gal/day/ft). Transmissivities within the Eleana Formation are expected to be less than that in the dolomites by at least an order of magnitude. Aqueous geochemistry samples should exhibit an Na-Ca-HCO_3 water type, which is characteristic of groundwater that has reacted or mixed with tuffaceous and carbonate rocks.

REFERENCES

Clebsch, A., 1961. Tritium age of groundwater at the NTS, Nye County Nevada: U.S. Geological Survey Professional Paper 424-C, p. C122-125.

Dinwiddie, G.A. and J.E. Wier, 1979. Summary of hydraulic tests and hydraulic data for holes UE-16d and UE-16f, Syncline Ridge Area, Nevada Test Site: U.S. Geological Survey Report USGS-1543-3, 20 p.

Gibbons, A.B., E.N. Hinrichs, W.R. Hansen and R.N. Lemke, 1963. Geology of the Rainier Mesa Quadrangle, Nye County Nevada: U.S. Geological Survey Geologic Quadrangle Map GQ-215.

Russell, C.E., 1988. Hydrogeologic investigation of flow in fractured tuff, Rainier Mesa, Nevada Test Site: Desert Research Institute Report 45062, Las Vegas and Reno, Nevada, 47 p.

Schoff, S.L. and I.J. Winograd, 1961. Hydrologic significance of six coreholes in carbonate rocks of the Nevada Test Site: U.S. Geological Survey Open-File Report TEI-787, 97 p.

Thordarson, W., 1965. Perched groundwater in zeolitized-bedded tuff, Rainier Mesa and vicinity, Nevada Test Site, Nevada: U.S. Geological Survey Open-File Report TEI-862, 85 p.

Thordarson, W., R.A. Young and I.J. Winograd, 1967. Records of wells and test holes in the Nevada Test Site and vicinity (through December, 1966): U.S. Geological Survey Open-File Report TEI-872, 23 p.

Waddell, R.K., J.H. Robison and R.K. Blankennagel, 1984. Hydrology of Yucca Mountain and vicinity, Nevada-California-investigative results through mid-1983:U.S. Geological Survey Water-Resources Investigations Report 84-4267, 40 p.

Winograd, I.J. and W. Thordarson, 1975. Hydrogeologic and hydrochemical framework, south-central Great Basin, Nevada-California, with special reference to the Nevada Test Site: U.S. Geological Survey Professional Paper 712-C, 126 p.

APPENDIX C

ABRIDGED DRILL HOLE STATISTICS FOR ER-12-1

1. Location

Coordinates: N270,248.5 E195,236.6 m N886,640.26 E640,538.85 ft

Ground Elevation: 1773.51 m 5817.12 ft

Top of 13.97 cm (5.5 in) casing is at an elevation of 1774.0 m (5818.19 ft)

2. Drilling data

Spud Date: 19 July 91

Drill Rig: Cardwell 500

Total Depth (TD): 1093.6 m 3588 ft

Date Reached TD: 17 October 91

Summary of Drilling Technique:

Rotary drilled surface hole to 16.2 m (53 ft) using mud and convention circulation. Rotary drilled 0.47 m (18.5 in) hole to 30.5 m (100 ft) using water and conventional circulation, used reverse circulation with air and water to 65.5 m (215 ft). Drilled 0.445 m (17.5 in) hole to 520.9 m (1709 ft) using an Air Hammer with conventional circulation and air/foam. Rotary drilled 0.311 m (12.25 in) hole using conventional circulation and airfoam from 520.9 to 556.9 m (1709 to 1827 ft). Continued 0.311 m (12.25 in) hole using conventional circulation and bentonite mud from 556.9 m (1827 ft) to TD.

Cut four conventional cores:

#1 at 539.2 to 543.8 m (1769 to 1784 ft)
#2 at 548.0 to 556.3 m (1798 to 1825 ft)
#3 at 751.0 to 757.7 m (2464 to 2486 ft)
#4 at 895.2 to 903.1 m (2937 to 2963 ft)

3. Casing record

Surface to 15.8 m (52 ft)

Outside diameter: 0.508 m (20 in)

Weight: 104.13 lb/ft

Intermediate to 449.3 m (1474 ft)*

Outside diameter: 0.34 m (13.375 in)

Weight: 54.5 lb/ft

*Although 450.6 m (1478.27 ft) was reported by the Driller, geophysical logs indicate bottom of casing at 449.3 m (1474 ft).

Completion string to 1072.9 m (3520 ft)

Outside diameter: 0.219 m (8.625 in)

Type: Carbon Steel

Screened intervals:

1. 516.0 to 555.0 m (1693 to 1821 ft)
2. 585.2 to 597.4 m (1920 to 1960 ft)
3. 764.7 to 790.6 m (2509 to 2594 ft)
4. 911.3 to 963.8 m (2990 to 3162 ft)
5. 1023.5 to 1049.1 m (3358 to 3442 ft)

Gravel packed intervals:

6. 500.2 to 562.7 m (1641 to 1846 ft)
7. 573.9 to 591.3 m (1883 to 1940 ft)
8. 746.4 to 793.1 m (2449 to 2602 ft)
9. 901.6 to 979.0 m (2958 to 3212 ft)
10. 1008.6 to 1040.6 m (3309 to 3414 ft)

Production string to 1047.0 m (3435 ft)

Outside diameter: 0.14 m (5.5 in)

Type: Carbon Steel

Location of packers:

11. 510.6 to 512.8 m (1675 to 1682 ft)
12. 557.3 to 559.5 m (1828 to 1836 ft)
13. 582.4 to 584.5 m (1911 to 1918 ft)

14. 599.3 to 601.5 m (1966 to 1973 ft)
15. 761.9 to 764.1 m (2500 to 2507 ft)
16. 793.4 to 795.6 m (2603 to 2610 ft)
17. 907.9 to 910.1 m (2979 to 2986 ft)
18. 965.2 to 967.4 m (3167 to 3174 ft)
19. 1020.5 to 1022.7 m (3348 to 3355 ft)

Location of sliding sleeves:

20. 536.3 to 536.8 m (1759 to 1761 ft)
21. 590.6 to 591.8 m (1938 to 1942 ft)
22. 776.9 to 778.1 m (2549 to 2553 ft)
23. 938.6 to 939.8 m (3079 to 3083 ft)
24. 1036.6 to 1037.7 m (3401 to 3405 ft)

4. Well site geology

Raytheon Services Nevada

5. Drilling Contractor:

Reynolds Electrical and Engineering Company

6. Geophysical logs:

Atlas Wireline Services (main logging suite), Schlumberger, Lawrence Livermore National Laboratory, Desert Research Institute (specialty logs), Westech Engineering (downhole camera).

7. Hydrologic testing:

Desert Research Institute (pumping tests) and Schlumberger (straddle packer tests)

APPENDIX D

SEQUENCE OF EVENTS AT ER–12–1

19 Jul 91	begin drilling
19 Aug 91	penetrate static water level at aproximately 469.4 m (1540 ft)
20 Aug 91 through 21 Aug 91	conduct dry hole geophysical logs
22 Aug 91 through 3 Sept 91	set intermediate casing to 657.1 m (2156 ft)
4 Sep 91	collect water sample from 509.3 m (1671 ft)
17 Oct 91	total depth reached at 1093.6 m (3588 ft)
18 Oct 91 through 22 Oct 91	conduct wet hole geophysical logs
23 Oct 91	Begin initial well development using sodium tetraphosphate
28 Oct 91	stop well development due to hole instability
13 Jan 92 through 24 Jan 92	clean and condition hole using first mud and then polymer
25 Jan 92 through 31 Jan 92	set 19.4 cm (7 5/8 in) intermediate casing to TD
20 Feb 92 through 24 Feb 92	continue well development using sodium tetraphosphate to clean hole
25 Feb 92	remove fluid from well by "dipstick" method
26 Feb 92 through 28 Feb 92	remove fluid from well by "swabbing" method
05 Mar 92 through 06 Mar 92	pump well using medium–size pump
07 Mar 92 through 11 Mar 92	replace medium–size pump with small–size pump
12 Mar 92 through 15 Mar 92	develop well by pumping with small–size pump
16 Mar 92 through 6 Apr 92	conduct aquifer tests and initial chemistry samples
14 Sep 92 through 21 Sep 92	develop well using Sodium Acid Pyrophosphate and air-lifting fluids from well
24 Sep 92 through 2 Oct 92	conduct straddle packer tests
16 Oct 92 through 23 Oct 92	set 14 cm (5 1/2 in) casing with packers and sliding sleeves in well
5 Jan 93 through 6 Jan 93	conduct aquifer test and geochemical sampling (upper zone only)

DISTRIBUTION

Bob Bangerter
Environmental Restoration Division
Nevada Operations Office
U.S. Department of Energy
P.O. Box 98518
Las Vegas, NV 89193-8518

Joanne M. Bradbery, Director
Contract Management Division
Nevada Operations Office
U.S. Department of Energy
P.O. Box 98518
Las Vegas, NV 89193-8518

David Bedsun
Defense Special Weapons Agency
Field Command
Nevada Operations Office
P.O. Box 208
Mercury, NV 89023–0208

Mary Lou Brown
International Technology Corporation
4330 S. Valley View
Suite 114
Las Vegas, NV 89103

James Cebe
Energy Technologies Division
Nevada Operations Office
U.S. Department of Energy
P.O. Box 98518
Las Vegas, NV 89193-8518

Beverly Colbert
Contract Management Division
Nevada Operations Office
U.S. Department of Energy
P.O. Box 98518
Las Vegas, NV 89193-8518

Frank Di Sanza, Director
Energy Technologies Division
Nevada Operations Office
U.S. Department of Energy
P.O. Box 98518
Las Vegas, NV 89193-8518

Brian Dozier
Bechtel Nevada Corporation
P.O. Box 98521
Las Vegas, NV 89193-8521

Doug Duncan
Hydrology Program Manager
Environmental Protection Division
Nevada Operations Office
U.S. Department of Energy
P.O. Box 98518
Las Vegas, NV 89193-8518

Dennis Farmer
Radiation Sciences Laboratory
Office of Radiation and Indoor Air
U.S. Environmental Protection Agency
P.O. Box 98517, M/S 513
Las Vegas, NV 89193–8517

Larry Franks
Nevada State Health Department
Radiological Health Section
620 Belrose Avenue
Las Vegas, NV 89158

Joseph M. Ginanni
Waste Management Division
Nevada Operations Office
U.S. Department of Energy
P.O. Box 98518
Las Vegas, NV 89193–8518

Kenneth Hoar, Director
Environmental Protection Division
Nevada Operations Office
U.S. Department of Energy
P.O. Box 98518
Las Vegas, NV 89193-8518

Kathy Izell
Assistant Manager for Technical Services
Nevada Operations Office
U.S. Department of Energy
P.O. Box 98518
Las Vegas, NV 89193-8518

Roger Jacobson
Desert Research Institute
Water Resources Center
P.O. Box 19040
Las Vegas, NV 89132-0040

Marjory Jones
Desert Research Institute
Water Resources Center
P.O. Box 60220
Reno, NV 89506-0220

Jim Kannard
Bechtel Nevada Corporation
P.O. Box 98521
Las Vegas, NV 89193-8521

Randy Laczniak
U.S. Geological Survey
Water Resources Division
6770 S. Paradise Rd.
Las Vegas, NV 89119

Steve Lawrence
Engineering Division
Nevada Operations Office
U.S. Department of Energy
P.O. Box 98518
Las Vegas, NV 89193-8518

Steve Leedom
Stockpile Stewardship Division
Nevada Operations Office
U.S. Department of Energy
P.O. Box 98518
Las Vegas, NV 89193-8518

Charles E. McWilliam, Director
Defense Projects Division
Nevada Operations Office
U.S. Department of Energy
P.O. Box 98518
Las Vegas, NV 89193-8518

Steve Mellington, Director
Environmental Restoration Division
Nevada Operations Office
U.S. Department of Energy
P.O. Box 98518
Las Vegas, NV 89193-8518

Leslie A. Monroe
Environmental Protection Division
Nevada Operations Office
U.S. Department of Energy
P.O. Box 98518
Las Vegas, NV 89193–8518

Ken Rehfeldt
Geotrans, c/o IT
4330 Valley View
Suite 112, MS-439
Las Vegas, NV 89103

Stuart E. Rawlinson
Bechtel Nevada Corporation
P.O. Box 95487, M/S 580
Las Vegas, NV 89193–5487

Monica Salazar-Sanchez
Environmental Restoration Division
Nevada Operations Office
U.S. Department of Energy
P.O. Box 98518
Las Vegas, NV 89193-8518

Ralph Smiecinski
Energy Technologies Division
Nevada Operations Office
U.S. Department of Energy
P.O. Box 98518
Las Vegas, NV 89193-8518

David K. Smith
Isotopes Sciences Division
Lawrence Livermore National Laboratory
P.O. Box 808, M/S L231
Livermore, CA 94550

Michael J. Sully
Bechtel Nevada Corporation
P.O. Box 98521, M/S 966
Las Vegas, NV 98193–8521

Joe Thompson
Los Alamos National Laboratory
INC-11, MS J514
P.O. Box 1663
Los Alamos, NM 87545

Doug Trudeau
U.S. Geological Survey
Water Resources Division
6770 S. Paradise Rd.
Las Vegas, NV 89119

Janet Wiley
International Technology Corporation
4330 S. Valley View
Suite 114
Las Vegas, NV 89103

Annie Kelley
State Documents Department
Nevada State Library
Capitol Complex
Carson City, NV 89710

Archives
Getchell Library
University of Nevada, Reno

Beverly Carter
MacKay School of Mines Library
University of Nevada, Reno

Document Section, Library
University of Nevada, Las Vegas
4505 Maryland Parkway
Las Vegas, NV 89154

Library (Stead)
Desert Research Institute
P.O. Box 60220
Reno, Nevada 89506–0220

Library
IT Corporation
4330 S. Valley View
Suite 114
Las Vegas, NV 89103
ATTN: Toni Miller

Library
Southern Nevada Science Center
Desert Research Institute
P.O. Box 19040
Las Vegas, NV 89132-0040

Public Reading Facility
Bechtel Nevada Corporation
P.O. Box 98521
Las Vegas, NV 89193-8521

Technical Information Resource Center
Nevada Operations Office
U.S. Department of Energy
P.O. Box 98518
Las Vegas, NV 89193–8518

Librarian
Water Resources Center Archives
410 O'Brien Hall
University of California
Berkeley, CA 94720-1718

Office of Scientific and Technical Information
U.S. Department of Energy
P.O. Box 62
Oak Ridge, TN 37831–9939