U.S. Department of the Interior
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Geohydrology of Monitoring Wells Drilled in Oasis Valley near Beatty, Nye County, Nevada, 1997

Water-Resources Investigations Report 98-4184
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U.S. DEPARTMENT OF ENERGY
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By Armando R. Robledo, Philip L. Ryder, Joseph M. Fenelon,
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U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
THOMAS J. CASADEVALL, Acting Director

For additional information contact:

District Chief
U.S. Geological Survey
333 West Nye Lane, Room 203
Carson City, NV 89706-0866

email: usgsinfo_nv@usgs.gov

http://nevada.usgs.gov

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Geohydrology of Monitoring Wells Drilled in Oasis Valley near Beatty, Nye County, Nevada, 1997

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ABSTRACT

Twelve monitoring wells were installed in 1997 at seven sites in and near Oasis Valley, Nevada. The wells, ranging in depth from 65 to 642 feet, were installed to measure water levels and to collect water-quality samples. Well-construction data and geologic and geophysical logs are presented in this report. Seven geologic units were identified and described from samples collected during the drilling: (1) Ammonia Tanks Tuff; (2) Tuff of Cutoff Road; (3) tuffs, not formally named but informally referred to in this report as the “tuff of Oasis Valley”; (4) lavas informally named the “rhyolitic lavas of Colson Pond”; (5) Tertiary colluvial and alluvial gravelly deposits; (6) Tertiary and Quaternary colluvium; and (7) Quaternary alluvium. Water levels in the wells were measured in October 1997 and February 1998 and ranged from about 18 to 350 feet below land surface. Transmissive zones in one of the boreholes penetrating volcanic rock were identified using flowmeter data. Zones with the highest transmissivity are at depths of about 205 feet in the “rhyolitic lavas of Colson Pond” and 340 feet within the “tuff of Oasis Valley.”

INTRODUCTION

Between 1957 and 1992, 828 underground tests consisting of 921 underground nuclear detonations were reported beneath the Nevada Test Site (NTS), most in Pahute Mesa, Rainier Mesa, and Yucca Flat (U.S. Department of Energy, 1994). These nuclear devices were detonated underground to contain their explosive force and radioactive by-products. Although water levels in the NTS region are generally more than 800 ft below land surface, many of the intermediate- and large-yield devices were detonated at depths near or below the water table. Some of these detonations have resulted in the introduction of radioactive and chemical contaminants into the regional ground-water flow system (Laczniak and others, 1996).

The investigation and remediation of radioactive and other contaminants at the NTS are the focus of the U.S. Department of Energy (USDOE) Environmental Restoration Program (U.S. Department of Energy, 1991). One of the objectives of the long-term program is to assess the extent of contamination on, and potentially off, the NTS. The U.S. Geological Survey (USGS) is contributing to this objective by providing USDOE with a hydrogeologic understanding of the NTS and vicinity. The USGS is involved with drilling and monitoring test wells for geologic, hydrologic, and chemical characterization. The information from these characterizations is used to identify ground-water flow paths and quantify ground-water flow through areas of interest. A more complete understanding of the ground-water flow system on and adjacent to the NTS will provide for future evaluation of environmental risks and remediation strategies.

Oasis Valley is a USDOE area of concern because it is downgradient from Pahute Mesa, one of the sites of intensive underground nuclear testing (fig. 1). Because ground water from parts of western and central Pahute Mesa may discharge into Oasis Valley (Laczniak and others, 1996), the USGS installed a network of wells in the valley to help characterize the geology and understand the ground-water flow system. Additionally, water-quality samples were collected from these wells during November 3-19, 1997, by the following agencies (types of analyses are listed after agency name): USGS (dissolved organic carbon, chlorofluorocarbons, and strontium and uranium isotopes); Lawrence Livermore National Laboratory (noble gasses, tritium, and dissolved inorganic carbon); Desert

Research Institute (major ions, deuterium, oxygen-18, and dissolved inorganic carbon); HSI-GeoTrans, Inc. (trace elements); and State of Nevada, Department of Environmental Protection (radionuclides). Water-quality data are not included in this report. The wells in Oasis Valley have been incorporated as part of a regional NTS ground-water-monitoring network under the USDOE Environmental Restoration Program.

Purpose and Scope

The purpose of this report is to present geologic, geophysical, and hydrologic data obtained from the drilling of test holes in Oasis Valley in support of the USDOE Environmental Restoration Program at the NTS. The report documents drilling procedures and well-completion information for the 12 monitoring wells that were installed in 11 test holes during 1997. A geologic interpretation for each test hole is provided. Hydrologic information presented consists of two sets of water levels measured in October 1997 and one set in February 1998, and data obtained from a heat-pulse flowmeter in well ER-OV-06a. The relative transmissivities of different water-bearing zones in this well are interpreted from the flowmeter data.

Description of Study Area

The study area is the central part of the Oasis Valley Hydrographic Area[1], about 14 mi west of NTS. The altitude of Oasis Valley ranges from approximately 3,500 to 4,000 ft above sea level. From its southern extent near Beatty, Nev., the valley trends north-northwest for approximately 14 mi (figs. 1 and 2). The valley is bounded by Pahute Mesa on the north, Oasis Mountain and the Bullfrog Hills on the west, Bare Mountain on the south, and Timber Mountain and Beatty Wash on the east and southeast. The Amargosa River, an ephemeral steam, flows south through the center of the valley. Although the river is usually dry, local seeps provide for wetlands along its course. Beatty Wash, an ephemeral tributary to the Amargosa River, flows only during periods of heavy rain. Hot and cold springs are found within the Amargosa River valley and some of the tributary drainages.

Approximately 1,600 of the 4,200 people living in Oasis Valley on July 1, 1997, were residents of Beatty (State Demographer, State of Nevada, written commun., 1998). The remainder of the population is distributed throughout the valley between Beatty and Springdale. The town of Springdale, about 8 mi north of Beatty, has a population of about 75.

Geohydrologic Framework

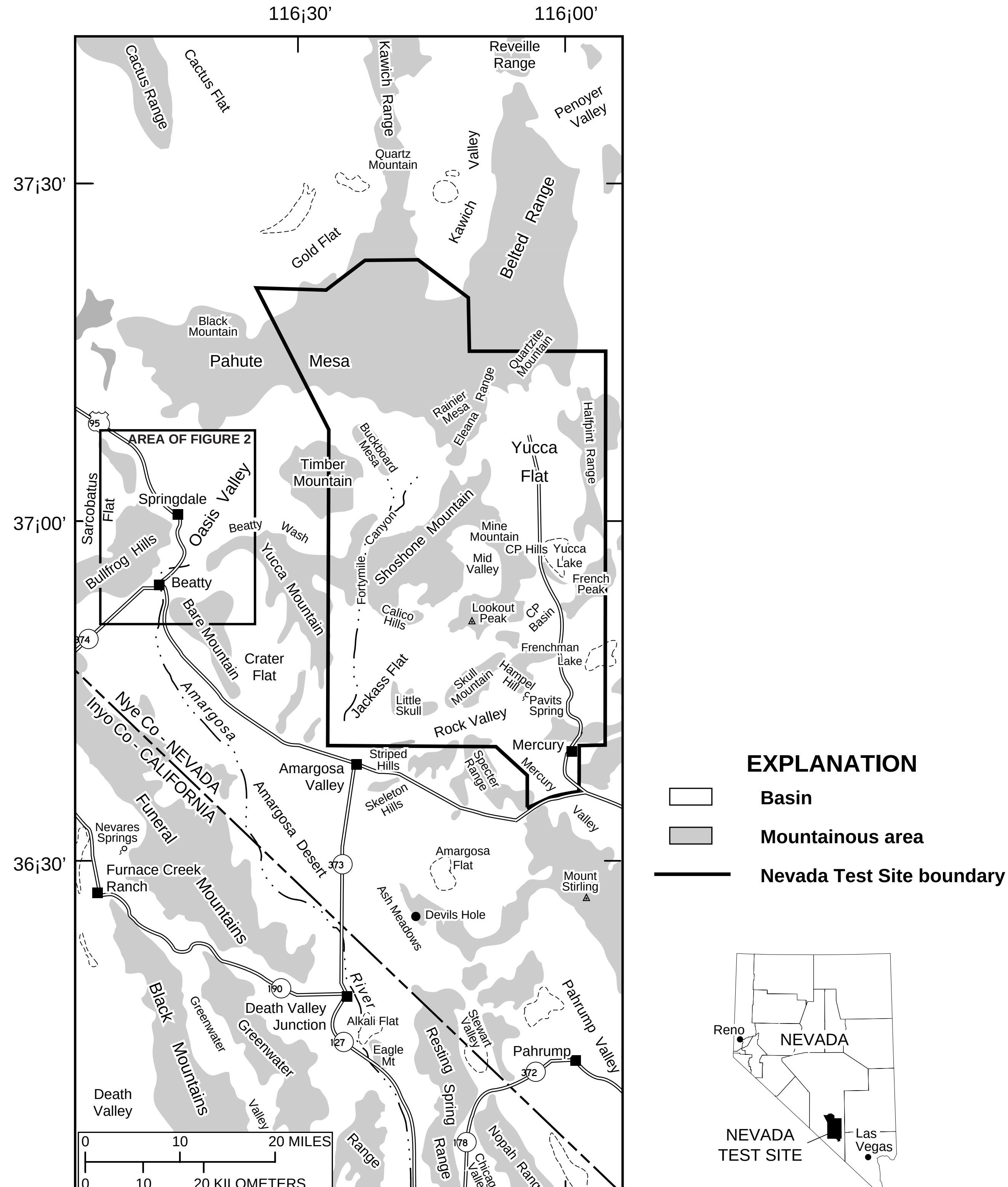
Geology

The rocks of hydrogeological significance that underlie the region surrounding Oasis Valley are grouped into several major units. These include a sequence of Paleozoic and older sedimentary and metamorphic rock (600 to 280 million years before present [Ma]), an assemblage of Miocene volcanic rocks (16 to 8 Ma), and locally thick deposits of post-volcanic valley fill composed of gravel, sand, and silt (fig. 3).

The Paleozoic and older rocks in this region consist of (1) a basement unit and (2) a younger regional carbonate-rock unit (Laczniak and others, 1996). The rocks that make up the basement unit consist of quartzite, micaceous quartzite, siltstone, and dolomite of Cambrian and older age. The regional carbonate-rock unit consists of about 15,000 ft of limestone, dolomite, and some shale and quartzite, of Cambrian through Devonian age.

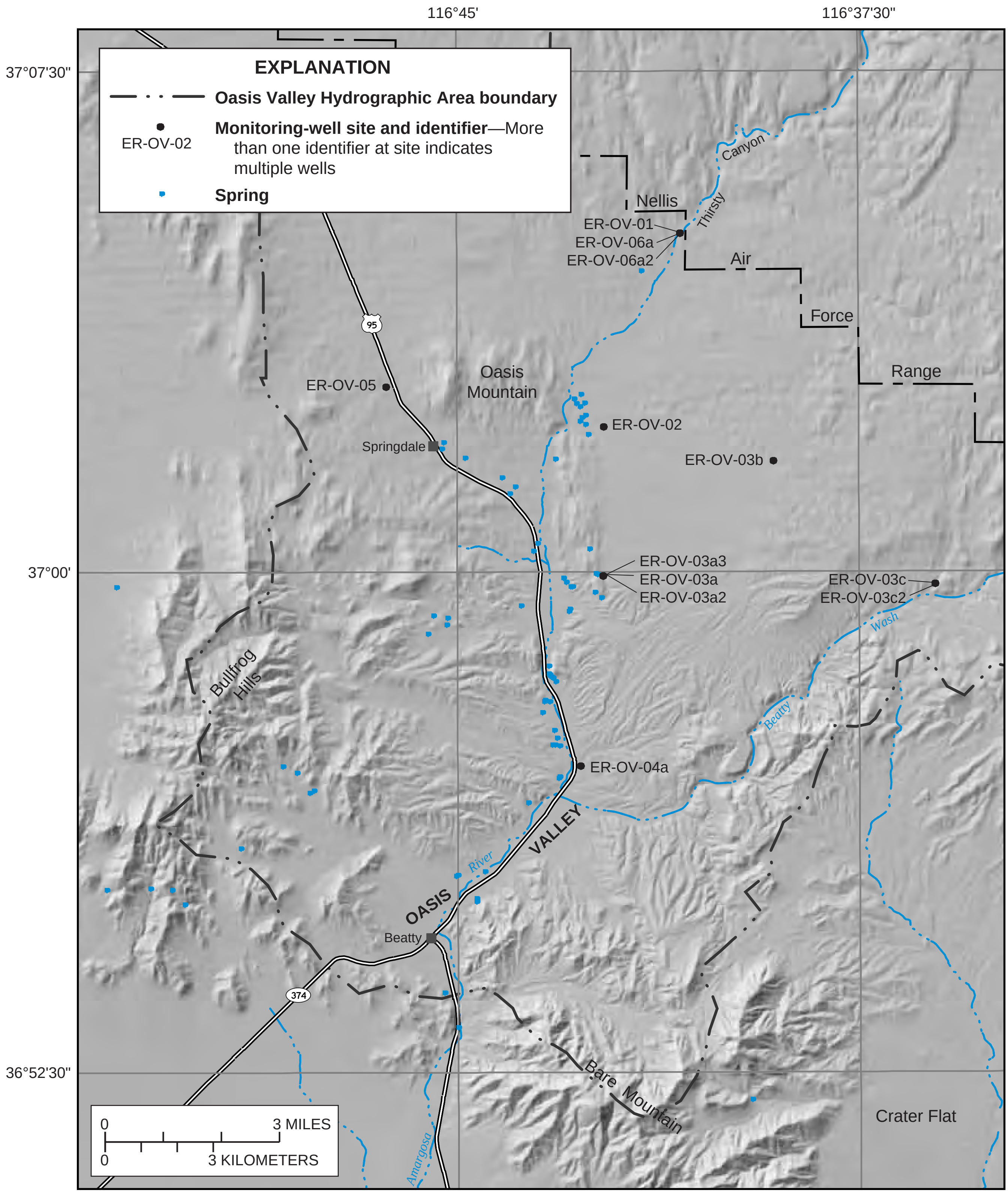
The Miocene volcanic rocks were deposited along an east-trending belt of several partly overlapping caldera or caldera complexes (fig. 3), which were subsequently filled by lava and vast blankets of tuff. The volcanic activity took place between 16 and 8 Ma, overlapping the latter phases of Basin and Range extensional faulting (Byers and others, 1976; Hamilton, 1988; Wernicke and others, 1988; Sawyer and others, 1994). Deposits associated with the caldera complexes include glassy and crystalline lava flows; air-fall, ash-flow, and reworked tuffs; and tectonic, eruptive, and flow breccias. These rocks vary in age, composition, amount of hydrothermal alteration, and diagenesis. Principle volcanic rocks in Oasis Valley consist of rhyolitic lava and variably welded ash-flow tuffs of the Timber Mountain Group and the Thirsty Canyon Group. Extensional faulting during and after the eruptions caused tilting and lateral crustal-block movement.

[1]Formal hydrographic areas in Nevada were delineated systematically by the U.S. Geological Survey and Nevada Division of Water Resources in the late 1960’s (Rush, 1968; Cardinalli and others, 1968) for scientific and administrative purposes. The official hydrographic-area names, numbers, and geographic boundaries continue to be used in Geological Survey scientific reports and Division of Water Resources administrative activities.



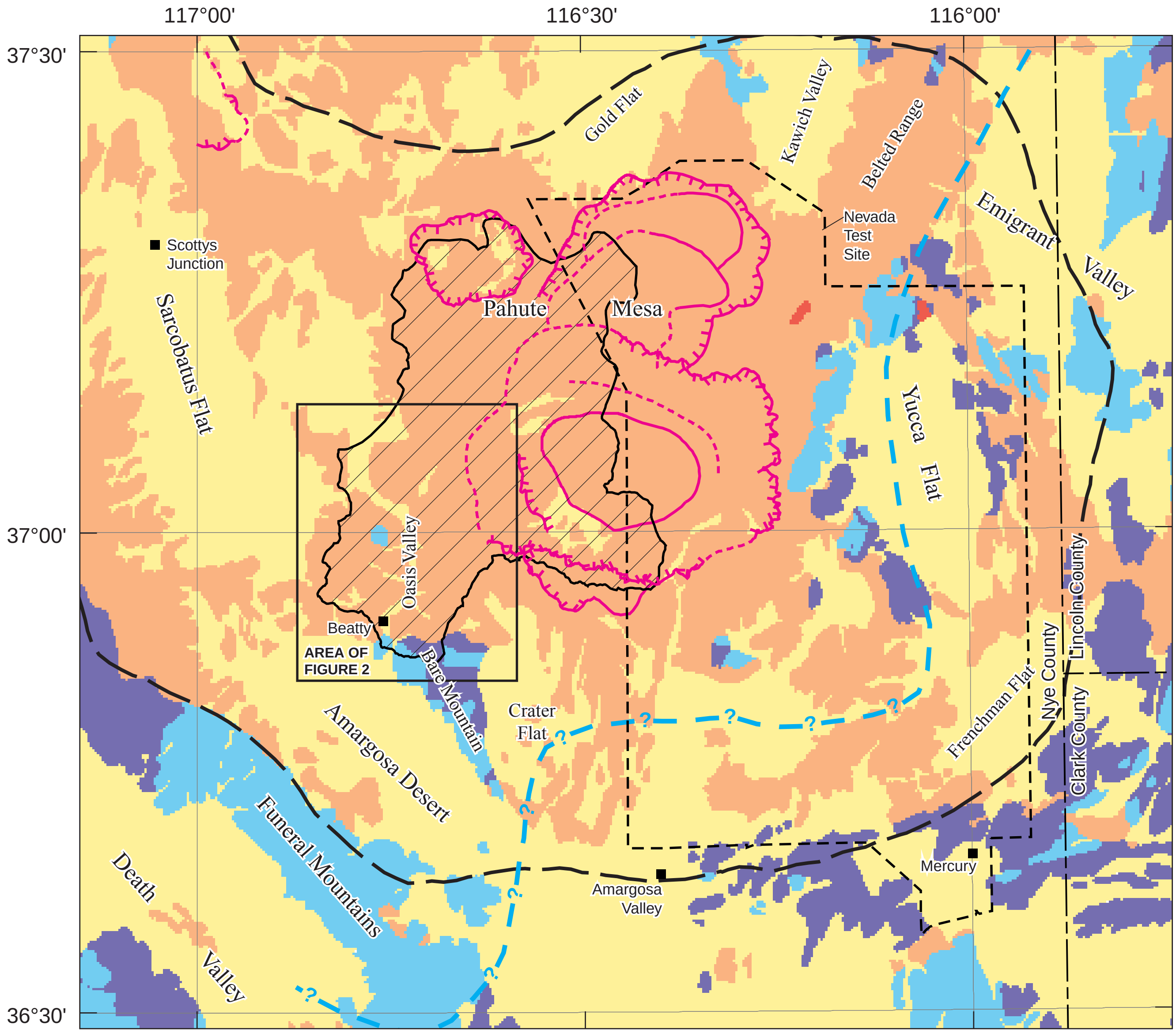
Base from U.S. Geological Survey digital data, 1:250,000
Universal Transverse Mercator projection, Zone 11

Figure 1. Regional features near Oasis Valley, Nevada (modified from Laczniak and others, 1996, fig. 1)



Base from U.S. Geological Survey digital data, 1:100,000, 1978-89:
Universal Transverse Mercator Projection, Zone 11. Shaded-relief
base from 1:250,000-scale Digital Elevation Model; sun illumination
from northwest at 30 degrees above horizon

Figure 2. General features and monitoring wells in Oasis Valley, Nevada.



Base from U.S. Geological Survey digital data, 1:100,000 1979-89
Universal Transverse Mercator projection
Zone 11

0 5 10 15 20 MILES
0 5 10 15 20 KILOMETERS

Geology modified from Streitz and Stinson (1974), and Stewart and Carlson (1978)

EXPLANATION

- **Valley fill**
- **Volcanic rock**
- **Carbonate rock**
- **Clastic (siliceous) rock**
- **Granitic rock**
- **Oasis Valley Hydrographic Area**

Boundary of southwest Nevada volcanic field—Modified from Carr and others (1986, fig. 1)

Subsurface boundary of regional carbonate-rock aquifer—Approximate western limit of area where carbonate-rock aquifer is known to dominate ground-water flow system. Modified from Laczniak and others (1996, fig. 4)

Edge of caldera or caldera complexes—Hatured lines are caldera complex boundaries; solid lines are intra-caldera boundaries. Dashed where approximately located. From Wahl and others (1997)

Alluvial deposits are the dominant fill in Oasis Valley and other basins that formed as a result of the extensional faulting. The basins contain gravel, sand (eolian and fluvial), silt, clay, and locally fine-grained playa-lake deposits. In the northeastern part of Oasis Valley, the thickness of basin fill (referred to as alluvium) ascertained from drilling logs and from geophysical studies, ranges from 0 to more than 830 ft (G.L. Dixon, U.S. Geological Survey, written commun., 1997).

Hydrology

Oasis Valley is centrally located within the Death Valley ground-water flow system, one of the major hydrologic subdivisions of the southern Great Basin (Harrill and others, 1988). An estimated 70,000 acre-ft of ground water flows through the system annually (Blankennagel and Weir, 1973; Winograd and Thordarson, 1975; Harrill and others, 1988; Dettinger, 1989). Most ground water moves through the thick sequences of volcanic and carbonate rocks, from high-altitude areas of recharge north and east of Oasis Valley, toward areas of surface discharge at Oasis Valley, Ash Meadows, Alkali Flat, and Death Valley. Ground water has been used for domestic and public supplies, agriculture, and mining at many locations in the valleys. In addition, springs and seeps in these valleys sustain wetlands, which support a variety of wildlife.

Recharge for the Oasis Valley ground-water basin is derived primarily from precipitation that falls on mountain ranges to the north, which may include the Cactus Range, Quartz Mountain, Black Mountain, and the western part of Pahute Mesa (Laczniak and others, 1996). Annual discharge in Oasis Valley was estimated by Malmberg and Eakin (1962) to be 2,000 acre-ft. Blankennagel and Weir (1973) suggested that rates may be two to three times higher than that. Outflow from Oasis Valley is thought to be controlled by a basement confining unit of clastic siliceous rocks, which crops out near Oasis Valley. The confining unit may divert water upward through faults in the area (Laczniak and others, 1996).

The major regional aquifers have been designated (1) the carbonate-rock aquifer, (2) the volcanic-rock aquifer, and (3) the valley-fill aquifer (Laczniak and others, 1996). The carbonate-rock aquifer is the primary aquifer within the Death Valley flow system because of its high transmissivity and large areal extent. It is underlain by the basement unit, which forms a lower confining zone. In places, the carbonate-rock aquifer is confined on top by the Eleana Formation; in other locations the Eleana Formation divides the aquifer into two parts—a lower and an upper carbonate-rock aquifer. In places where the confining unit is not present, the carbonates function as a single aquifer.

A series of complexly interbedded volcanic-rock aquifers and confining units overlie the carbonate-rock aquifer. The volcanic-rock aquifers consist of dense, highly fractured, welded tuffs outside the calderas and highly fractured lava flows and thick welded tuff bodies within the calderas. The volcanic confining units tend to be zeolitically altered, non-welded tuff units (Winograd and Thordarson, 1975; Byers and others, 1976).

Valley-fill aquifers have high porosity and permeability; however, they are commonly unsaturated or have little saturated material. In the northwestern part of Oasis Valley, the maximum saturated thickness of alluvium determined from well logs, static water levels, and geophysical studies is about 470 ft (G.L. Dixon, U.S. Geological Survey, written commun., 1997). Along the Amargosa River within the valley, data from well logs indicate the saturated thickness is greater than 150 ft.

Acknowledgments

This study was made in cooperation with the U.S. Department of Energy (Interagency agreement DE-AI08-96NV11967). The authors express their appreciation to the following individuals for their support during this study. Jeffery D. Eman and John C. Palmer, U.S. Geological Survey Central Region Drill Rig crew members, drilled and constructed all the wells in the heat of August and September. The following USGS personnel—Kevin D. Knutson, Barbara S. Corland, Richard E. Hodges, Thomas A. Wickham, Owen D. Young, and Douglas K. Maurer—did geophysical logging, on-site geology, and other work necessary to complete the drilling. Thomas Spicer allowed access to the sites through his property and allowed the water tanker to be filled from his supply. The Beatty Sanitation District allowed the storage of drilling supplies at their facility.

WELL DRILLING

Site Selection

Sites were selected to develop a long-term ground-water monitoring network in the Oasis Valley area. The objective of the network is to define spatial changes in the chemical and isotopic character of the ground water. Information from the network may be used to (1) refine the current understanding of the ground-water flow system through a better understanding of the ground-water chemistry and subsurface geology and (2) to monitor potential changes in ground-water chemistry related to past underground testing activities at the NTS.

Seven sites were chosen in which to install single or multiple wells (fig. 2). Multiple wells, where present, were less than 30 ft from each other but screened at different depths (wells ER-OV-03a2 and ER-OV-03a3 were nested within the same borehole). The sites chosen were upgradient from the major spring-discharge area in Oasis Valley. Some wells were installed adjacent to or within fault zones that may be pathways for upward ground-water flow in the area. Twelve monitoring wells (in 11 boreholes) were installed at these sites during August through October 1997.

Drilling Procedures

Two drilling methods were used—mud rotary and down-hole air hammer. The mud-rotary method is excellent for drilling deep holes and commonly is used to drill through unconsolidated or loosely consolidated sediments because the borehole walls can be stabilized or supported. During mud-rotary drilling, the borehole is drilled by the action of a rotating bit, and the cuttings are removed by the circulation of drilling fluid. The fluid used in the drilling process was a mixture of water and bentonite (sodium montmorillonite). The viscosity of the fluid was varied during drilling to control the circulation loss of drilling fluid and to stabilize the borehole wall when drilling in unconsolidated materials. Down-hole air-hammer drilling works well in conditions where the predominant material drilled is consolidated rock and where high rates of drilling are desirable. The down-hole air hammer uses a pneumatically operated hammer to break the rock into fragments, which are then transported to the surface with compressed air. Water was injected into the compressed air stream to assist in the lifting of the fragments and to control dust. Most wells were drilled for this study using only one method—either the mud-rotary or down-hole air hammer technique (table 1). However, in wells ER-OV-03c and ER-OV-03c2, the unconsolidated materials were drilled using mud-rotary techniques and the bedrock was drilled using a down-hole air hammer. For these two wells, the objective was to prevent caving or collapsing of the upper unconsolidated layers.

Most of the wells, except ER-OV-02, -03a, -04a, and -05, were drilled initially with a $5^{7}/_{8}$- or $6\ ^{3}/_{4}$-in.-diameter pilot bit to depth where bedrock was contacted or the hole was deep enough to support the installation of steel surface casing. Some of the holes drilled with a pilot bit were then enlarged with a 12-in.-diameter bit to allow the installation of 6-in.-diameter surface casing (table 1). After the surface casing was installed, the borehole was drilled with a 6-in.-diameter air-hammer bit to the desired depth or to the limitations of the equipment. Wells ER-OV-03c and ER-OV-06a were planned to depths in excess of 600 ft, but limitations of the air compressor and the introduction of high volumes of water from fractures limited the completed depths to 542 ft and 536 ft, respectively.

Sample cuttings were collected from every borehole at 10-ft intervals and split three ways. Two of the splits were sent to the USGS Core Library and Data Center in Mercury, Nev., for washing and retention, and the other split was used for the lithologic analysis included in this report.

Well Construction and Development

Well construction was in accordance with project requirements and State regulations (Nevada Division of Water Resources, 1997). Well-construction data for all sites are presented in table 1. Most wells extend the length of the borehole and consist of a 2.5-in.-diameter schedule-40 or schedule-80 polyvinyl-chloride riser, 0.020-in.-slot stainless-steel wire-wrapped screen, and a 10- or 20-ft sump at the bottom of the well (fig. 4, table 1). A filter pack of coarse sand was put into the borehole from the bottom to above the screen using a tremie. A bentonite annular seal was then grouted from the top of the filter pack to either (1) the bottom of the surface casing, where present, or (2) to land surface. Where surface casing was installed (table 1), neat cement was added to the hole from the bottom of the

Table 1. Characteristics of monitoring wells in Oasis Valley, Nevada

[All depths are in feet below land surface unless otherwise indicated. Abbreviation: n.a., not applicable]
Drilling method—AH, air hammer; MR, mud rotary; MR-AH, mud rotary and air hammer
Land-surface altitude and measuring-point altitude—Altitudes were surveyed from nearby benchmarks
Inside casing type—PVC, schedule-40 or schedule-80 polyvinyl chloride; CS, schedule-40 carbon steel
Screen type—SS, 304 stainless steel; PVC, schedule-40 polyvinyl chloride

Well name	USGS site identification number[1]	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Date well completed	Site number	Number of wells at site[2]	Drilling method	Land- surface altitude (feet above sea level)	Measuring-point altitude (feet above sea level)
ER-OV-01	370504116404901	370504	1164049	08-04-97	01/06	3	AH	4,007.3	4,009.79
ER-OV-02	370210116421501	370210	1164215	08-20-97	02	1	MR	3,880.3	3,883.01
ER-OV-03a	365956116421601	365956	1164216	08-22-97	03a	3	MR	3,844.4	3,847.12
ER-OV-03a2	365956116421602	365956	1164216	09-12-97	03a	3	MR	3,843.8	3,845.54
ER-OV-03a3	365956116421603	365956	1164216	09-12-97	03a	3	MR	3,843.8	3,845.59
ER-OV-03b	370139116390501	370139	1163905	09-29-97	03b	1	MR	4,232.6	4,234.60
ER-OV-03c	365948116360401	365948	1163604	09-18-97	03c	2	MR-AH	4,191.5	4,194.34
ER-OV-03c2	365948116360402	365948	1163604	09-26-97	03c	2	MR-AH	4,191.9	4,194.97
ER-OV-04a	365705116424201	365705	1164242	10-11-97	04	1	MR	3,491.4	3,493.69
ER-OV-05	370246116461901	370246	1164619	08-02-97	05	1	MR	3,937.8	3,939.14
ER-OV-06a	370504116404902	370504	1164049	08-09-97	01/06	3	AH	4,007.5	4,009.48
ER-OV-06a2	370504116404903	370504	1164049	08-11-97	01/06	3	AH	4,007.0	4,009.28

Well name	Well depth (feet)	Borehole		Well casing			Open interval		
		Borehole depth (feet)	Average diameter, below surface casing (inches)	Surface casing depth (feet)	Inside casing diameter (inches)	Inside casing type	Screen type	Top and bottom of screened interval (feet)	Top and bottom of filter pack interval (feet)
ER-OV-01	180	180	6.75	n.a.	2.5	PVC	SS	150-170	142-180
ER-OV-02	200	200	6.75	n.a.	2.5	PVC	SS	170-190	160-200
ER-OV-03a	251	251	6.75	n.a.	2.5	PVC	SS	220-240	198-251
ER-OV-03a2	642	821	6.75	40	2.5	PVC	SS	602-622	560-655
ER-OV-03a3	133	821	6.75	40	2.0	PVC	PVC	113-133	88-160
ER-OV-03b	395	400	8	40	4.0	CS	SS	353-373	272-400
ER-OV-03c	542	542	6.75	40	2.5	PVC	SS	512-532	496-542
ER-OV-03c2	321	321	6.75	32	2.5	PVC	SS	292-312	270-321
ER-OV-04a	151	151	6.75	n.a.	2.5	PVC	SS	111-131	89-151
ER-OV-05	200	200	6.75	n.a.	2.5	PVC	SS	170-190	136-200
ER-OV-06a	536	536	6.75	n.a.	2.5	PVC	SS	506-526	488-536
ER-OV-06a2	65	71	6.75	n.a.	2.5	PVC	SS	56-65	44-65

[1] The standard site identification is based on the grid system of latitude and longitude. The number consists of 15 digits. The first six digits denote the degrees, minutes, and seconds of latitude; the next seven digits denote degrees, minutes, and seconds of longitude; and the last two digits (assigned sequentially) identify the sites within a 1-second grid. For example, site 370504116404901 is at 37°05′04″ latitude and 116°40′49″ longitude, and it is the first site recorded in that 1-second grid. The assigned number is retained as a permanent identifier even if a more precise latitude and longitude are later determined.

[2] Multiple wells at a site are clustered within 30 feet of each other and screened at different depths. With the exception of wells ER-OV-03a2 and ER-OV-3a3, which are nested within the same borehole, multiple wells at a site are emplaced within individual boreholes.

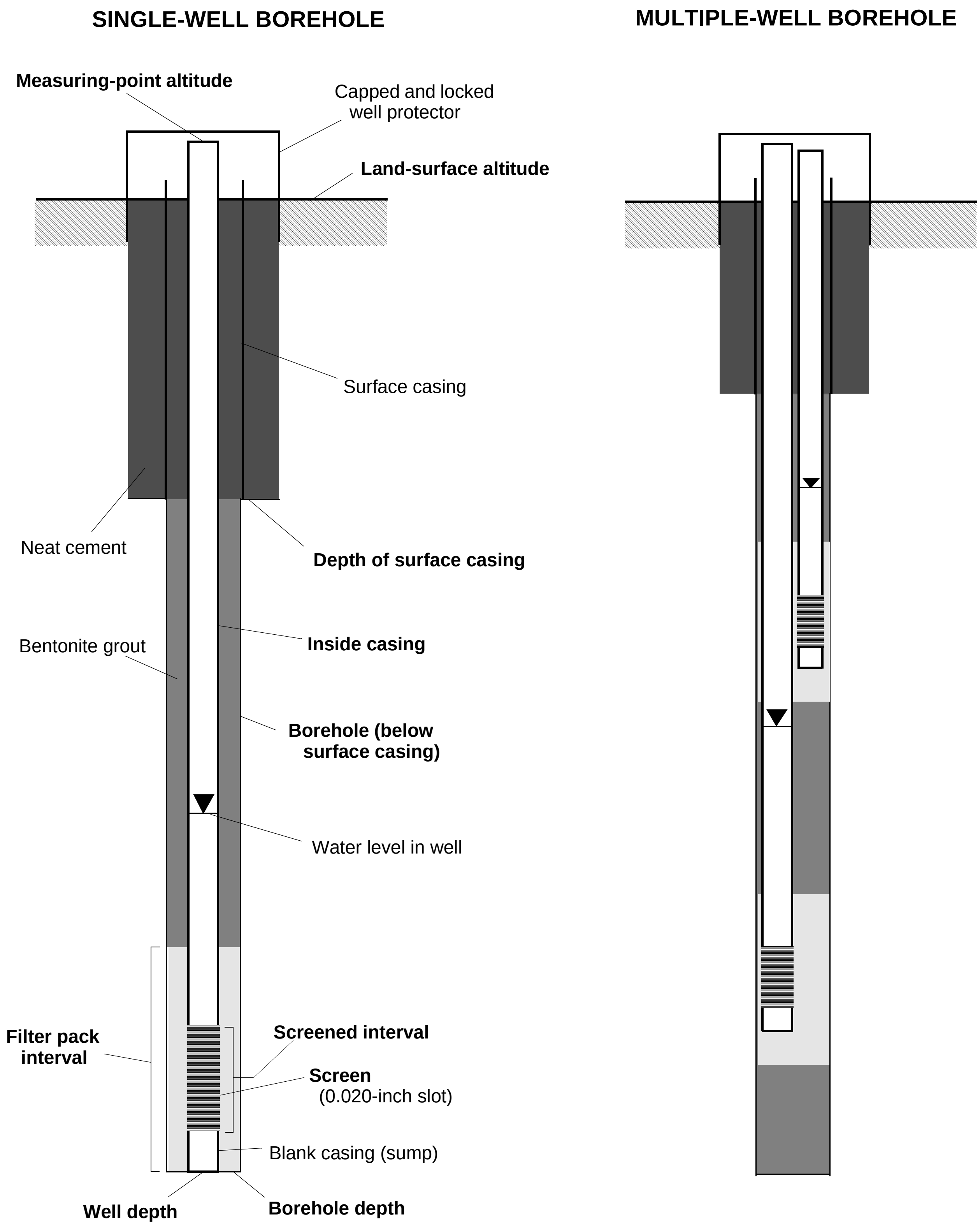


Figure 4. Typical construction of single- and multiple-well boreholes in Oasis Valley, Nevada. Wells ER-OV-03a2 and ER-OV-03a3 are the only pair of wells nested within one borehole. Labels in bold correspond with column headings in table 1.

surface casing (top of the grout) to land surface. Exceptions to the typical well construction, wells ER-OV-03a2, -03a3, -03b, and -06a2, are discussed below.

Wells ER-OV-03a2 and ER-OV-03a3 were nested within a single 821-ft-deep borehole (fig. 4, see “multiple-well borehole”). On the basis of geophysical log analysis, two zones were identified for well completion: a lower zone from 580 to 640 ft below land surface and an upper zone from 88 to 160 ft below land surface. The borehole was filled with bentonite grout from 821 ft to 655 ft to seal the bottom of the hole from the lower zone of interest. A 2.5-in.-diameter deep well was screened over the lower zone, and a filter pack of sand was placed around the screen using a tremie. Then bentonite grout was added into the annular space to the upper zone of interest. A second sand filter pack was installed around a 2-in.-diameter shallow well. Finally, grout was added to the borehole from the upper filter pack to land surface.

Well ER-OV-03b was constructed of 4-in.-diameter carbon steel casing and 0.020-in. stainless-steel screen. The casing string was supported 5 ft above the bottom of the borehole, and sand was placed over the desired interval using a tremie. The casing was supported to keep the screen from collapsing under the weight of the steel casing.

Well ER-OV-06a2 differed from typical well construction in that the bottom 6 ft of the borehole was sealed with grout before well construction. The lower part of the hole was grouted to seal off upward ground-water flow from fractures observed on the geophysical logs.

Immediately after completion, all wells were developed using compressed air to alternately surge and lift out the water column inside the well. Well ER-OV-03b produced turbid water at slow rates; therefore, water was injected into the air stream to assist in development. Wells were developed until the discharge water was clear. Rates and volumes of water removed during development are listed in table 2.

Table 2. Development rates, times, and volumes of water pumped for monitoring wells in Oasis Valley, Nevada

[Symbol: <, less than]

Well name	Average pumping rate (gallons per minute)	Time of development (minutes)	Minimum volume pumped (gallons)
ER-OV-01	20	90	1,800
ER-OV-02	20	155	3,100
ER-OV-03a	20	210	4,200
ER-OV-03a2	<1	600	600
ER-OV-03a3	20	270	5,400
ER-OV-03b	5	300	1,500
ER-OV-03c	7	75	525
ER-OV-03c2	7	85	595
ER-OV-04a	20	135	2,700
ER-OV-05	20	240	4,800
ER-OV-06a	20	95	1,900
ER-OV-06a2	<1	110	<110

GEOPHYSICAL LOGGING METHODS

Boreholes in Oasis Valley were geophysically logged to define the lithology, stratigraphy, and geohydrologic characteristics of the rock units penetrated during drilling. Geophysical logs were run in an open-hole filled with drilling fluid if the hole was mud-rotary drilled or water if the hole was partly or totally drilled with an air hammer. The boreholes were allowed to equilibrate for at least 3 hours after drilling completion before logging started; deep boreholes (greater than 200 ft) were allowed to set for at least 12 hours. The types of geophysical logs collected and their applications are listed in table 3. A typical suite of logs for each borehole consisted of a caliper log, natural-gamma log, conductivity log, resistivity log, resistance log, and spontaneous-potential log. Additionally, some of the boreholes have the following logs: short- and long-normal resistivity, lateral resistivity, acoustic velocity, fluid temperature, fluid resistivity, fluid specific conductance, acoustic televiewer, and heat-pulse flowmeter. A borehole video log was run in well ER-OV-06a. The set of logs obtained from each borehole is presented in figures 6–16 in the supplementary data section. Logs of spontaneous potential in wells ER-OV-02, -03a, -06a, and -06a2 recorded interference from a poorly grounded generator and, therefore, are not shown.

Table 3. Types, properties measured, and application of geophysical logs used in Oasis Valley, Nevada (modified from Keys, 1990)

Type of log	Properties measured	Application
Caliper	Borehole diameter	Provides borehole corrections for other logs, lithology, fractures, and hole volume
Natural gamma	Gamma radiation from natural sources in formation	Assists in the identification of lithology and stratigraphic correlation; may be related to clay content
Dual induction, multi-electrode, resistivity (conductivity, resistivity, short- and long-normal resistivity, and lateral resistivity)	Apparent resistivities of formation at different distances from borehole	Assists in the identification of lithology and stratigraphic correlation of units; provides qualitative or relative data on water quality
Single-point resistance	Resistance of formation and fluids in borehole and adjacent formations	Assists in the identification of lithology
Spontaneous potential	Electric potential between fluids in borehole and adjacent formations	Defines lithology, clay and shale content, and formation water quality
Acoustic velocity	Compressional-wave velocity through fluids and formations	Helps determine saturated zones, water levels, and lithology; indicator of fractures; used to estimate primary porosity
Fluid (temperature, fluid resistivity, and specific conductance)	Temperature, resistivity, and specific conductance of borehole fluids	Quality of borehole fluid, flow in borehole, and geothermal gradients
Acoustic televiewer	Acoustic reflectivity of borehole wall	Lithology determination; fracture location, width, orientation and character, strike and dip of beds. Additional processing provides deviation from the vertical of the borehole
Heat-pulse flowmeter	Vertical flow within the borehole	In-hole flow from fractures; apparent hydraulic conductivity of permeable zones

GEOHYDROLOGY

Description of Stratigraphic Units in Boreholes

Lithologic samples collected from each borehole were visually analyzed for mineralogic content and lithology. Seven distinct units, listed from oldest to youngest, were identified from the samples: (1) Ammonia Tanks Tuff; (2) Tuff of Cutoff Road; (3) tuffs, not formally named but informally referred to in this report as the “tuff of Oasis Valley”; (4) lavas also informally named in this report as the “rhyolitic lavas of Colson Pond”; (5) Tertiary colluvial and alluvial gravelly deposits; (6) Tertiary and Quaternary colluvium; and (7) Quaternary alluvium. A general description of each unit based on work by Scott Minor and others (U.S. Geological Survey, written commun., 1998) is given below.

The Ammonia Tanks Tuff (Tma) [11.45 Ma] is a member of the Timber Mountain Group. The tuff was erupted from the Timber Mountain caldera complex and is described as a light- to medium-gray-brown, metaluminous, welded ash-flow tuff. It is compositionally zoned and grades from a volumetrically dominant rhyolite (abundant sanidine, common quartz and plagioclase, sparse biotite and sphene, and rare clinopyroxene) in its lower part to a crystal-rich trachyte (abundant sanidine and biotite, common plagioclase and quartz, and sparse clinopyroxene and sphene) in its upper part. Sanidine and large (as much as 0.2 in. in diameter) equant and euhedral quartz are characteristic of the unit. It locally contains basaltic xenoliths as large as several meters across. In general, the tuff is distinguished by high quartz and mafic contents and sparse sphene. In a north-trending fault zone on the western side of the Oasis Valley, this unit has undergone intense hydrothermal alteration and brecciation.

The Tuff of Cutoff Road (Tfc) [11.1 Ma] also is a member of the Timber Mountain Group. The tuff is described as a light-pinkish-gray to light-yellowish-tan, moderately welded ash-flow tuff that forms a single unit. It has a pumiceous base with white, pale pink, and tan pumice clasts from about 0.5 in. to as large as 1 ft in diameter. The tuff contains 5 to 15 percent phenocrysts with the following mineralogy: abundant sanidine; common plagioclase and biotite, sparse hornblende and quartz, and common accessory sphene (Fridrich and others, 1994). Small lithic fragments within the tuff are moderately abundant. Locally, this tuff unit has undergone intense hydrothermal alteration.

The “tuff of Oasis Valley” is a grayish-white to light brown, non- to moderately welded, pumiceous and shard-rich sequence of ash-flow and air-fall tuffs. It contains pink, yellow, tan, and light-gray pumice clasts ranging from less than 0.5 in. to greater than 4 in., that are commonly zeolitized. This unit is bracketed stratigraphically between the 11.1 Ma Timber Mountain lavas and tuffs and the 9.5 Ma “rhyolitic lavas of Colson Pond.” It locally contains reworked ash from the Rainbow Mountain volcanic sequence to the south and west (C.J. Fridrich, U.S. Geological Survey, oral commun., 1998). The “tuff of Oasis Valley” contains 5-15 percent phenocrysts of plagioclase, sanidine, quartz, biotite, iron-titanium oxides, and some clinopyroxene, hornblende, and accessory sphene.

The “rhyolitic lavas of Colson Pond” (9.5 Ma) consist of multiple rhyolitic lava domes, lava flows, and ash-flow tuff sheets. The unit is well exposed at, and appears to be limited to, the mouth of Thirsty Canyon and the area near the present-day Colson Pond (less than 1 mi southwest of well ER-OV-01). The rhyolitic lavas are flow-banded and bluish-gray to black where glassy. Where the lavas are devitrified (and locally spherulitic), they are bluish-gray, pale reddish-brown, and medium brown in color. Based on argon-40/argon-39 isotope dating, the age of the unit is estimated to be approximately 9.5 Ma (D.A. Sawyer, U.S. Geological Survey, oral commun., 1998). The lavas contain approximately 5 to 15 percent phenocrysts of plagioclase, sanidine, biotite, some quartz, and lesser amounts of clinopyroxene and hornblende.

The Tertiary gravels (Tgs) are principally colluvial and alluvial gravel with some beds of sand and tuffaceous sand. The alluvial gravels are medium-gray to brownish-gray, subangular to well-rounded, poorly to moderately well-sorted, and well-bedded to nonbedded. Clasts within the colluvium and alluvium consist primarily of Paleozoic carbonate and clastic (siliceous) rocks and Tertiary volcanic rocks; the clasts include boulders as large as 10 ft in diameter. The gravels are well cemented by carbonate minerals (calichified) and locally form resistant ledges. North of Beatty Wash, the unit intertongues locally with volcanic rocks of local origin (Swadley and Parrish, 1988).

The Tertiary and Quaternary colluvium (QTc) consists of unsorted, nonbedded, unconsolidated to moderately consolidated, angular pebble-to-boulder talus. Landslide deposits and sandy slope-wash and alluvial deposits also are included within this unit. The unit is present along or at the base of moderate to steep bedrock slopes.

The Quaternary alluvium (Qal) is poorly sorted, poorly bedded, unconsolidated to weakly consolidated, gravel, gravelly sand, and sand. Gravel clasts are angular to rounded and consist mainly of Miocene tuff and lava of local provenance. Sand grains are poorly sorted, fine to very coarse, and locally silty and clayey. The alluvium forms channel deposits of active streams, terrace deposits along some large washes, and extensive alluvial fans that commonly form the lower part of fan aprons flanking bedrock uplands. Localized sandy-silty-clayey paleo-stream channels occur throughout the alluvium. Additionally, localized zones of reddish hydrothermal alteration or subaerially weathered surfaces are present throughout the deposit.

Stratigraphic and lithologic units in the boreholes were identified by analysis of cuttings and interpretation of geophysical logs (table 4). The principal geophysical logs used in the determination of intervals were caliper, natural gamma, conductivity, induction resistivity, and resistance.

Geophysical Logs

Geophysical logs collected from each borehole are presented in figures 6 through 16. A geologic log of the major stratigraphic units is shown with the geophysical logs. Horizontal scales for each type of geophysical log are the same for all boreholes with the exception of the induction resistivity log for borehole ER-OV-03a2 and ER-OV-03a3 (fig. 8), which is expanded 10 times. The vertical scale for each set of geophysical logs is different among boreholes.

Table 4. Stratigraphic and lithologic descriptions of monitoring wells in Oasis Valley, Nevada

[Stratigraphic unit: Qal, Quaternary alluvium; QTc, Quaternary and Tertiary colluvium; Tfc, Tuff of Cutoff Road, Tgs, Tertiary colluvial and alluvial gravel; Tma, Ammonia Tanks Tuff]

Stratigraphic unit	Depth interval (feet below land surface)	Lithology
Well ER-OV-01		
"rhyolitic lavas of Colson Pond"	0-68	Rhyolitic lava — bluish grey to grey brown; vitric
do.	68-90	Rhyolitic lava — grey; devitrified
do.	90-147	Rhyolitic lava and tuff — grey brown to red brown; moderately welded; pumiceous; devitrified(?); phenocrysts of quartz, plagioclase, and sanidine
"tuff of Oasis Valley"	147-180	Tuff — red brown to grey; moderately welded; pumiceous; hydrothermally altered; phenocrysts of plagioclase, quartz, sanidine, and biotite
Well ER-OV-02		
Qal	0-52	Alluvium — thin (less than 1 foot) interbedded gravels, sands, and clays; well sorted; subrounded gravels
QTc	52-148	Colluvium — thick (greater than 2 feet) lenses of sandy, silty, and clayey gravels; angular to subangular, poorly sorted, moderately to well cemented gravels and cobbles
Tgs	148-200	Colluvium and alluvium — clay with rounded to angular fine gravel consisting of altered tuff(?) or rhyolitic lava(?); some Paleozoic clasts
Well ER-OV-03a		
Qal	0-35	Alluvium — sandy clayey gravels
Tgs	35-80	Colluvium and alluvium — thin (less than 1 foot) interbedded gravelly clays and sandy gravels; Paleozoic clasts
Tfc	80-130	Tuff — grey pink; densely welded
Tma	130-209	Tuff — grey pink; clayey; phenocrysts of quartz
do.	209-241	Tuff — grey pink; welded; phenocrysts of quartz
do.	241-251	Tuff — grey pink; clayey; phenocrysts of quartz
Wells ER-OV-03a2 and ER-OV-03a3		
Qal	0-23	Alluvium — sandy clayey gravels
Tfc	23-75	Tuff—pink grey; phenocrysts of quartz; densely welded
Tma	75-133	Tuff — pink grey; moderately to densely welded; phenocrysts of quartz, biotite, and feldspars
do.	133-201	Tuff — pink grey to brown; moderately welded; phenocrysts of quartz, biotite, and feldspars; native sulfur crystals; highly fractured zone
do.	201-259	Tuff — pink grey; altered to clay; phenocrysts of quartz, biotite, and feldspars
do.	259-266	Fault gouge — brown clay; grey-pink tuff fragments
do.	266-310	Tuff — pink grey to pink brown; altered to clay; pink-grey tuff fragments; phenocrysts of quartz, biotite, and feldspars
do.	310-321	Fault gouge — red-brown clay
do.	321-821	Tuff — white, orange, tan, green, grey pink, and red; altered to clay; pumiceous; tuff fragments; basalt lithics; phenocrysts of quartz, biotite, sanidine, feldspars, and clinopyroxene

Table 4. Stratigraphic and lithologic descriptions of monitoring wells in Oasis Valley, Nevada—Continued

Stratigraphic unit	Depth interval (feet below land surface)	Lithology
Well ER-OV-03b		
Qal	0-56	Alluvium — thin, unconsolidated, silty, sandy, and clayey gravels
do.	56-60	Playa deposits — evaporites interbedded with clay and very fine-grained silts and sands
do.	60-70	Alluvium — thin, unconsolidated, silty, sandy, and clayey gravels
Tgs	70-179	Colluvium and alluvium — clayey, sandy, very coarse gravels with scattered cobbles and boulders
do.	179-269	Alluvium — sandy, clayey gravels
do.	269-400	Alluvium — silty, clayey, coarse sand
Well ER-OV-03c		
Qal	0-32	Alluvium — thin, unconsolidated, clayey, sandy gravels
Tma	32-56	Tuff — orange to red clay; hydrothermally altered; fragments of unaltered tuff
do.	56-85	Tuff — red clay; hydrothermally altered
do.	85-520	Tuff — grey pink to grey; non to moderately welded; lithic fragments; ashy; vitrified; phenocrysts of quartz and feldspars
do.	520-542	Tuff — medium gray purple; densely welded; phenocrysts of quartz, feldspars, biotite, clinopyroxene
Well ER-OV-03c2		
Qal	0-30	Alluvium — thin, unconsolidated, clayey, sandy gravels
Tma	30-87	Tuff — red clay; hydrothermally altered; fragments of unaltered tuff
do.	87-321	Tuff — grey pink to grey; non to moderately welded; lithic fragments; ashy; vitric; phenocrysts of quartz and feldspars
Well ER-OV-04a		
Qal	0-11	Alluvium — thin, unconsolidated, clayey, sandy gravels
do.	11-34	Alluvium — sandy gravels; moderately to well cemented
do.	34-151	Alluvium — silty, sandy gravels; non to moderately cemented; clay lenses
Well ER-OV-05		
Qal	0-80	Alluvium — unconsolidated, silty, sandy gravels
do.	80-200	Alluvium — coarse gravels interbedded with silty, sandy clay
Well ER-OV-06a		
“rhyolitic lavas of Colson Pond”	0-325	Rhyolitic lava — bluish grey to grey brown; poorly to moderately welded; scattered hydrothermally altered stringers
“tuff of Oasis Valley”	325-431	Tuff — red brown to grey banded; poorly to moderately welded; pumiceous; hydrothermally altered; phenocrysts of plagioclase, quartz, and sanidine
do.	431-536	Tuff — tan to brown; moderately to densely welded; lithics
Well ER-OV-06a2		
“rhyolitic lavas of Colson Pond”	0-71	Rhyolitic lava — bluish grey to grey brown; contains hydrothermally altered stringers

Water Levels

Two sets of water-level measurements are presented in table 5. Depths to water ranged from about 18 to 350 ft below land surface. Regional ground-water flow through the Oasis Valley study area is primarily to the south (Laczniak and others, 1996). Water levels measured in Oasis Valley (table 5) generally match the regional water-level contours shown by Laczniak and others (1996, pl. 1). Little temporal variation was observed in water levels. For example, sets of measurements made more than 3 months apart (October 27, 1997, and February 10, 1998) were all within 0.8 ft of each other. A strong downward vertical gradient in the borehole with nested wells ER-OV-03a2 and ER-OV-03a3 may result from a fault that separates a shallow flow system monitored by well ER-OV-03a3 from a deeper flow system monitored by well ER-OV-03a2.

Ground-Water Flow in Well ER-OV-06a

Flow-producing fractures or bedding planes in six water-bearing zones (A–F in fig. 5) were identified in borehole ER-OV-06a with the aid of acoustic televiewer, temperature, caliper, and heat-pulse flowmeter logs (Hess, 1986). Interpretation of the flowmeter log (fig. 5) was difficult because of the large scatter in the data, primarily in the interval where flow was greatest. Most of the scatter is attributed to the rugged borehole (as shown on the caliper log), which did not allow a good seal between aquifer zones. The probable inflow or outflow points shown in table 6 are taken as the center of the zones where inflow or outflow actually occurs as inferred from inflections on the temperature log. Ambient upflow in the well was approximately 0.5 to 0.6 gal/min, which was only partly reduced when water was injected into the well. The temperature log supports the interpretation that the greatest ambient flow (both inflow and outflow) is in the interval between 210 and 340 ft. In this interval, the temperature log is nearly isothermal because the flow is so fast that it does not cool much as it travels up the borehole.

Although transmissivities of the water producing zones cannot be directly calculated from the flowmeter data, differences of inflow rates that are proportional to transmissivity may be used to determine the relative transmissivities of the zones (Paillet, 1998). When flow is measured in a borehole, the amount of flow entering from a given bed or zone is proportional to the product of two unmeasured variables—the transmissivity of the zone and the change in hydraulic head across the borehole wall. [The change in head is defined as the hydraulic head within a zone (which was not measured) minus the hydraulic head in the borehole.]

Table 5. Water levels in 12 monitoring wells in Oasis Valley, Nevada, October 1997 and February 1998

Well name	Measured October 27, 1997		Measured February 10, 1998	
	Water level (feet below land surface)	Water-level altitude (feet above sea level)	Water level (feet below land surface)	Water-level altitude (feet above sea level)
ER-OV-01	18.2	3,989.1	18.3	3,989.1
ER-OV-02	28.8	3,851.5	28.5	3,851.8
ER-OV-03a	56.5	3,787.9	56.6	3,787.8
ER-OV-03a2	160.0	3,683.8	159.9	3,683.9
ER-OV-03a3	56.3	3,787.5	56.4	3,787.4
ER-OV-03b	346.8	3,885.9	346.8	3,885.9
ER-OV-03c	214.4	3,977.1	214.5	3,977.0
ER-OV-03c2	214.2	3,977.7	214.8	3,977.1
ER-OV-04a	24.5	3,466.9	23.7	3,467.7
ER-OV-05	32.1	3,905.8	32.1	3,905.7
ER-OV-06a	15.3	3,992.2	15.4	3,992.1
ER-OV-06a2	18.6	3,988.4	18.7	3,988.4

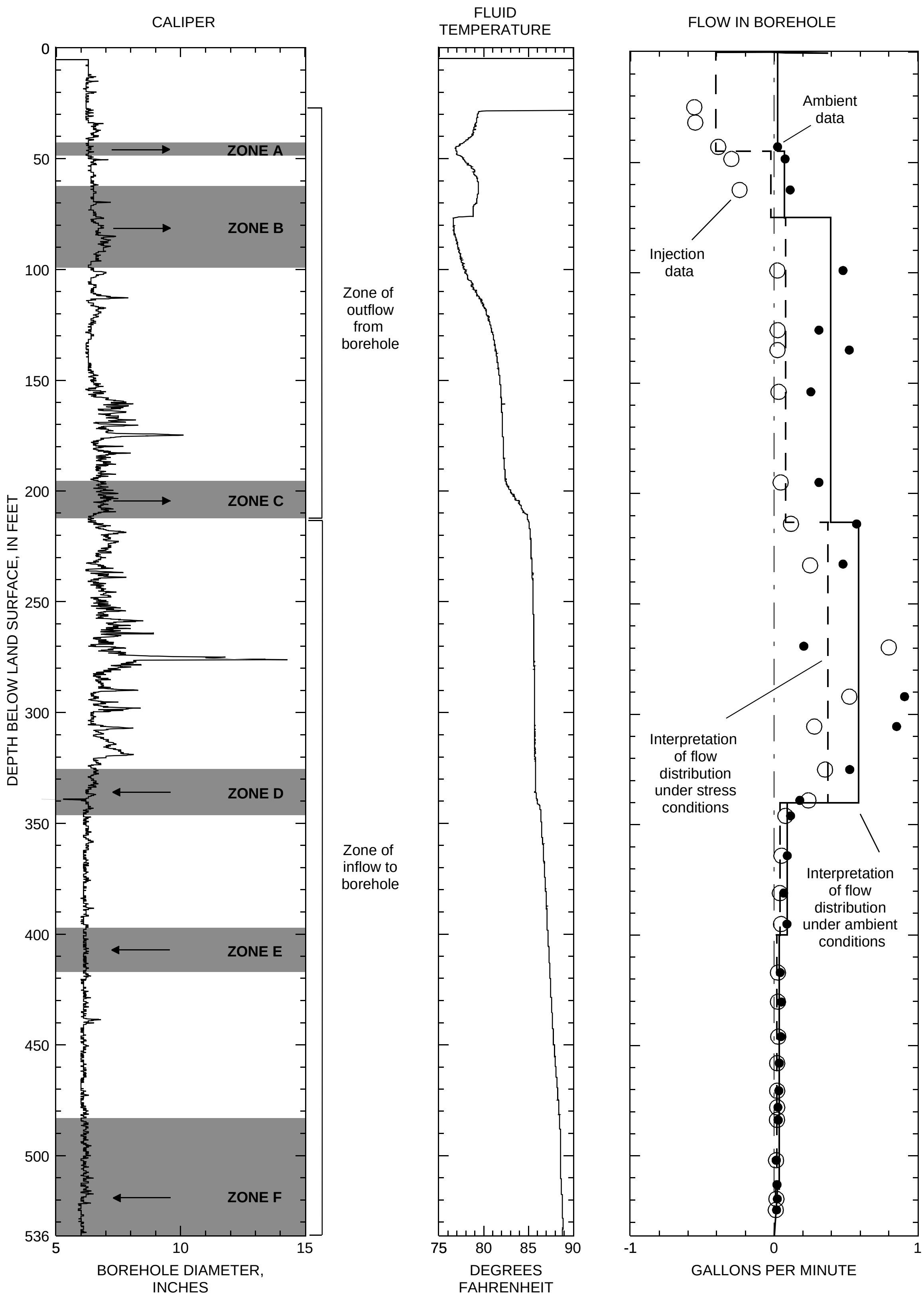


Figure 5. Caliper and fluid-temperature logs and heat-pulse flowmeter interpretation from well ER-OV-06a, Oasis Valley, Nevada

Table 6. Summary of inflow and outflow zones and relative transmissivities in borehole ER-OV-06a, Oasis Valley, Nevada

Zone	Depth of inflow or outflow zone (feet below land surface)	Probable inflow or outflow point (feet below land surface)	Inflow or outflow (gallons per minute)			Percent difference between ambient and injection inflow or outflow[2]	Relative transmissivity
			Ambient[1]	Injection[1]	Difference		
A	43.0 - 48.5	45	-0.10	-0.10	0.00	<1	Low
B	62.5 - 99.0	75	-.30	-.32	.02	5.1	Low
C	195.0 - 213.0	205	-.20	-.37	.17	43.6	High
D	325.5 - 346.0	340	.50	.34	.16	41.0	High
E	397.0 -417.0	400	.06	.03	.03	7.7	Low
F	483.0 - 536.0	515	.04	.03	.01	2.6	Low
	Total		0.00	-.39	.39	100	

[1] By convention, inflow (water flowing into well) is shown as positive number and outflow is shown as negative number.

[2] Percent difference for zone is calculated using following equation:
100 x [(ambient inflow) - (injection inflow)]/(sum of differences between ambient and injection inflow for all zones). Precision implied by percent differences for zone exceeds intended accuracy.

Relative transmissivity for a given zone is determined from the following equation that describes the change in flow, ΔQ, for a given fracture zone:

$$\Delta Q = \Delta i * T$$

where Δi is the change in gradient from the fracture zone to the borehole between ambient and injection conditions, and T is the transmissivity of the fracture zone. If it is assumed that the change in head difference or gradient between the borehole and the aquifer at each zone is the same, then the change in flow is directly proportional to the difference in transmissivity of the fracture zones. This difference between inflow under two head conditions is used to determine the relative transmissivity.

To determine relative transmissivities for each zone in borehole ER-OV-06a, the differences of inflows and outflows between ambient and steady injection conditions were calculated (table 6). During ambient conditions, the water level in the borehole was at equilibrium with the surrounding water-bearing zones, whereas during steady injection conditions, a constant rate of 0.39 gal/min of water was injected into the borehole. During injection conditions, flows into the borehole from all zones systematically decrease. That is, more water flows out of the borehole (which is expressed mathematically as a decrease of inflow) and less water flows into the borehole. To make the net difference between ambient and injection inflows (column 6 of table 6) a positive number, injection inflows are subtracted from ambient inflows. For example, in zone C, the ambient inflow (-0.20 gal/min) minus the injection inflow (-0.37 gal/min) equals 0.17 gal/min. Because this difference (43.6 percent) is a large percentage of the total difference between ambient and injection inflows, the relative transmissivity of zone C is ranked high relative to other zones in the borehole.

The flowmeter analysis is based on a “difference of a difference”; therefore, errors in measurements are magnified. That is, the inflow or outflow within a zone is calculated as the difference in flow between the top and bottom of the zone. Then the difference between two such sets of data (at different head conditions in the well) is used to estimate the relative transmissivity. Thus, the relative transmissivities of zones are rough estimates. These estimates were especially subject to error in the 150- to 320-ft interval (which includes zone C) where the borehole is rugged, and a great deal of scatter in the flow measurements occurs.

The zones of greatest transmissivity in borehole ER-OV-06a were in zone C (in the “rhyolitic lavas of Colson Pond”) and zone D (near the top of the “tuff of Oasis Valley”). Transmissivities in the remaining four zones were relatively low. In zone A, the difference between ambient and injection data is zero, implying no transmissivity. However, the zone was clearly transmissive because it accepted flow (fig. 5 and column 4 in table 6); the transmissivity was just an order or two of magnitude smaller than that of some of the other zones.

SUMMARY

The investigation and remediation of radioactive and other contaminants at the NTS are the focus of the U.S. Department of Energy Environmental Restoration Program (U.S. Department of Energy, 1991). One of the objectives of the long-term program is to assess the extent of contamination on, and potentially off, the NTS. Oasis Valley is one U.S. Department of Energy area of concern because it is downgradient from Pahute Mesa, one of the sites of intensive underground nuclear testing. In 1997, the U.S. Geological Survey installed a network of wells in the valley because ground water from parts of western and central Pahute Mesa may discharge into Oasis Valley.

Monitoring-well sites were selected with the purpose of developing a long-term ground-water monitoring network in the Oasis Valley area. The objective of the network is to define spatial and temporal changes in the chemical and isotopic character of the ground water. Information from the network may be used (1) to refine the current understanding of the ground-water flow system through a better understanding of the ground-water chemistry and subsurface geology and (2) to monitor potential changes in ground-water chemistry related to past underground testing activities at the NTS.

Seven sites were chosen in which to install single or multiple wells. Multiple wells, where present, were less than 30 ft from each other and screened at different depths. The selected sites are upgradient from the major spring-discharge area in Oasis Valley. Twelve monitoring wells (in 11 boreholes) were installed at these sites. The wells range in depth from 65 to 642 ft.

Boreholes in Oasis Valley were geophysically logged to define the lithology, stratigraphy, and geohydrologic character of the rock units penetrated during drilling. A typical suite of logs for each borehole includes a caliper log, natural-gamma log, conductivity log, resistivity log, resistance log, and spontaneous-potential log. Additionally, some of the boreholes have the following logs: short- and long-normal resistivity, lateral, acoustic velocity, fluid temperature, fluid resistivity, fluid specific conductance, acoustic televiewer, and heat-pulse flowmeter.

The rocks of hydrogeological significance that underlie the region surrounding Oasis Valley are grouped into several major units. These include a sequence of Paleozoic and older sedimentary and metamorphic rocks, an assemblage of Miocene volcanic rocks, and locally thick deposits of post-volcanic valley fill composed of gravel, sand, and silt. The major regional aquifers have been designated (1) the carbonate-rock aquifer, (2) the volcanic-rock aquifer, and (3) the valley-fill aquifer. Only volcanic rocks and valley-fill deposits were penetrated in boreholes drilled for this study. Seven geologic units were identified and described from samples collected during the drilling: (1) Ammonia Tanks Tuff; (2) Tuff of Cutoff Road; (3) tuffs, not formally named but informally referred to in this report as the "tuff of Oasis Valley"; (4) lavas informally named the "rhyolitic lavas of Colson Pond"; (5) Tertiary colluvial and alluvial gravelly deposits; (6) Tertiary and Quaternary colluvium; and (7) Quaternary alluvium.

Hydrologic data collected from the wells include two sets of water levels in October 1997 and February 1998. Water levels ranged from about 18 to 350 ft below land surface. Additional hydrologic data include flowmeter data from a borehole penetrating volcanic rock on the north side of Oasis Valley. Six water-producing zones were identified in the borehole with the aid of an acoustic televiewer and a heat-pulse flowmeter. The zones of greatest transmissivity in the borehole (as determined from the flowmeter data) are at depths of about 205 ft in the "rhyolitic lavas of Colson Pond" and 340 ft near the top of the "tuff of Oasis Valley."

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Drilling of well ER-OV-03c near Beatty Wash on the eastern side of Oasis Valley study area (Photograph by Douglas Trudeau, U.S. Geological Survey)

Wells ER-OV-01, ER-OV-06a, and ER-OV-06a2 near Thirsty Canyon on the northern side of Oasis Valley study area (Photograph by Steve Reiner, U.S. Geological Survey)

SUPPLEMENTAL DATA: WELL LOGS

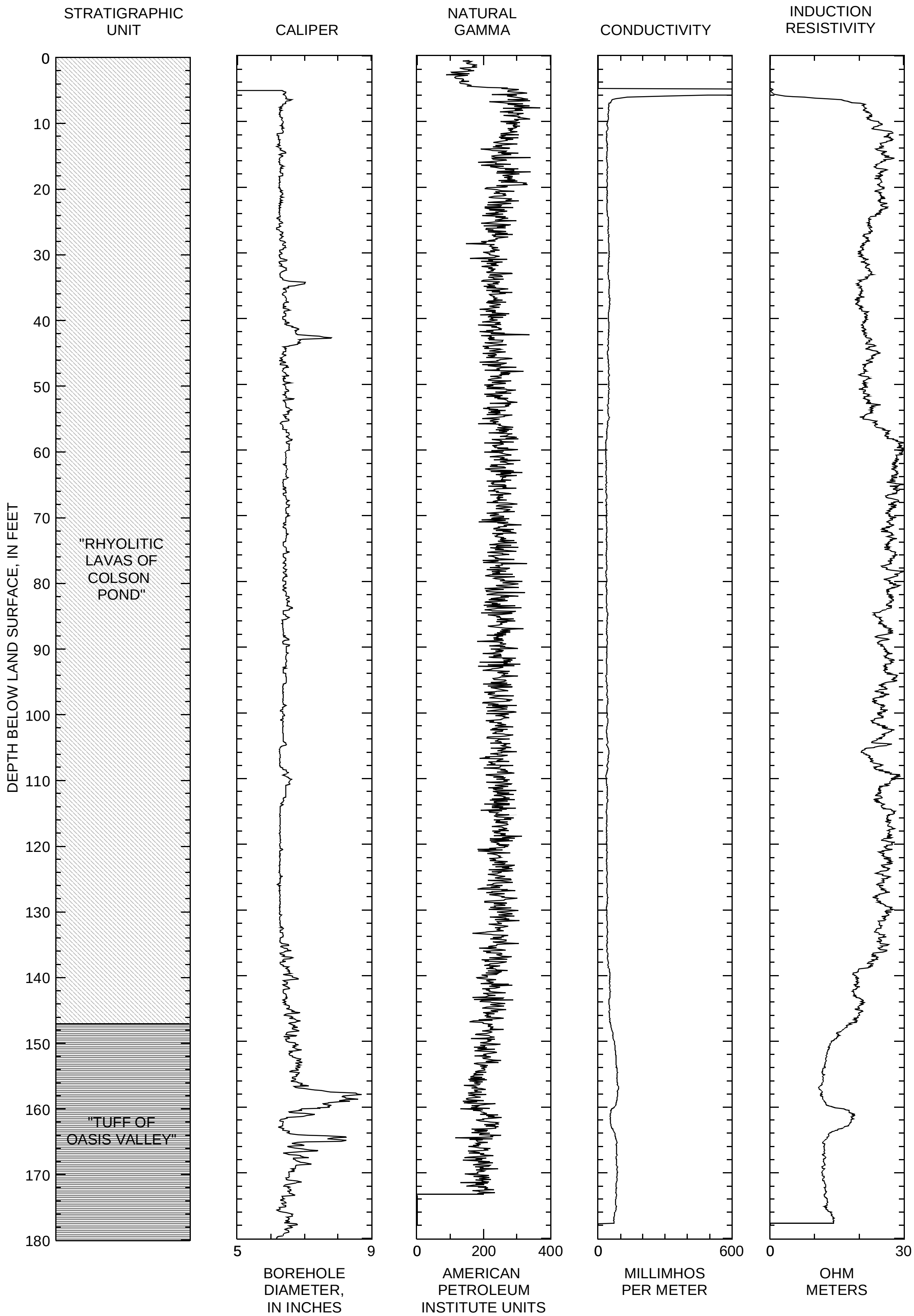
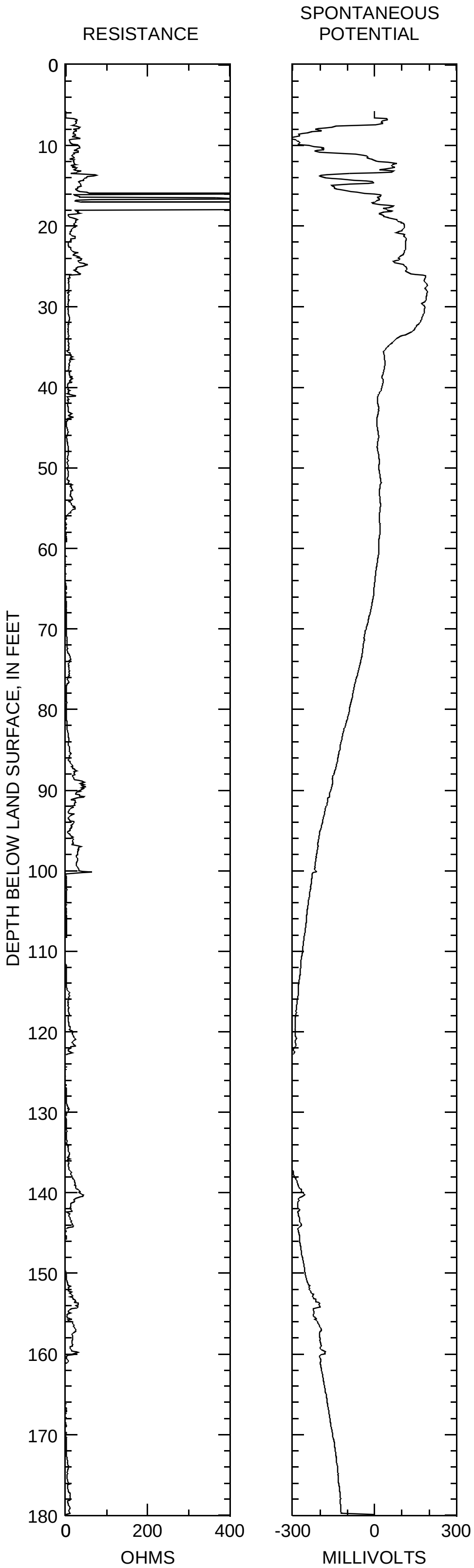


Figure 6. Geologic and geophysical logs from well ER-OV-01, Oasis Valley, Nevada.



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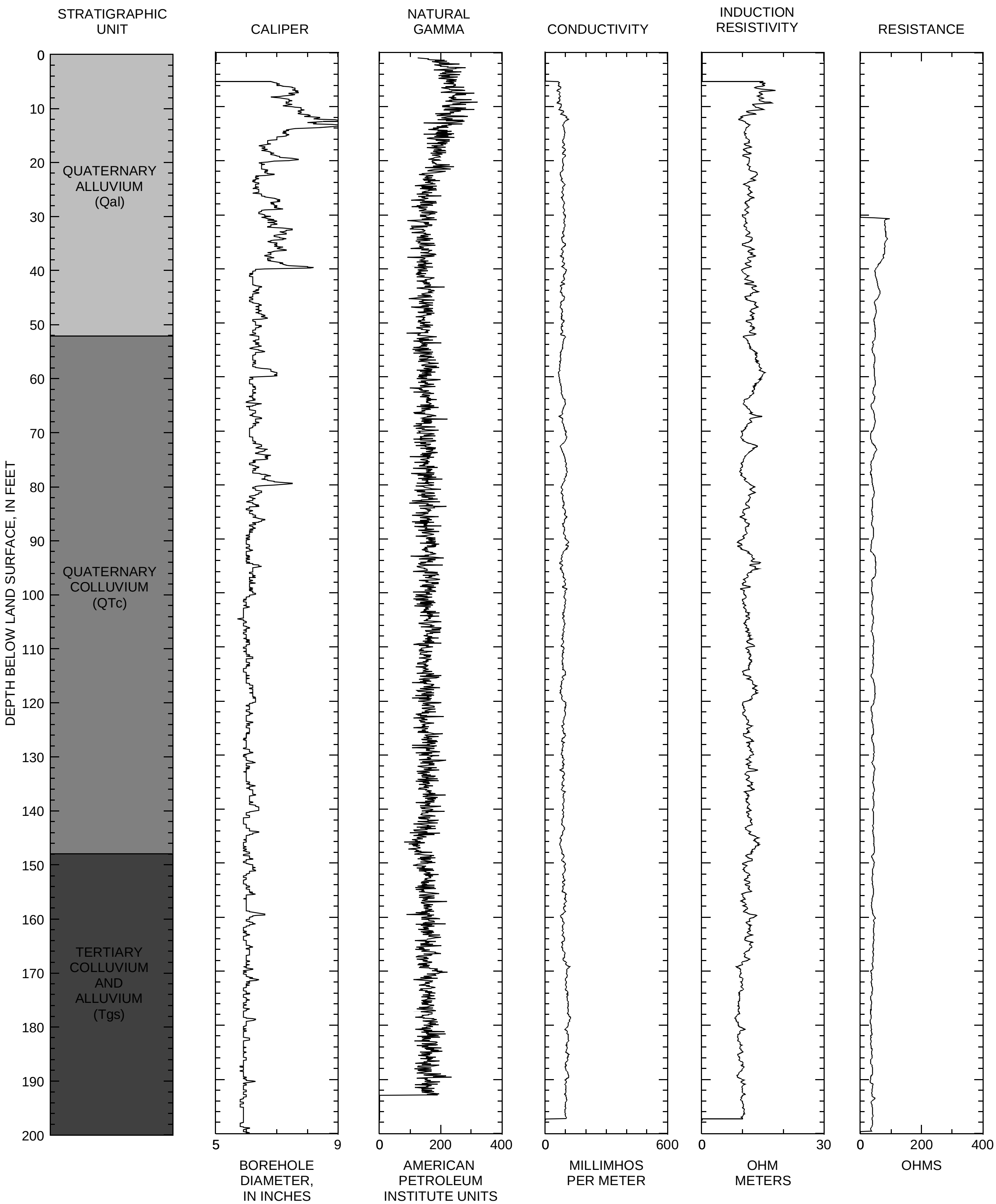


Figure 7. Geologic and geophysical logs from well ER-OV-02, Oasis Valley, Nevada.

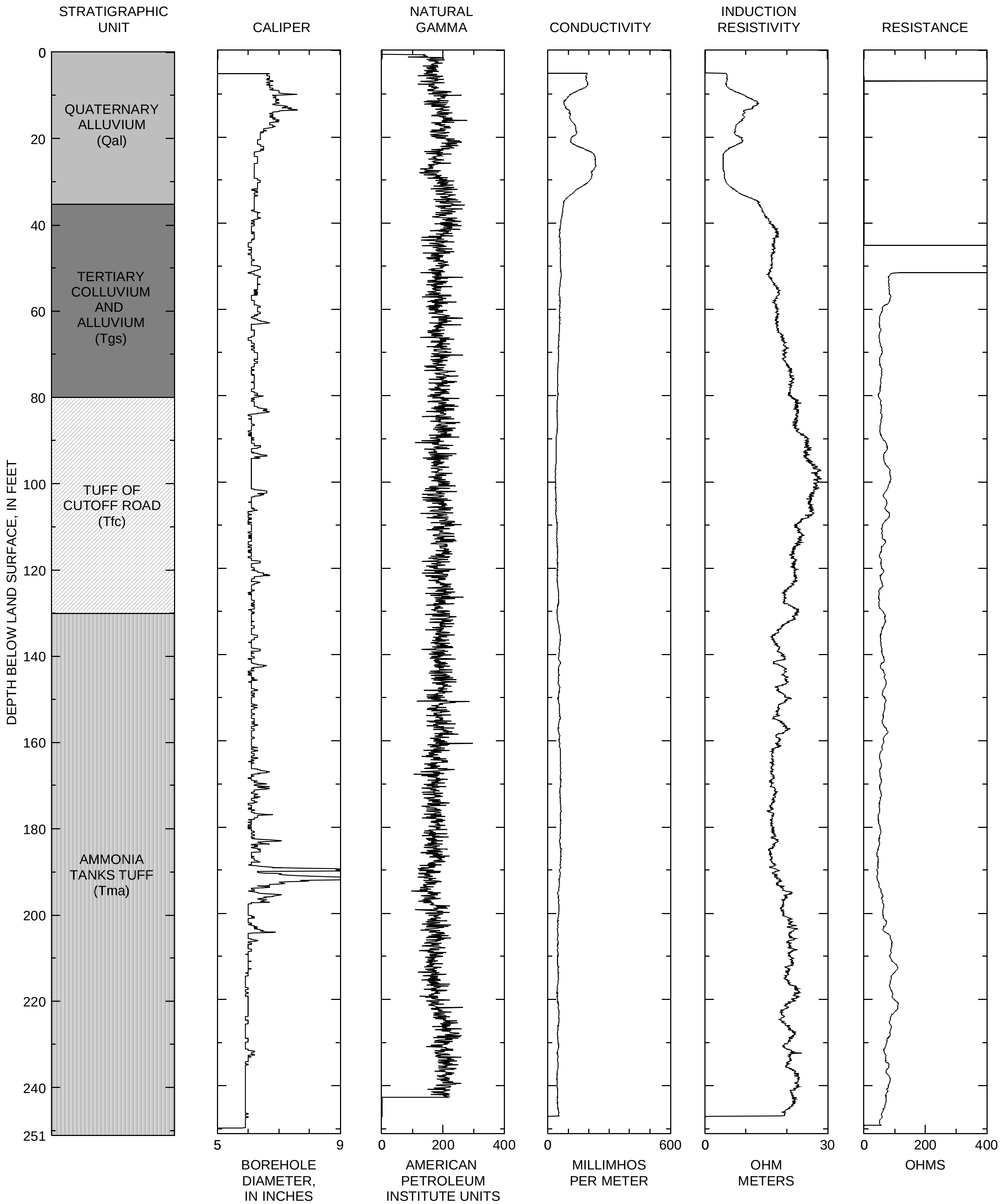


Figure 8. Geologic and geophysical logs from well ER-OV-03a, Oasis Valley, Nevada.

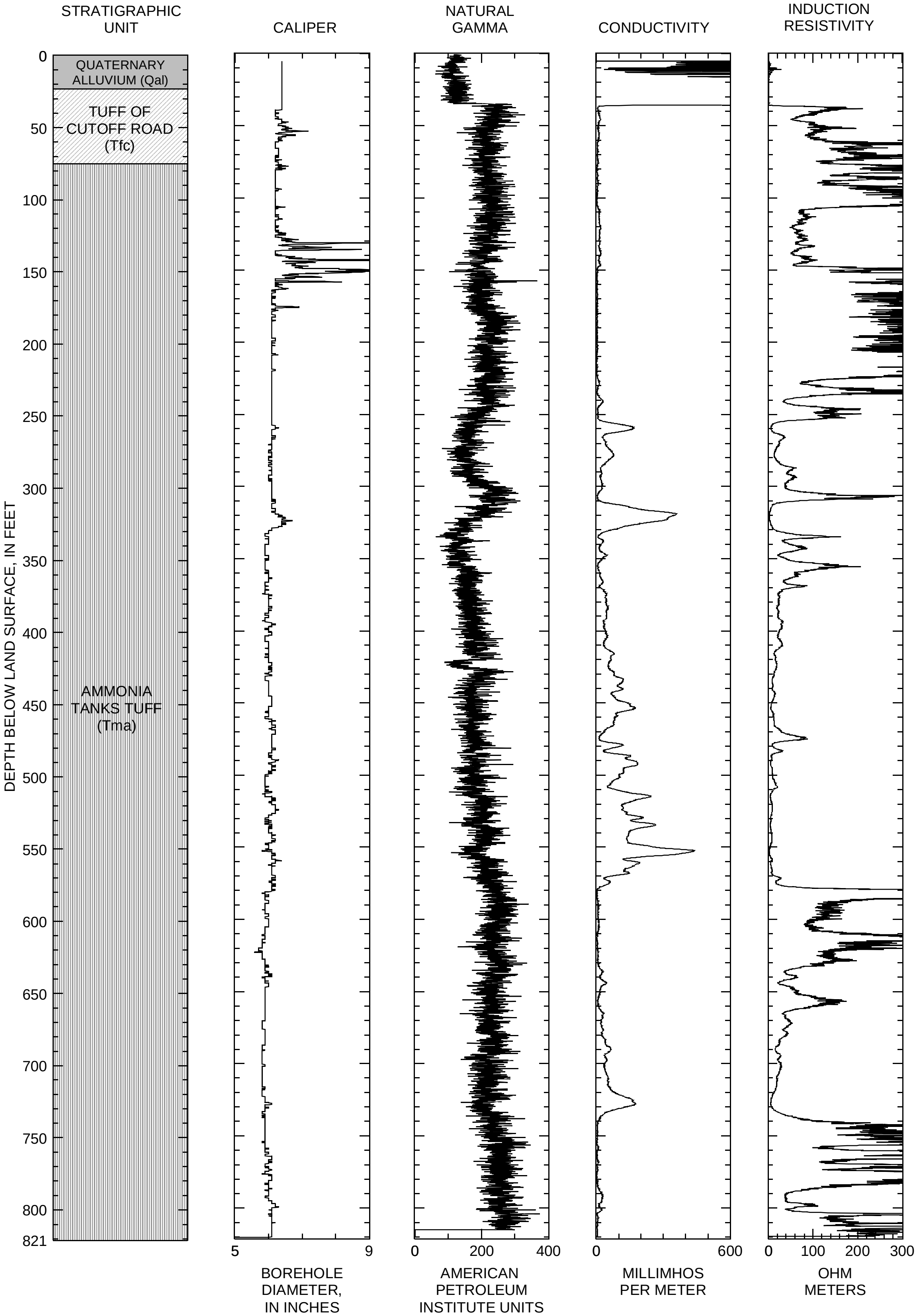
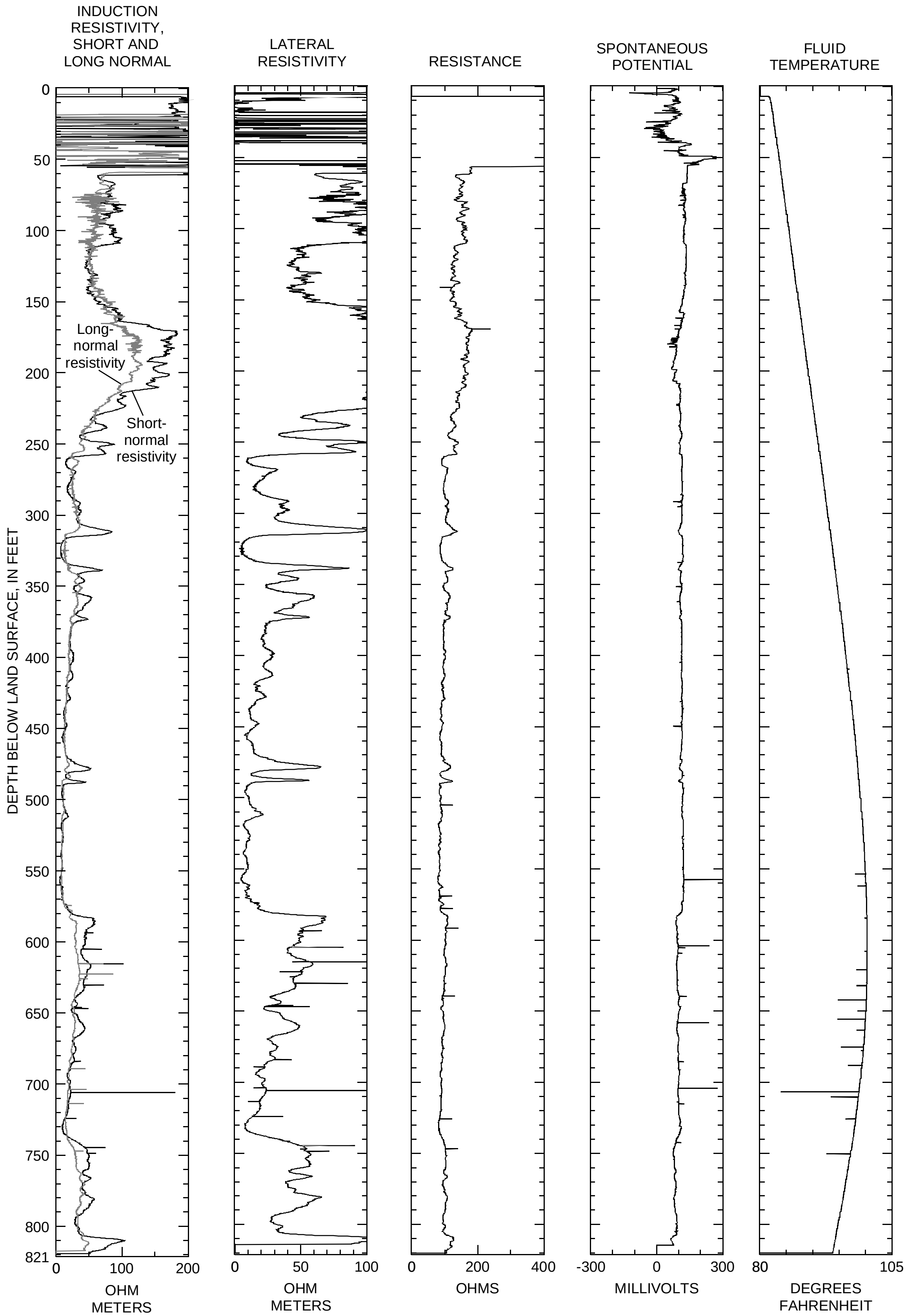


Figure 9. Geologic and geophysical logs from wells ER-OV-03a2 and ER-OV-03a3, Oasis Valley, Nevada.



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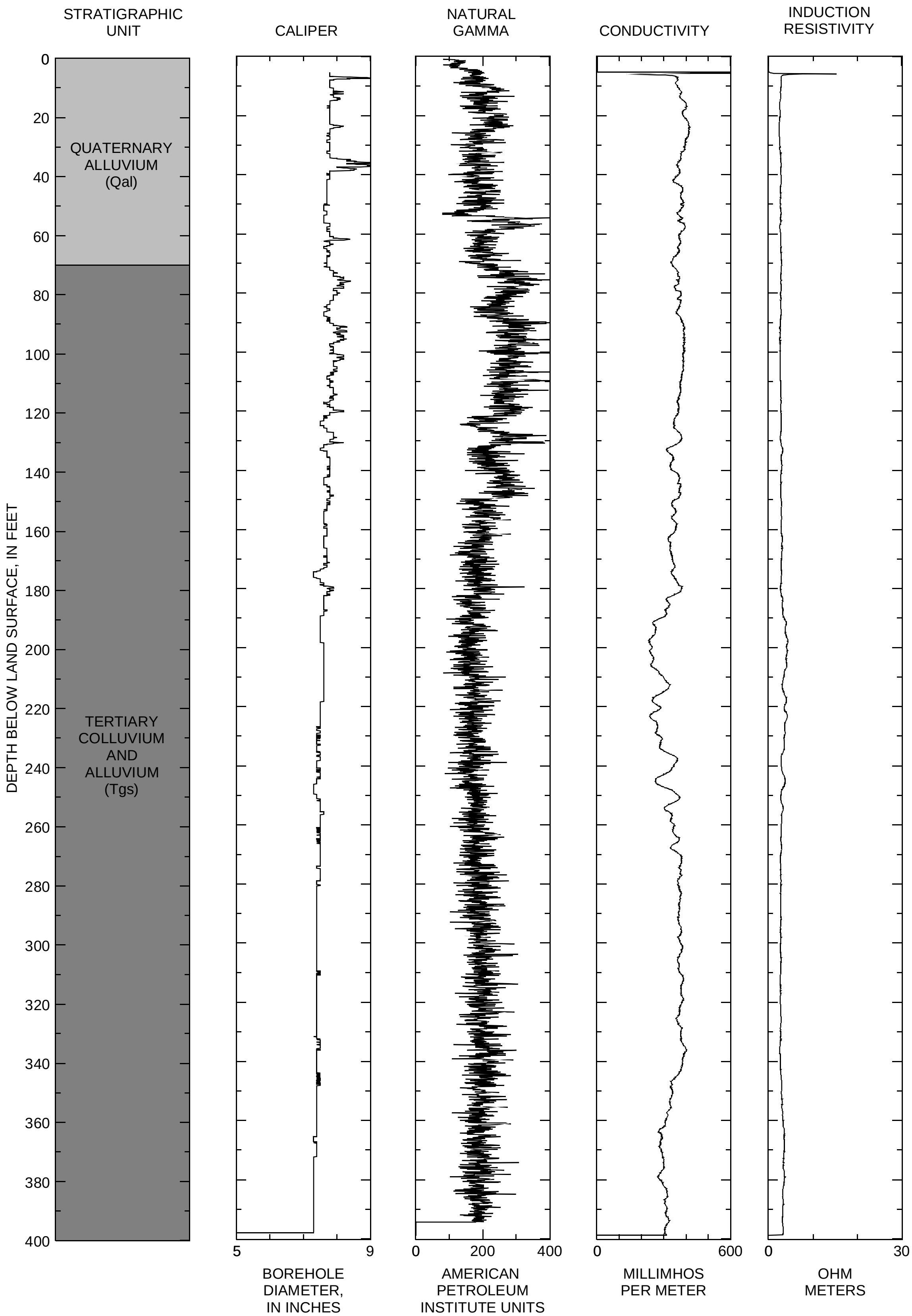
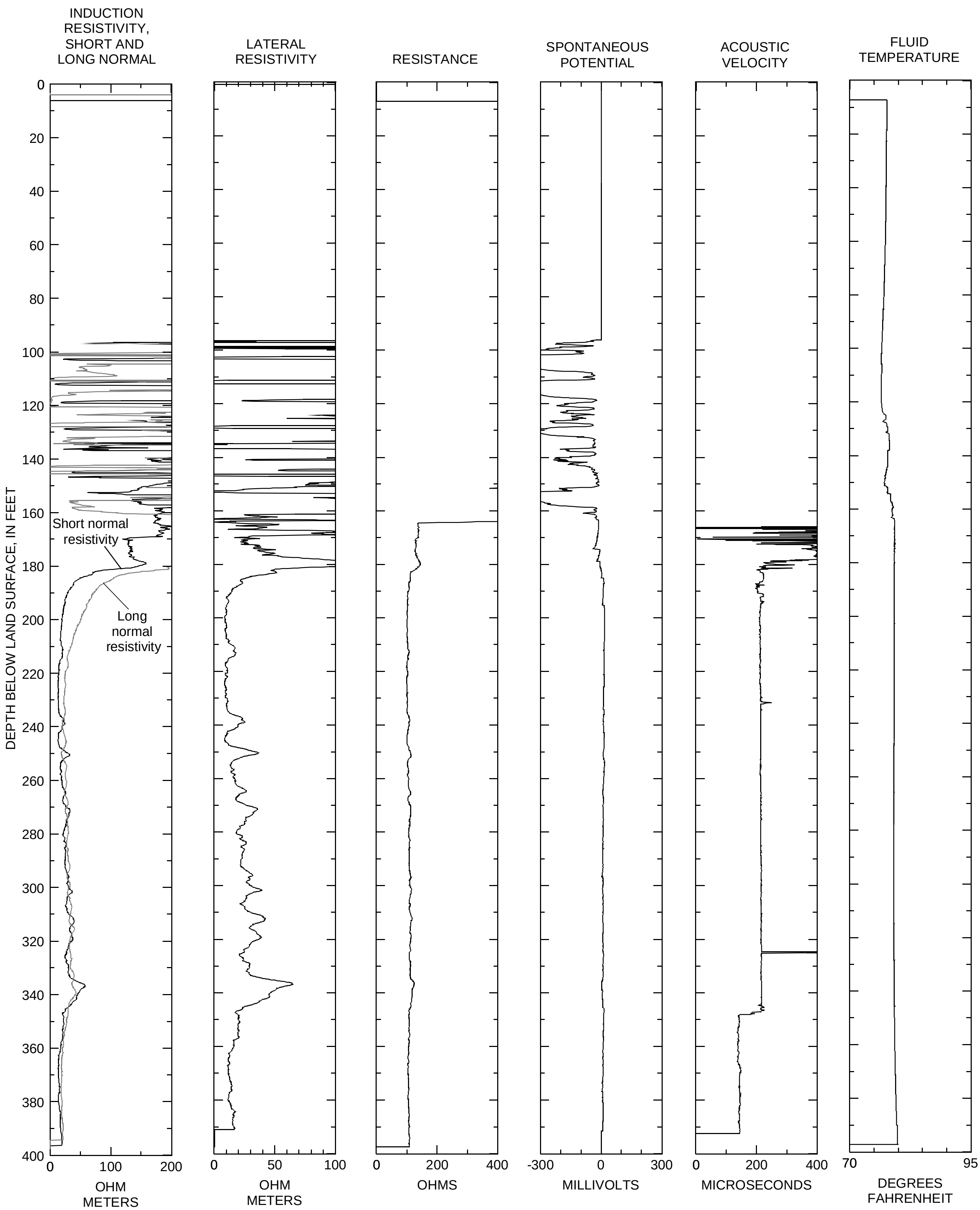


Figure 10. Geologic and geophysical logs from well ER-OV-03b, Oasis Valley, Nevada.



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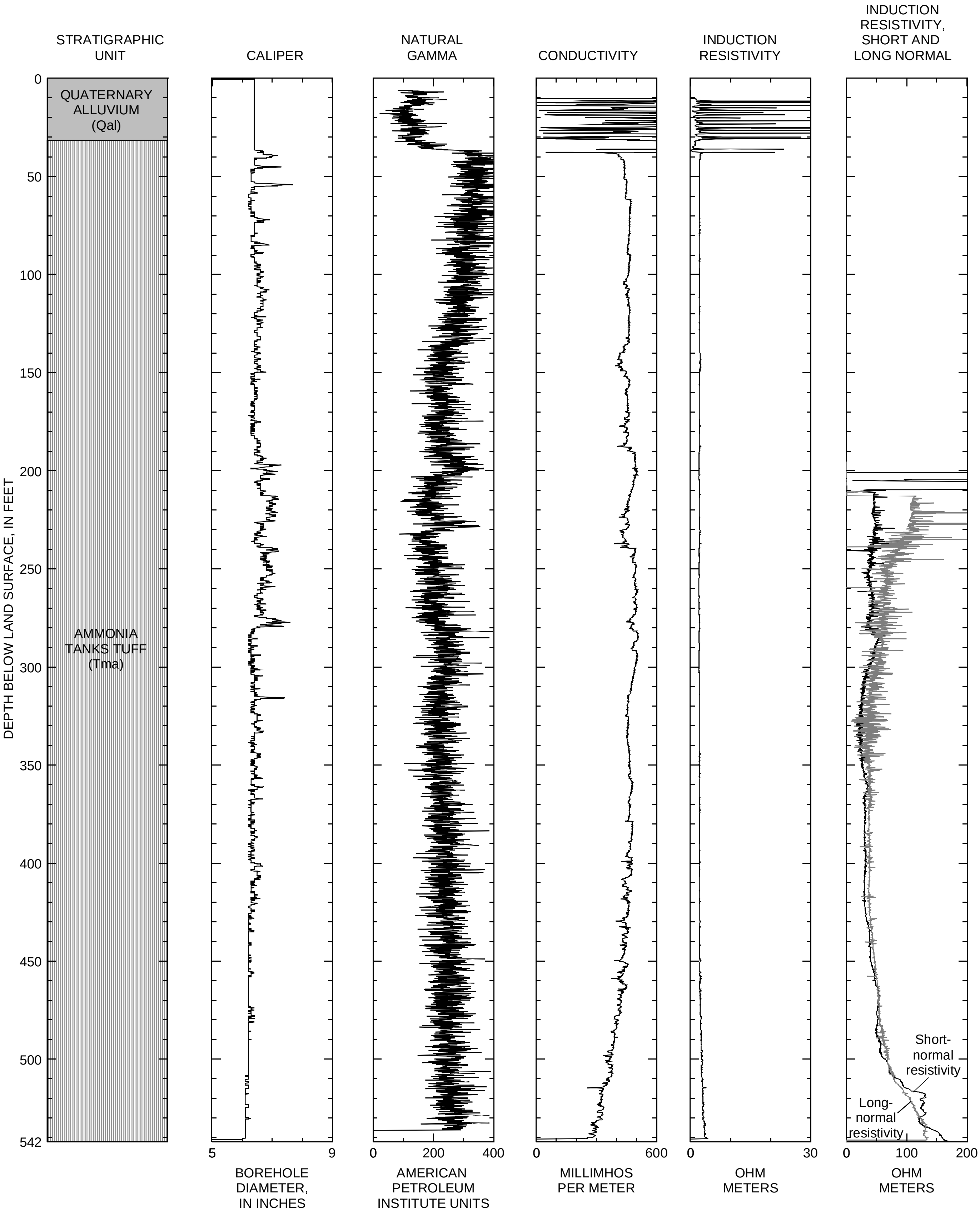
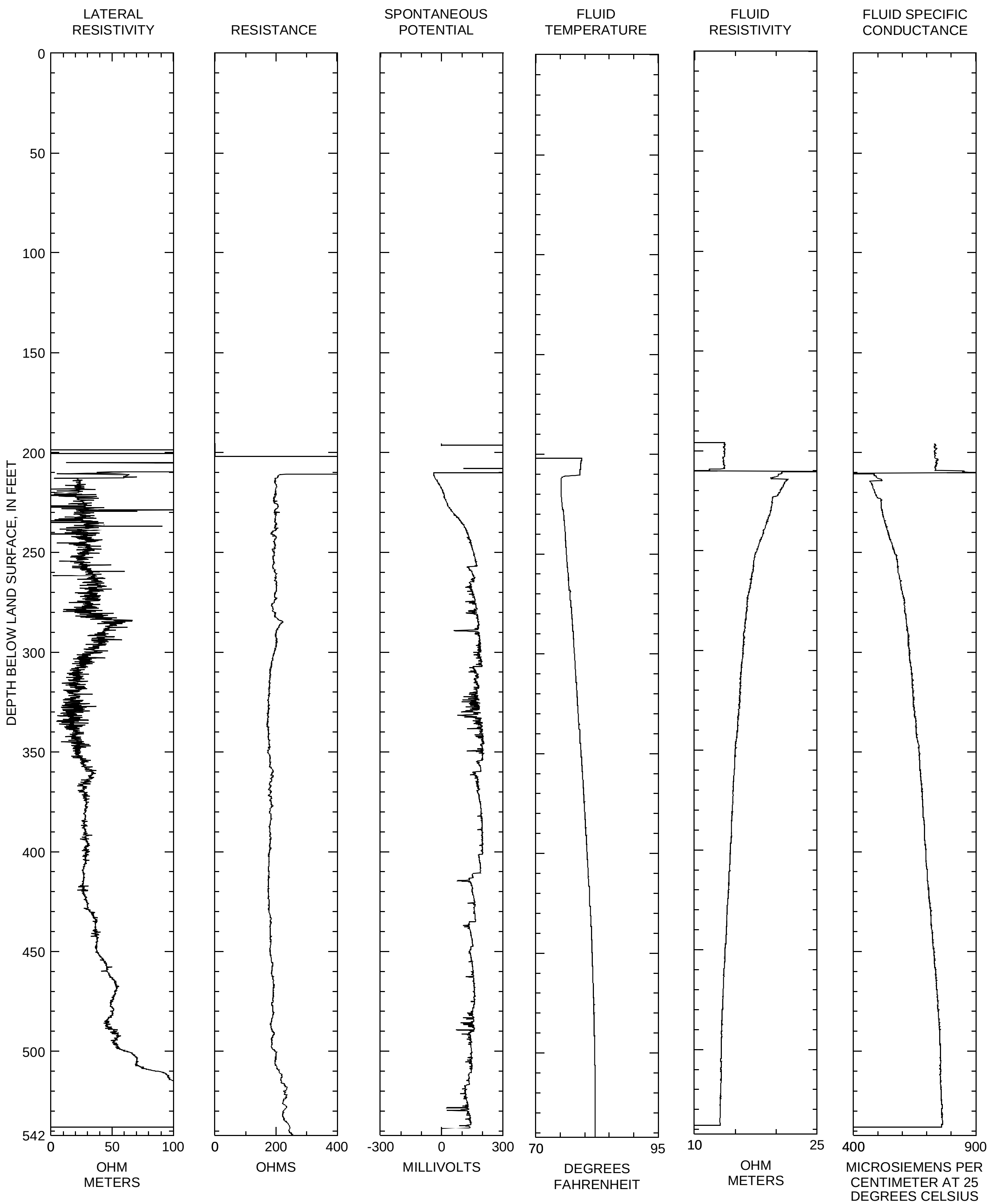


Figure 11. Geologic and geophysical logs from well ER-OV-03c, Oasis Valley, Nevada.



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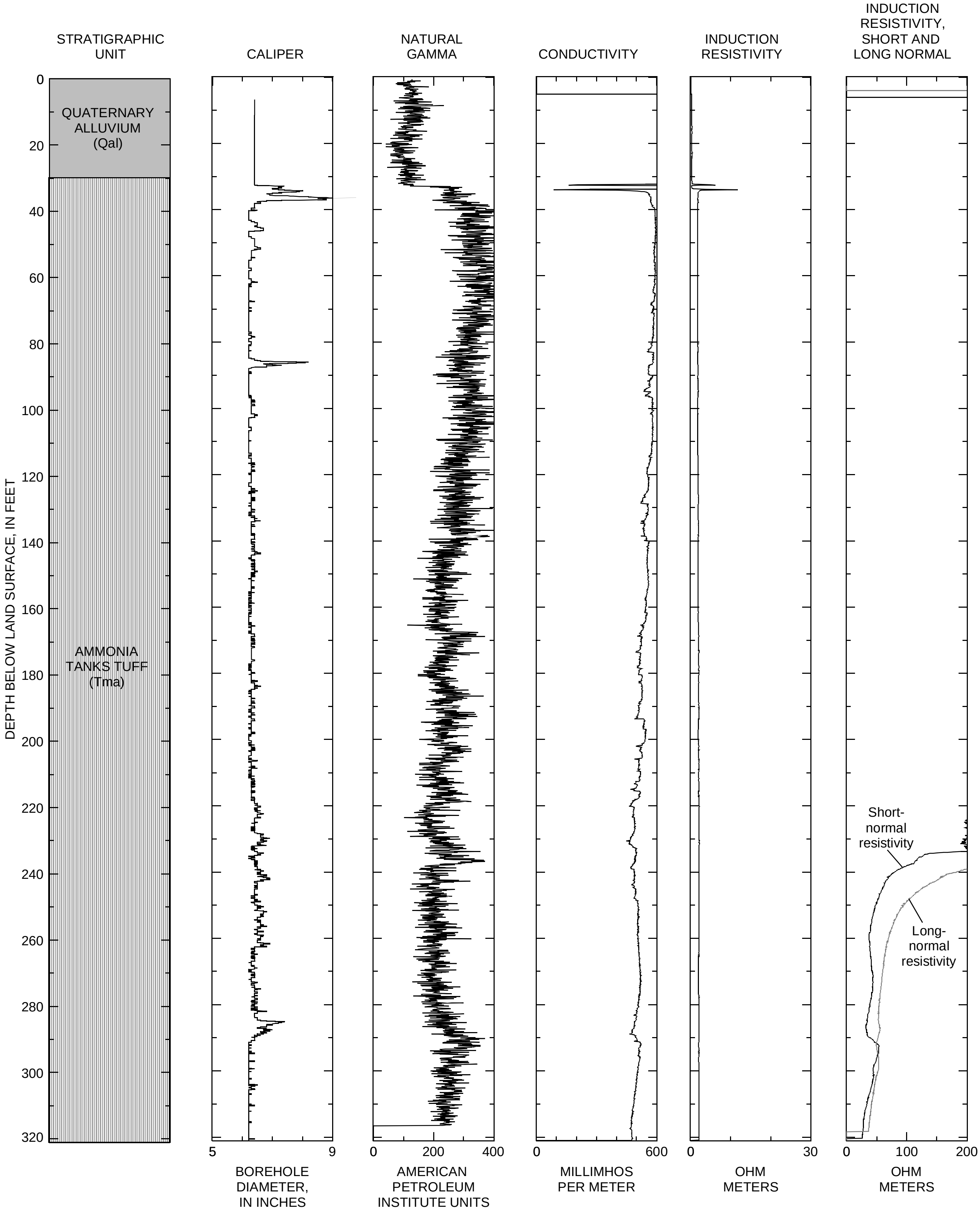
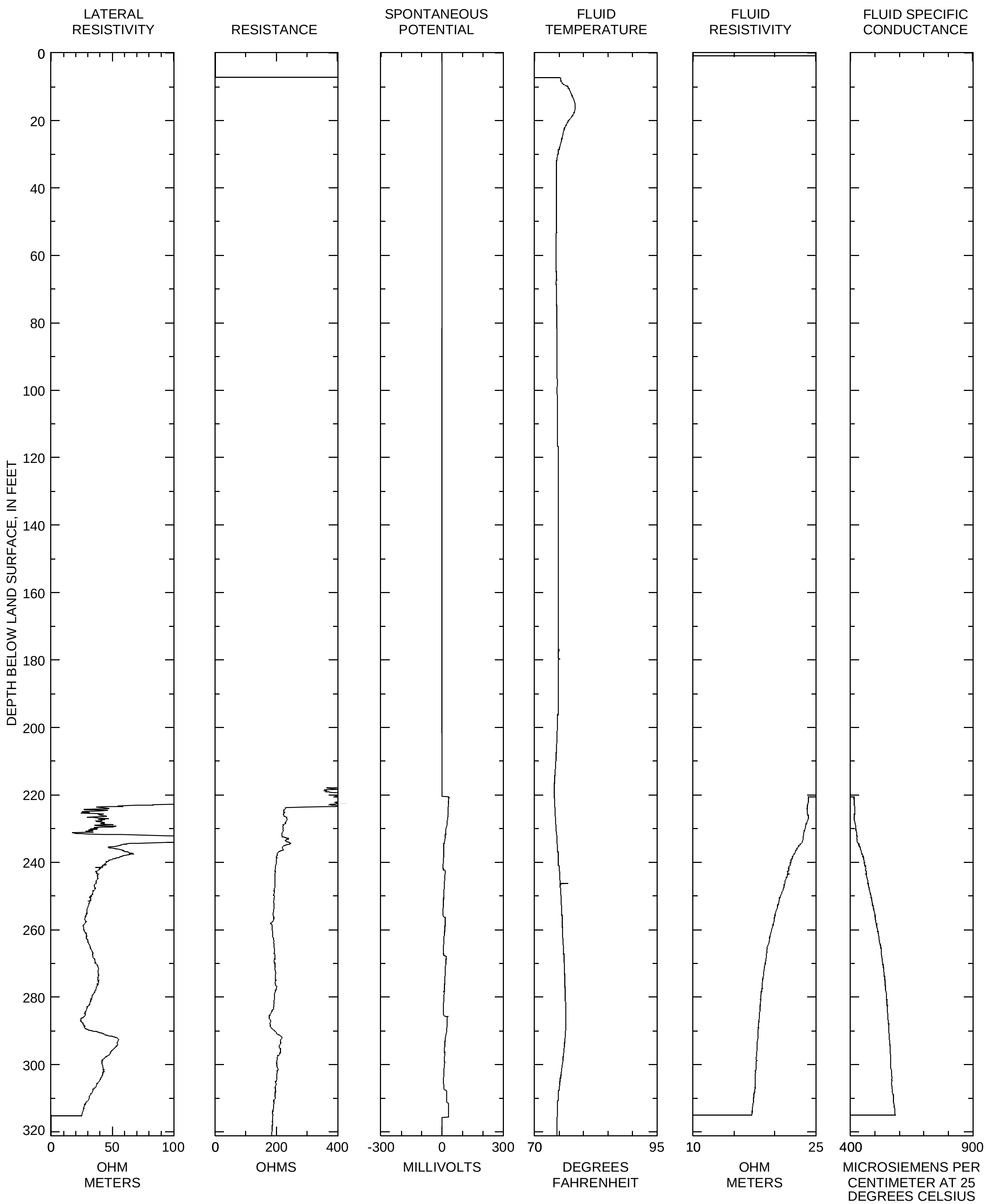


Figure 12. Geologic and geophysical logs from well ER-OV-03c2, Oasis Valley, Nevada.



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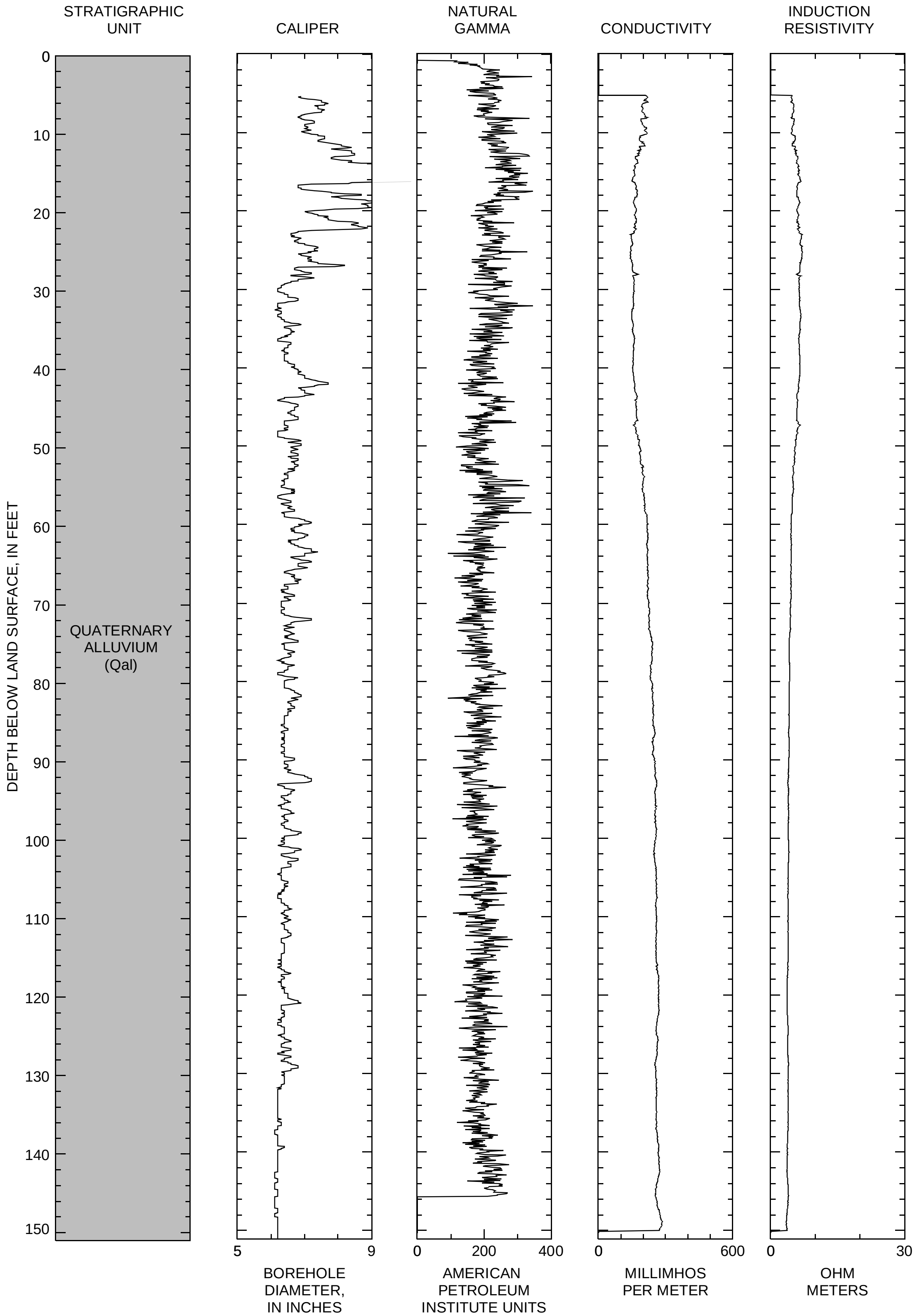
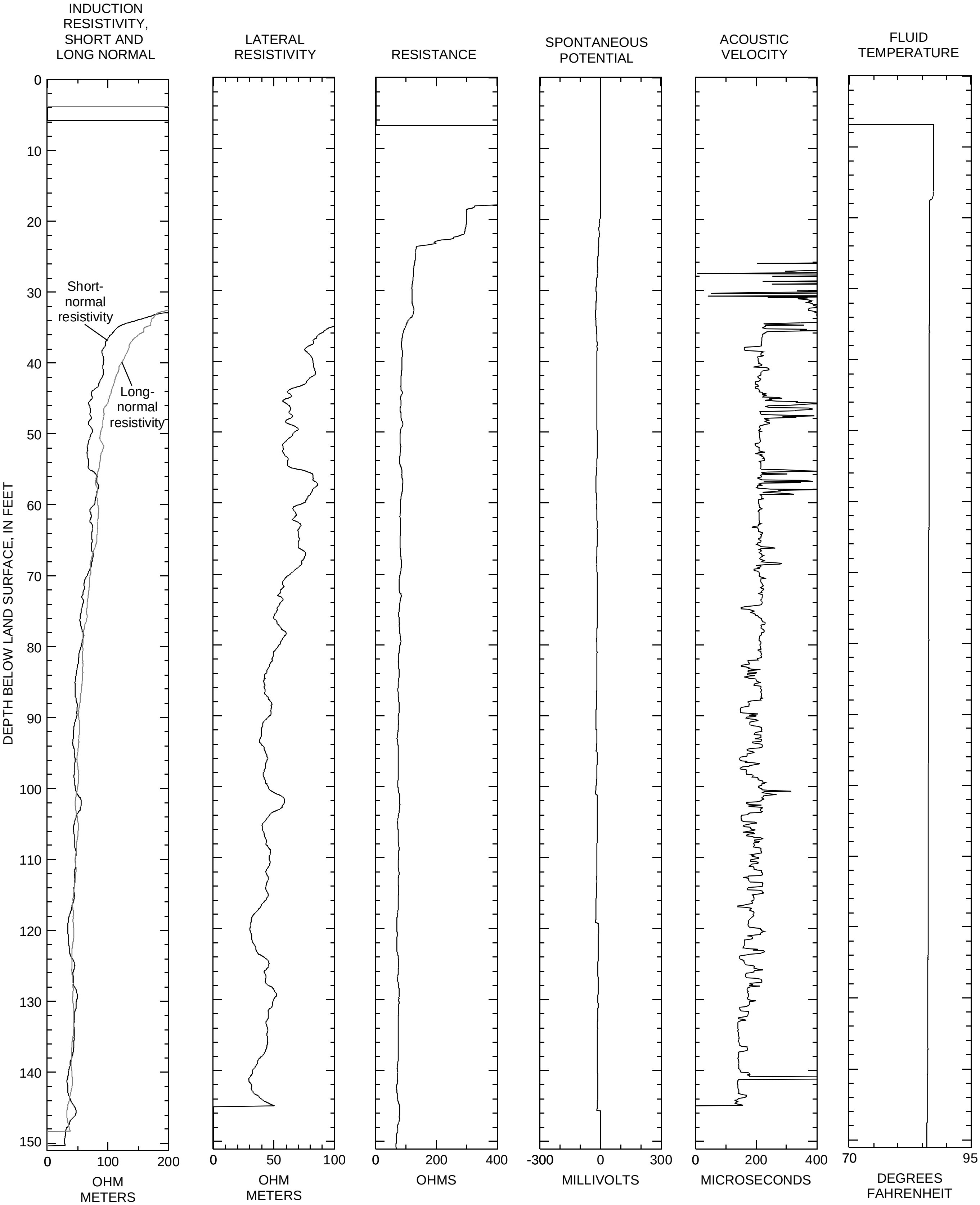


Figure 13. Geologic and geophysical logs from well ER-OV-04a, Oasis Valley, Nevada.



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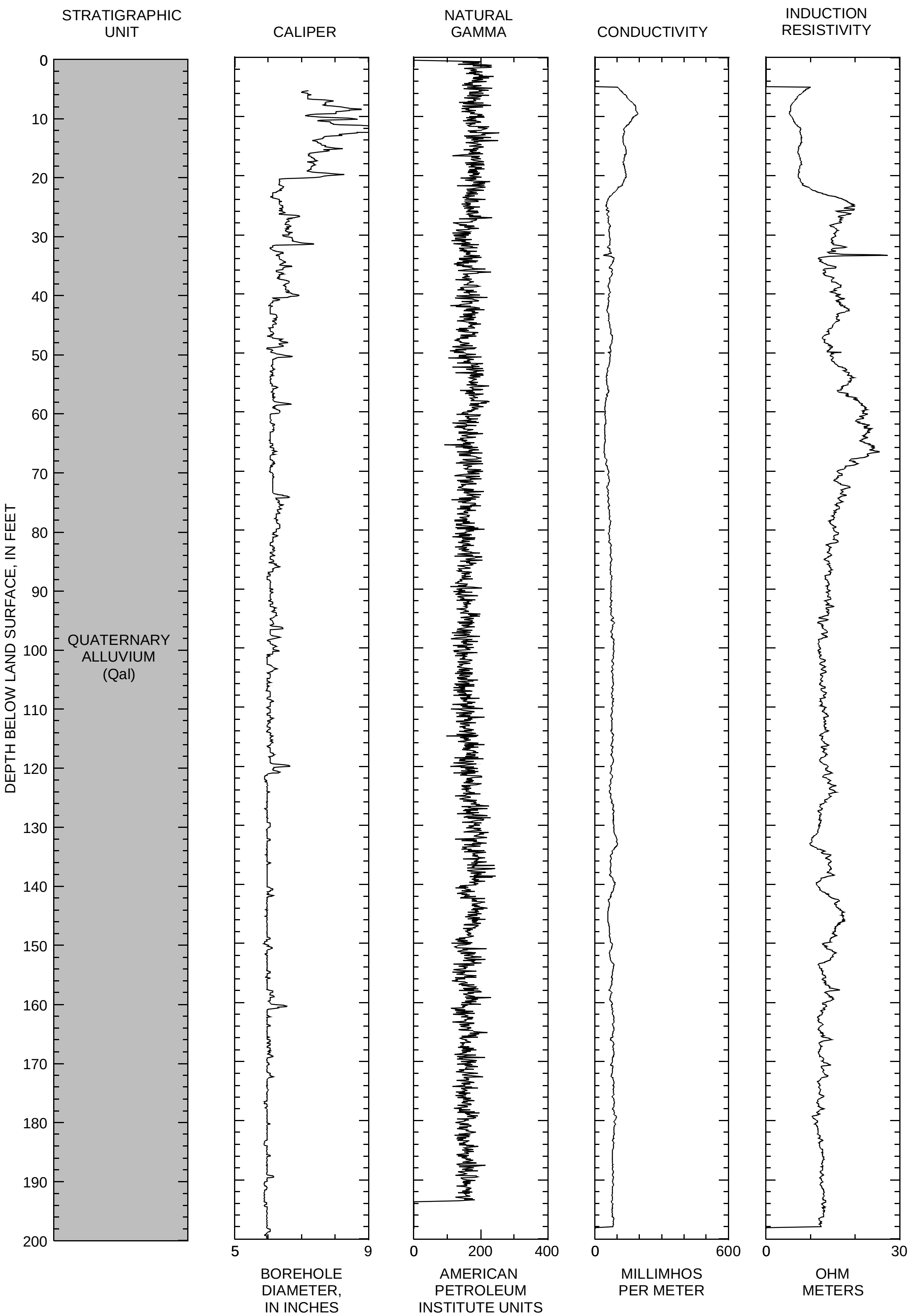
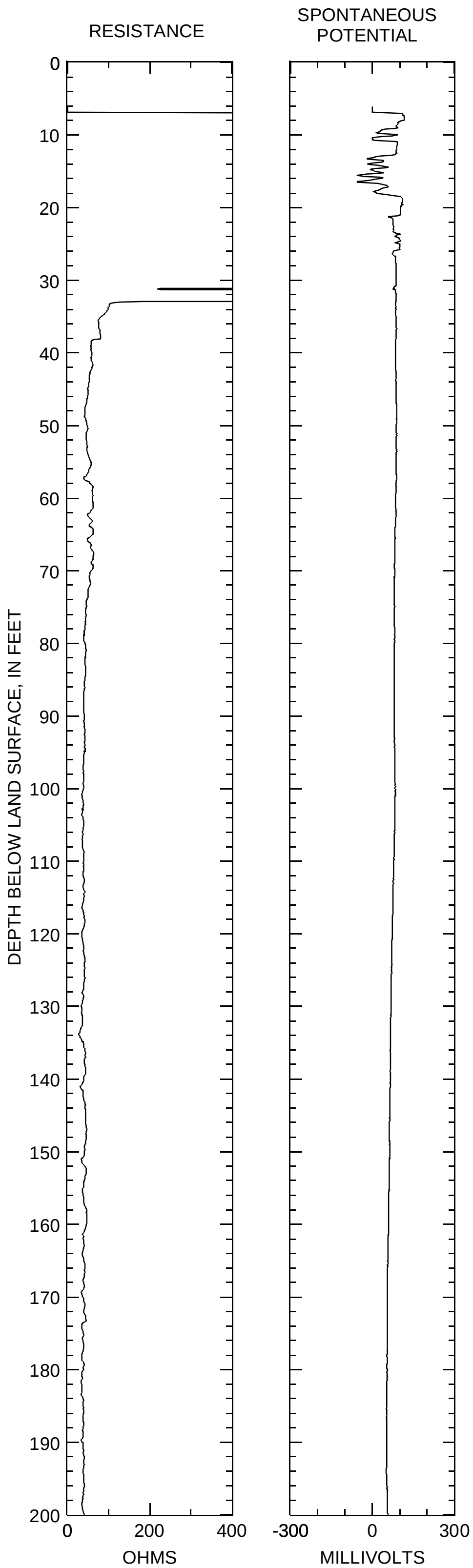


Figure 14. Geologic and geophysical logs from well ER-OV-05, Oasis Valley, Nevada.



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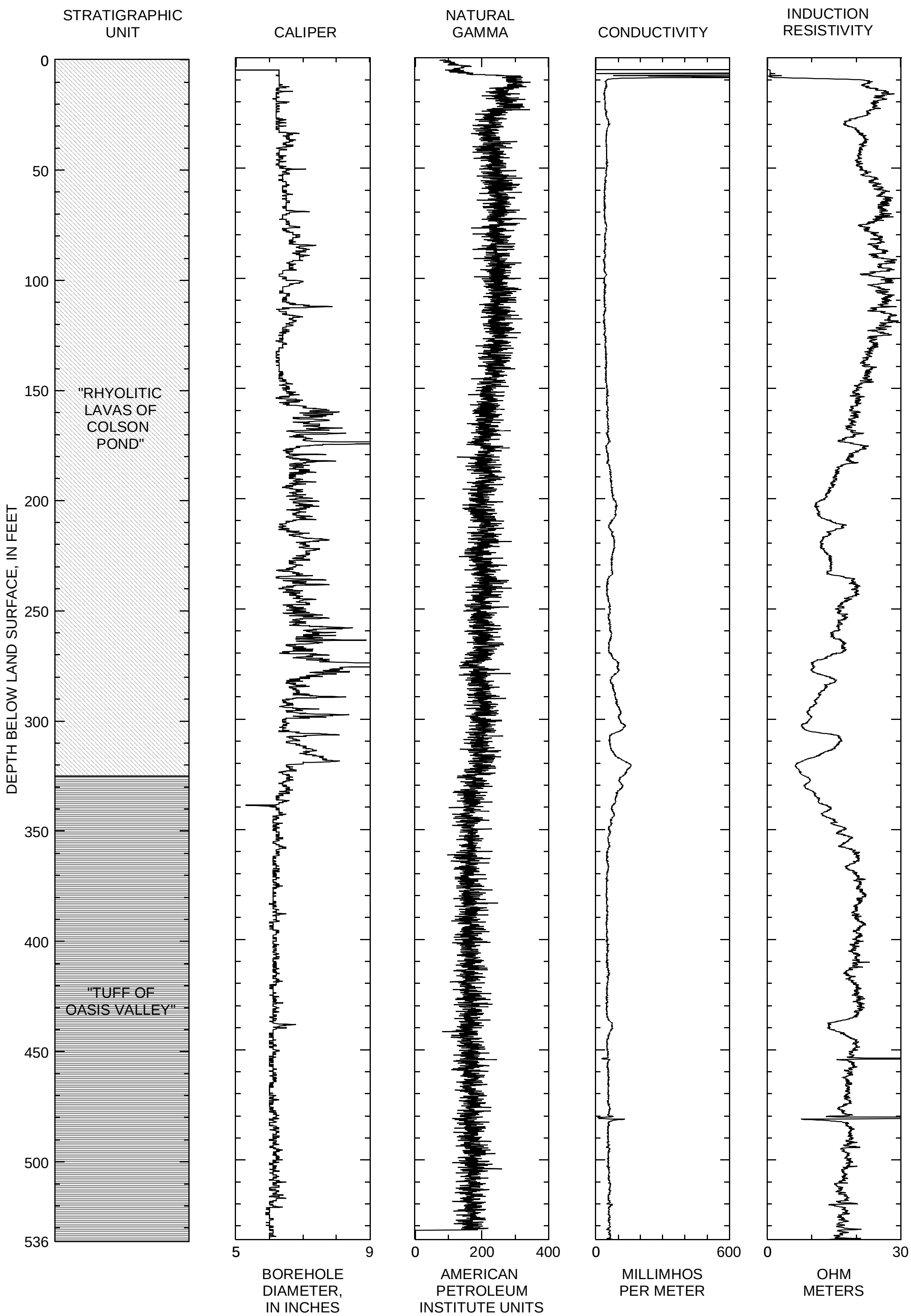
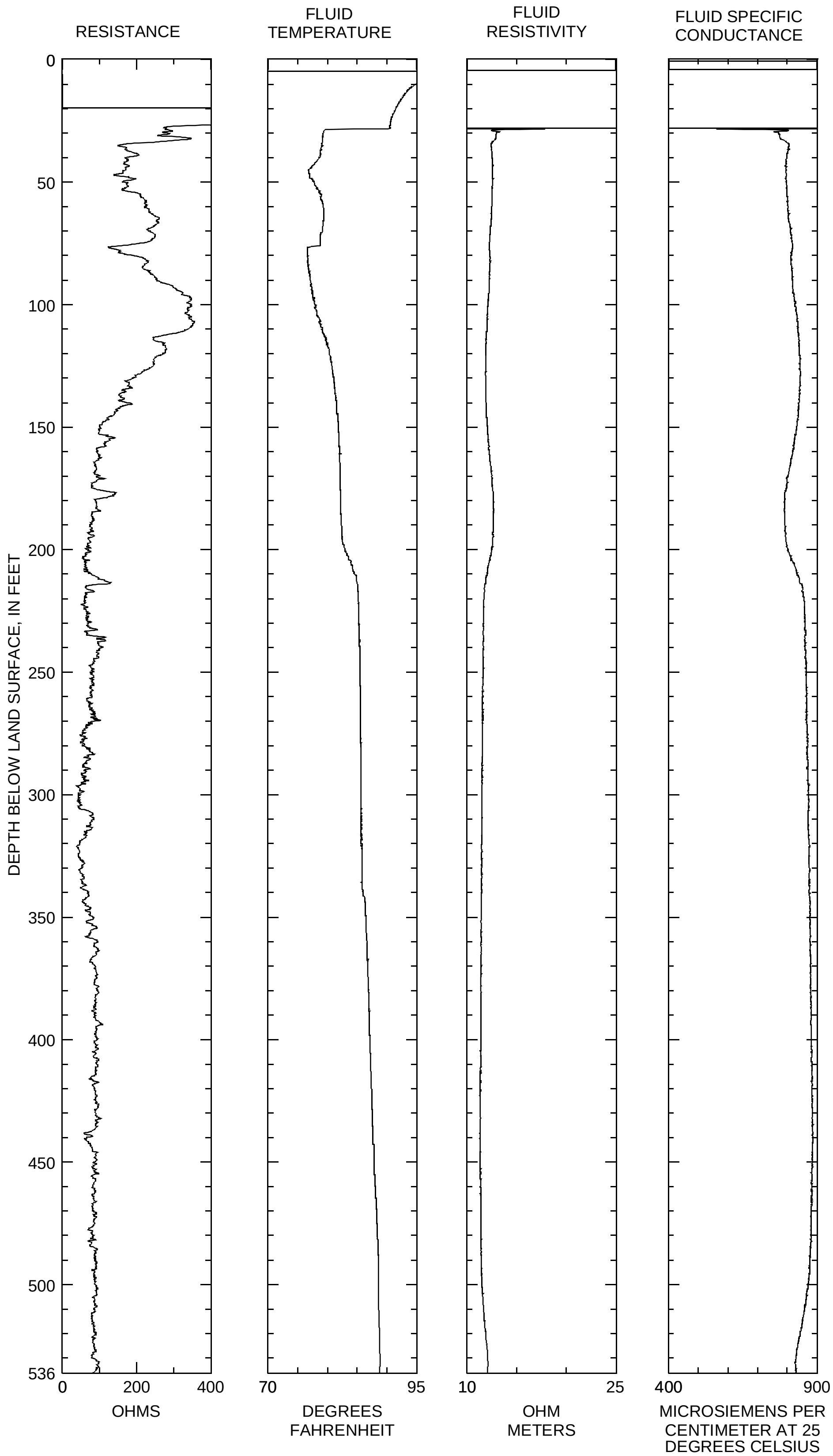


Figure 15. Geologic and geophysical logs from well ER-OV-06a, Oasis Valley, Nevada.



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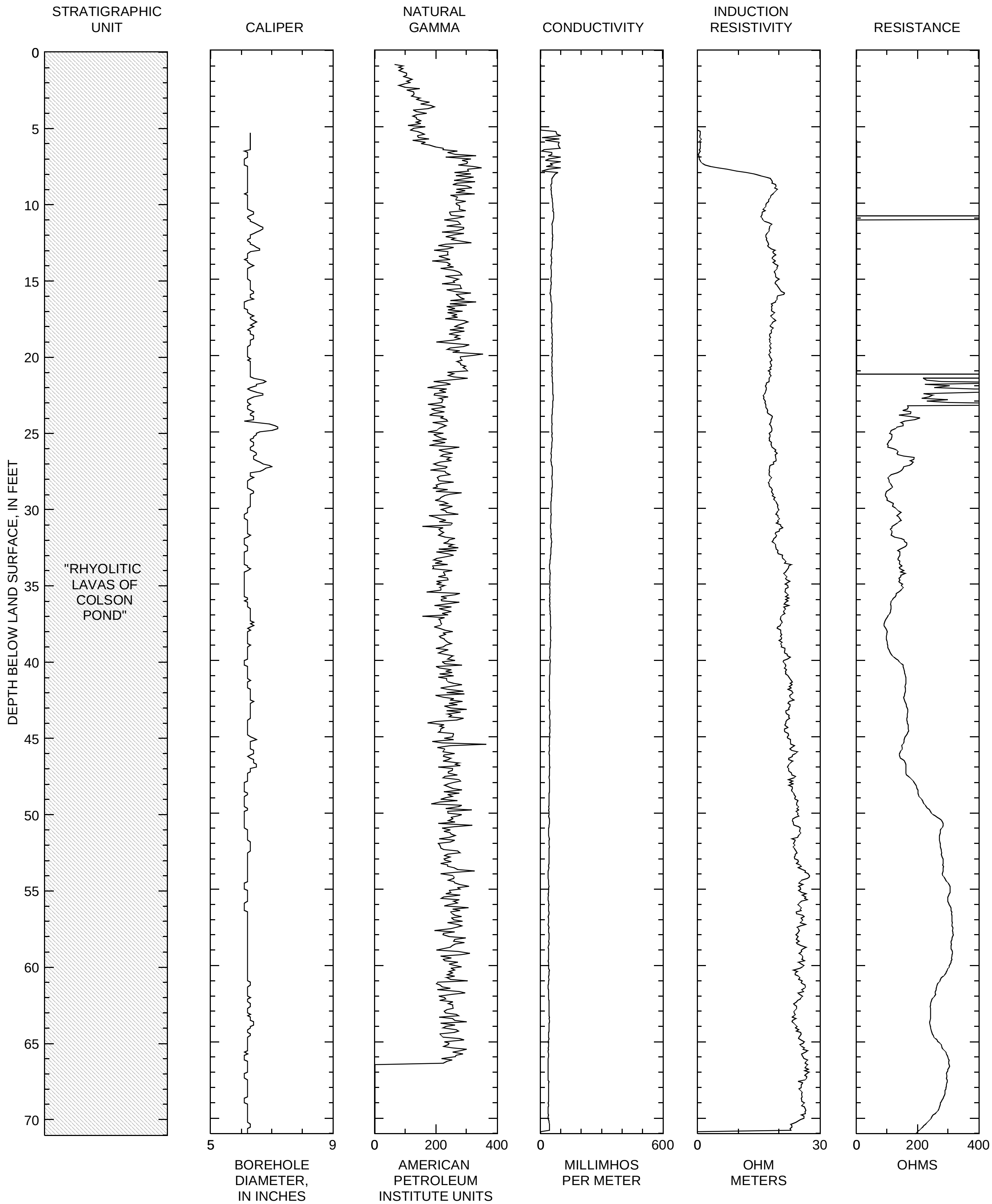

Figure 16. Geologic and geophysical logs from well ER-OV-06a2, Oasis Valley, Nevada.