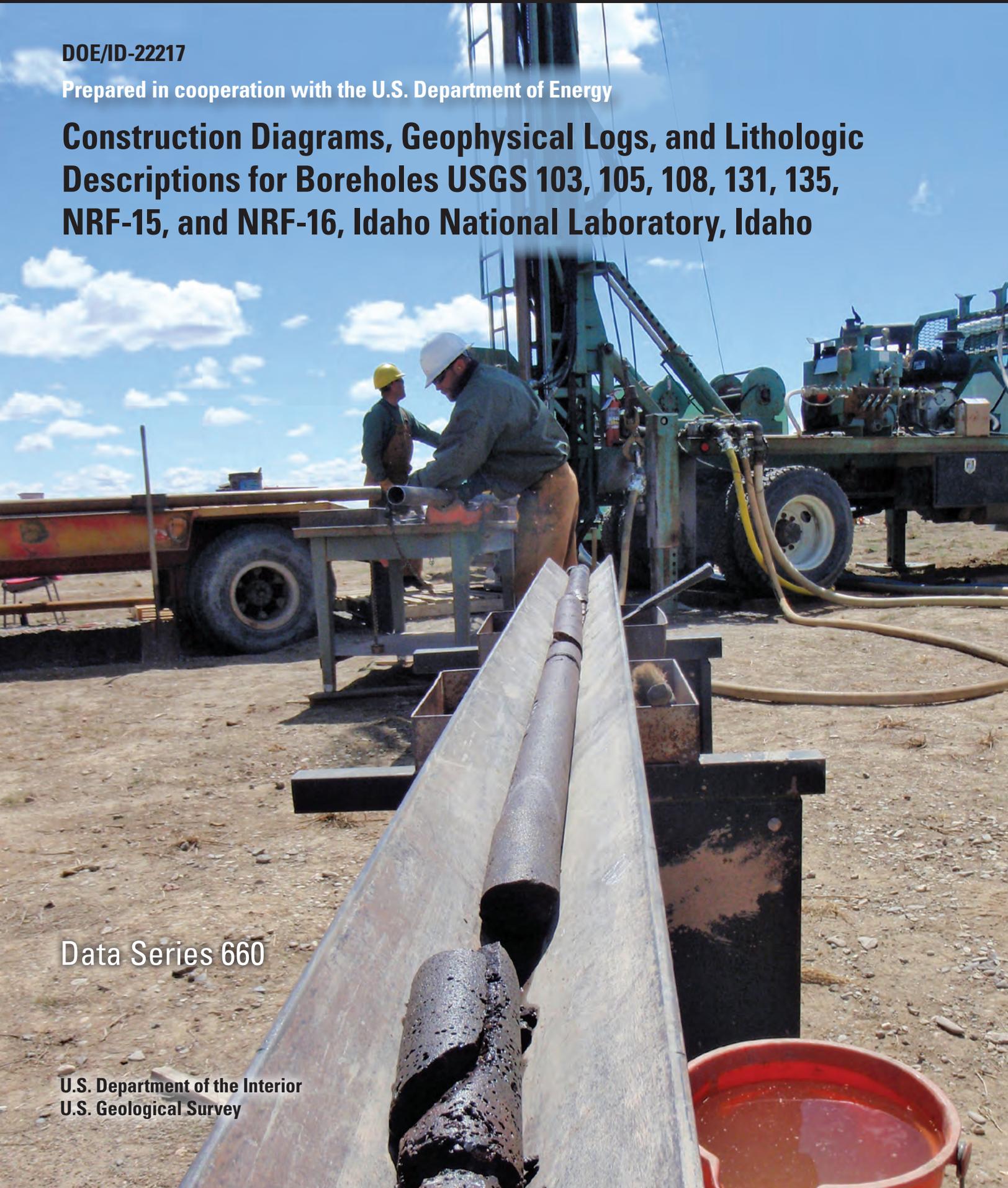


DOE/ID-22217

Prepared in cooperation with the U.S. Department of Energy

Construction Diagrams, Geophysical Logs, and Lithologic Descriptions for Boreholes USGS 103, 105, 108, 131, 135, NRF-15, and NRF-16, Idaho National Laboratory, Idaho

Data Series 660



Cover: Photograph of basalt core (foreground) and U.S. Geological Survey drilling crew and drill rig at a drill site on the Idaho National Laboratory, Idaho. Photograph taken by Brian V. Twining, Hydrologist, U.S. Geological Survey Idaho National Laboratory Project Office, Idaho Falls, Idaho.

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By Mary K.V. Hodges, Stephanie M. Orr, Katherine E. Potter, and Tynan LeMaitre

Prepared in cooperation with the
U.S. Department of Energy (DOE/ID 22217)

Data Series 660

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2012

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Conversion Factors and Datums

Conversion Factors

| Multiply | By | To obtain |
|--------------------------------|-----------|-------------------------------------|
| Length | | |
| inch (in.) | 2.54 | centimeter (cm) |
| inch (in.) | 25.4 | millimeter (mm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| Area | | |
| square mile (mi ²) | 259.0 | hectare (ha) |
| square mile (mi ²) | 2.590 | square kilometer (km ²) |

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1929 (NAVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Altitude, as used in this report, refers to distance above the vertical datum.

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Construction Diagrams, Geophysical Logs, and Lithologic Descriptions for Boreholes USGS 103, 105, 108, 131, 135, NRF-15, and NRF-16, Idaho National Laboratory, Idaho

By Mary K.V. Hodges, Stephanie M. Orr, Katherine E. Potter, and Tynan LeMaitre

Abstract

This report, prepared in cooperation with the U.S. Department of Energy, summarizes construction, geophysical, and lithologic data collected from about 4,509 feet of core from seven boreholes deepened or drilled by the U.S. Geological Survey (USGS), Idaho National Laboratory (INL) Project Office, from 2006 to 2009 at the INL. USGS 103, 105, 108, and 131 were deepened and cored from 759 to 1,307 feet, 800 to 1,409 feet, 760 to 1,218 feet, and 808 to 1,239 feet, respectively. Boreholes USGS 135, NRF-15, and NRF-16 were drilled and continuously cored from land surface to 1,198, 759, and 425 feet, respectively. Cores were photographed and digitally logged by using commercially available software. Borehole descriptions summarize location, completion date, and amount and type of core recovered.

Introduction

The Idaho National Laboratory (INL), operated by the U.S. Department of Energy (DOE), occupies about 890 mi² of the eastern Snake River Plain (ESRP) in eastern Idaho ([fig. 1](#)). Facilities at the INL are used in the development of peacetime atomic-energy applications, nuclear safety research, defense programs, environmental research, and advanced energy concepts. Wastewater containing radionuclide and chemical wastes generated at these facilities was discharged to onsite infiltration ponds, evaporation ponds, and disposal wells from 1952 to 1983. Most aqueous wastes have been discharged to infiltration ponds since 1983. Solid and liquid radioactive and chemical wastes have been buried in trenches and pits excavated in surficial sediment at the Radioactive Waste Management Complex (RWMC, [fig. 1](#)). Past disposal practices have resulted in detectable concentrations of selected

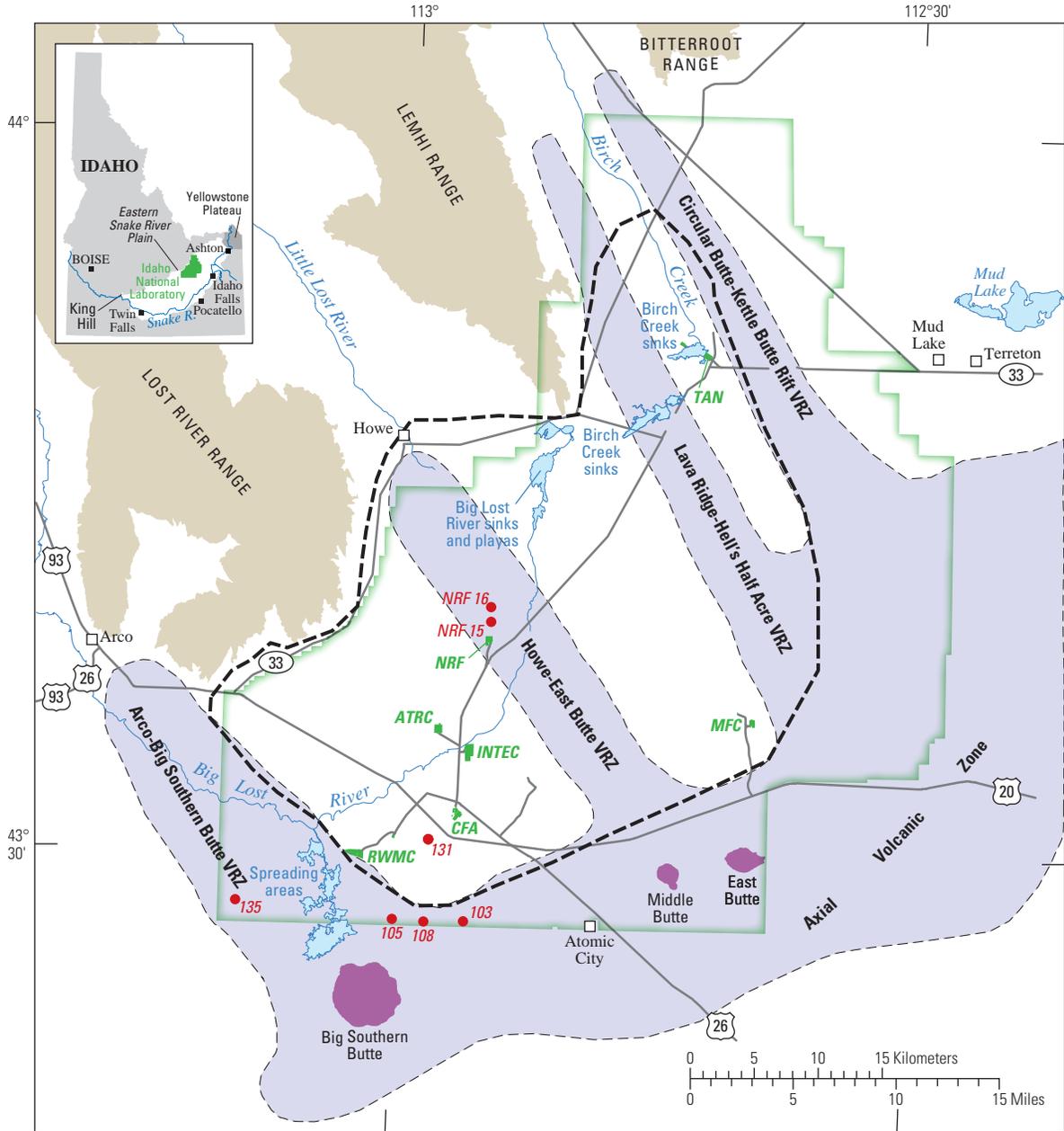
radiochemical, inorganic, and organic waste constituents in water collected from INL monitoring wells completed in the ESRP aquifer (Mann and Beasley, 1994; Cecil and others, 1998; Bartholomay and Tucker, 2000; Davis, 2010).

The U.S. Geological Survey (USGS) has conducted hydrologic, geologic, and geophysical research at the INL since 1949. Early work characterized water resources and geology in the INL area prior to construction of nuclear-reactor testing facilities. Since completion of those studies, the USGS has maintained groundwater quality and water-level monitoring networks at the INL to collect data for research on hydrologic trends, and to trace the movement of facility-related radiochemical and chemical contaminants in the ESRP aquifer.

Hundreds of monitoring wells at the INL penetrate the upper 200 ft of the ESRP aquifer where most groundwater movement probably occurs (Ackerman and others, 2006, p. 39). Additional boreholes were core drilled to investigate the geology and hydrology of the ESRP aquifer because recently published data indicate that boreholes that extend several hundred feet into the aquifer provide data useful for constructing and evaluating groundwater conceptual, flow, and transport models.

Between 2006 and 2009, the USGS, in cooperation with the DOE Idaho Operations Office, deepened and cored four boreholes originally drilled from 759 to 808 ft below land surface (BLS). The USGS also cored three new boreholes from land surface—USGS 135, NRF-15, and NRF-16. Boreholes USGS 103, 105, 108, 131, and 135 were cored to install multilevel monitoring systems (Bartholomay and Twining, 2010; Fisher and Twining, 2010). Boreholes NRF-15 and NRF-16 were cored to provide monitoring wells for the Naval Reactor Facility (NRF). Geologic information collected from these boreholes is used to refine the three-dimensional geologic framework of the ESRP aquifer at the INL.

2 Construction Diagrams , Geophysical Logs, and Lithologic Descriptions for Boreholes, Idaho National Laboratory, Idaho



Base from U.S. Geological Survey digital data, 1:24,000 and 1:100,000; Universal Transverse Mercator projection, Zone 12. Datum is North American Datum of 1927. Modified from Kuntz and others, 1992, fig. 7.

EXPLANATION

- Approximate area of volcanic rift zones (VRZ) and axial volcanic zone (AVZ)—contact inferred
- Rhyolite domes
- Idaho National Laboratory boundary
- Mountain ranges
- Outline of approximate location of Big Lost Trough
- Local well identifier—Number only shows USGS well, other names are local well names
- Site facilities with location identifier
 - ATR*C—Advanced Test Reactor Complex
 - CFA*—Central Facilities Area
 - INTEC*—Idaho Nuclear Technology and Engineering Center
 - MFC*—Materials and Fuels Complex
 - NRF*—Navel Reactor Facility
 - RWMC*—Radioactive Waste Management Complex
 - TAN*—Test Area North

Figure 1. Location of selected facilities and U.S. Geological Survey boreholes, Idaho National Laboratory, Idaho.

Purpose and Scope

This report summarizes the geologic setting of the ESRP aquifer, describes geophysical methods used to help characterize the subsurface, and presents information collected from each borehole. Of the seven boreholes, four were continuously cored and three were partially cored. Wireline geophysical logs were run through drill stem and in open boreholes to better define stratigraphy and hydrologic properties of the ESRP aquifer. Cores were examined, described, and photographed.

Geologic Setting

The ESRP formed when the North American Plate moved southwestward across a fixed melting anomaly that severely disrupted the crust (Pierce and Morgan, 1992; Pierce and others, 2002; Morgan and McIntosh, 2005, p. 288). Thermal disruption caused a series of volcanic fields characterized by initial uplift, followed by bimodal magmatism (rhyolitic resurgent caldera eruptions followed and buried by basalt eruptions) and ongoing subsidence caused by emplacement of a mafic midcrustal sill (Braile and others, 1982; Anders and Sleep, 1992, p. 15, 379; Peng and Humphries, 1998, p. 7,171; Rodgers and others, 2002; Shervais and others, 2006, p. 365). The resulting volcanic plain is 200 mi long from southwest to northeast and roughly 50 mi wide from southeast to northwest. The ESRP rises from King Hill, Idaho (altitude 2,492 ft National Geodetic Vertical Datum of 1929 (NGVD 1929), stream gage on Snake River, (U.S. Geological Survey 2011d) to the edge of the Yellowstone Plateau volcanic field (altitude 6,710 ft, NGVD 1929, stream gage on Henry's Fork near Ashton, Idaho, (U.S. Geological Survey, 2011c), a difference of 4,218 ft.

Olivine tholeiitic basalt flows, erupted as tube-fed, inflated, pahoehoe, comprise more than 85 percent of the subsurface volume of the ESRP at the INL (Kuntz and others, 1992; Anderson and Liszewski, 1997). A typical ESRP basalt flow has vesicular zones and cooling fractures on the top and sides, with vesicle sheets, pipe vesicles, megavesicles in the interior, and a diktytaxitic to massive core (fig. 2) (Self and others, 1998; Hughes and others, 2002). We consider a basalt flow group to be the product of a single monogenetic volcano, and a basalt flow as the result of a single eruption episode. Paleomagnetic or geochemical analyses are required to distinguish flow groups. Flows can be distinguished by inspection of core and geophysical logs, especially caliper, gamma-gamma, natural gamma, and neutron, natural gamma, logs used in concert, which allows identification of the vesicular tops and bases of the flows. Where flows succeed each other without sediment deposition, flows may make molds of the underlying surface ("flow and mold structures," see appendixes A–G). Near-vent flows are thinner than more distal flows, and accumulations of thin flows have a larger

volume of high conductivity zones than the same volume of thick flows; therefore, spaces occupied by vents tend to have more fractured, high-conductivity volume than spaces distal to vents (Anderson and others, 1999). Distribution of basalt flows is controlled by previously existing topography, rate of effusion, and duration of eruption.

Eolian, fluvial, alluvial, and lacustrine sediments are found in ESRP drill cores, and are predominantly fine grained (Bestland and others, 2002; Blair, 2002), although difficulty in retrieving coarse-grained sediments in core may have biased the core record to some extent. Provenance and detrital-zircon studies indicate that the Big Lost River has been the main source of sediment since late Pliocene time on the part of the ESRP occupied by the INL. A depocenter informally named the Big Lost Trough is the result of the deposition from the Big Lost River around the INL (Geslin and others, 2002).

Sediment layers penetrated by these boreholes are as much as 146 ft (USGS 103). The Big Lost Trough (fig. 1) (Bestland and others, 2002; Blair, 2002; Geslin and others, 2002) is bounded to the northwest by mountains and on the other three sides by informally named volcanic highlands—the Axial Volcanic Zone and the Arco-Big Southern Butte Volcanic Rift Zone (fig. 1). Boreholes in and near the Big Lost Trough (fig. 1), such as USGS 103, 108, 131, and NRF-15, contain substantially greater amounts of sediment than boreholes in other parts of the INL site, such as USGS 135.

Deposits of rhyolitic and other evolved-composition ashes are rare, but can be useful time markers. Preservation of such deposits depends on the simultaneous occurrence of an ash-producing eruption upwind of the ESRP and either a basaltic eruption or a sedimentary depositional environment that allows quick burial of the ash. None of the boreholes reported here penetrated to the depth of the caldera-related rhyolitic rocks that underlie the ESRP basalts (Doherty, 1979; Doherty and others, 1979).

Borehole Construction

The USGS INL Drilling Program uses a truck-mounted wireline core rig, two coring systems, and support equipment for rotary coring in volcanic rock and sediment. This rig is capable of drilling depths that exceed 1,400 ft. The USGS INL Project Office drilling crew drills PQ- and HQ-diameter core (fig. 3). The PQ rotary coring produces a 4.8-in. borehole and a 3.3-in. diameter core (fig. 3C). The HQ rotary coring system produces a 3.8-in. borehole and a 2.5-in. diameter core (figs. 3A and 3B). PQ and HQ rotary core systems use similar diamond and carbide bits, core catchers, latch assemblies, and retrieval systems (fig. 4). Core was retrieved by using a wireline latching mechanism (quadlatch) at the top of the core barrel assembly. Support equipment includes a 350 lb/in², 900 ft³/min capacity diesel air compressor, pipe trailer, and a 3,000-gal water truck.

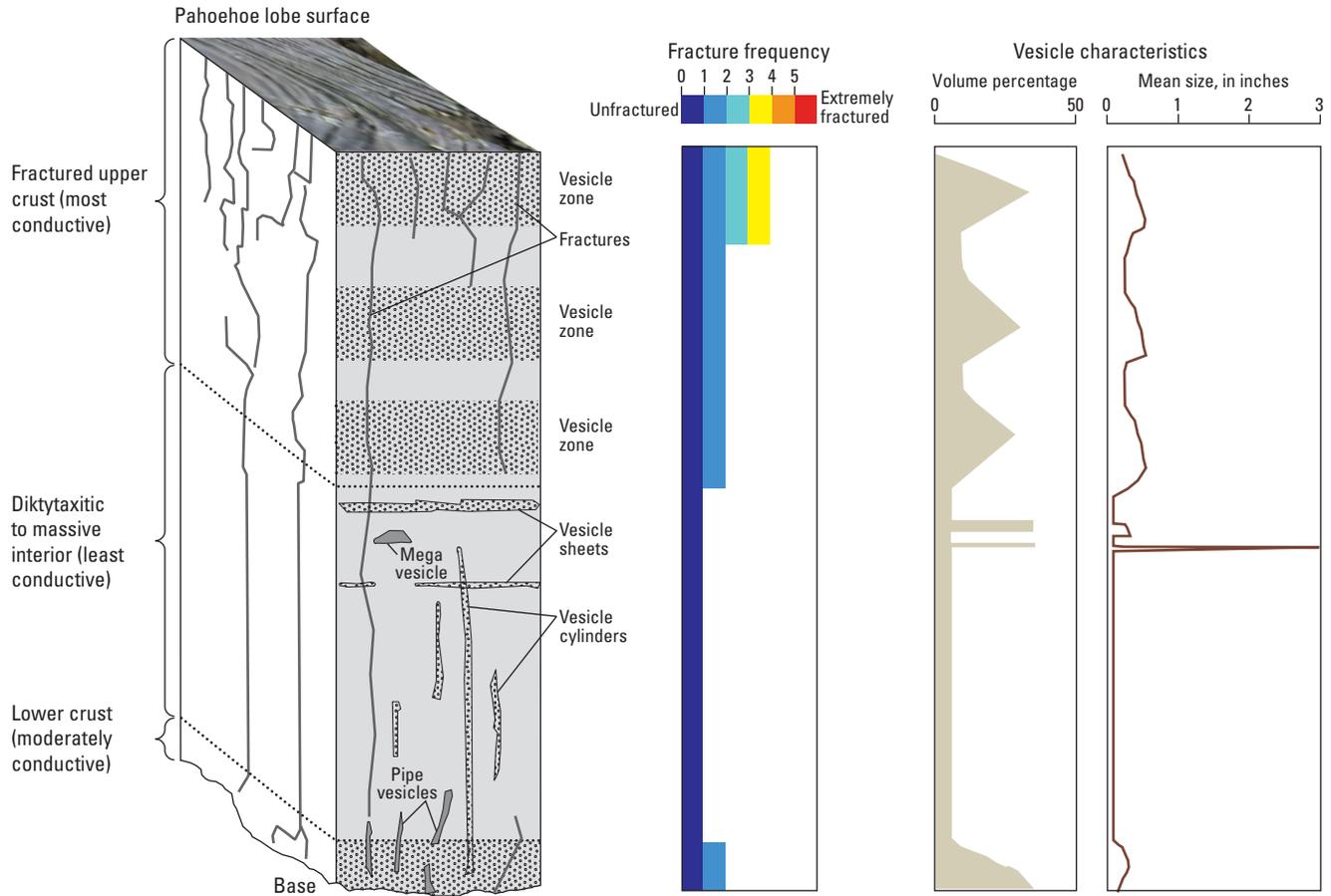


Figure 2. Typical olivine tholeiitic pahoehoe basalt flow, showing zones and structures and fracture frequency and vesicle characteristics (modified from Self and others, 1998, p. 90, fig. 3). Photograph of pahoehoe lobe surface courtesy of Scott Hughes, Idaho State University, Pocatello, Idaho.

For boreholes drilled from the surface, casing was driven through surficial sediment. Once surface casing was placed, boreholes USGS 135, NRF-15, and NRF-16 were continuously cored to 1,198; 759; and 423 ft, respectively. Borehole USGS 131, previously cored to 808 ft (Twining and others, 2008), was deepened to 1,239 ft in 2010. Borehole USGS 103 had 6-in. casing set to 752 ft and then cored to 1,307 ft. Borehole USGS 105 had 5-in. casing set to 801 ft and then cored to a total depth of 1,409 ft. Borehole USGS 108 had 5-in. casing set to 758 ft and then cored to 1,218 ft.

Drilling fluid included a mixture of air and water used to cool the bit face and circulate drill cuttings. Under rare circumstances, foam additives were used to help stabilize the borehole and lift the cuttings to the surface.

Boreholes drilled on the ESRP mostly penetrate basalt; thickness of sediment layers varied from less than a foot to

tens of feet. Generally, diktytaxitic to massive basalt cored well; sediment layers, flow tops, and flow bottoms caused problems, especially where series of thin flows resulted in unstable rock. Core recovery of fine sediment usually is more successful than recovery of coarse sand and gravel. Under saturated conditions, sediment recovery results were mixed because it was difficult to trap wet sediment inside of the core barrel during retrieval.

Boreholes USGS 103, 105, 108, and 135 were completed as monitoring wells with Westbay™ multilevel monitoring systems. Borehole NRF-15 was completed as a two-piezometer, water-level monitoring well. Borehole NRF-16 was screened to be used as a water-quality and water-level monitoring well. Borehole USGS 131 was damaged during drilling and is currently (2011) on standby.

A.

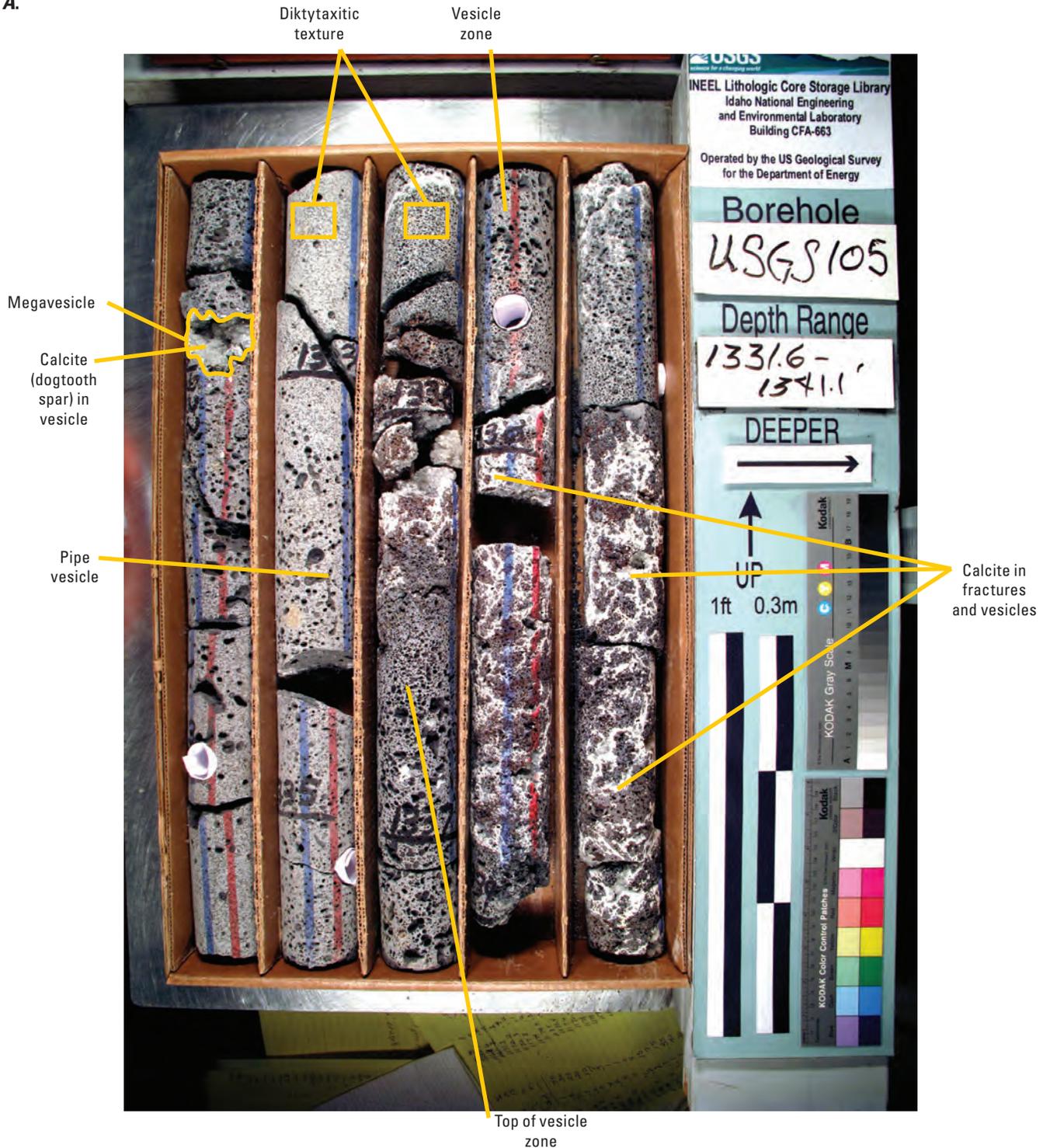


Figure 3. Examples of HQ core from borehole USGS 105 (A and B) and PQ core from borehole NRF 15 (C) at the Idaho National Laboratory, Idaho, with typical structures annotated.

B.

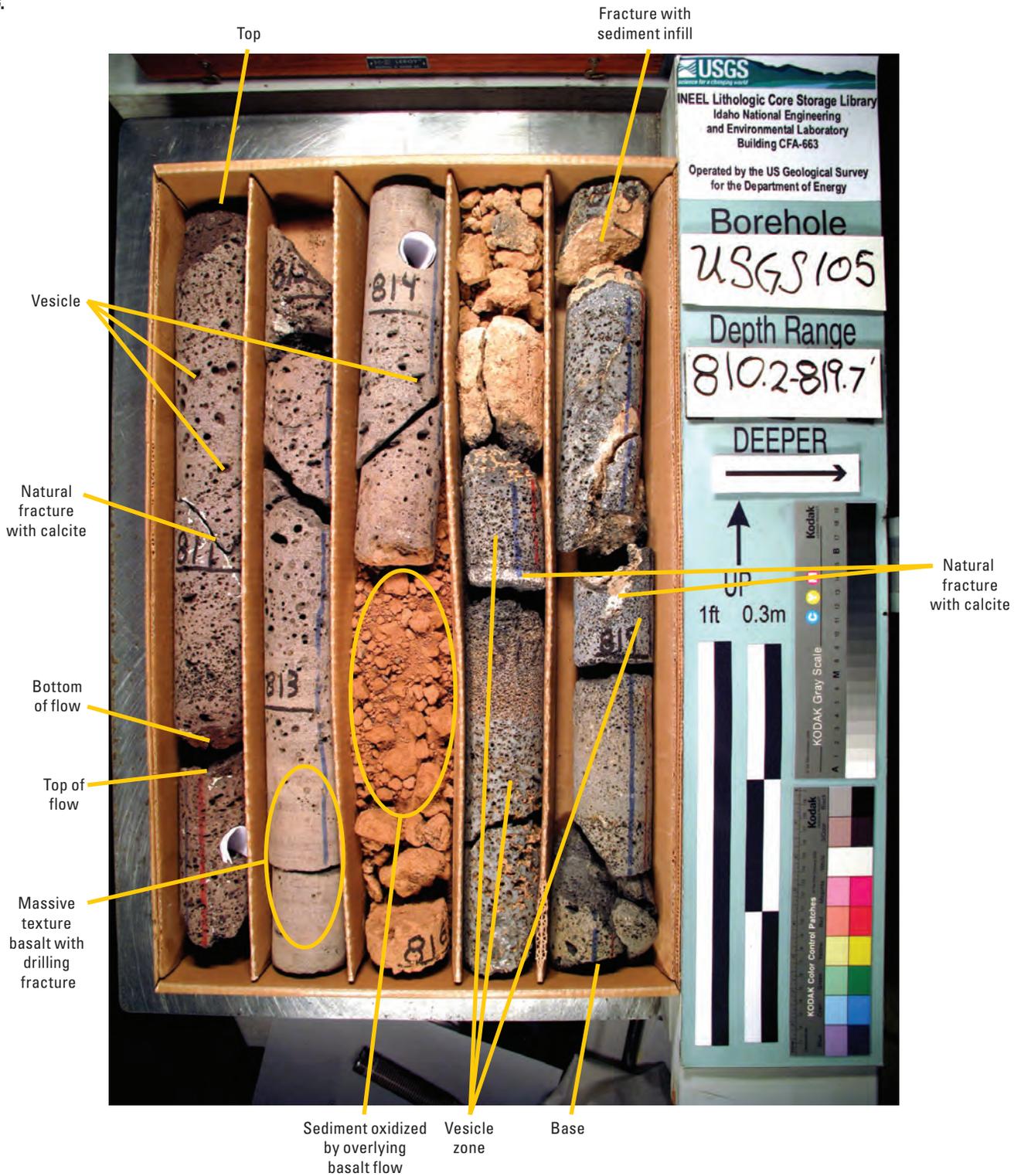


Figure 3.—Continued.

C.

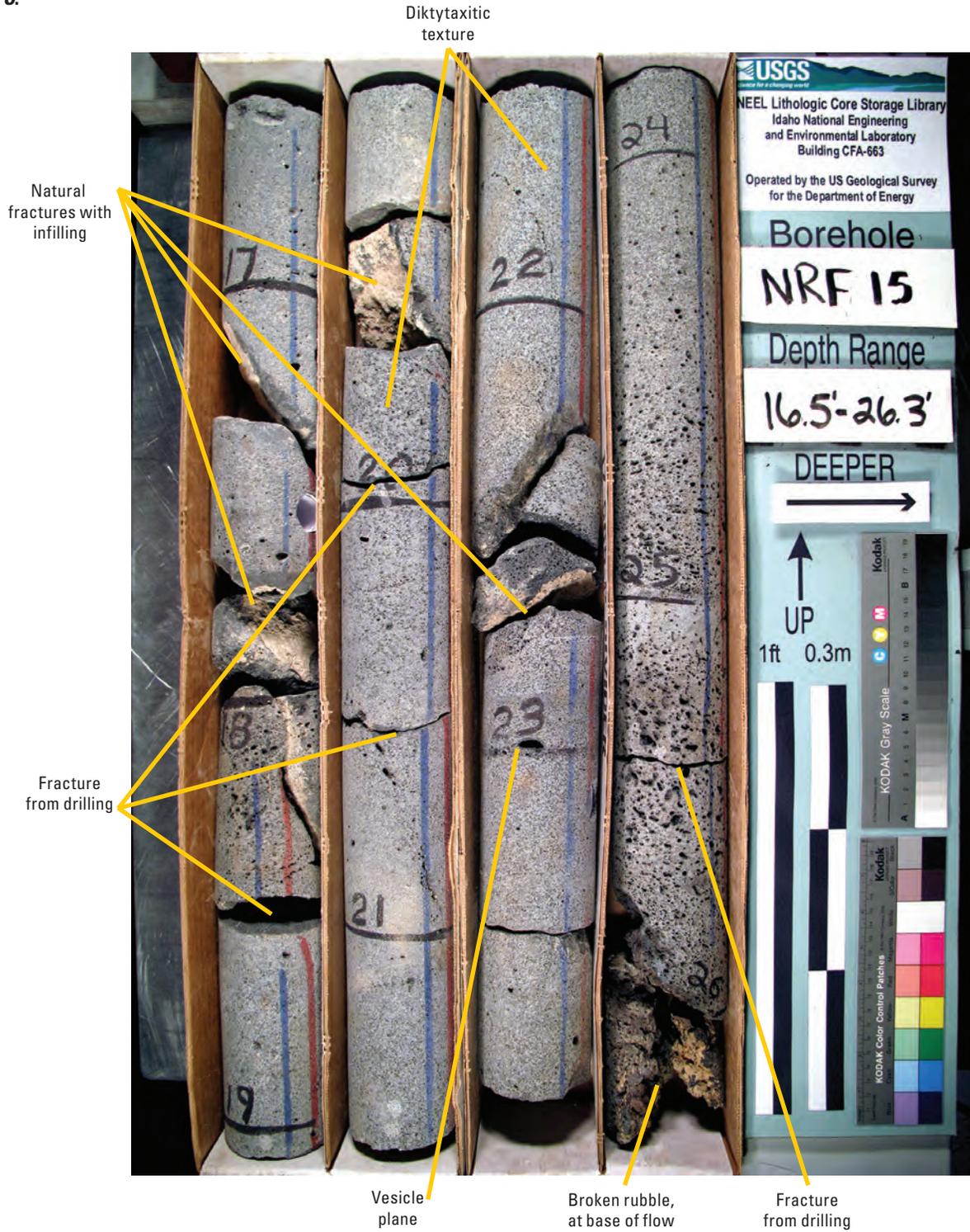
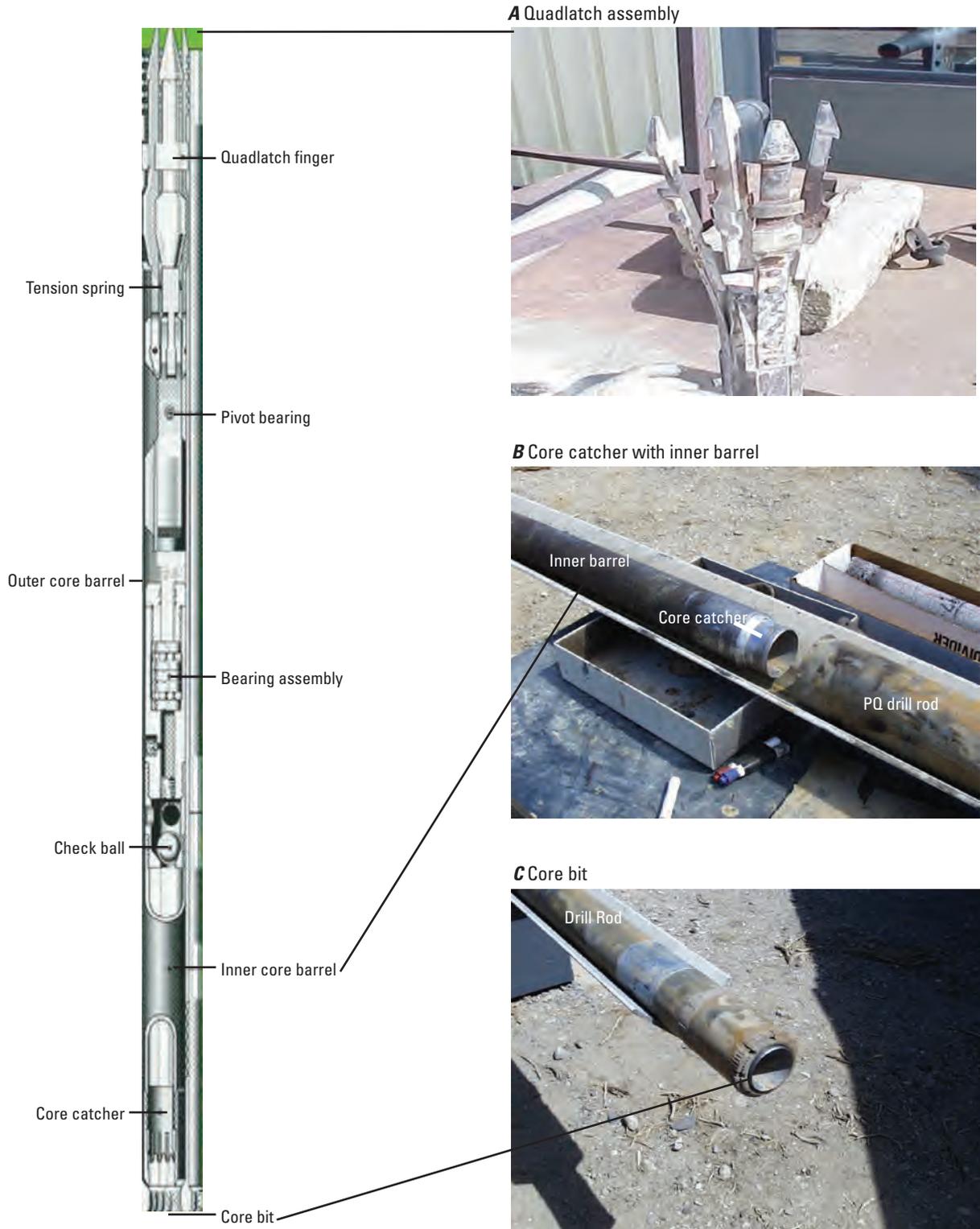


Figure 3.—Continued.



Modified from Twining and others, 2008, fig. 4.

Figure 4. Coring assembly and components used to drill and retrieve core. (Modified from Twining and others, 2008, fig. 4.)

Geophysical Logs

The USGS has been collecting geophysical data at the INL since 1952. These data have been used to characterize subsurface basalt and sediment in the ESRP aquifer.

The borehole geophysical data used in this report include: caliper, gamma-gamma, natural gamma, and neutron logs. Borehole video logs were used to corroborate stratigraphic information where necessary. [Figure 5](#) shows examples of features that can be identified with geophysical logging techniques.

Borehole geophysical logs are available in Log ASCII Standard and LOG format (a proprietary binary format) and are available through the USGS INL Project Office (U.S. Geological Survey 2011b) or through the INL Hydrologic Data Repository. The following summary describes the four types of geophysical logs used in this report.

Caliper Logs

The caliper tool provides an electronic wall trace of the drill-hole diameter by using three extendable spring-loaded arms that are capable of detecting limited changes in borehole diameter (changes in diameter larger than 0.15 in.). Changes in borehole diameter, detected by the amount of deflection of the caliper arms, are recorded as the caliper tool is brought up from the bottom of the borehole.

Caliper logs were run in open boreholes immediately after the drill string was removed. Borehole caving prevented a continuous caliper profile in some boreholes. As the drill string was being removed, multiple caliper logs were run, when necessary, to capture borehole diameter data above and below intervals prone to caving, and these multiple logs were consolidated where feasible. Caliper data were used to identify fracture locations, areas of competent basalt, and cavernous zones ([fig. 5](#)). Caliper logs also were used when designing monitoring wells to determine location of casing, annular seal, and well screen.

Gamma-Gamma Logs

The gamma-gamma density log, also known as the induced gamma-density log, measures bulk density of the formation near the borehole. Two separately spaced detectors record induced gamma-radiation intensity from an encapsulated radioactive source after the gamma signal is backscattered or absorbed in a drill hole, borehole fluid, or surrounding media (Chase and others, 1964). The induced gamma signal is attenuated in direct proportion to the bulk density of a formation.

Very dense materials increase scatter and cause increased absorption of gamma radiation; the increased absorption of gamma radiation results in fewer particles returning to the detector. The opposite is true for fractured and low-density materials. Examples of density differences recorded by gamma-gamma logs are shown in [figure 5](#).

Gamma-gamma logging requires one source and two separately spaced detectors, referred to as the short- and long-spaced detectors. The short-spaced detector has a smaller area of investigation than the long-spaced detector. Although the resolution of the long-spaced detector is lower than the short-spaced detector, data from the long-spaced detector are less affected by well casing and near-borehole conditions than are data from the short-spaced detector (Glover and others, 2002). Gamma-gamma logs included in this report show data collected from the long-spaced detector.

Natural Gamma Logs

Natural gamma logs record gamma radiation emitted by naturally occurring radioisotopes. Natural gamma logs are used at the INL to identify sedimentary layers in boreholes and basalts that contain higher or lower potassium-40 concentrations than the basalts layers above or below. Some examples of naturally occurring radioisotopes in the ESRP are potassium-40, bismuth-214, lead-214, actinium-228, thorium-232, and uranium-238 (Barraclough and others, 1976). Sediments, which mostly consist of mineral grains eroded from nearby mountains, naturally contain greater concentrations of gamma-emitting isotopes, usually potassium-40, than basalts. Most ESRP basalts do not contain large amounts of naturally occurring gamma-emitting isotopes. The gamma detector measures total gamma radiation without distinguishing between individual contributions of the various isotopes.

The probe used for recording the natural gamma log contains a single pressure-housed sodium iodide scintillation detector. Naturally occurring gamma radiation hits the sodium iodide crystal and causes a visible light emission called a scintillation. A photomultiplier tube detects scintillations and transforms those emissions into pulses of electrical energy, which are recorded and a digital image produced in a log of gamma-radiation responses.

Examples of elevated natural gamma response caused by the sediment layers and changes in natural gamma signal resulting from basalts with different potassium-40 concentrations are shown in [figure 5](#).

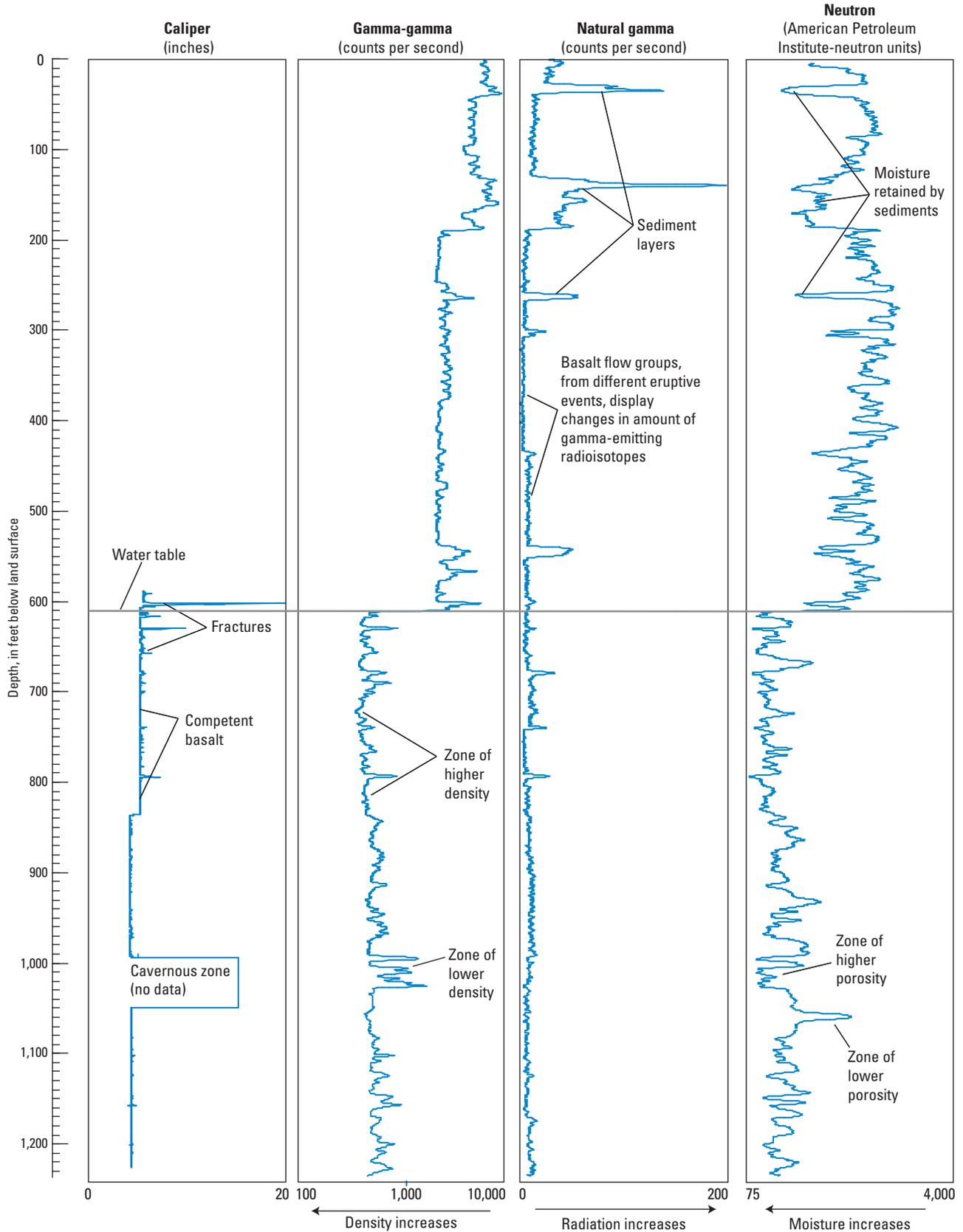


Figure 5. Typical hydrogeologic features that are discernible in caliper, gamma-gamma, natural gamma, and neutron logs in boreholes at the Idaho National Laboratory, Idaho.

Neutron Logs

The neutron log records the continuous measurement of the induced radiation produced by bombarding surrounding media (casing, formation, and fluid) with fast neutrons (energies greater than 105 electron volts) from a sealed neutron source, which collide with surrounding atomic nuclei until captured (Keys, 1990, p. 95). The neutron tool used by the USGS INL Project Office has an Americium/Beryllium neutron source, and a Helium-3 detector that counts slow (thermal) neutrons (those neutrons that have energies less than 0.025 electron volt).

Hydrogen nuclei have about the same mass as neutrons, so neutrons that collide with hydrogen nuclei are slowed and are recorded at a lower rate than those neutrons that collide with nuclei other than hydrogen. Hydrogen content is inversely proportional to thermal neutron count at the detector, when the spacing between source and detector is greater than 11.8 in., as in the neutron tool used by the USGS INL Project Office (Keys, 1990, p. 95–96). Because water is the most common hydrogen-bearing substance in ESRP boreholes, neutron logs are considered to be good indicators of saturated formation porosity. When combined with natural gamma logs to provide information about sediment location, neutron logs also may help identify perched water zones in the unsaturated zone ([fig. 5](#)). Neutron response changes related to perched water and zones of higher and lower water-filled porosity are shown in [figure 5](#).

Core Logs

Core logs ([appendixes A–G](#)) were created by using a standardized method to record lithologic logs with photographs of core (Johnson and others, 2005). Core was logged with commercial logging software by using a procedure developed by the USGS INL Project Office for use at the Lithologic Core Storage Library (U.S. Geological Survey, 2011a). The method deliberately maximizes description and minimizes interpretation.

Data recorded are: depth below land surface; core photograph; igneous, soil, and sedimentary structures; miscellaneous information (such as notes about where samples were collected); a lithologic description; a histogram of numeric value for fracture frequency; a line graph of mean vesicle size for an interval; and a colored curve of vesicle volume percentage. Core logs in this report show fracture values for natural fractures, fractures related to drilling are ignored.

Core logs for boreholes in this report, including depth, core photographs, major structures, lithologic description, degree of fracture, and size and frequency of vesicles are in [appendixes A–G](#).

Core Log Columns

The left-most column of every core log is depth, in feet BLS ([fig. 6](#)). The second column contains a photograph of the core. The third column contains igneous, soil, or sedimentary symbols to highlight structures of particular interest. Basalt structures of interest were vesicle zones, large vesicles, vesicle planes, megavesicles, vesicle cylinders, pipe vesicles, vesicle sheets, flow and mold structures, and spatter features (agglomerated spatter). Sediment was classified based on soil texture (American Society for Testing and Materials, 1985) unified soil classification system ([table 1](#)) and particle size ([table 2](#)). Some intervals of sediment core were sampled for sediment property analysis before being logged.

The fourth column contains a colored lithology symbol ([fig. 6](#)). The fifth column is for miscellaneous text, such as notes about where samples were collected. The sixth column is for written lithologic descriptions. Lithology was described in standard geological terms for color, texture, composition (minerals), xenoliths, alteration, and major structures. Color was visually matched by using a Munsell® Rock Color Chart (Rock Color Chart Committee, 2009). Soil structures were logged according to information from the Soil Survey Manual (Soil Survey Division Staff, 1993).

The seventh column is a histogram representation for fracture frequency, a numeric value based on number of fractures per interval. Fracture data for the core in this report are derived from natural fractures, not drilling fractures. Fracture frequency numeric values are 0 for intervals of unfractured core, 1 for very slightly fractured core (pieces averaged 3–5 ft), 2 for slightly fractured core (pieces averaged 1–3 ft), 3 for moderately fractured core (pieces averaged 0.33–1.0 ft), 4 for intensely fractured core (pieces averaged 0.0875–0.33 ft), 5 for extremely fractured core (pieces averaged less than 0.0875 ft).

The eighth column contains a line graph of estimated mean vesicle size in 0.1 in. and a yellow-filled curve that describes the estimated volume percentage of vesicles per interval of basalt. Vesicle size and percentage were visually estimated by using charts adapted from Compton (1962).

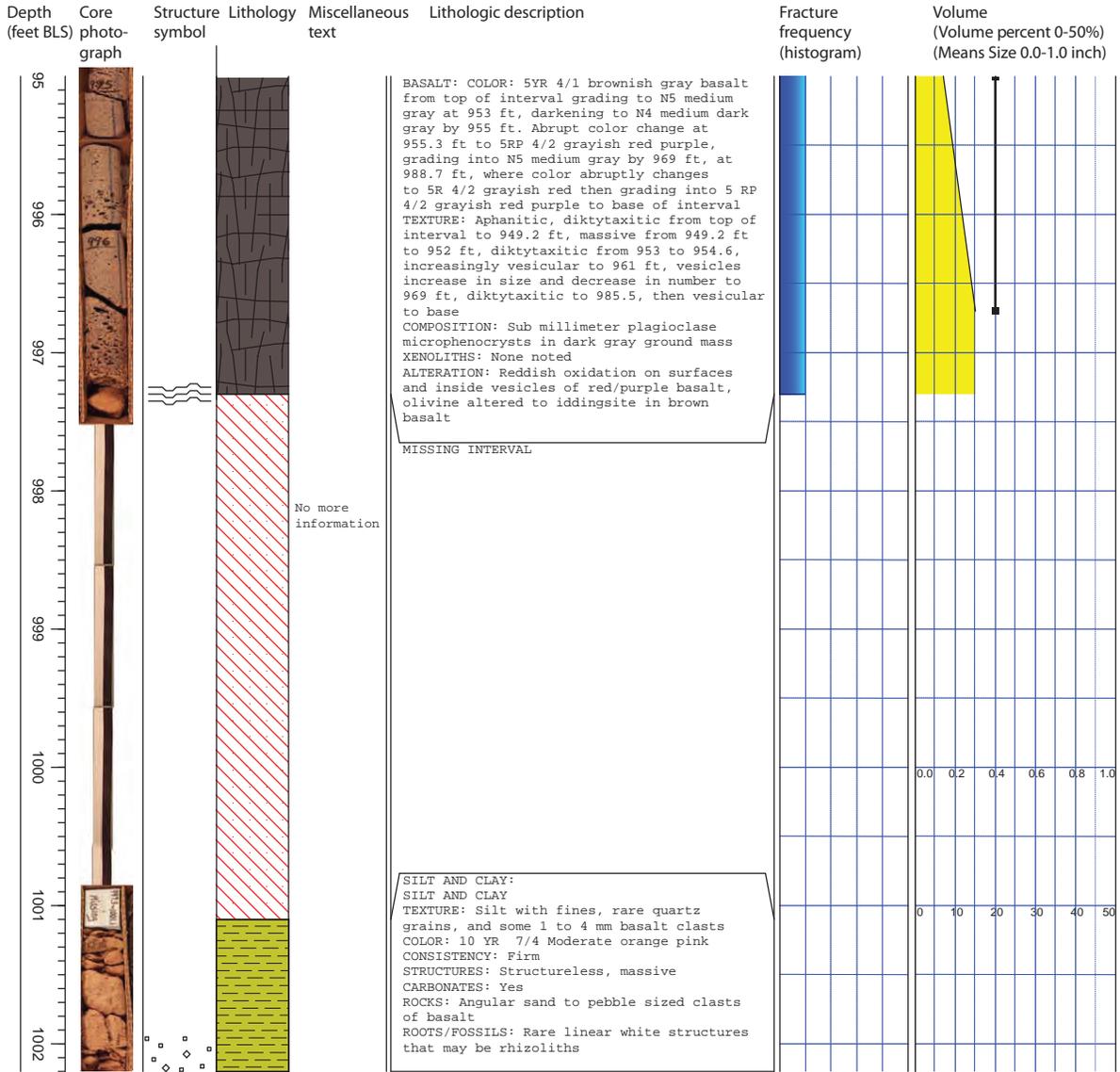


Figure 6. Example of a lithologic log for borehole USGS 105, Idaho National Laboratory, Idaho. (See [appendixes A-G](#) for explanations of symbols.)

Table 1. American Society for Testing and Materials (ASTM) unified soil classification system used in core logs.

[American Society for Testing and Materials, 1985. **Abbreviations:** μm , micrometer; mm, millimeter; >, greater than]

| Major divisions | | | Group symbol | Group name |
|---|--|--|--------------|---|
| Coarse grained soils (> 50 percent retained on #200 sieve, aperture 75 μm) | Gravel (> 50 percent of coarse fraction retained on #4 sieve, aperture 4.75 mm) | Clean gravels | GW | Well-graded gravel, Fine to coarse gravel |
| | | | GP | Poorly graded gravel |
| | | Gravels with fines (appreciable amount of fines) | GM | Silty gravel |
| | | | GC | Clayey gravel |
| | Sand (>50 percent of coarse fraction passes #4 sieve, aperture 4.75 mm) | Clean sands (little or no fines) | SW | Well-graded sand, Fine to coarse sand |
| | | | SP | Poorly graded sand |
| | | Sand with fines (appreciable amount of fines) | SM | Silty sand |
| | | | SC | Clayey sand |
| Fine grained soils (fines) (> 50 percent passes #200 sieve aperture 75 μm) | Silt and clay | Inorganic | ML | Silt |
| | | | CL | Clay |
| | | Organic | OL | Organic silt, organic clay |
| | Silt and clay | Inorganic | MH | Silt of high plasticity, elastic silt |
| | | | CH | Clay of high plasticity, fat clay |
| | | Organic | OH | Organic clay, organic silt |
| Highly organic soils | | | PT | Peat |

Table 2. Wentworth scale of particle sizes used in core logs.

[Modified from Wentworth, 1922]

| Wentworth grain-size scale | |
|----------------------------|----------------------|
| Millimeters (mm) | Wentworth size class |
| 4,0915 | Boulder |
| 2.56 | Cobble |
| 64 | Pebble |
| 4 | Granule |
| 2 | Very coarse sand |
| 1 | Coarse sand |
| 0.5 | Medium sand |
| 0.25 | Fine sand |
| 0.125 | Very fine sand |
| 0.0625 | Coarse silt |
| 0.031 | Medium silt |
| 0.0078 | Fine silt |
| 0.0039 | Very fine silt |
| 0.00006 | Clay |

Core Photographs

Photographs for logging are taken with a custom-built jig mounted on a rolling table (fig. 7). The jig controls depth of field, light intensity, angle, and position of core boxes assuring consistent photographs. Well name, depth intervals, and color charts are photographed with the core, to assist in photograph processing. Core photographs were stacked for presentation by using commercially available software.

Core Descriptions

Lithologic descriptions were constructed from examination of cores and supplemented with geophysical data. After the core was drilled and extracted, the core was marked in the field for vertical direction and depth. Examination of core was done at the Lithologic Core Storage Library at the INL Central Facilities Area. Geophysical data were used during the examination to identify areas of missing or lost core and to check the accuracy of depths marked on core.

Most of the core from boreholes the ESRP is olivine tholeiite basalt from flows that vary in thickness. Individual basalt flows could be distinguished from one another by locating vesicular and fractured flow tops, diktytaxitic to massive interiors, and vesicular flow bottoms. Basalt color, composition, and texture were described by using a standardized format. Alteration was described where appropriate.

Sediment layers are the other main core component, and these layers vary in composition and thickness. Most sediment layers generally are fine-grained, and include large amounts of silt, clay, fine sand, and limited amounts of coarse sand and gravel. Coarse-grained sediments may be under-represented because of the difficulty in recovering coarse-grained unconsolidated sediment, especially in the saturated zone. Fine-grained sediment is the result of eolian, fluvial, and lacustrine deposition (Blair, 2002). Some sediment tops were oxidized or baked (yellowish red to red in color) where heated by overlying basalt.

Borehole Descriptions

Borehole descriptions include: location, completion date, core size, core depth, core recovery footage, and a general description of recovered core (appendixes A–G). Four boreholes were continuously cored, and three were partially cored. Additional information includes sediment layer and basalt flow group thicknesses and the approximate number of basalt flow groups. A basalt flow group is composed of the

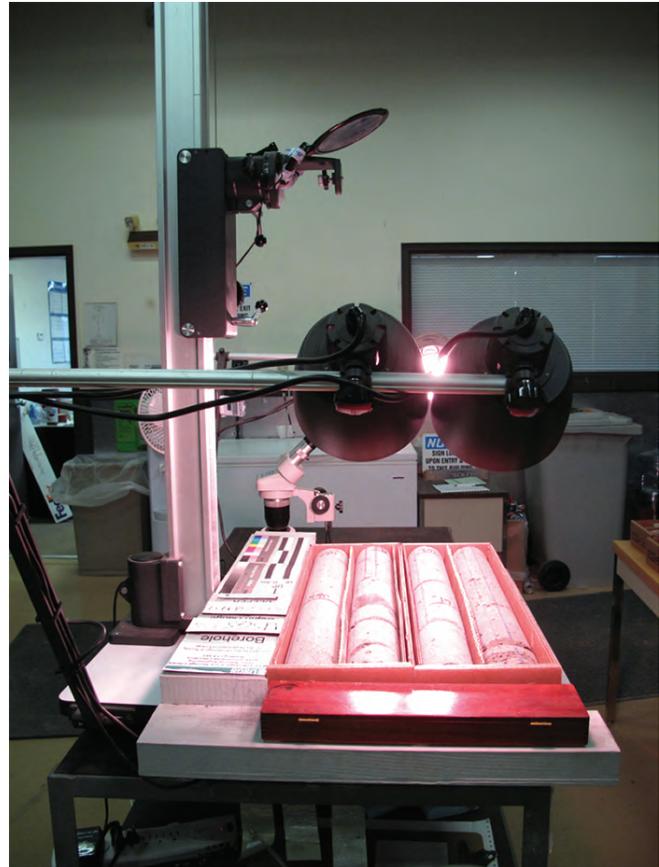


Figure 7. Rolling table and jig used to log and photograph cores collected at Idaho National Laboratory, Idaho.

basalt flows from one monogenetic volcano; basalt flows in a basalt flow group will have similar paleomagnetic inclinations and bulk chemistry. Thickness and number of basalt flow groups for three boreholes (USGS 103, 105, and 108) were approximated from neutron and natural gamma logs. Natural gamma logs are especially useful in separating basalt flow groups, because the logs reliably identify thin sediment layers. The number of basalt flow groups can be only approximated in uncored boreholes.

Four boreholes were cored from the surface, and core from these four boreholes was analyzed paleomagnetically (Duane E. Champion, U.S. Geological Survey, written commun., 2010; Champion and others, 2011), which allows a more accurate determination of the number of basalt flow groups penetrated by these boreholes, than estimation of the number of basalt flow groups by locating flow tops and bases through inspection of core or geophysical logs. Borehole data are summarized in table 3.

Table 3. Summary data for partially cored boreholes USGS 103, 105, and 108, and cored boreholes USGS 131, 135, NRF-15, and NRF-16, Idaho National Laboratory, Idaho.

[Summary of borehole core information from lithologic core logs and (or) geophysical data. Number of basalt and sediment layers and basalt flow and sediment thickness was approximated from lithologic core logs and (or) geophysical information where core was not collected. Depth to water table was referenced to land-surface datum. **Abbreviations:** USGS, U.S. Geological Survey; NAD 27, North American Datum of 1927; NGVD 29, National Geodetic Vertical Datum of 1929; ft, foot; bls, below land surface; mo-yr, month-year; NA, not applicable]

| Data type | Borehole designation | | | | | | | |
|--|----------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| | USGS 103 | USGS 105 | USGS 108 | USGS 131 | USGS 135 | NRF-15A | NRF-15B | NRF-16 |
| North latitude (NAD 27) | 43° 27' 13.57" | 43° 27' 3.40" | 43° 26' 58.79" | 43° 30' 36.28" | 43° 27' 53.47" | 43° 39' 42.18" | 43° 39' 42.18" | 43° 40' 51.40" |
| West longitude (NAD 27) | 112° 56' 6.53" | 113° 00' 17.78" | 112° 58' 23.34" | 112° 58' 16.05" | 113° 09' 35.62" | 112° 54' 50.60" | 112° 54' 50.60" | 112° 54' 51.40" |
| Altitude, land surface, NGVD 29 (ft) | 5,007.42 | 5,095.12 | 5,031.36 | 4,977.30 | 5,135.94 | 4,841.87 | 4,841.87 | 4,827.54 |
| Borehole depth (ft bls) | 1,307 | 1,409 | 1,218 | 1,239 | 1,198 | 759 | 759 | 425 |
| Core recovered (ft) | 538.6 | 595.3 | 458 | 1,129 | 1,139.7 | 652.5 | 652.5 | 392.2 |
| Surficial sediment thickness (ft) | ¹ 20 | ¹ 5 | ¹ 3 | 10 | 8 | 16.5 | 16.5 | 7 |
| Basalt thickness (ft) | 21,066 | 21,271 | 21,026 | 1,144 | 1,156.9 | 635 | 635 | 404 |
| Basalt core recovered (ft) | 516 | 585.8 | 434.7 | 1,091 | 1,115.9 | 600 | 600 | 388 |
| Number of basalt flow groups | ¹ 17 | ¹ 19 | ¹ 24 | ¹ 15 | 14 | 12 | 12 | 8 |
| Average basalt flow group thickness (ft) | 64 | 73 | 43 | 82 | 83 | 53 | 53 | 51 |
| Rhyolite thickness ^{2,3} (ft) | 100 | 100 | 45 | 2 | NA | NA | NA | NA |
| Total rhyolite recovered (ft) | 0 | 0 | 0 | 1.5 | NA | NA | NA | NA |
| Total sediment thickness ⁴ (ft) | 2,4132.6 | 2,424.5 | 2,4146.6 | 106 | 32.5 | 107 | 107 | 17 |
| Sediment core recovered (ft) | 22.6 | 9.5 | 9.9 | 53.7 | 14.3 | 52.5 | 52.5 | 4 |
| Number of sediment layers ⁴ | ¹ 10 | ¹ 8 | ¹ 10 | 14 | 12 | 7 | 7 | 4 |
| Depth to water table (ft) | 588.09 | 675.78 | 611.75 | 546.13 | 718.40 | 377.07 | 373.42 | 359.03 |
| Water level date (mo-yr) | April 2011 | March 2011 | April 2011 | June 2011 | April 2011 | June 2011 | June 2011 | June 2011 |

¹Indicates approximate number.

²Indicates approximate value.

³No core, rhyolite thickness estimated from drillers' notes and geophysical logs.

⁴Includes surface sediment and is estimated from geophysical logs where core is missing.

Borehole USGS 103

Borehole USGS 103 is near the southern boundary of the INL ([fig. 1](#)). Borehole USGS 103 was air rotary drilled from land surface to 760 ft BLS in 1980. USGS 103 was deepened and cored from 760 to 1,307 ft in 2006. The core is PQ size from 760 to 859 ft, and is HQ size from 859 to 1,307 ft. Combined recovery for basalt and sediment was about 96 percent for core drilled from 760 to 1,307 ft BLS ([table 3](#)). A well diagram, simplified lithology, and geophysical logs for borehole USGS 103 are shown in [figure 8](#).

Olivine tholeiite basalt from borehole USGS 103 is medium light to dark gray in color and vesicular to dense in texture. About 82 percent of the total thickness penetrated in this borehole is basalt, 10 percent is sediment (including

surface sediment), and 8 percent is rhyolite ([table 3](#)). About 17 basalt flow groups were identified in borehole USGS 103; those groups in the upper, uncored part were identified by geophysical logs. The approximate average thickness of basalt flow groups in borehole USGS 103 is 64 ft. Rhyolite in the upper uncored part of this well was identified from cuttings, geophysical logs, and drillers' notes. About 10 sediment layers were identified in borehole USGS 103; those layers in the upper, uncored part were identified in the natural gamma log. A multilevel monitoring system was permanently installed in borehole USGS 103 in 2007. Borehole USGS 103 is used for multilevel aquifer potentiometric head, temperature, and water-quality studies (Bartholomay and Twining, 2010; Fisher and Twining, 2011).

USGS 103

Altitude 5,007.42 feet above NGVD 1929

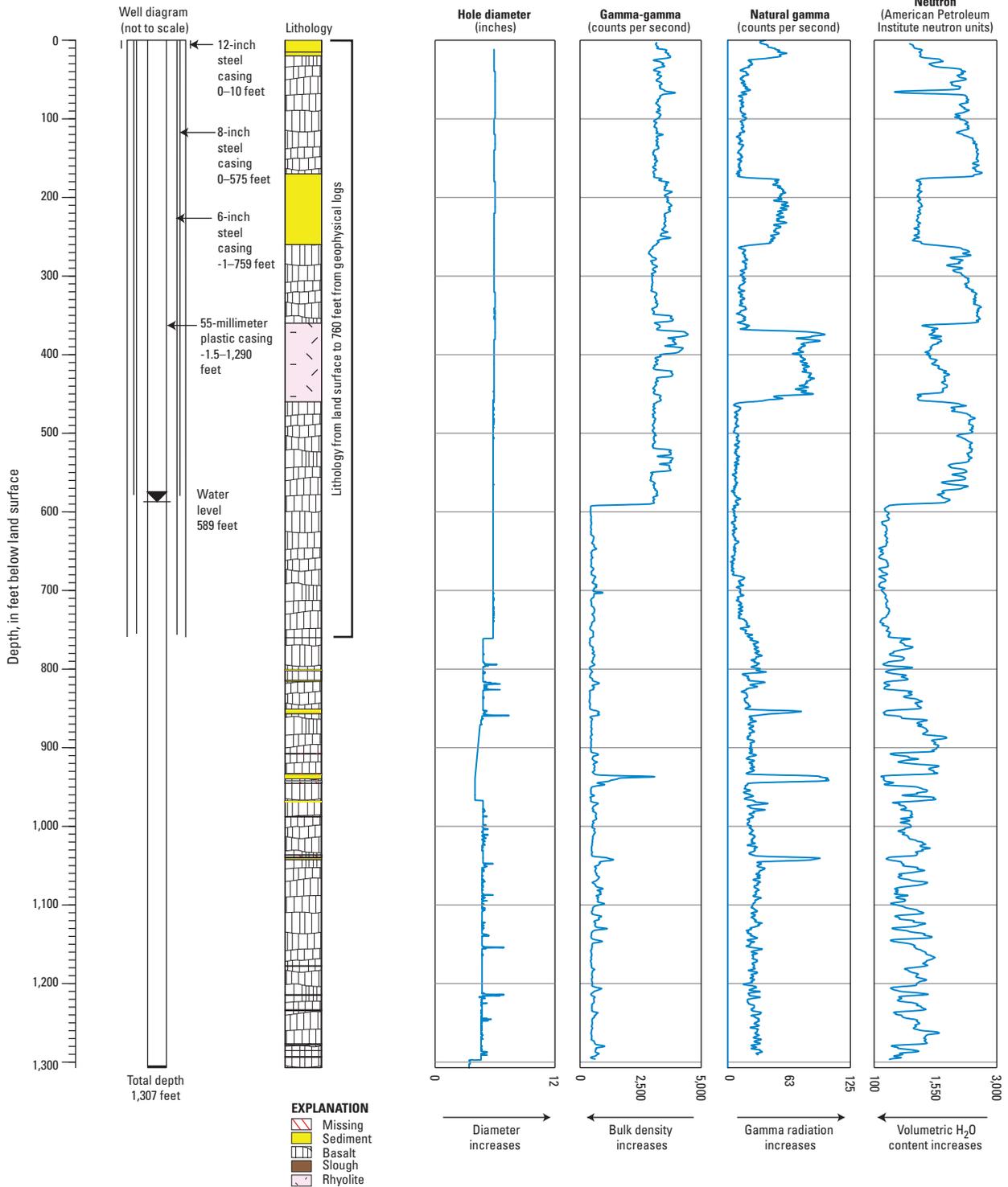


Figure 8. Borehole construction, simplified lithologic log, and geophysical logs for borehole USGS 103, Idaho National Laboratory, Idaho.

Borehole USGS 105

Borehole USGS 105 is near the southern boundary of the INL. Borehole USGS 105 was air rotary drilled from land surface to 800 ft BLS in 1980. Borehole USGS 105 was deepened and cored from 800 to 1,409 ft in 2008. Borehole USGS 105 core is HQ size from 800 to 1,409 ft BLS. Ninety-eight percent of the core from 800 to 1,409 ft BLS was recovered. A well diagram, simplified lithology, and geophysical logs for borehole USGS 105 are shown in [figure 9](#).

Olivine tholeiite basalt from borehole USGS 105 is medium light to dark gray to purple to red-brown in color, and vesicular to dense in texture. About 19 basalt flow groups were identified in borehole USGS 105; those groups in the upper, uncored part were identified by geophysical logs.

The approximate average thickness of basalt flow groups in borehole USGS 105 is 73 ft. Rhyolite in the upper uncored part of this well was identified from cuttings, geophysical logs, and drillers' notes. About eight sediment layers were identified in borehole USGS 105; those layers in the upper, uncored part were identified in the natural gamma log. About 91 percent of the thickness penetrated by borehole USGS 105 is basalt, 2 percent is sediment (including surface sediment), 7 percent is rhyolite ([table 3](#)).

A multilevel monitoring system was permanently installed in borehole USGS 105 in 2009. Borehole USGS 105 is used for multilevel aquifer potentiometric head, temperature, and water-quality studies. Examples of such data collected for other wells are given in Bartholomay and Twining (2010), and in Fisher and Twining (2011).

USGS 105

Altitude, 5,095.12 feet ngvd 29

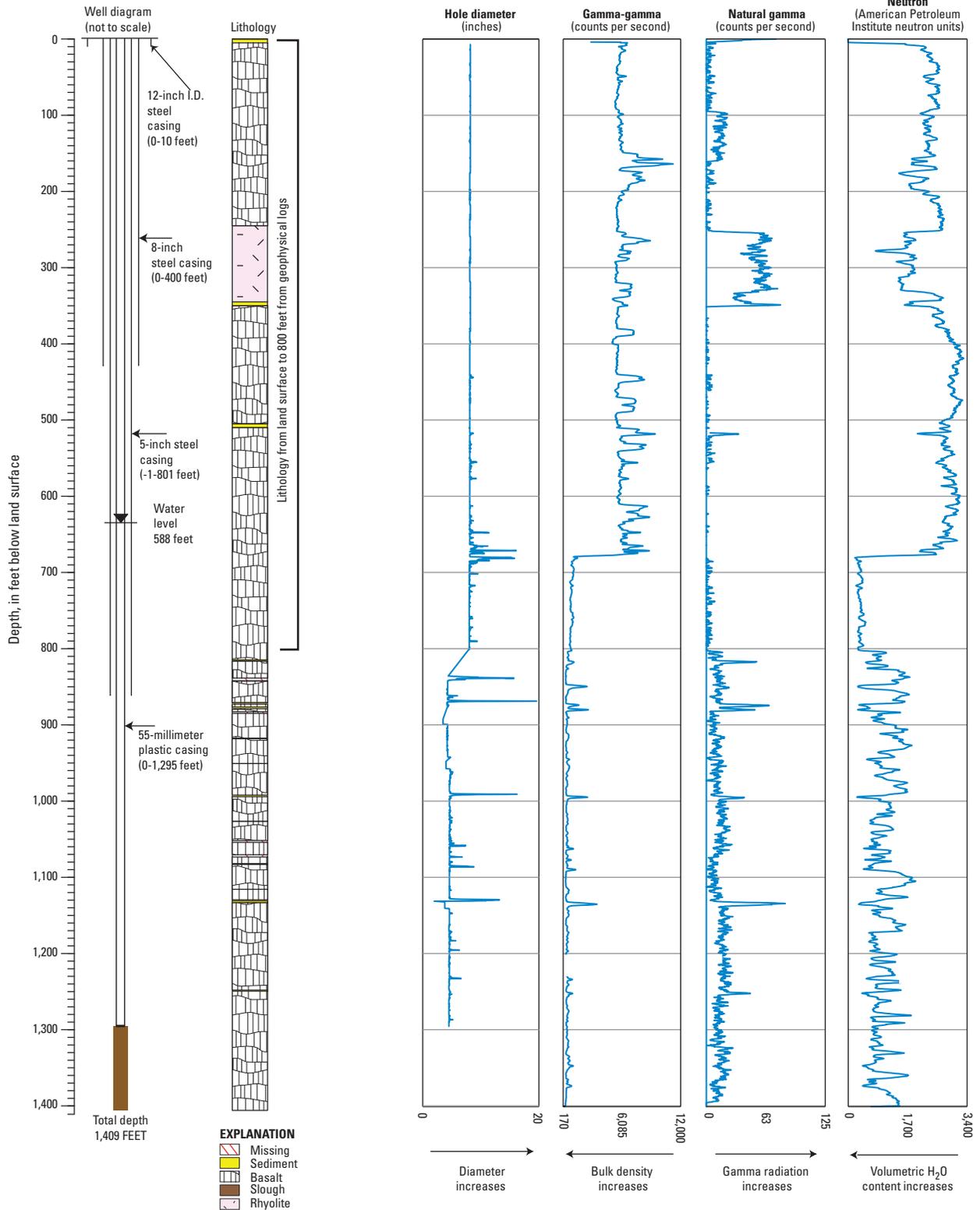


Figure 9. Borehole construction, simplified lithologic log, and geophysical logs for borehole USGS 105, Idaho National Laboratory, Idaho.

Borehole USGS 108

Borehole USGS 108 is near the southern boundary of the INL ([fig. 1](#)). Borehole USGS 108 was air rotary drilled from land surface to 760 ft BLS in 1980. Borehole USGS 108 was deepened and cored from 760 to 1,218 ft in 2008. The core is HQ size from 760 to 1,218 ft. About 97 percent of the core drilled from 760 to 1,218 ft BLS was recovered. A well diagram, simplified lithology, and geophysical logs for borehole USGS 108 are shown in [figure 10](#).

Olivine tholeiite in borehole USGS 108 is medium light to dark gray to purple to red-brown in color, and vesicular to dense in texture. About 24 basalt flow groups were identified in borehole USGS 108; those groups in the upper, uncored part were identified by geophysical logs. Approximate average

thickness of basalt flow groups in USGS 108 is 43 ft. About 84 percent of the thickness penetrated by borehole USGS 108 is basalt, 12 percent is sediment (including surface sediment), 4 percent is rhyolite. Rhyolite in the upper uncored part of this well was identified from cuttings, geophysical logs, and drillers' notes. About 10 sediment layers were identified in borehole USGS 108; those layers in the upper, uncored part were identified in the natural gamma log.

A multilevel monitoring system was permanently installed in borehole USGS 108 in 2010. The well is used for multilevel aquifer potentiometric head, temperature, and water-quality studies. Examples of such data collected for other boreholes are given in Bartholomay and Twining (2010), and in Fisher and Twining (2011).

USGS 108
 Altitude 5,031.36 feet above NGVD 1929

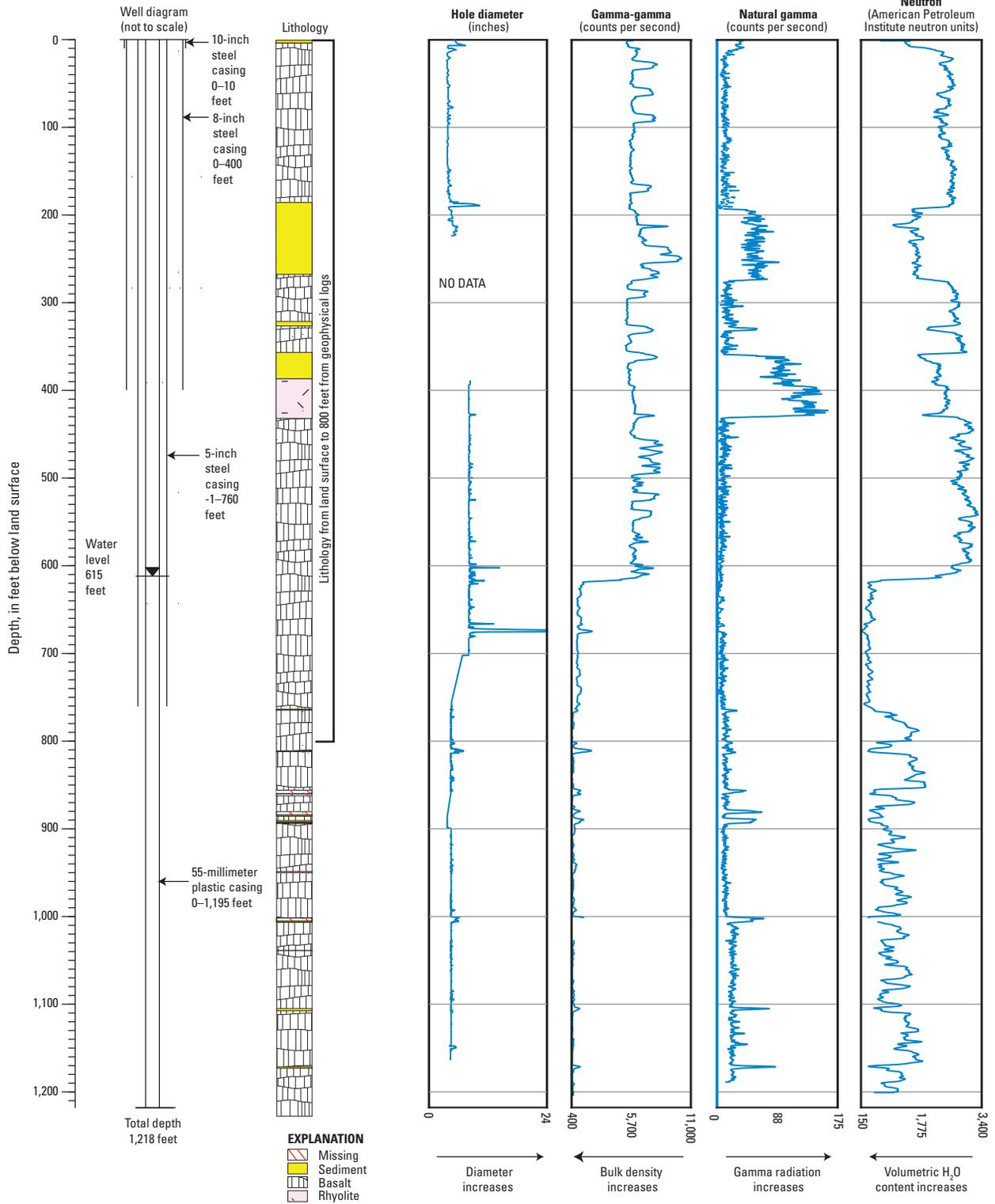


Figure 10. Borehole construction, simplified lithologic log, and geophysical logs for borehole USGS 108, Idaho National Laboratory, Idaho.

Borehole USGS 131

Borehole USGS 131 is south of Central Facilities Area, near Highway 26 ([fig. 1](#)). Borehole USGS 131 was cored from land surface to 808 ft BLS in 2003, and a core log of borehole USGS 131 to 808 ft BLS was published in 2008 (Twining and others, 2008). Borehole USGS 131 was deepened and cored from 808 to 1,239 ft in 2010. Borehole USGS 131 core is PQ size from 10 to 619 ft BLS, and core is HQ size from 619 to 1,239 ft BLS. About 97 percent of the core drilled from 808 to 1,239 ft BLS was recovered. A well diagram, simplified lithology, and geophysical logs for borehole USGS 131 are shown in [figure 11](#).

Olivine tholeiite basalt in borehole USGS 131 is medium-gray to blackish-red in color and vesicular to dense

in texture. Paleomagnetic measurements on core from 10 to 808 ft BLS indicate that 11 basalt flow groups are in that interval. Preliminary paleomagnetic analyses and geophysical logs indicate that three or four more flow groups are in the interval from 808 to 1,239 ft BLS (Duane E. Champion, U.S. Geological Survey, written commun., November 2010). Basalt flow group thickness averaged 82 ft ([table 3](#)). About 92 percent of the thickness penetrated by borehole USGS 131 is olivine tholeiite basalt, and 8 percent is sediment (including surface sediment), which ranges in particle size from clay to gravel. Paleomagnetic measurements on basalt core from land surface to 808 ft BLS from borehole USGS 131 are available in Champion and others (2011). Borehole USGS 131 was damaged during drilling and is on standby until further notice.

USGS 131

Altitude 4,977.30 feet above NGVD 1929

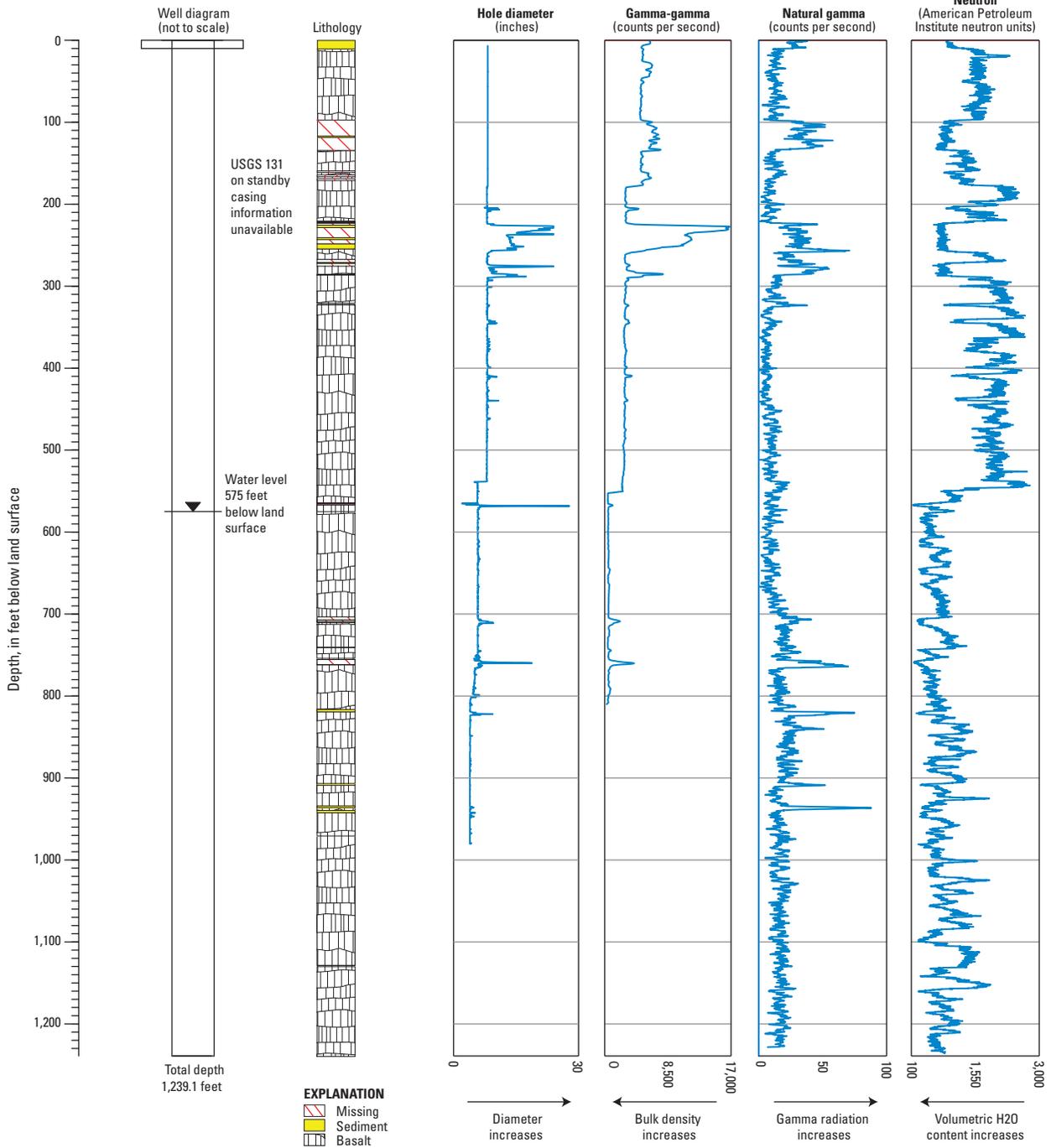


Figure 11. Borehole construction, simplified lithologic log, and geophysical logs for borehole USGS 131, Idaho National Laboratory, Idaho.

Borehole USGS 135

Borehole USGS 135 is in the extreme southwestern corner of the INL. Borehole USGS 135 was cored from land surface to 1,198 ft BLS in 2007. Borehole USGS 135 core is PQ size from land surface to 803 ft BLS and HQ from 803 ft to 1,198 ft. About 96 percent of the core drilled from 8 to 1,198 ft BLS was recovered. A well diagram, simplified lithology, and geophysical logs for USGS 135 are shown in [figure 12](#).

Olivine tholeiite basalt core from USGS 135 ranges from scoriaceous to dense, and from dark gray to brownish gray to very light gray in color. Basalt samples from borehole USGS 135 was analyzed for bulk rock major and trace element

geochemistry. Results of geochemical analysis of borehole USGS 135 were reported in Potter (2010). Paleomagnetic measurements on basalt core from borehole USGS 135 were made, and results were reported in Champion and others (2011). Average basalt flow group thickness in borehole USGS 135 is 83 ft. About 97 percent of the thickness penetrated by borehole USGS 135 is basalt, and 3 percent is sediment (including surface sediment).

A multilevel monitoring system was permanently installed in borehole USGS 135 in 2009. Borehole USGS 135 is used for multilevel aquifer potentiometric head, temperature, and water-quality studies. Examples of such data collected for other boreholes are given in Bartholomay and Twining (2010), and in Fisher and Twining (2011).

USGS 135

Altitude 5,135.94 feet above NGVD 1929

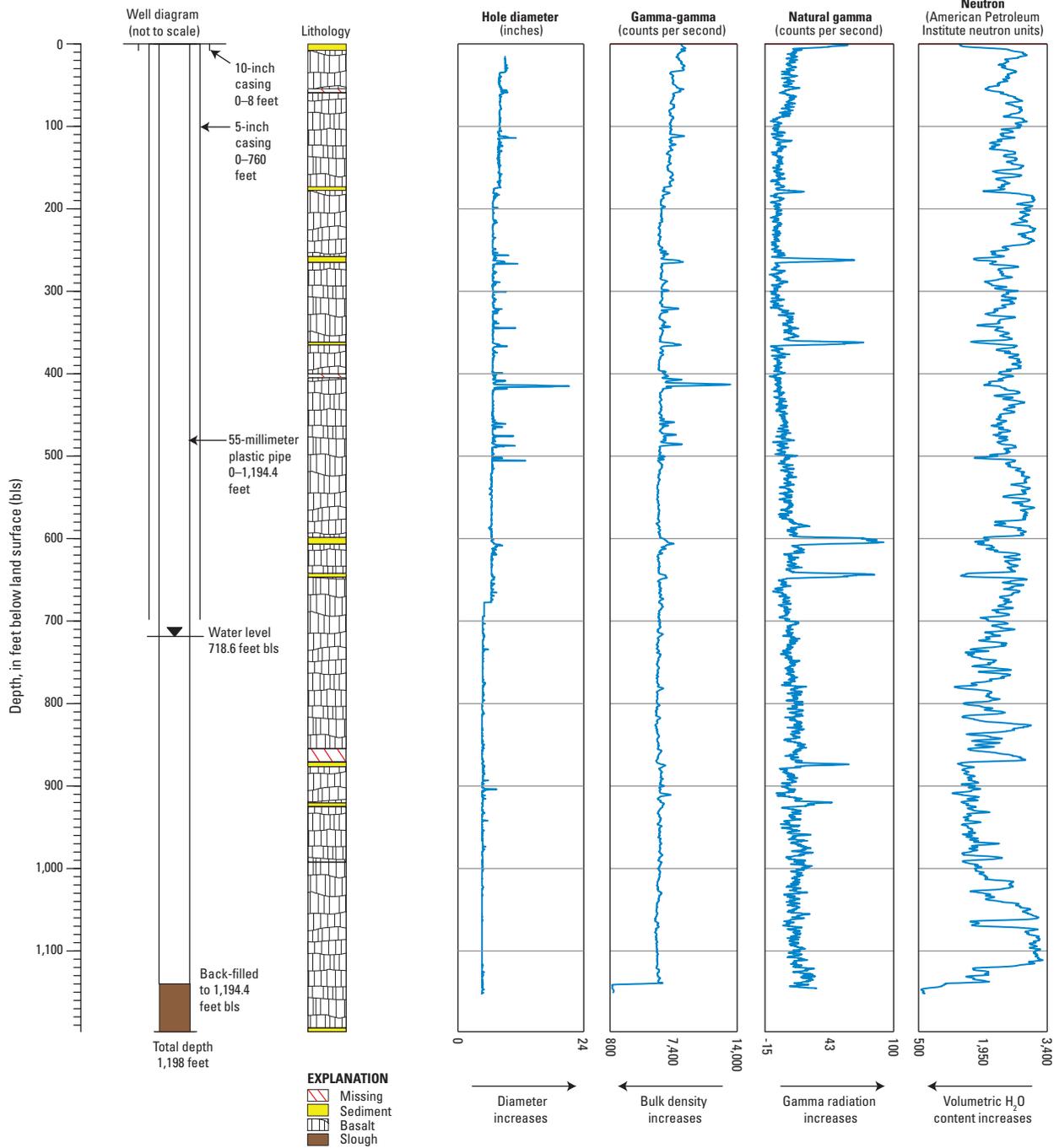


Figure 12. Borehole construction, simplified lithologic log, and geophysical logs for borehole USGS 135, Idaho National Laboratory, Idaho.

Borehole NRF-15

Borehole NRF-15 is about 0.5 mi north of the Naval Reactor Facility ([fig. 1](#)). Borehole NRF-15 was cored from 17 to 759 ft BLS in 2008. Borehole NRF-15 core is PQ size from land surface to 514 ft BLS, and is HQ size from 514 to 759 ft BLS. About 88 percent of the core drilled from 16.5 to 759 ft BLS was recovered. A well diagram, simplified lithology, and geophysical logs for borehole NRF-15 are shown in [figure 13](#).

Olivine tholeiite basalt from borehole NRF-15 is gray, dark gray, blackish red, or brownish gray in color,

and vesicular to dense in texture. Sediment size ranges from clay to sand. Paleomagnetic measurements indicate that 14 basalt flow groups are in borehole NRF-15 (Duane E. Champion, U.S. Geological Survey, written commun., 2010). Borehole NRF-15 penetrates 12 basalt flow groups that average 53 ft thick. About 84 percent of the thickness penetrated by borehole NRF-15 is basalt, and 16 percent is sediment (including surface sediment). Borehole NRF-15 was completed as a dual piezometer water-level monitoring well in 2010.

NRF 15

Altitude 4,841.87 feet above NGVD 1929

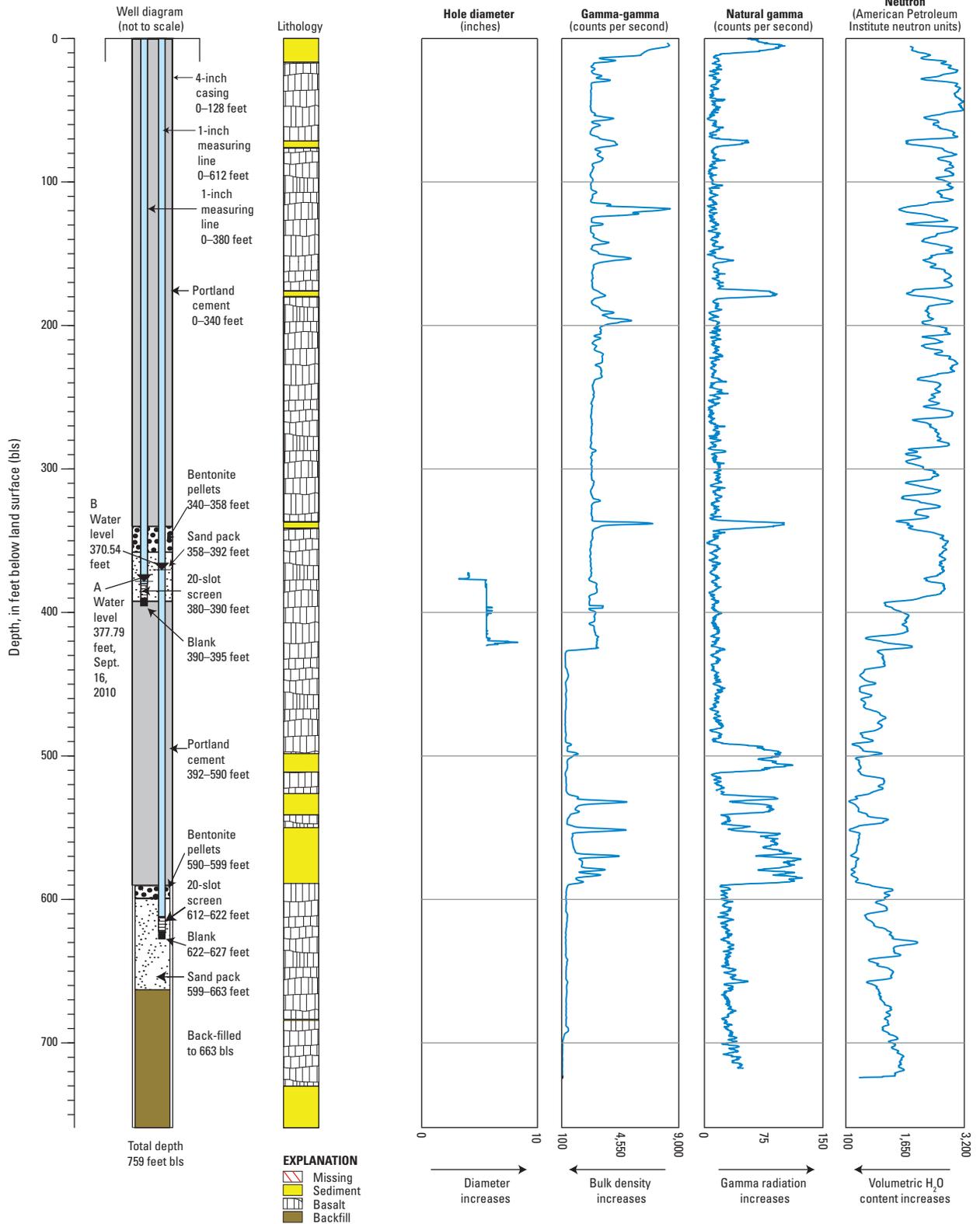


Figure 13. Borehole construction, simplified lithologic log, and geophysical logs for borehole NRF-15, Idaho National Laboratory, Idaho.

Borehole NRF-16

Borehole NRF-16 is about 1.5 mi north of the Naval Reactor Facility ([fig. 1](#)). Borehole NRF-16 was cored from 7 to 425 ft BLS in 2009. Borehole NRF-16 core is PQ size from land surface to 425 ft BLS. About 94 percent of the core drilled from 7 to 424 ft BLS was recovered. [Figure 14](#) shows a well diagram, simplified lithology, and geophysical logs.

Olivine tholeiite basalt from borehole NRF-16 ranges from vesicular to dense in texture and is dark gray to grayish red to light gray in color. Sediment in core from borehole NRF-16 ranges from clay to fine sand in size. Paleomagnetic

measurements (Duane E. Champion, U.S. Geological Survey, written commun., May 2011) of basalt core from borehole NRF-16 indicate that eight basalt flow groups are an average of 51 ft thick in borehole NRF-16. About 95 percent of the thickness penetrated by borehole NRF-16 is basalt, 4 percent is sediment (including surface sediment), and 1 percent is missing core that cannot be assigned to either sediment or basalt. A completion summary for borehole NRF-16 including drilling and borehole construction methods, geophysical logging, hydrologic description, aquifer test, water quality analysis and hydraulic property estimates is available in Twining and others (2010).

NRF 16

Altitude 4,827.54 feet above NGVD 1929

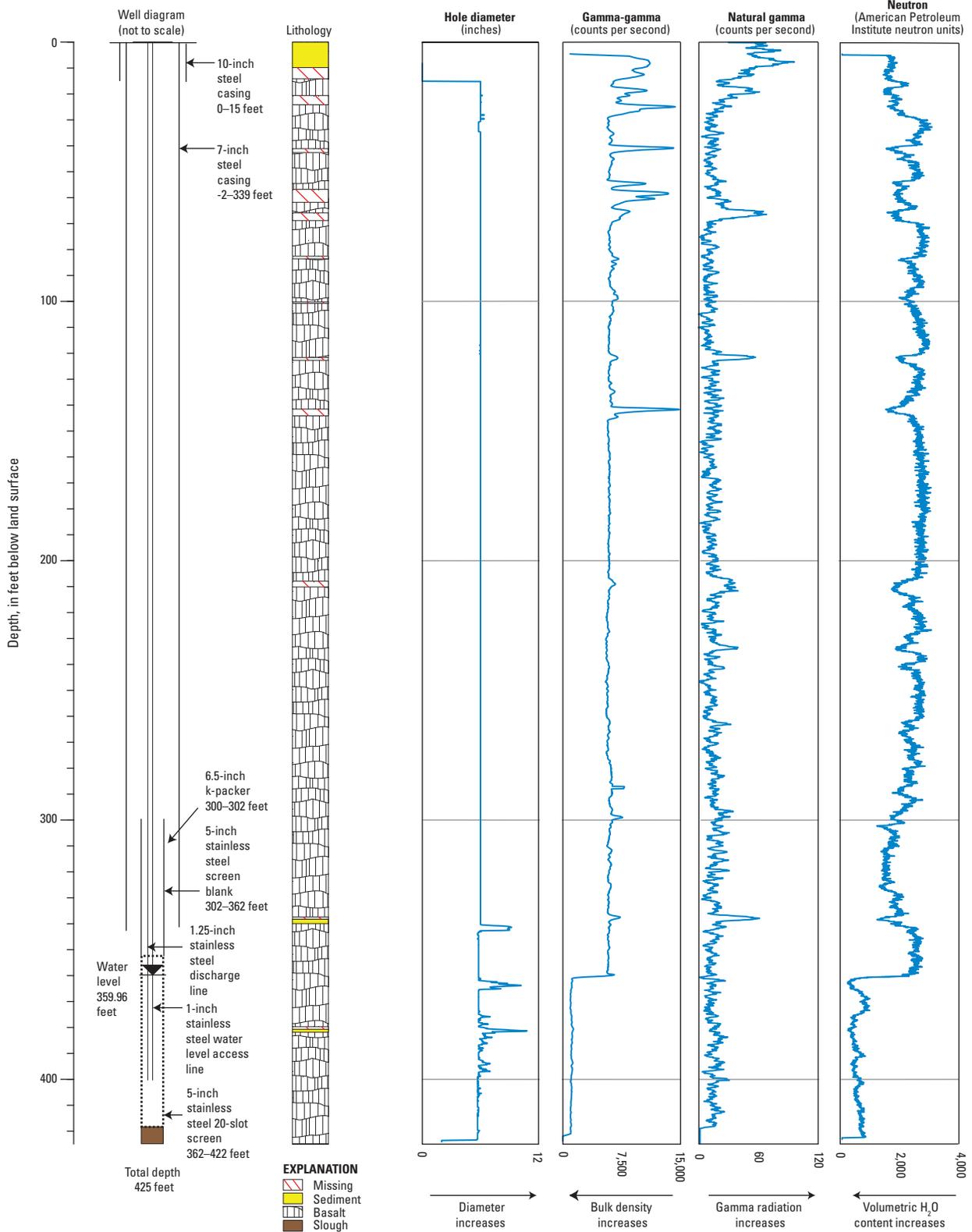


Figure 14. Borehole construction, simplified lithologic log, and geophysical logs for borehole NRF-16, Idaho National Laboratory, Idaho.

Summary

Seven boreholes with depths ranging from 425 to 1,409 feet below land surface (BLS) were drilled or deepened from 2006 to 2009. About 4,509 feet of core were recovered. Olivine tholeiite basalt is the dominant rock type penetrated by all boreholes in this report, ranging from 82 percent in borehole USGS 103 to 97 percent basalt in borehole USGS 135. Sediment layers penetrated by these boreholes range from 1 to 100 feet thick (estimated from geophysical logs in boreholes USGS 103, 105, and 108), with grain sizes ranging from clay to gravel. Boreholes USGS 103, 108, 131, and NRF-15 yielded the most sediment. Depth to water ranged from 359.03 ft BLS in borehole NRF-16, the northernmost borehole in the report to 718.40 feet BLS in borehole USGS 135, the borehole farthest to the southwest.

Boreholes USGS 103, 105, and 108 penetrate 45–100 feet of rhyolite, according to geophysical logs and drillers' notes. No rhyolite was recovered from these boreholes. Borehole USGS 131 has two limited intervals of reworked rhyolite ash.

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Appendix A. Partial Core Log for Borehole USGS 103, 760–1,307 Feet Below Land Surface, Idaho National Laboratory, Idaho

Data are available for download at <http://pubs.usgs.gov/ds/660/>.

Appendix B. Partial Core Log for Borehole USGS 105, 800–1,409 Feet Below Land Surface, Idaho National Laboratory, Idaho

Data are available for download at <http://pubs.usgs.gov/ds/660/>.

Appendix C. Partial Core Log for Borehole USGS 108, 760–1,218 Feet Below Land Surface, Idaho National Laboratory, Idaho

Data are available for download at <http://pubs.usgs.gov/ds/660/>.

Appendix D. Partial Core Log for Borehole USGS 131, 808–1,238 Feet Below Land Surface, Idaho National Laboratory, Idaho

Data are available for download at <http://pubs.usgs.gov/ds/660/>.

Appendix E. Core Log for Borehole USGS 135, Idaho National Laboratory, Idaho

Data are available for download at <http://pubs.usgs.gov/ds/660/>.

Appendix F. Core Log for Borehole NRF-15, Idaho National Laboratory, Idaho

Data are available for download at <http://pubs.usgs.gov/ds/660/>.

Appendix G. Core Log for Borehole NRF-16, Idaho National Laboratory, Idaho

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