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

# Drilling, Construction, Geophysical Log Data, and Lithologic Log for Boreholes USGS 142 and USGS 142A, Idaho National Laboratory, Idaho


Data Series 1058

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

**COVER:** Photograph of U.S. Geological Survey driller setting drill rod at borehole USGS 142, Idaho National Laboratory, Idaho.
Photograph by Brian Twining, U.S. Geological Survey, October 5, 2015.

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By Brian V. Twining, Mary K.V. Hodges, Kyle Schusler, and Christopher Mudge

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RYAN K. ZINKE, Secretary

**U.S. Geological Survey**
William H. Werkheiser, Acting Director

U.S. Geological Survey, Reston, Virginia: 2017

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# Conversion Factors

Inch/Pound to International System of Units

| Multiply | By | To obtain |
|---|---|---|
| | Length | |
| inch (in.) | 2.54 | centimeter (cm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| | Volume | |
| gallon (gal) | 3.785 | liter (L) |
| | Flow rate | |
| foot per day (ft/d) | 0.3048 | meter per day (m/d) |
| gallon per minute (gal/min) | 0.06309 | liter per second (L/s) |
| | Mass | |
| ounce, avoirdupois (oz) | 28.35 | gram (g) |
| pound, avoirdupois (lb) | 0.4536 | kilogram (kg) |
| | Pressure | |
| pound per square inch (lb/in$^2$) | 6.895 | kilopascal (kPa) |
| | Specific capacity | |
| gallon per minute per foot [(gal/min)/ft)] | 0.2070 | liter per second per meter [(L/s)/m] |
| | Hydraulic conductivity | |
| foot per day (ft/d) | 0.3048 | meter per day (m/d) |
| | Hydraulic gradient | |
| foot per mile (ft/mi) | 0.1894 | meter per kilometer (m/km) |
| | Transmissivity* | |
| foot squared per day (ft$^2$/d) | 0.09290 | meter squared per day (m$^2$/d) |

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8×°C)+32.$$

## Datums

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 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.

## Supplemental Information

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [($ft^3$/d)/$ft^2$]ft. In this report, the mathematically reduced form, foot squared per day ($ft^2$/d), is used for convenience.

## Abbreviations

| | |
|---|---|
| ATR Complex | Advanced Test Reactor Complex |
| BLS | below land surface |
| CFA | Central Facilities Area |
| CPS | counts per second |
| DOE | U.S. Department of Energy |
| ESRP | eastern Snake River Plain |
| INL | Idaho National Laboratory |
| INTEC | Idaho Nuclear Technology and Engineering Center |
| MFC | Materials and Fuels Complex |
| NRF | Naval Reactors Facility |
| PBF | Power Burst Facility |
| PQ | core rod sizing |
| RWMC | Radioactive Waste Management Complex |
| SS | stainless steel |
| TAN | Test Area North |
| TRA | Test Reactor Area |
| USGS | U.S. Geological Survey |
| WRDT | Western Region Drill Team |

# Drilling, Construction, Geophysical Log Data, and Lithologic Log for Boreholes USGS 142 and USGS 142A, Idaho National Laboratory, Idaho

By Brian V. Twining, Mary K.V. Hodges, Kyle Schusler, and Christopher Mudge

## Abstract

Starting in 2014, the U.S. Geological Survey in cooperation with the U.S. Department of Energy, drilled and constructed boreholes USGS 142 and USGS 142A for stratigraphic framework analyses and long-term groundwater monitoring of the eastern Snake River Plain aquifer at the Idaho National Laboratory in southeast Idaho. Borehole USGS 142 initially was cored to collect rock and sediment core, then re-drilled to complete construction as a screened water-level monitoring well. Borehole USGS 142A was drilled and constructed as a monitoring well after construction problems with borehole USGS 142 prevented access to upper 100 feet (ft) of the aquifer. Boreholes USGS 142 and USGS 142A are separated by about 30 ft and have similar geology and hydrologic characteristics. Groundwater was first measured near 530 feet below land surface (ft BLS) at both borehole locations. Water levels measured through piezometers, separated by almost 1,200 ft, in borehole USGS 142 indicate upward hydraulic gradients at this location. Following construction and data collection, screened water-level access lines were placed in boreholes USGS 142 and USGS 142A to allow for recurring water level measurements.

Borehole USGS 142 was cored continuously, starting at the first basalt contact (about 4.9 ft BLS) to a depth of 1,880 ft BLS. Excluding surface sediment, recovery of basalt, rhyolite, and sediment core at borehole USGS 142 was approximately 89 percent or 1,666 ft of total core recovered. Based on visual inspection of core and geophysical data, material examined from 4.9 to 1,880 ft BLS in borehole USGS 142 consists of approximately 45 basalt flows, 16 significant sediment and (or) sedimentary rock layers, and rhyolite welded tuff. Rhyolite was encountered at approximately 1,396 ft BLS. Sediment layers comprise a large percentage of the borehole between 739 and 1,396 ft BLS with grain sizes ranging from clay and silt to cobble size. Sedimentary rock layers had calcite cement. Basalt flows ranged in thickness from about 2 to 100 ft and varied from highly fractured to dense, and ranged from massive to diktytaxitic to scoriaceous, in texture.

Geophysical logs were collected on completion of drilling at boreholes USGS 142 and USGS 142A. Geophysical logs were examined with available core material to describe basalt, sediment and sedimentary rock layers, and rhyolite. Natural gamma logs were used to confirm sediment layer thickness and location; neutron logs were used to examine basalt flow units and changes in hydrogen content; gamma-gamma density logs were used to describe general changes in rock properties; and temperature logs were used to understand hydraulic gradients for deeper sections of borehole USGS 142. Gyroscopic deviation was measured to record deviation from true vertical at all depths in boreholes USGS 142 and USGS 142A.

## Introduction

The U.S. Geological Survey (USGS), in cooperation with the U.S. Department of Energy (DOE), has collected borehole information at the Idaho National Laboratory (INL) since 1949 to provide baseline data concerning the migration and disposition of radioactive and chemical wastes in the eastern Snake River Plain (ESRP) aquifer. The USGS uses borehole data to construct numerical models to characterize the movement of groundwater in the ESRP aquifer. Borehole core and geophysical data for deeper sections of the ESRP aquifer (greater than about 730 feet below land surface [ft BLS]) are necessary to investigate the geology and hydrology near the western edge of the INL. Additional data gathered near the west-central part of the INL will be used to better understand groundwater flow at the INL (fig. 1).

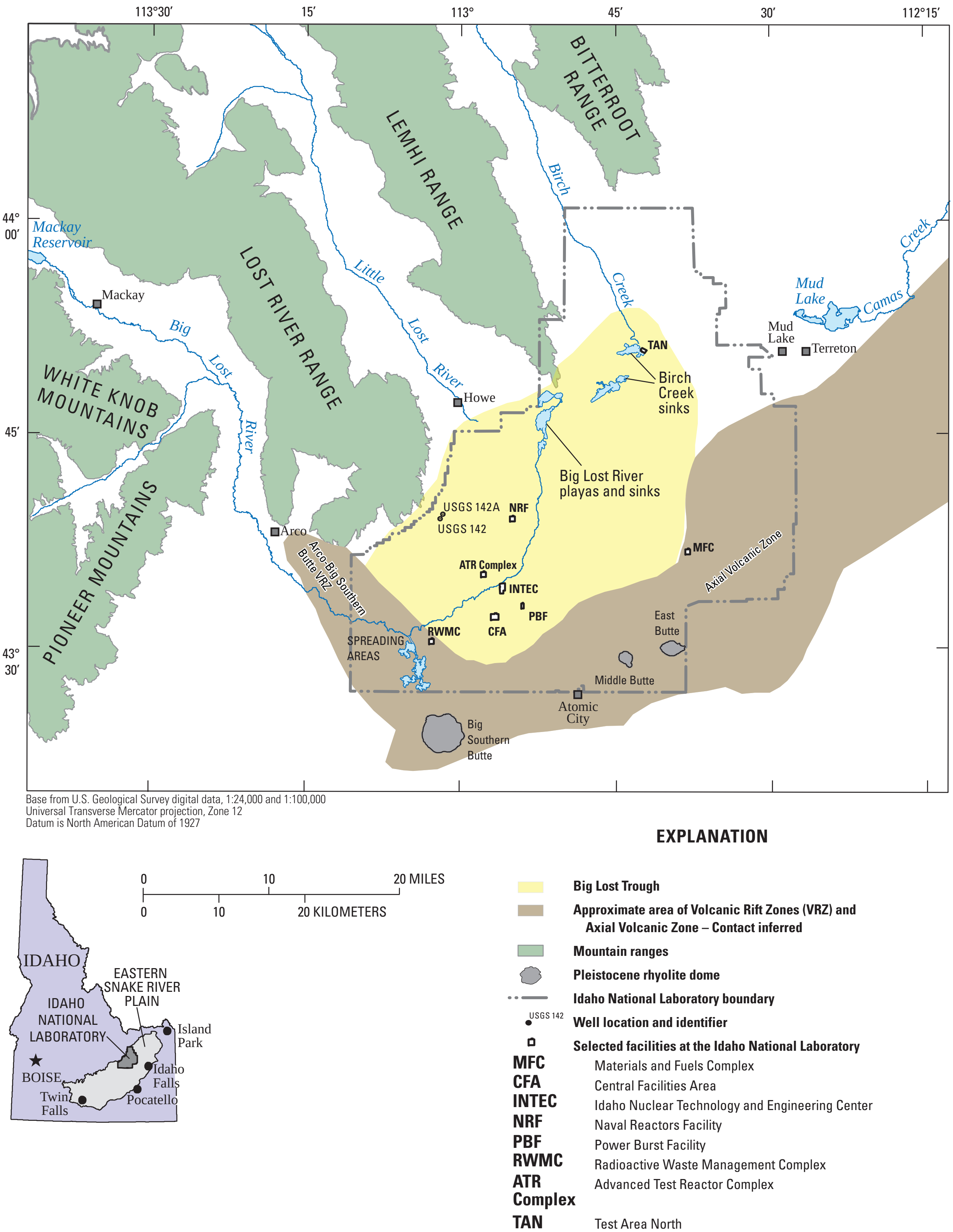


**Figure 1.** Location of boreholes USGS 142 and USGS 142A along with selected facilities at the Idaho National Laboratory, Idaho.

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). Sediment layering between basalt flows can result in changes in hydraulic head pressure, as reported from multilevel monitoring wells located on the INL (Fisher and Twining, 2011; Twining and Fisher, 2015) (fig. 1). Boreholes USGS 142 and USGS 142A are within the Big Lost Trough, and borehole USGS 142 displays increased sediment in deeper sections of the aquifer; therefore, measurements of hydraulic head in the area would provide valuable data for numerical model verification along the western edge of the INL model area (fig. 1).

Boreholes USGS 142 and USGS 142A were drilled about 30 ft apart. Borehole USGS 142 was drilled to a depth of 1,880 ft BLS and borehole USGS 142A was drilled to a depth of 560 ft BLS. Borehole USGS 142 was continuously core drilled and was constructed in several phases between July, 2014, and July, 2016. Borehole USGS 142A was drilled using a hammer rotary system between July, 2016, and August, 2016. Objectives for drilling borehole USGS 142 were to understand the basalt and sediment stratigraphy of the ESRP aquifer and underlying rhyolite to help refine stratigraphic models, and to provide better definition as to the base of the regional ESRP aquifer system. After core drilling and geophysical logging, borehole USGS 142 was constructed with a screened piezometer. The objective for drilling borehole USGS 142A was to provide water level data for the shallower ESRP aquifer.

## Purpose and Scope

This report presents results of the drilling, construction, geophysical logging, lithologic descriptions, and hydrologic data collection for boreholes USGS 142 and USGS 142A. Geologic and geophysical data were collected and analyzed to a depth of about 1,880 ft BLS in borehole USGS 142 and geophysical data were collected to about 560 ft BLS in borehole USGS 142A. Additionally, hydrologic data were collected from each borehole after construction and between various drilling phases within borehole USGS 142 over a 2-year period to describe hydraulic head changes with depth. A core log for USGS 142, including lithologic descriptions, core photographs, vesicle abundance and volume, and rock structure data are in the appendix.

## Hydrogeologic Setting

The INL is in the west-central part of the ESRP (fig. 1), a northeast-trending structural basin about 200 miles (mi) long and 50–70 mi wide. The ESRP is a structural downwarp, the result of severe crustal disruption from the passage of the North American tectonic plate over the Yellowstone Hot Spot (Pierce and Morgan, 1992). The ESRP is subject to continuing basaltic volcanism and subsidence because disruption to the crust resulted in increased heat flow (Blackwell and others, 1992) and emplacement of a dense, mid-crustal sill (Shervais and others, 2006). The subsiding ESRP basin was filled with interbedded eolian and terrestrial sediments and Pleistocene to late Pliocene basalt, 0.6–1.2 mi thick (Whitehead, 1992).

The ESRP is composed mostly of olivine tholeiite basalt flows, which erupted as tube-fed, inflated, pahoehoe flows that make up more than 85 percent of the subsurface volume of the ESRP at the INL (Anderson and Liszewski, 1997). Figure 2 includes a diagram of a lobe of a tube-fed, pahoehoe ESRP basalt flow, showing cooling fractures that develop perpendicular to the exterior surfaces, vesicle zones and sheets, pipe vesicles, interior mega vesicles, and a diktytaxitic to massive core. The distribution of basalt flows is controlled by topography, rate of effusion, and duration of eruption. Near-vent flows are thinner than distal flows, and accumulations of thin flows have a larger volume of high conductivity zones than the same volume of thick flows (Anderson and others, 1999).

The percentage of sediment penetrated by individual boreholes at the INL ranges from less than 5 percent of the stratigraphic column to more than 50 percent near the terminus of the Big Lost River and Little Lost Rivers in an inferred depositional center known informally as the Big Lost Trough (fig. 1) (Geslin and others, 1997; Gianniny and others, 1997). Most sediments in the ESRP aquifer below the INL are fine-grained loess. In the Big Lost Trough, sediments also may include stream-deposited sand and gravel, and lake-deposited clay, carbonates and silt (Geslin and others, 2002). Within the Big Lost Trough, sediments grade from fluvial, sandy gravel in stream channels to finer-grained clayey silt in terminal playas at the distal ends of the river streams that historically have drained into this structural depression. In addition to stream deposits, lakes have often formed throughout the Pleistocene within the Big Lost Trough and include: Olduvai Lake, Diamictic Lake, and Lake Terreton (Gelsin and others, 1997; Bestland and others, 2002). In general, lake deposits represent the fine grained facies, whereas the more coarse grained sediment deposits were likely from stream deposits.

Basalt lavas are commonly interlayered with eolian clastic and waterborne sediment derived from nearby mountain ranges (Geslin and others, 2002). Accumulations of basalt and sediment in the ESRP have largely buried the underlying rhyolitic rocks and caldera systems. Virtually no unambiguous rhyolite outcrops are exposed on the plain, aside from those in the Yellowstone area (including Island Park). Rhyolites are exposed on mountain ranges along the edges of the plain. Volumes and sources of rhyolites in those regions are inferred almost entirely from spatial distributions and depositional features of ignimbrite and fall deposits marginal to the plain, a small number of deep boreholes, and geophysical surveys (McCurry and others, 2016).

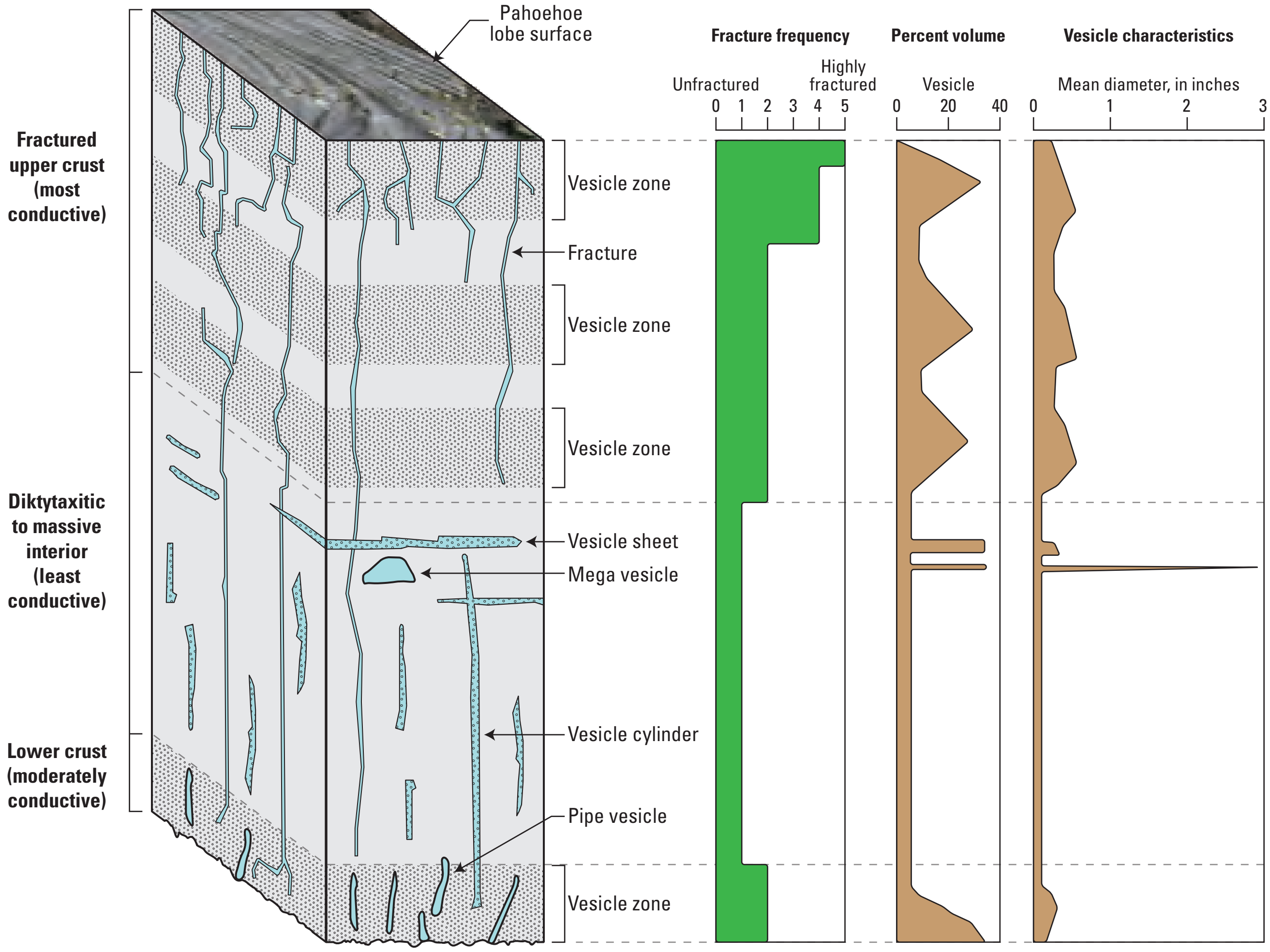


**Figure 2.** Idealized typical olivine tholeiite pahoehoe basalt flow (modified from Self and others, 1998, fig. 3, p. 90). The basalt flow is divided into three sections on the basis of vesicle characteristics and fracture frequency. Hydraulic conductivity is highest for the fractured outer crust, moderate for the less fractured inner crust, and lowest for the diktytaxitic to massive interior. The photograph of the pahoehoe lobe surface is courtesy of Scott Hughes, Emeritus Professor, Idaho State University, Pocatello, Idaho.

The Snake River Plain aquifer that underlies the ESRP is one of the most productive aquifers in the United States (U.S. Geological Survey, 1985, p. 193). Groundwater in the ESRP aquifer generally moves from northeast to southwest, eventually discharging to springs along the Snake River downstream of Twin Falls, Idaho—about 100 mi southwest of the INL (Whitehead, 1992). Water moves through basalt fracture zones at the tops, bases, and sides of basalt flows. Infiltration of surface water, groundwater pumping, geologic conditions, and seasonal fluxes of recharge and discharge locally affect the movement of groundwater (Garabedian, 1986). Recharge to the ESRP aquifer is primarily from infiltration of applied irrigation water, streamflow, direct infiltration of areal precipitation, and groundwater inflow from adjoining mountain drainage basins (Ackerman and others, 2006).

Throughout the INL, the March–May 2015 water-table altitude ranged from about 4,560 to 4,410 ft (Bartholomay and others, 2017, fig. 9). Depth to water ranges from about 200 ft BLS in the northern part of the INL to more than 900 ft BLS in the southeastern part; depth to water measured in boreholes USGS 142 and USGS 142A measures about 530 ft BLS for measurements taken within the upper 300 ft of the regional ESRP aquifer. Most groundwater moves through the upper 200–800 ft of basaltic rocks (Mann, 1986, p. 21). The estimated transmissivity for the upper part of the ESRP aquifer is 1.1 to 760,000 square feet per day ($ft^2/d$), reported by Ackerman (1991, p. 30) and Bartholomay and others (1997, table 3). The hydraulic gradient at the INL ranges from 2 to 10 feet per mile (ft/mi); the average is about 4 ft/mi (Bartholomay and others, 2017, fig. 9). Horizontal flow velocities of 2–20 ft/d were calculated from the movement of various chemical and radiochemical constituents in different areas of the ESRP aquifer at the INL (Robertson and others, 1974; Mann and Beasley, 1994; Cecil and others, 2000; Busenberg and others, 2001). These flow rates suggest travel times of 70–700 years for INL groundwater to travel to springs that discharge at the terminus of the ESRP aquifer near Twin Falls, Idaho (fig. 1). Localized tracer tests at the INL have shown vertical and horizontal transport rates as high as 60 and 150 ft/d, respectively (Nimmo and others, 2002; Duke and others, 2007).

# Drilling and Borehole Construction Methods

Core drilling and well construction for borehole USGS 142 started July 8, 2014; final construction was completed August 11, 2016. Drilling equipment, drilled depths, and a brief summary of daily activity during the 2-year period are provided in appendix A. Drilling activities were conducted by the USGS INL Project Office and the USGS Western Region Drilling Team (WRDT). The USGS INL Project Office cored USGS 142 from land surface to 844 ft, the USGS WRDT cored from about 844 to 1,880 ft BLS. For the purpose of this report, core drilling and construction at borehole USGS 142 are outlined in four phases to communicate drilled depth in relation to the water level and temperature data observations reported in the sections that follow. Drilling and construction activities were conducted in accordance with the USGS INL Site Safety Plan and the INL Environmental Checklist requirements.

Borehole USGS 142 drilling phases 1, 2, and 4 were completed by the USGS INL Project Office; phase 3 core drilling was conducted by the USGS WRDT. During phase 1, core drilling was completed down to 677 ft BLS and halted after snow prohibited access to the drill site. It took approximately 45 days to complete core drilling and construction to this depth during phase 1 (July 8 to November 18, 2014); construction involved enlarging (reaming) the borehole and setting 6-in. casing to 506 ft BLS (fig. 3; appendix A). During phase 2, core drilling was completed to a depth of 844 ft BLS (appendix A). It took about 22 days to complete phase 2 core drilling to this depth (March 10 to May 5, 2015). During phase 3, core drilling was completed to a depth of 1,880 ft BLS (appendix A). It took about 13 days to complete phase 3 core drilling, operating 24-hour, 7-day per week drilling shifts to advance through difficult sediment sections (September 29 to October 13, 2015). Final construction of borehole USGS 142 was completed during phase 4 (June 6 to July 5, 2016). This involved setting a screened piezometer (screened from 810 to 840 ft BLS) and placing a cement seal to restrict annular flow between zones. Borehole USGS 142 measures the composite head pressure from approximately 790 to 1,164 ft BLS. The final construction diagram for borehole USGS 142 is in figure 3.

Drilling and well construction for borehole USGS 142A was completed by the USGS INL Project Office between July 27 and August 11, 2016. Drilling equipment, drilled depths, and a general summary of daily activity are provided in appendix B. The final construction diagram for borehole USGS 142A is shown in figure 4. Boreholes USGS 142 and USGS 142A are located approximately 30 ft apart and both are currently used to measure and report water level observations (table 1).

## Borehole USGS 142 Drilling and Construction Methods

Borehole USGS 142 was continuously core drilled from about 5 to 1,880 ft BLS during 2014 and 2015; however, final piezometer construction for borehole USGS 142 was completed in 2016. The USGS INL Project Office completed core drilling to a depth of 844 ft BLS, but unstable sediment prevented core drilling past 844 ft BLS (appendix A). At a depth of 844 ft BLS, the USGS INL Project Office made the decision to stop drilling because it became too difficult to keep enough drill fluid on site to operate efficiently.

The USGS WRDT completed the core drilling from 844 to 1,880 ft BLS (appendix A). To overcome layers of unstable sediment, the WRDT ran a continuous core drilling operation (24 hours per day) of two crews in 12-hour shifts, which allowed them to advance core drilling between 844 and 1,880 ft BLS. Drill water was continuously hauled using 3,000 gallon (gal) tanker trucks, to keep up with demand during core operation, and stored in a 21,000 gal holding tank. About 25,000–40,000 gal of drilling fluid were used daily during coring operation by the WRDT. Furthermore, almost no drill fluid returned to land surface (lost circulation) during core drilling operation, even after attempts to condition the hole with drilling mud. Core drilling difficulties at this location were the result of changes in basalt and sediment composition, ranging from vesicular to dense and from clay to gravel, respectively. Sediment layer thickness and occurrence increased between 739 and 1,396 ft BLS, resulting in increased formation pressure and less than ideal drilling conditions (appendix A). Near the basalt/rhyolite contact (about 1,396 ft BLS) core drilling conditions improved and borehole USGS 142 was quickly advanced to total depth of 1,880 ft BLS. After reaching total depth, select geophysical logs were collected prior to removing drill rod (table 2).

On October 18, 2015, a 2.7-in. drill rod was placed near 1,866 ft BLS to allow access for data collection following phase 3 drilling. Drill rod remained in borehole from October 18, 2015 to June 5, 2016, afterwards it was used as a tremie rod during final construction, starting June 6, 2016.

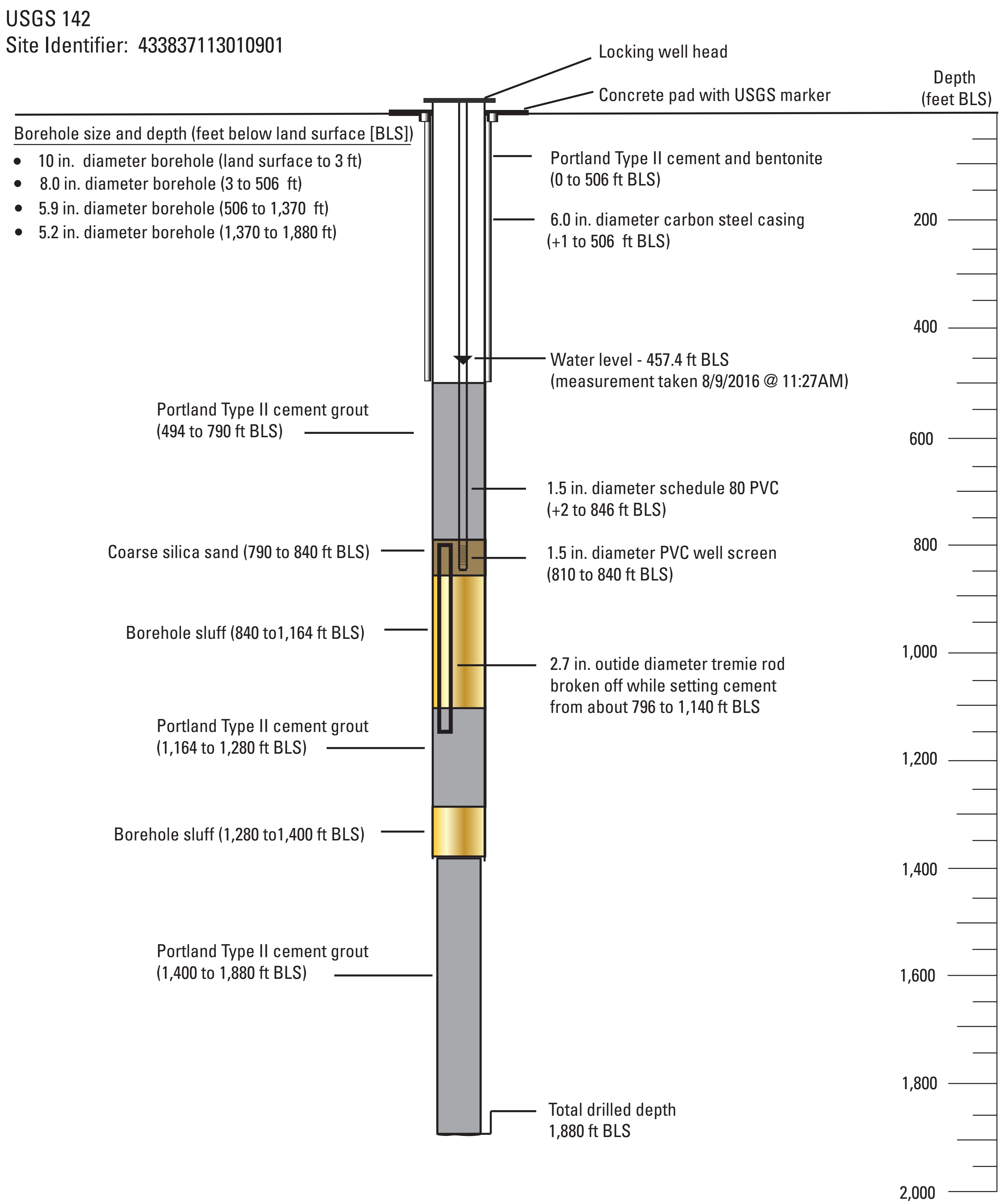


**Figure 3.** Final construction diagram for borehole USGS 142, Idaho National Laboratory, Idaho.

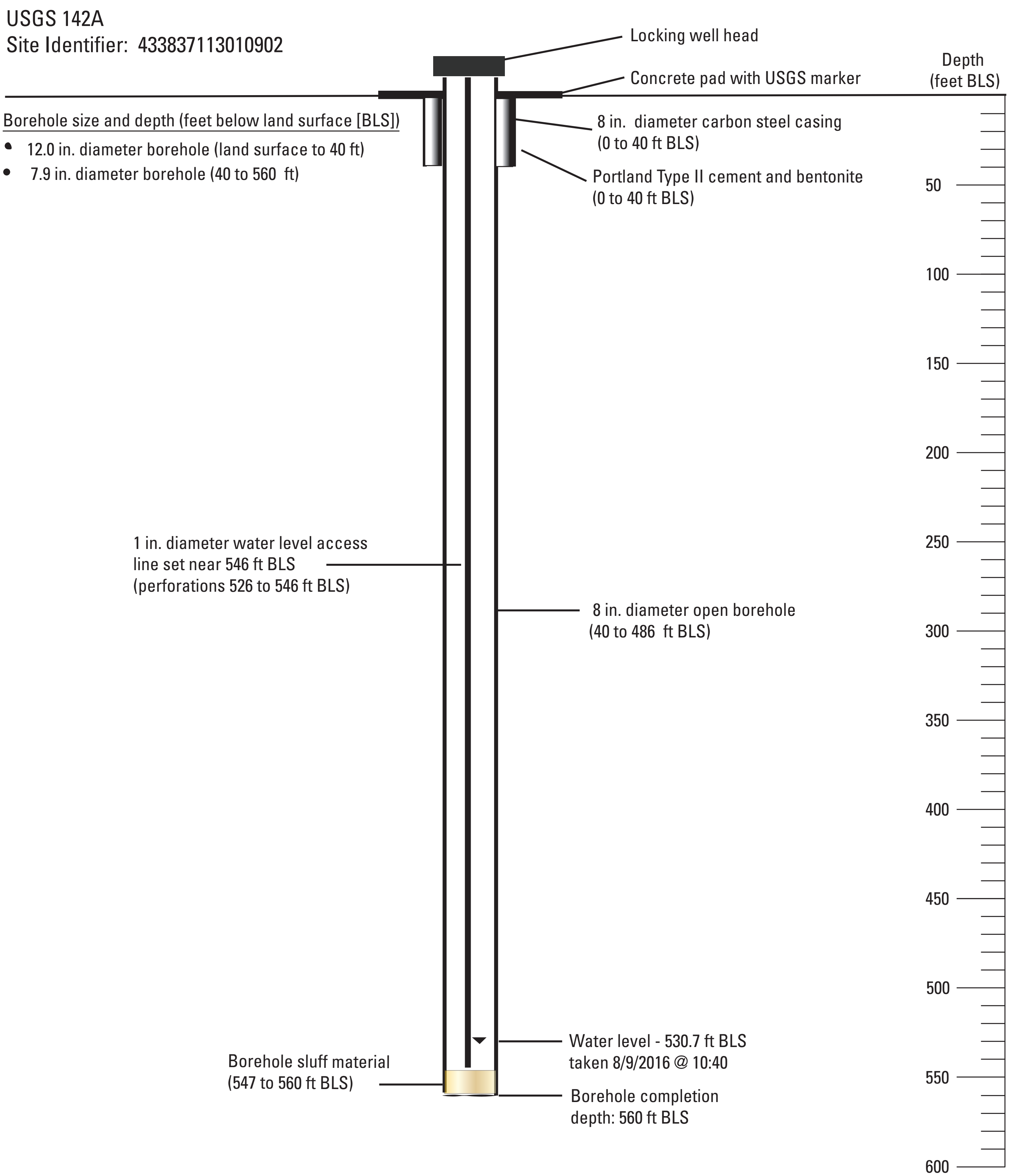


**Figure 4.** Final construction diagram for borehole USGS 142A, Idaho National Laboratory, Idaho.

**Table 1.** Location and completion information for boreholes USGS 142 and USGS 142A, Idaho National Laboratory, Idaho.

[**Borehole parameters:** Location of boreholes are shown in figure 1. Site identifier—Unique numerical identifier used to access well data (http://waterdata.usgs.gov/nwis). Longitude, Latitude, and Measurement point elevation—Survey taken at brass survey marker (brass cap) located adjacent to well head on cement pad. Aquifer thickness is the altitude of the base of the aquifer as interpreted from basalt/rhyolite contact at borehole USGS 142 (about 1,396 ft) subtracted from depth to regional aquifer (about 530 ft). Top and bottom of screened interval based on placement of well screen used to measure depth to water. **USGS 142** and **USGS 142A:** Local well identifiers used in this study. **Abbreviations:** NAD 27, North American Datum of 1927; NGVD 29, National Geodetic Vertical Datum of 1929; BLS, below land surface; ft, foot; in., inch]

| Borehole parameters | USGS 142 | USGS 142A |
|---|---|---|
| Site identifier | 433837113010901 | 433837113010902 |
| Longitude | 113°01′09.41″ (NAD 27) | 113°01′09.01″ (NAD 27) |
| Latitude | 43°38′37.32″ (NAD 27) | 43°38′37.53″ (NAD 27) |
| Measurement point elevation | 4,991.81 ft (NGVD 29) | 4,991.75 ft (NGVD 29) |
| Aquifer thickness | 866 ft | 866 ft (based on borehole USGS 142) |
| Completion depth | 840 ft BLS | 547 ft BLS |
| Drill depth | 1,880 ft BLS | 560 ft BLS |
| Top of screened interval | 810 ft BLS | 526 ft BLS |
| Bottom of screened interval | 840 ft BLS | 546 ft BLS |
| Depth to water | 457.4 ft BLS, measured August 9, 2016 at 11:27 a.m. | 530.7 ft BLS, measured August 9, 2016 at 10:34 a.m. |

The drill rod helped prevent formation collapse after drilling stopped; additionally, the drill rod was used to access the borehole for water level and temperature data referenced in the sections that follow.

Final construction of borehole USGS 142 started June 6, 2016. The original design for borehole USGS 142 was revised after the tremie rod (2.7-in. outside diameter) became stuck and twisted off in the borehole, leaving a section from about 796 to 1,140 ft BLS (fig. 3). The depth range for the cement mixture (grout) placed in borehole USGS 142 was estimated in the final construction diagram based on volumes pumped through the tremie rod (fig. 3). A high capacity grout pump and tremie rod were used to pump a mixture of Portland Type II cement with 3 percent bentonite (grout) to desired depths during construction of borehole USGS 142. The tremie rod was removed in stages, after grout was pumped; however, formation pressure could have shifted where the grout was placed, as described in driller notes (appendix A). After placing grout to seal off the bottom 480 ft of borehole USGS 142 (1,400–1,880 ft), the tremie rod became stuck but was recovered. After pulling and clearing the tremie rod, more grout was pumped to seal the borehole to just below where the lower screened piezometer was planned, near 1,200 ft BLS. On June 13, 2016, after pumping grout, the tremie rod would not move and eventually was twisted off in the borehole. The design for borehole USGS 142 was revised, and a new screened interval was placed from 810 to 840 ft BLS (fig. 3). Coarse sand was placed above and below the well screen and tagged after placement. Additional grout was pumped for 2 days to seal above the screened zone, starting June 28, 2016. On the second day, the grout bridged near 494 ft BLS. Attempts made to remove the grout were not successful and resulted in drilling a second borehole (USGS 142A) approximately 30 ft away. The replacement borehole (USGS 142A) was used to measure water-level data near the top of the aquifer.

## Borehole USGS 142A Drilling and Construction Methods

From July 27 to August 11, 2016, borehole USGS 142A was air-rotary drilled using a down-hole hammer (appendix B). Borehole USGS 142A was not cored, but geophysical data was collected on completion of the borehole. The drilled depth was about 560 ft BLS, but sluff material (red sand) filled in the bottom, and final completion depth settled near 547 ft BLS (fig. 4). After drilling, a 1-in. access line was placed down near 546 ft BLS, and perforated from 526 to 546 ft BLS to allow collection of water-level data.

**Table 2.** Summary of geophysical data collected from boreholes USGS 142 and USGS 142A, Idaho National Laboratory, Idaho.

[Geophysical data presented in this report were collected using one or more of the following logging tools listed below. **Log type:** Description of geophysical log trace presented. **Local name:** Local borehole identifier used in this study. Borehole locations are shown in figure 1. **Tool ID:** Century Geophysical Corporation ™ tool number as referenced at http://www.century-geo.com/. **Depth:** Refers to logging depth reported from land surface measurement point. **Date** and **Time:** Refer to time the log was time (local) stamped in calender month-day-year (mm-dd-yy) and hours:minutes (hh:mm). **Sensor uncertainty:** Uncertainty specified by tool manufacturer. **Comments:** Explanations where needed. **Abbreviations:** BLS, below land surface; in., inch; ft, foot; deg., degree, %, percent]

| U.S. Geological Survey geophysical logging files | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Log type | Local name | Tool ID | Depth (ft BLS) | | Date | Time | Sensor uncertainty | Comments |
| | | | Top | Base | (mm-dd-yy) | (hh:mm) | | |
| Natural gamma | USGS 142 | 9057A | 0 | 1,858 | 10-12-15 | 11:06 | ± 5% | 2.7-in. drill rod at 1,860 ft BLS |
| | USGS 142A | 9057A | 0 | 549 | 08-09-16 | 12:05 | ± 5% | Run through drill rod set near 560 ft BLS |
| Neutron | USGS 142 | 9057A | 0 | 1,858 | 10-12-15 | 11:06 | ± 5% | 2.7-in. drill rod at 1,860 ft BLS |
| | USGS 142A | 9057A | 0 | 549 | 08-09-16 | 12:05 | ± 5% | Run through drill rod set near 560 ft BLS |
| Gamma-gamma density | USGS 142 | 0024A | 0 | 1,857 | 10-12-15 | 12:37 | ± 5% | 2.7-in. drill rod at 1,860 ft BLS |
| | USGS 142A | 0024A | 0 | 549 | 08-09-16 | 11:41 | ± 5% | Run through drill rod set near 560 ft BLS |
| Temperature | USGS 142 | 9057 | 0 | 840 | 04-29-15 | 10:55 | ± 5% | 3.8-in. drill rod placed near 844 ft BLS |
| | | 9042A | 0 | 1,864 | 11-23-15 | 10:57 | ± 5% | 2.7-in. drill rod at 1,860 ft BLS |
| | | 9042A | 0 | 1,855 | 05-31-16 | 11:20 | ± 5% | 2.7-in. drill rod at 1,860 ft BLS |
| Gyroscopic deviation | USGS 142 | 9095 | 0 | 1,818 | 10-12-15 | 14:04 | ± 0.5 deg. | 2.7-in. drill rod at 1,860 ft BLS (Down Log) |
| | | 9095 | 0 | 1,818 | 10-12-15 | 14:44 | ± 0.5 deg. | 2.7-in. drill rod at 1,860 ft BLS (Up Log) |
| | USGS 142A | 9095 | 0 | 535 | 08-09-16 | 13:10 | ± 0.5 deg. | Run through drill rod set near 560 ft BLS (Down Log) |
| | | 9095 | 0 | 535 | 08-09-16 | 13:33 | ± 0.5 deg. | Run through drill rod set near 560 ft BLS (Up Log) |

# Geologic, Geophysical, and Hydrologic Data

Geologic and geophysical data were collected and analyzed from core material and (or) continuous geophysical logs to provide rock and sediment descriptions along with contacts for borehole USGS 142. Geophysical data were used to infer geologic contacts for borehole USGS 142A because core was not collected. Geophysical logs provide a complete and continuous representation of the physical properties of the formation adjacent to the well bore and may offer more consistency when selecting depths for geologic contacts, because core recovery is sometimes incomplete. Boreholes USGS 142 and USGS 142A show similar geologic features within the first 560 ft, as interpreted from geophysical logs. Core from borehole USGS 142 was photographed and labeled to provide detailed lithologic descriptions from 4.9 to 1,880 ft BLS. A core log including photographs, selected physical properties, and a lithologic log are shown in appendix C.

Wireline geophysical logs were collected on completion of drilling, by the USGS INL Project Office, to determine geologic and hydrologic characteristics. Geophysical log data presented for this report include natural gamma, neutron, gamma-gamma dual density, and temperature; logs were collected with drill rod and or temporary casing in place. Open-hole geophysical data were not collected because sections of the borehole were unstable. The geophysical log data are summarized in table 2 and are available upon request through the USGS INL Project Office (http://id.water.usgs.gov/INL/). Gyroscopic deviation surveys were collected to determine wellbore deviation after drilling following procedures outlined in Twining (2016).

## Geology

The land surface at boreholes USGS 142 and USGS 142A consists of sparsely vegetated loess, and depth to underlying basalt is relatively shallow, 4.9 ft for USGS 142 and about 5 ft for USGS 142A. Surface soil samples were not collected at either borehole location; however, unconsolidated sedimentary materials were described from drill cuttings when driving surface casing to the top of the uppermost basalt flow (figs. 5 and 6).

Examination of borehole USGS 142 core and geophysical data shows that the stratigraphic section consists of basalt and sediment from land surface to about 1,396 ft BLS. From 1,396 ft to total depth, the entire core is rhyolite tuff, mostly welded. Borehole USGS 142A was drilled to 560 ft BLS and terminates in sediment. Sixteen sediment layers were observed between the depths of 4.9 and 1,396 ft BLS in borehole USGS 142 (fig. 5); five sediment layers were observed in geophysical logs between 5 and 560 ft BLS in borehole USGS 142A (fig. 6). Including surficial sediment, sediment constitutes 36 percent by volume (0–1,396 ft BLS) of borehole USGS 142; sediment layers ranged from 4 to 146 ft in thickness. Grain size of sediment recovered in USGS 142 ranges from clay to cobbles (appendix C).

Based on inspection of recovered core and geophysical data from 4.9 to 1,396 ft BLS, about 45 basalt flows were observed in borehole USGS 142 (fig. 5 and appendix C). Basalt texture for borehole USGS 142 varied between aphanitic, phaneritic, diktytaxitic, and porphyritic; rhyolite textures include lithophysal, spherulitic, porphyritic, foliated, and eutaxitic. In general, the basalts vary from dark to light gray in color; welded rhyolite tuffs are light gray, pale red, pinkish gray and pale red purple. Basalt flows in borehole USGS 142 ranged in thickness from less than 2 ft to about 100 ft and varied from massive to fractured or massive to scoriaceous. Detailed core descriptions and photographs for borehole USGS 142 (4.9–1,880 ft BLS) are included in appendix C.

## Geophysical Logs

Geophysical data were collected using Century Geophysical Corporation™ logging equipment, and the resulting data files were processed using WellCAD™ analytical software. A summary of geophysical data collected is shown in table 2. The USGS calibrates geophysical logging equipment annually, or more frequently if required; logging equipment sensor uncertainty is specified in table 2.

### Natural Gamma Logs

Natural gamma logs record gamma radiation emitted by naturally occurring radioisotopes. The USGS uses these logs at the INL to identify sedimentary layering, rhyolite contacts, and basalt contacts because these geologic materials exhibit changes in background gamma through varying potassium-40 content. The natural gamma detector measures total gamma radiation without distinguishing between individual contributions of the various isotopes. Most wireline logging tools collect natural gamma; therefore, natural gamma can be used to make depth adjustments, if needed.

Natural gamma logs were collected through a drill rod on completion of core drilling in borehole USGS 142 and after drilling in borehole USGS 142A. Natural gamma logs were used to (1) confirm contacts between basalt and sediment layers; (2) approximate sediment layer thickness for 16 sediment layers identified in borehole USGS 142 and five sediment layers in USGS 142A; (3) infer changes in sediment composition; and (4) identify contact between basalt and rhyolite (figs. 5 and 6).

Natural gamma logs examined for borehole USGS 142 indicate sediment layers below about 739 ft were generally thicker than those above this contact. The abundance of sediment layering below 739 ft BLS shows that an extensive period of sediment deposition occurred in this area.

### Neutron Logs

Neutron measurements are a general indicator of hydrogen content; when they are combined with natural gamma logs for sediment location, they can be used to identify perched groundwater zones in the unsaturated zone. 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 $10^5$ electron volts) from a sealed neutron source, which collide with surrounding atomic nuclei until they are captured (Keys, 1990, section 5, 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 that have energies less than 0.025 electron volts).

Neutron logs were collected on completion of drilling and through a drill rod placed near the bottom of the borehole. The neutron log trace represents reasonable agreement with drill core collected from borehole USGS 142 (fig. 5, appendix C), where areas of low hydrogen content correlate with areas of dense and massive basalt, and areas of high hydrogen content correlate with areas of fractured and vesicular basalt. On the basis of basalt-hydrogen correlations, neutron logs provide evidence for fractured and vesicular basalt, indicative of more productive water-producing zones and areas of dense basalt that are indicative of less productive water-producing zones. Based on typical basalt flow layering (fig. 2), neutron logs in conjunction with core collected indicate approximately 45 basalt flows within borehole USGS 142. The same analysis was not used to interpret USGS 142A; however, similar basalt and sediment contacts are expected within the upper 560 ft of both boreholes (figs. 5 and 6).

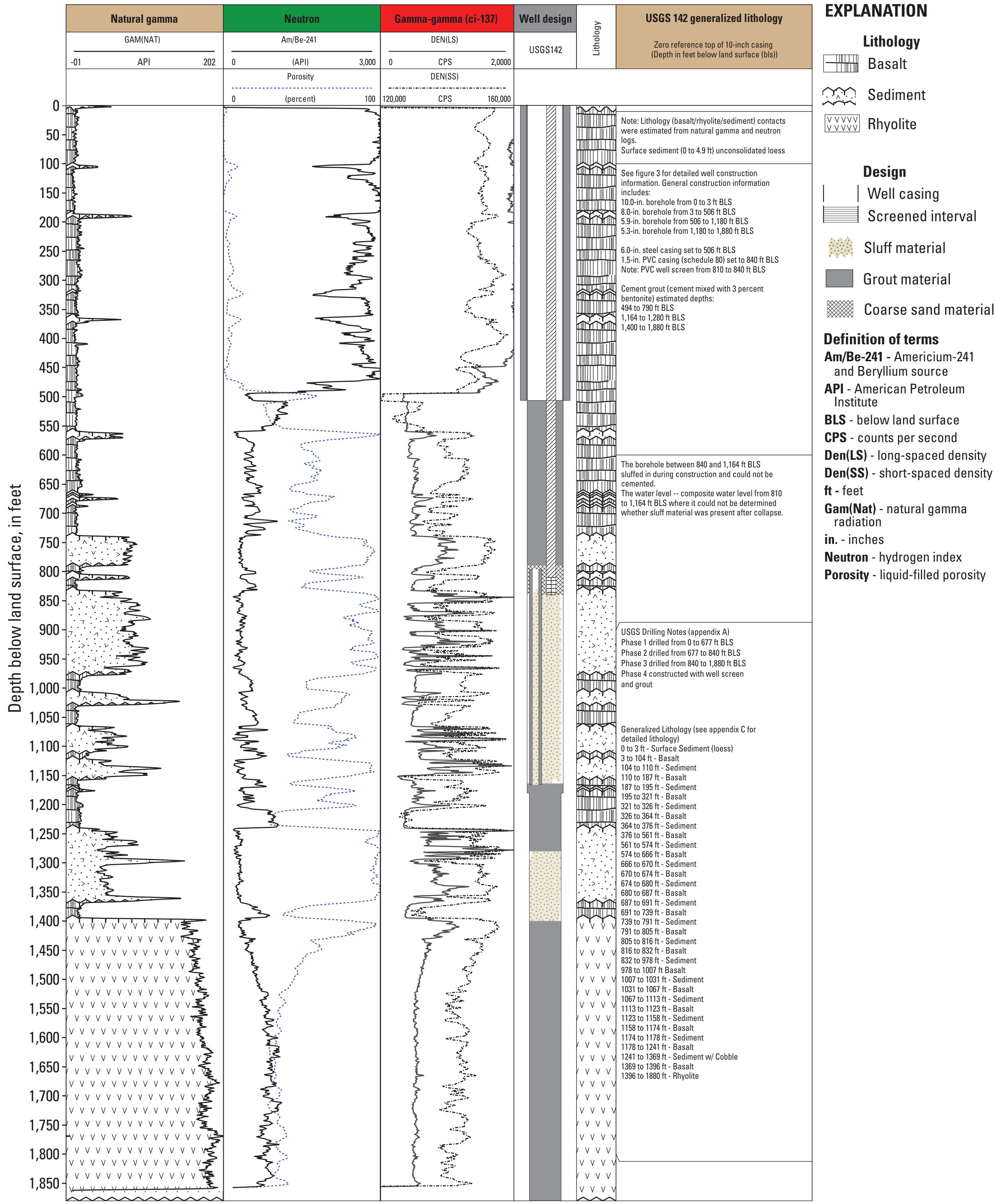


**Figure 5.** Geophysical and lithologic logs from total depth to land surface, with lithologic logs based on cores and geophysical logs, for borehole USGS 142, Idaho National Laboratory, Idaho.

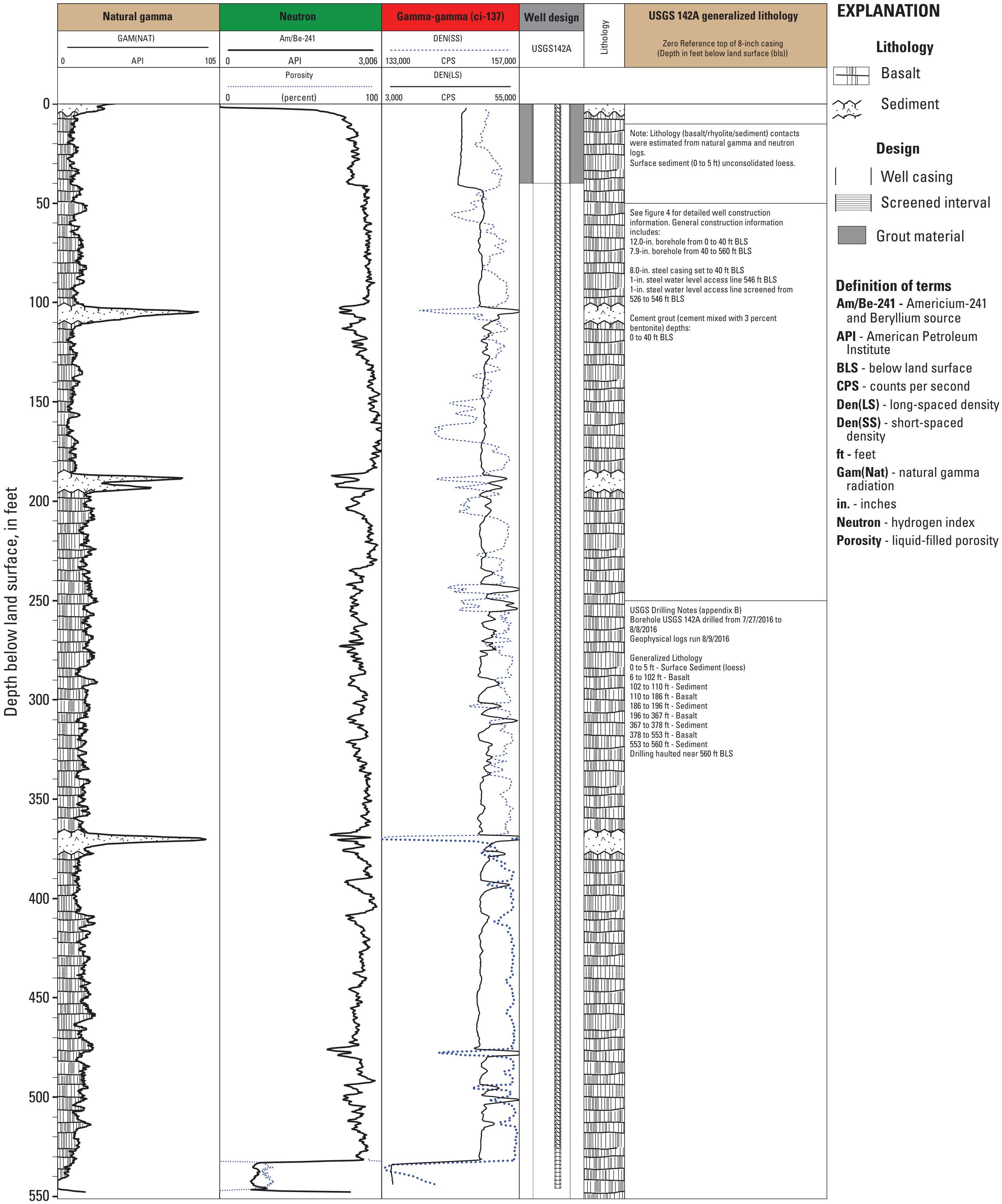


**Figure 6.** Geophysical and lithologic logs from total depth to land surface, with lithologic logs based on cores and geophysical logs, for borehole USGS 142A, Idaho National Laboratory, Idaho.

## Gamma-Gamma Dual Density Logs

The principle behind density logging is the detection of Compton-scattered gamma rays that originate from a small radioactive source. The intensity of the gamma radiation reflected back to the probe is primarily a function of electron density of the media after it is backscattered or absorbed in a drill hole, borehole fluid, or surrounding media. The type of density probe used for this investigation is the omni-directional, dual detector sonde that responds to density variation in counts per second (CPS), registering higher CPS counts for lower density material.

Gamma-gamma dual density logs were collected in borehole USGS 142 and USGS 142A on completion of drilling (figs. 5 and 6). Density logs were used to identify areas of dense, as opposed to fractured, basalt. Synergistically, the location of fracture zones indicated by gamma-gamma logs are consistent with zones indicated by other geophysical methods.

## Temperature Logs

Fluid temperature measurements were collected three different times in borehole USGS 142 (fig. 7; table 2). The initial temperature measurement taken on April 29, 2015, was collected during phase 2, several days after drilling was completed to 844 ft; the temperature measurements taken on November 11, 2015, and May 31, 2016, were collected during phase 3, several weeks or more after drilling was completed down to 1,880 ft BLS, but before final construction of the borehole (table 2, appendix A). Fluid temperature measurements were not collected for borehole USGS 142A.

The two temperature measurements collected during phase 3 show similar profile shapes and a similar temperature range, with water temperatures ranging from about 59 to 88 °F (fig. 7). The temperature measurements collected during phase 2 show a slightly different profile shape than those collected during phase 3, with water temperature ranging from 63 to 68 °F (fig. 7). The temperature profile presented during phase 2 was collected a few days after drilling halted, but shows the general range in temperature prior to drilling to 1,880 ft BLS. Comparison between temperature data collected between phase 2 and phase 3 indicate a notable change in the temperature profile shape, where data collected during phase 3 display a temperature inflection starting near 600 ft BLS not present in phase 2 data (fig. 7). The temperature inflection, shown in phase 3 data, suggest warmer water at depth moving up the borehole annulus until mixing with colder groundwater from the active, shallower part of the aquifer. The phase 2 temperature data reflect the upper 300 ft of the ESRP aquifer, to about 840 ft BLS (fig. 7).

The temperature data collected during phase 3 suggest deep warmer water (about 88 °F) is flowing up the annular space between the drilled hole and 2.7-in. casing and moving out into fractured basalt between about 574 and 666 ft BLS (fig. 7). Within this 92 ft thick section of basalt (574–666 ft BLS) there is a 21 °F temperature change over a relatively short section of borehole (fig. 7). A uniform temperature profile, from about 700 to 1,880 ft BLS, suggest that groundwater is moving up the borehole annulus under pressure and not cooling. Above about 700 ft BLS, groundwater is flowing out horizontally into fractured basalt and dispersing the heat flux out away from the borehole, bringing groundwater temperature back near background conditions.

## Gyroscopic Deviation Survey

Borehole gyroscopic deviation surveys were run on completion of coring and drilling for boreholes USGS 142 and USGS 142A, respectively. The gyroscopic deviation survey procedure and equations used to compute calculated offset, northing, easting, distance, and azimuth are explained in Twining (2016). Gyroscopic deviation data are continuously collected at regular spaced intervals (0.20 ft) and post-processing software, proprietary to Century™, is used to compute the well bore path using reference angles SANG and SANGB, referred to as the slant angle (inclination) and slant angle bearing (azimuth), respectively.

Deviation survey data are shown in 100-ft increments from 0 to 1,800 ft BLS in borehole USGS 142 and from 0 to 500 ft BLS in borehole USGS 142A (table 3; fig. 8). The calculated offset for boreholes USGS 142 and USGS 142A account for horizontal and vertical displacements at various depths; however, at a survey depth near 500 ft, the calculated offset in both boreholes were less than 0.10 ft (table 3). The USGS uses a water-level correction when the gyroscopic deviation survey suggests the calculated offset exceeds 0.20 ft (Twining, 2016); therefore, no water-level corrections were necessary for boreholes USGS 142 and USGS 142A. The borehole-deviation survey results are summarized in table 3.

The well path presented for boreholes USGS 142 and USGS 142A show the final completion in three-dimensional format (fig. 8). Both USGS 142 and USGS 142A show similar calculated offset up to 500 ft BLS; however, borehole USGS 142 shows significant directional change that occurs near 1,200 ft BLS (fig. 8; table 3). This directional change was likely the result of changes to well diameter and material density differences, changing from soft sediment to hard rock. Review of well drilling notes show that borehole USGS 142 was reamed from 5.3 to 5.9-in. to a depth of about 1,180 ft BLS because of continued problems with sediment layers above this section (appendix A).

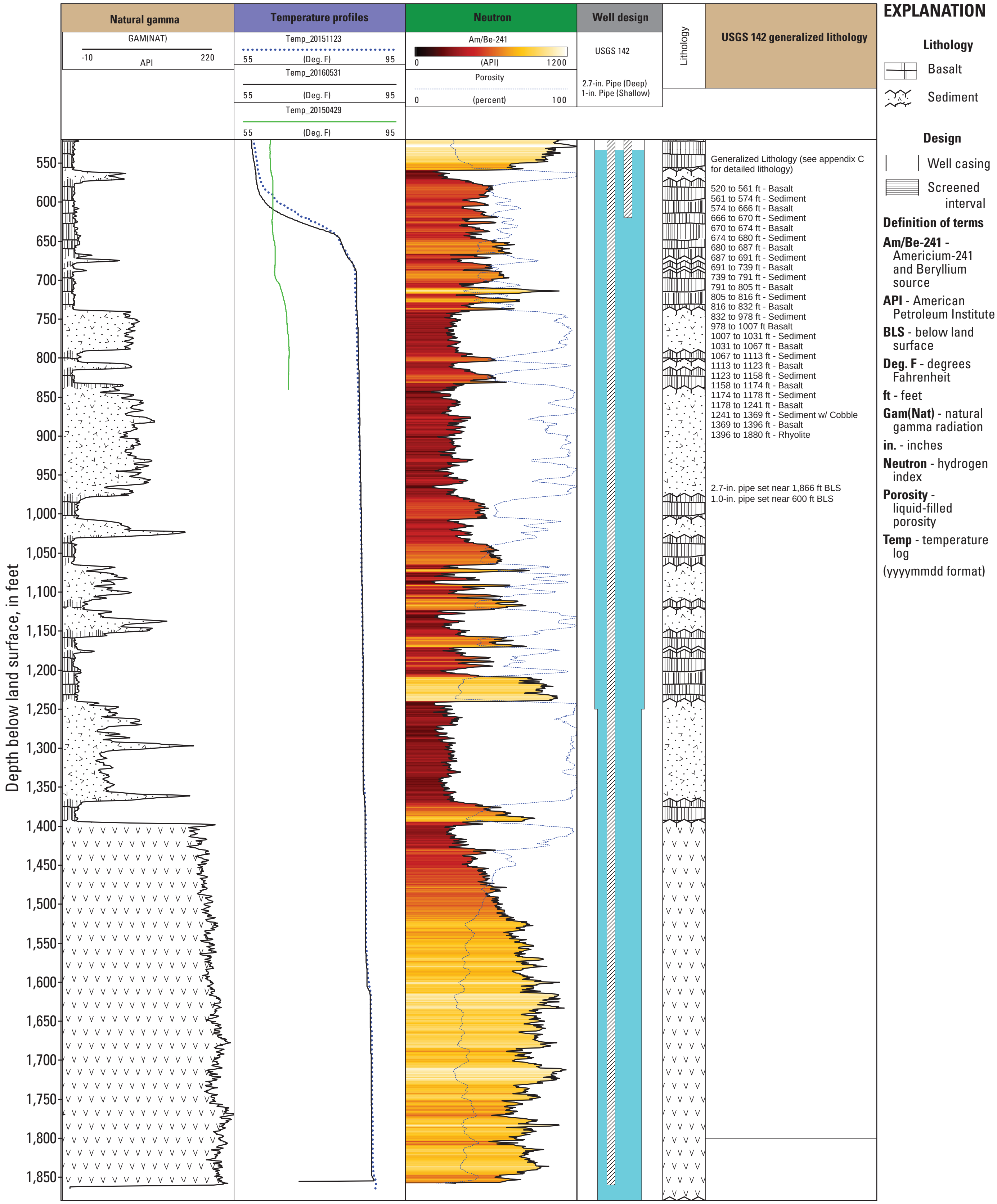


**Figure 7.** Geophysical and lithologic logs run from total depth to 530 ft BLS for borehole USGS 142, Idaho National Laboratory, Idaho.

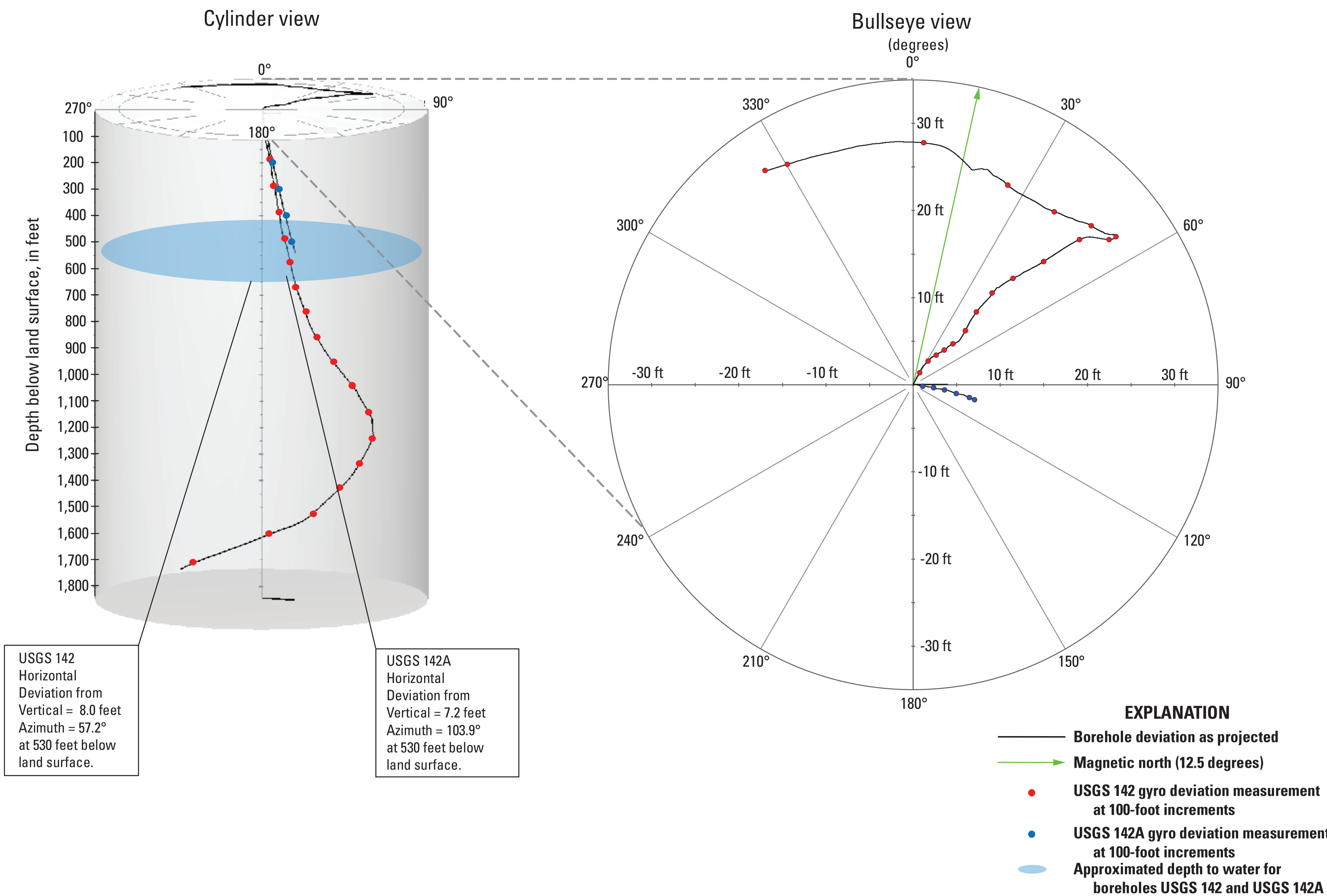


**Figure 8.** Gyroscopic deviation data collected for boreholes USGS 142 and USGS 142A, Idaho National Laboratory, Idaho.

**Table 3.** Gyroscopic deviation data from processed survey for boreholes USGS 142 and USGS 142A, Idaho National Laboratory, Idaho.

[Borehole deviation profile shown in figure 8, measurements are shown at 100 ft increments. Survey performed using a Century Geophysical Corporation™ 9095 logging tool with magnetic declination was set at constant 12.5 degrees. **Local name** is the local well identifier used in this study. **CD** (cable depth) is reported from wireline depth. **TVD** (true vertical depth) is computed depth using average angles equation (Twining, 2016). **CO** (calculated offset) is computed (CD - TVD). **Northing**, **Easting**, **Distance**, and **Azimuth** are computed from the well path survey using SANG and SANGB data. **SANG** refers to inclination or slant angle. **SANGB** refers to azimuth or slant angle bearing from well survey **Abbreviations:** BLS, below land surface; ft, foot; deg., degree]

| Local name | CD (ft BLS) | TVD (ft BLS) | CO (CD-TVD) (ft) | Northing (ft) | Easting (ft) | Distance (ft) | Azimuth (deg.) | SANG (deg.) | SANGB (deg.) |
|---|---|---|---|---|---|---|---|---|---|
| USGS 142 | 100 | 99.99 | 0.01 | 1.4 | 0.7 | 1.6 | 28.2 | 0.6 | 20.2 |
| | 200 | 199.97 | 0.03 | 2.7 | 1.7 | 3.2 | 32.3 | 0.7 | 16.8 |
| | 300 | 299.96 | 0.04 | 3.4 | 2.6 | 4.3 | 37.6 | 0.8 | 78.9 |
| | 400 | 399.95 | 0.05 | 4.0 | 3.6 | 5.4 | 41.8 | 0.8 | 49.4 |
| | 500 | 499.94 | 0.06 | 4.7 | 4.6 | 6.6 | 44.4 | 1.2 | 58.6 |
| | 600 | 599.91 | 0.09 | 6.2 | 6.0 | 8.6 | 43.9 | 1.3 | 28.7 |
| | 700 | 699.88 | 0.12 | 8.4 | 7.3 | 11.1 | 41.0 | 1.4 | 39.2 |
| | 800 | 799.84 | 0.16 | 10.5 | 9.1 | 13.9 | 40.8 | 1.9 | 37.2 |
| | 900 | 899.79 | 0.21 | 12.2 | 11.5 | 16.7 | 43.2 | 2.1 | 62.0 |
| | 1,000 | 999.71 | 0.29 | 14.1 | 15.0 | 20.6 | 46.6 | 2.7 | 57.9 |
| | 1,100 | 1,099.59 | 0.41 | 16.7 | 19.1 | 25.3 | 48.9 | 2.6 | 66.7 |
| | 1,200 | 1,199.53 | 0.47 | 16.7 | 22.5 | 28.0 | 53.4 | 1.9 | 95.7 |
| | 1,300 | 1,299.52 | 0.48 | 17.2 | 23.2 | 28.9 | 53.4 | 1.1 | 267.0 |
| | 1,400 | 1,399.47 | 0.53 | 18.3 | 20.4 | 27.4 | 48.2 | 1.8 | 276.3 |
| | 1,500 | 1,499.36 | 0.64 | 19.9 | 16.2 | 25.6 | 39.2 | 3.5 | 285.2 |
| | 1,600 | 1,599.16 | 0.84 | 22.9 | 10.9 | 25.4 | 25.4 | 3.9 | 314.5 |
| | 1,700 | 1,698.48 | 1.52 | 27.8 | 1.2 | 27.8 | 2.5 | 7.7 | 276.8 |
| | 1,800 | 1,797.19 | 2.81 | 25.3 | 14.4 | 29.1 | 330.3 | 8.9 | 252.1 |
| USGS 142A | 100 | 99.99 | 0.01 | -0.2 | 1.1 | 1.1 | 99.5 | 0.9 | 85.6 |
| | 200 | 199.98 | 0.02 | -0.3 | 2.4 | 2.4 | 98.1 | 0.6 | 116.5 |
| | 300 | 299.98 | 0.02 | -0.6 | 3.6 | 3.7 | 99.4 | 0.7 | 93.8 |
| | 400 | 399.97 | 0.03 | -1.0 | 5.0 | 5.1 | 101.5 | 0.9 | 110.9 |
| | 500 | 499.95 | 0.05 | -1.5 | 6.5 | 6.6 | 103.0 | 0.9 | 110.8 |

Review of the gyroscopic deviation data and driller notes both indicate the direction change resulted when core drilling continued after reaming. The drill bit may have deflected to one side of the borehole and continued a northwestern trajectory when core drilling restarted after about 1,180 ft BLS (fig. 8; table 3). Near the bottom of borehole USGS 142, between 1,400 and 1,800 ft BLS, slant angle data (SANG) show a sharp increase from 1.8 to 8.9 degrees over 400 ft (table 3). The increased slant angle suggests a change in material density or increased down pressure on the core drilling system (fig. 8).

# Hydrologic Data

Water level measurements were made at different times and locations within borehole USGS 142 to provide evidence of temporal variability in vertical hydraulic gradients. Measurements taken for phase 1, 2, 3, and 4 during 2015 and 2016 were shown to the nearest foot because those measurements were taken after drilling halted and there was uncertainty with regard to changes in the land surface datum (table 4).

During phase 1 and phase 2, the depth to water measured in borehole USGS 142 was 530 and 531 ft BLS, respectively (table 4), suggesting minimal pressure change in the first 300 ft of the aquifer. After deepening borehole USGS 142 to 1,880 ft (phase 3), and prior to final construction of the borehole, water levels were substantially higher and measured through shallow (1.0-in.) and deep (2.7-in.) pipes (piezometers) set near 600 and 1,866 ft BLS, respectively (fig. 7; table 4). Water levels measured in the shallow piezometer pipe show that the water level rose approximately 30 ft (to 496–504 ft BLS); however, water levels measured during that same time period in the deep piezometer pipe show that the water level rose approximately 80 ft (to 447–449 ft BLS) (table 4). The difference in hydraulic head pressure between piezometers is approximately 50 ft (22 psi) and suggest that the annulus at some depth is filled with material of sufficiently low permeability to limit flow that would otherwise equilibrate the hydraulic potential between the deep and shallow piezometers.

**Table 4.** Water level measurements taken for boreholes USGS 142 and USGS 142A during each drilling phase, Idaho National Laboratory, Idaho.

[Well locations are shown in figure 1. **Local name** is the local well identifier used in this study. **Site identifier** is the unique numerical identifier used to access well data from the USGS National Water Information System (http://waterdata.usgs.gov/nwis). **Depth drilled** refers to depth of hole during construction during phase 1, 2, 3, and 4. **Pipe set** is the depth of the measurement line and (or) open hole. **Date** and **Time** refers to the date and time (local) of the water level measurement. mm-dd-yy, calender month-day-year; hh:mm, hours and minutes. **Water level** refers to the tape down measurement. **Notes:** Comments related to measurement line where water level was measured. See figure 7 for more details on phase 3 water level measurements. **Abbreviations:** BLS, below land surface; S, shallow set 1-in. pipe; D, deep set 2.7-in. pipe; in., inch; ft, foot]

| Local name | Site identifier | Depth drilled (ft BLS) | Pipe set (ft BLS) | Date (mm/dd/yy) | Time (hh:mm) | Water level (ft BLS) | Notes |
|---|---|---|---|---|---|---|---|
| Phase 1 water levels (11-18-14 to 03-10-15) | | | | | | | |
| USGS 142 | 433837113010901 | 677 | 600 | 11-18-14 | 14:45 | 530 | 1-in. pipe set to 600 ft BLS |
| USGS 142 | 433837113010901 | 677 | 600 | 12-02-14 | 14:56 | 530 | 1-in. pipe set to 600 ft BLS |
| USGS 142 | 433837113010901 | 677 | 600 | 01-12-15 | 14:53 | 530 | 1-in. pipe set to 600 ft BLS |
| USGS 142 | 433837113010901 | 677 | 600 | 02-04-15 | 11:23 | 531 | 1-in. pipe set to 600 ft BLS |
| USGS 142 | 433837113010901 | 677 | 600 | 03-10-15 | 12:54 | 531 | 1-in. pipe set to 600 ft BLS |
| Phase 2 water levels (06-04-15 to 09-21-15) | | | | | | | |
| USGS 142 | 433837113010901 | 840 | 600 | 06-04-15 | 16:04 | 531 | 1-in. pipe set to 600 ft BLS |
| USGS 142 | 433837113010901 | 840 | 600 | 07-22-15 | 15:49 | 531 | 1-in. pipe set to 600 ft BLS |
| USGS 142 | 433837113010901 | 840 | 600 | 08-12-15 | 12:41 | 531 | 1-in. pipe set to 600 ft BLS |
| USGS 142 | 433837113010901 | 840 | 600 | 09-21-15 | 13:44 | 531 | 1-in. pipe set to 600 ft BLS |
| Phase 3 water levels (12-14-15 to 06-01-16) | | | | | | | |
| USGS 142 (S) | 433837113010901 | 1,880 | 600 | 12-14-15 | 16:18 | 496 | Measured through 1.0-in. pipe |
| USGS 142 (D) | 433837113010901 | 1,880 | 1,866 | 12-14-16 | 16:12 | 448 | Measured through the 2.7-in. pipe |
| USGS 142 (S) | 433837113010901 | 1,880 | 600 | 01-04-16 | 11:05 | 497 | Measured through 1.0-in. pipe |
| USGS 142 (D) | 433837113010901 | 1,880 | 1,866 | 01-04-16 | 11:08 | 449 | Measured through the 2.7-in. pipe |
| USGS 142 (S) | 433837113010901 | 1,880 | 600 | 02-09-16 | 12:03 | 497 | Measured through 1.0-in. pipe |
| USGS 142 (D) | 433837113010901 | 1,880 | 1,866 | 02-09-16 | 12:08 | 448 | Measured through the 2.7-in. pipe |
| USGS 142 (S) | 433837113010901 | 1,880 | 600 | 03-10-16 | 13:26 | 500 | Measured through 1.0-in. pipe |
| USGS 142 (D) | 433837113010901 | 1,880 | 1,866 | 03-10-16 | 13:32 | 447 | Measured through the 2.7-in. pipe |
| USGS 142 (S) | 433837113010901 | 1,880 | 600 | 04-05-16 | 09:10 | 503 | Measured through 1.0-in. pipe |
| USGS 142 (D) | 433837113010901 | 1,880 | 1,866 | 04-05-16 | 09:14 | 449 | Measured through the 2.7-in. pipe |
| USGS 142 (S) | 433837113010901 | 1,880 | 600 | 05-09-16 | 15:28 | 503 | Measured through 1.0-in. pipe |
| USGS 142 (D) | 433837113010901 | 1,880 | 1,866 | 05-09-16 | 15:33 | 447 | Measured through the 2.7-in. pipe |
| USGS 142 (S) | 433837113010901 | 1,880 | 600 | 06-01-16 | 15:29 | 504 | Measured through 1.0-in. pipe |
| USGS 142 (D) | 433837113010901 | 1,880 | 1,866 | 06-01-16 | 15:23 | 448 | Measured through the 2.7-in. pip |
| Phase 4 water levels (07-11-16 through 09-14-16) | | | | | | | |
| USGS 142 (Screen) | 433837113010901 | 1,880 | (810–840) | 08-09-16 | 11:27 | 457 | Final well completion (screen 810–840 ft) |
| | 433837113010901 | 1,880 | (810–840) | 09-14-16 | 14:31 | 455 | Final well completion (screen 810–840 ft) |
| Final borehole USGS 142A | | | | | | | |
| USGS 142A | 433837113010902 | 5,60 | (526–546) | 08-09-16 | 10:40 | 531 | 1-in. screened SS Line set to 546 ft BLS |
| | 433837113010902 | 5,60 | (526–546) | 09-14-16 | 14:37 | 532 | 1-in. screened SS Line set to 546 ft BLS |

Water levels collected during phase 4 were 457 and 455 ft BLS and were measured after final construction, which involved placing cement to prevent annular flow and screened piezometer line within borehole USGS 142 (figs. 3 and 5; table 4). Attempts were initially made to interrogate a discrete section of the borehole from about 800 to 850 ft BLS by placing cement in the borehole to seal off the annulus; however, persistent problems required a redesign of borehole USGS 142.

The zone from about 840 to 1,164 ft BLS sluffed in and could not be cemented after tremie pipe twisted off, leaving tremie pipe in borehole USGS 142 from about 796 to 1,140 ft BLS. The remnant tremie pipe prevented placement of additional cement seal; furthermore, after attempts to remove the tremie pipe failed, a decision was made to complete borehole USGS 142 near the top of the remnant tremie pipe. The final construction of borehole USGS 142 suggest the water level measurement(s) likely represent a composite level by interrogating several zones that exist between about 790 and 1,164 ft BLS (figs. 3 and 5). Several sediment layers and several basalt units, of varying thickness, exist between 790 and 1,164 ft BLS. It is not well understood which unit(s) within this interval creates the largest head response.

Based on the final construction of borehole USGS 142 and measured water level data, the screened piezometer represents a 75 ft (32 psi) change between phase 2 and phase 4 water level data (figs. 3 and 5; table 4). The ESRP aquifer geology (appendix C) suggest sediment layers range in composition and texture and likely restrict groundwater flow between basalt units, resulting in a stratified aquifer system at this location. The pressure response (about 32 psi) between phase 1 and 2 versus phase 3 and 4 all support upward hydraulic gradients, and also agrees with temperature profiles that suggest warmer water moving higher in the aquifer through the annulus (fig. 7).

Water level data collected for borehole USGS 142A agree with water levels collected during phase 1 and phase 2 in borehole USGS 142, where water levels were about 531 ft BLS. Water level data collected for the two boreholes (USGS 142 and USGS 142A) both support minimal pressure change occurs within the upper 300 ft of the ESRP aquifer (530–832 ft BLS); however, the deeper stratified system likely starts somewhere below the sediment layer starting near 832 ft LS (fig. 5; appendix C).

## Summary

From 2014 to 2016, the U.S. Geological Survey, in cooperation with the U.S. Department of Energy, drilled and constructed boreholes USGS 142 and USGS 142A for stratigraphic framework analyses and long-term groundwater monitoring of the eastern Snake River Plain aquifer at the Idaho National Laboratory. Borehole USGS 142 initially was cored to collect continuous geologic data and then re-drilled to complete construction as a monitoring well. Borehole USGS 142A was drilled and constructed as a monitoring well after efforts to interrogate the upper aquifer in borehole USGS 142 failed during construction. Boreholes USGS 142 and USGS 142A are separated by about 30 feet (ft) and have similar stratigraphic layers and hydrologic characteristics, as determined from geophysical data. Water-level access lines were placed in both borehole USGS 142 and USGS 142A after drilling to allow access for recurring water-level measurements.

Geophysical and borehole video logs were collected at various times during the drilling and construction process at boreholes USGS 142 and USGS 142A. Geophysical data were evaluated for the occurrence of fractured and (or) vesiculated basalt, dense basalt, sediment thickness and layering, and basalt/rhyolite contact. Natural gamma logs were used to confirm sediment layer thickness and suggest gradational changes (fine to coarse material). Neutron logs were used to confirm changes in basalt flow units and also to provide evidence for changes in porosity. Gamma-gamma logs were used to identify density changes in basalt and rhyolite. Temperature logs indicated that warm water at depth is moving up the annular space in borehole USGS 142; however, temperature logs were not collected for borehole USGS 142A. Gyroscopic deviation measurements were used to measure changes in slant angle and borehole azimuth and used to plot the down projection from land surface to total depth. Based on processed gyroscopic deviation data, and for a projected offset that was less than 0.20 ft, water level measurements do not require a measurement correction at USGS 142A or below about 900 ft BLS at USGS 142.

Water level measurements were taken during various phases of drilling. Measurements collected for the upper 300 ft of the aquifer suggest nominal change in hydraulic head pressure. Measurements collected during phase 3 and 4 suggest the aquifer below about 832 ft BLS is highly stratified and results in an upward hydraulic head potential. Water levels measured between phase 1 and phase 2 compared to water levels measured between phase 3 and phase 4 represent a head change of about 74 ft (32 psi). This data along with temperature data both suggest there is strong upward gradients at this location.

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# Appendixes

Appendixes A–C are PDF files available for download at https://doi.org/10.3133/ds1058.

## Appendix A. Driller Notes for Borehole USGS 142

## Appendix B. Driller Notes for Borehole USGS 142A

## Appendix C. Core Photographs and Descriptions for Borehole USGS 14

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