Doc No. RDS-ED-0005

Southern Nevada Water Authority

Geologic Data Analysis Report for Monitor Well 181M-1 in Dry Lake Valley

October 2007

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SOUTHERN NEVADA WATER AUTHORITY

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November 2007

SOUTHERN NEVADA WATER AUTHORITY
Groundwater Resources Department
Water Resources Division
snwa.com

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ACRONYMS

API GR	American Petroleum Institute gamma ray unit
BLM	Bureau of Land Management
RGU	regional geologic unit
SNWA	Southern Nevada Water Authority
TD	total depth
TDS	total dissolved solids
USGS	U.S. Geological Survey

ABBREVIATIONS

°C	degrees Celsius
amsl	above mean sea level
bgs	below ground surface (depth)
cps	counts per second
ft	foot
gpm	gallons per minute
gru	API gamma ray unit
I.D.	inside diameter (of casing)
in.	inch
lb	pound
m	meter
mi	mile
min	minute
µs	microsecond
mS	millisiemens
mV	millivolt
O.D.	outside diameter (of casing)
ppm	parts per million
psi	pounds per square inch
rpm	revolutions per minute

INTRODUCTION

In support of the Southern Nevada Water Authority's (SNWA) Clark, Lincoln, and White Pine Counties Groundwater Development Project, SNWA drilled 10 monitor wells in five hydrographic areas in Lincoln County, Nevada, between February and December 2005 (Figure 1).

Monitor Well 181M-1 is located in western Dry Lake Valley in Section 36, T1S, R63E, at an elevation of approximately 4,970 ft amsl (Figure 2). The site is approximately 22 mi west of Pioche, Nevada, and is accessed by multiple unpaved roads from U.S. Highway 93 and Nevada State Route 318. This site is just east of the North Pahroc Range and southwest of Bristol Wells, Nevada.

1.1 PURPOSE AND SCOPE

The purpose of this report is to describe the geologic, geophysical, and hydrologic data collected from Monitor Well 181M-1. The scope involves evaluation and comparison of borehole cuttings, drilling statistics, borehole geophysical logs, and hydraulic properties of the well. Geophysical data are compared to the borehole lithology to evaluate the geophysical response to geologic and hydrologic conditions, including the geologic units, geologic structures (fractures and faults), and hydrogeology. The drilling statistics are also correlated with the borehole lithology and geophysical logs. A discussion of hydrogeology is included to describe water levels, groundwater flow into the well, and geologic units and structure that provide this groundwater flow.

1.2 OBJECTIVES OF THE MONITOR WELL PROGRAM

The objectives for the 10 monitor wells are to:

- Further refine the distribution of regional aquifers and interbasin flow interpretations of those aquifers through the collection of additional hydrologic and geologic data, general groundwater chemistry and water-quality data, and water-level data.

- Provide long-term monitoring points for baseline depth-to-water levels, observe future pumping influences and climatic effects, and provide an accurate and timely assessment of groundwater conditions.

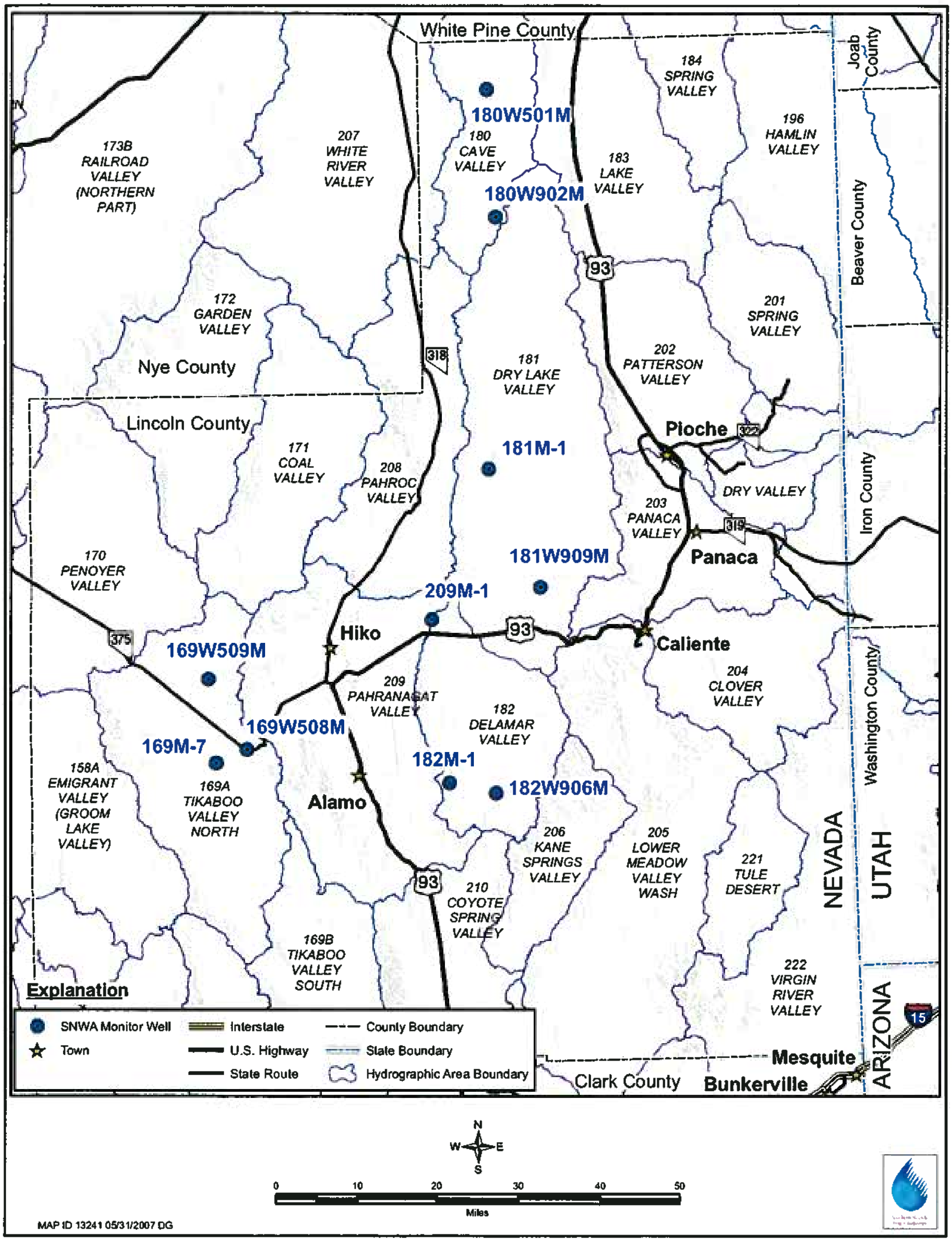
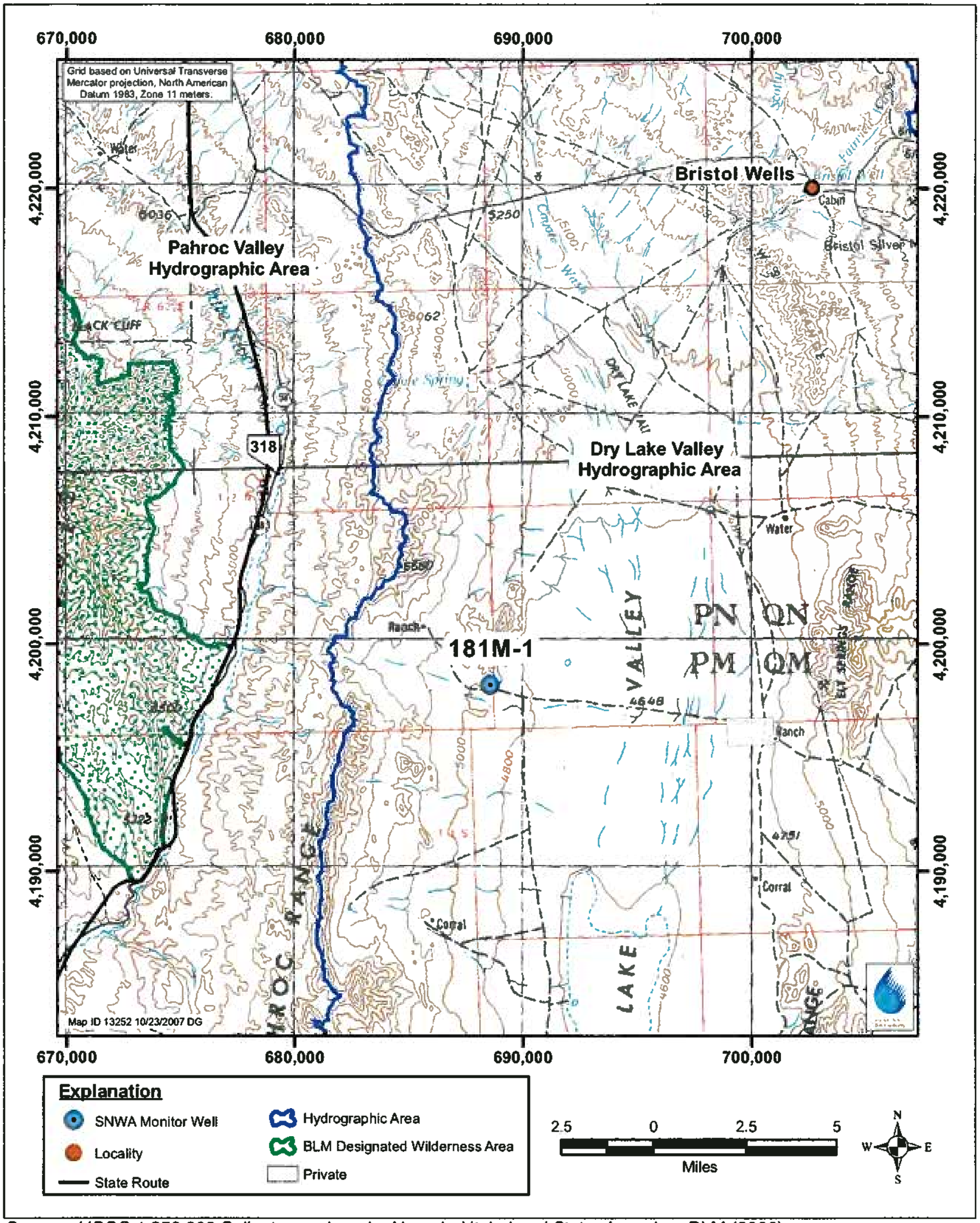


FIGURE 1
SNWA MONITOR WELL LOCATIONS, LINCOLN COUNTY, NEVADA



Source: USGS 1:250,000 Caliente quadrangle, Nevada-Utah; Land Status based on BLM (2006).

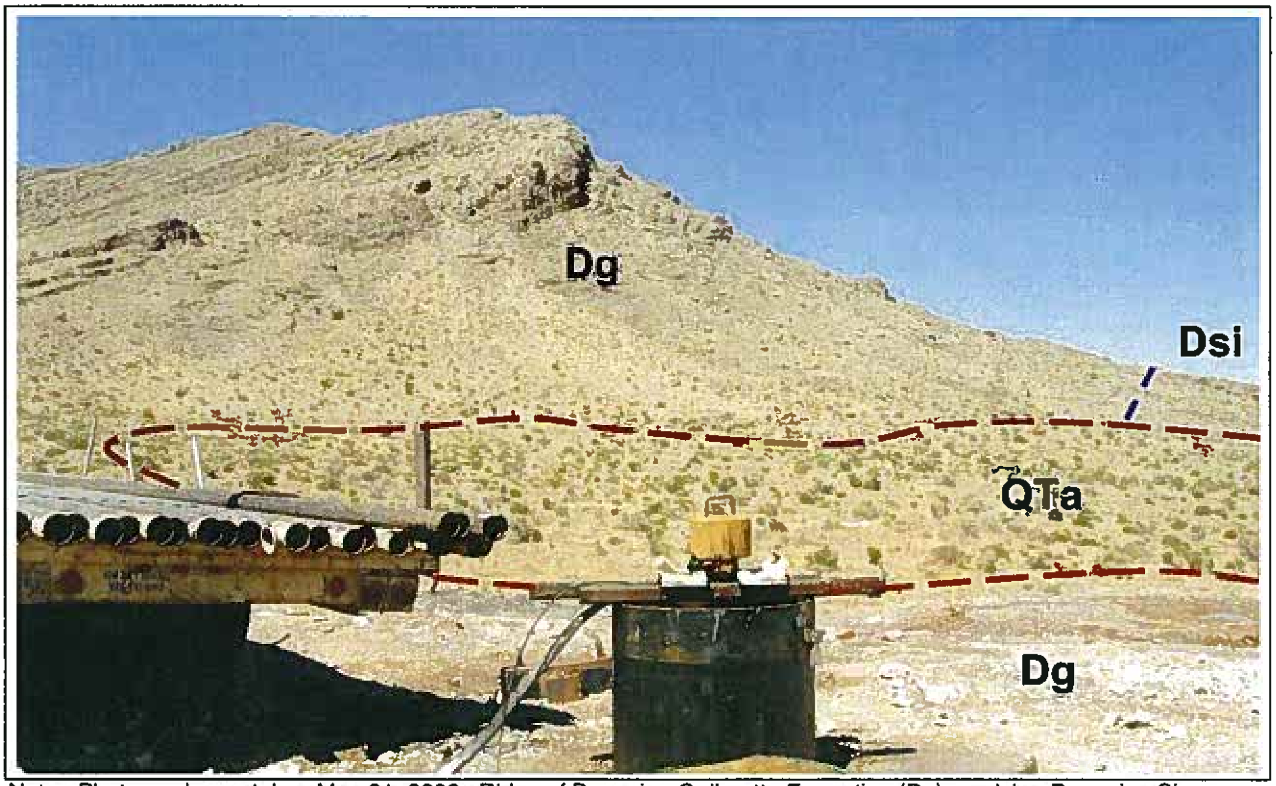
FIGURE 2
LOCATION OF MONITOR WELL 181M-1, LINCOLN COUNTY, NEVADA

1.3 SUMMARY OF MONITOR WELL CONSTRUCTION

Monitor Well 181M-1 was completed in two stages. Two initial (pilot) holes were drilled. The first initial hole was drilled to a depth of 620 ft bgs and later abandoned, and the second initial hole was completed to 1,430 ft bgs as a 5.625-in. borehole inside a temporary 9.625-in. O.D. surface casing on June 8, 2005, and this hole was abandoned at a later date. The monitor well was drilled and completed from August 12 to August 30, 2005, to a depth of 1,501 ft bgs. The well was completed with 14-in. O.D. conductor casing to 58 ft bgs and a 6.625-in. O.D. well casing from 2 ft above ground surface to 1,471 ft bgs with a slotted interval from 764.6 to 1,451.4 ft bgs.

The completion borehole was drilled using air-foam, conventional air, and flooded reverse circulation drilling techniques with a borehole diameter of 13.5 in. to a depth of 230 ft bgs and 12.25 in. from 230 ft bgs to the total depth.

Figure 3 is a photograph of the monitor well site. For additional information on the well construction, refer to Stoller (2006).



Note: Photograph was taken May 31, 2006. Ridge of Devonian Guilmette Formation (Dg) overlying Devonian Simonson Dolomite (Dsi) north of the monitor well. QTa = Quaternary alluvium. QTa and Dg are regional geologic units (RGUs), and Dsi is part of the Ds RGU (Dixon et al., 2007). Geology from Swadley et al. (1994).

FIGURE 3
VIEW OF MONITOR WELL 181M-1 DURING GEOCHEMICAL SAMPLING, LOOKING NORTH

DATA ANALYSIS

This section analyzes the lithology, geophysical logs, and drilling statistics to evaluate the geology encountered in Monitor Well 181M-1.

2.1 GEOLOGIC SETTING

Dry Lake Valley is a fault-block basin within the Great Basin subprovince (Fenneman, 1931) formed during the regional extension during the late Tertiary Period (Rowley and Dixon, 2001). The western margin of the valley is marked by a north-south trending Dry Lake Fault shown on the geologic map (Figure 4) that was formed by extension within the Great Basin region.

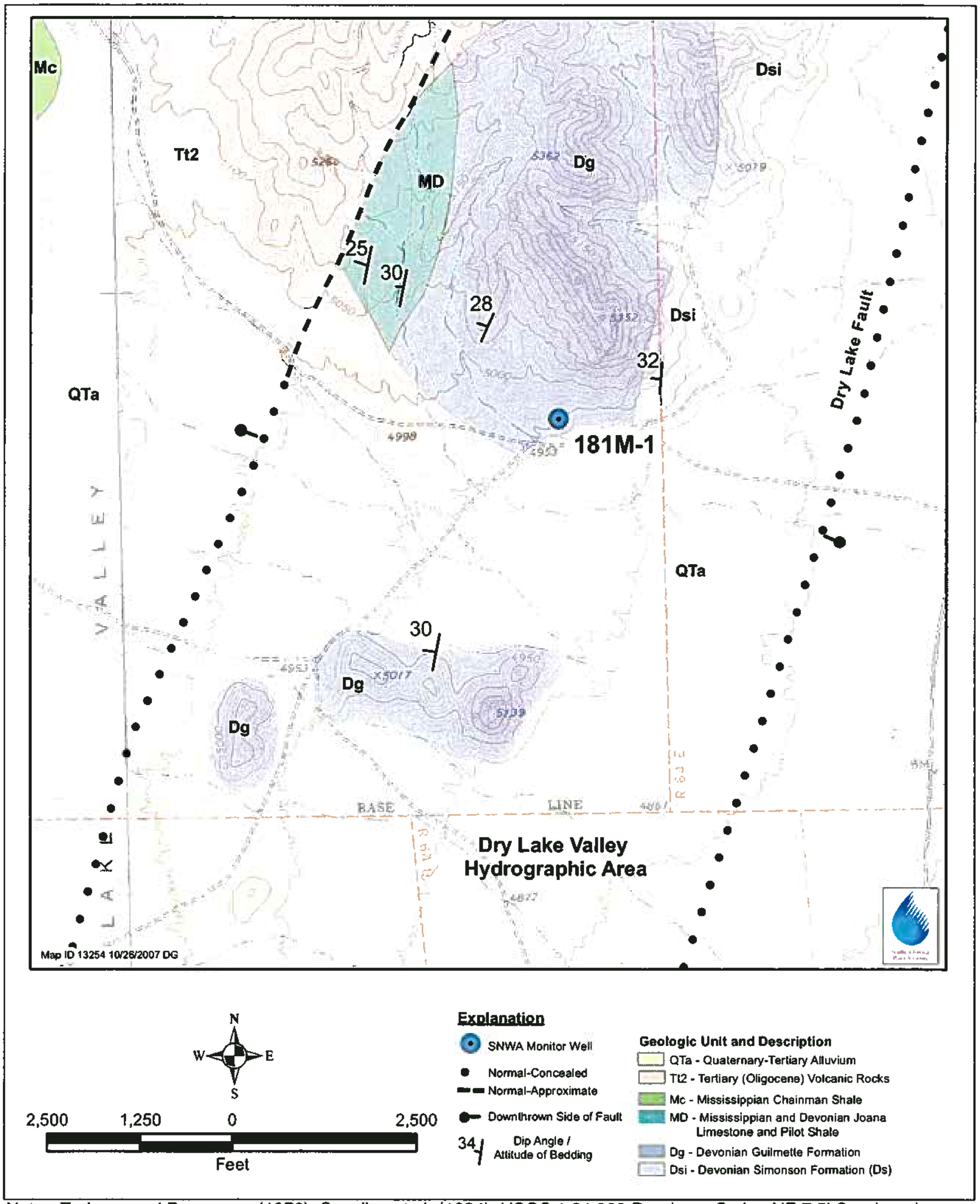
Monitor Well 181M-1 is situated on the western side of the Dry Lake Valley Hydrographic Area near the western margin of the alluvial basin (Figure 2). The surface geology at the monitor well site is of Devonian Guilmette Formation within a sequence of Paleozoic carbonate rocks including the Devonian Simonson Dolomite that crops out to the northeast of the site (Figure 3). A major, unnamed, north-south structure crosses through the area near the monitor well site. The surface geology is displayed on Figure 4.

2.1.1 GEOLOGIC UNITS ENCOUNTERED AT THE MONITOR WELL

The geologic units encountered during the drilling of Monitor Well 181M-1 consist of the Silverhorn Dolomite facies of the Devonian Guilmette Formation, in which the monitor well was collared, and the Simonson Dolomite (Figure 3). The Guilmette Formation is the Guilmette Formation (Dg) regional geologic unit (RGU), and the Simonson Dolomite is part of the Simonson Dolomite and Sevy Dolomite (Ds) RGU (Dixon et al., 2007). As depicted in Figure 3 and mapped in Figure 4, the dip of the beds is to the west at 25 to 32 degrees.

Tschanz and Pampeyan (1970) and Swadley et al. (1994) provided descriptions of the lithology and thicknesses of the units. The Devonian Guilmette varies from 1,400 to 3,500 ft thick (Tschanz and Pampeyan, 1970) and locally is approximately 2,000 ft thick (Swadley et al., 1994). At this location the Guilmette Formation is primarily a dolomite, and Tschanz and Pampeyan (1970, p. 37) state, "[t]hese dolomites are very difficult to distinguish from the Simonson Dolomite".

Swadley et al. (1994) described upper, middle, and lower parts of the Guilmette Formation near the monitor well site. The lower part of the Guilmette Formation is about 500 ft thick and consists of dark gray to medium gray dolomite and limestone (Figure 5). The lowermost 100 ft of the lower Guilmette Formation is medium gray dolomite and Tschanz and Pampeyan (1970, p. 36) further describe a basal unit of yellowish gray dolomite, "a thin-bedded, grayish to dusky yellow silty dolomite 50 to 70 ft thick". The middle part consists of 200 ft of medium dark gray to dark gray stromatoporoid biostromal dolomite (Swadley et al., 1994). The upper part is about 1,300 to 1,475 ft thick and is of dark gray dolomite with subordinate dark gray limestone beds and contains several light brownish gray to medium gray quartzite and sandstone beds from 3 to 70 ft thick (Swadley et al., 1994).



Note: Tschanz and Pampeyan (1970); Swadley et al. (1994); USGS 1:24,000 Deadman Spring NE 7.5' Quadrangle. Unit designations in parentheses are the RGUs defined in Dixon et al. (2007).

FIGURE 4
GEOLOGIC MAP AROUND MONITOR WELL 181M-1, WESTERN DRY LAKE VALLEY

Note: Northeast of monitor well, near base of formation. The Devonian Guilmette Formation is the Dg RGU (Dixon et al., 2007).

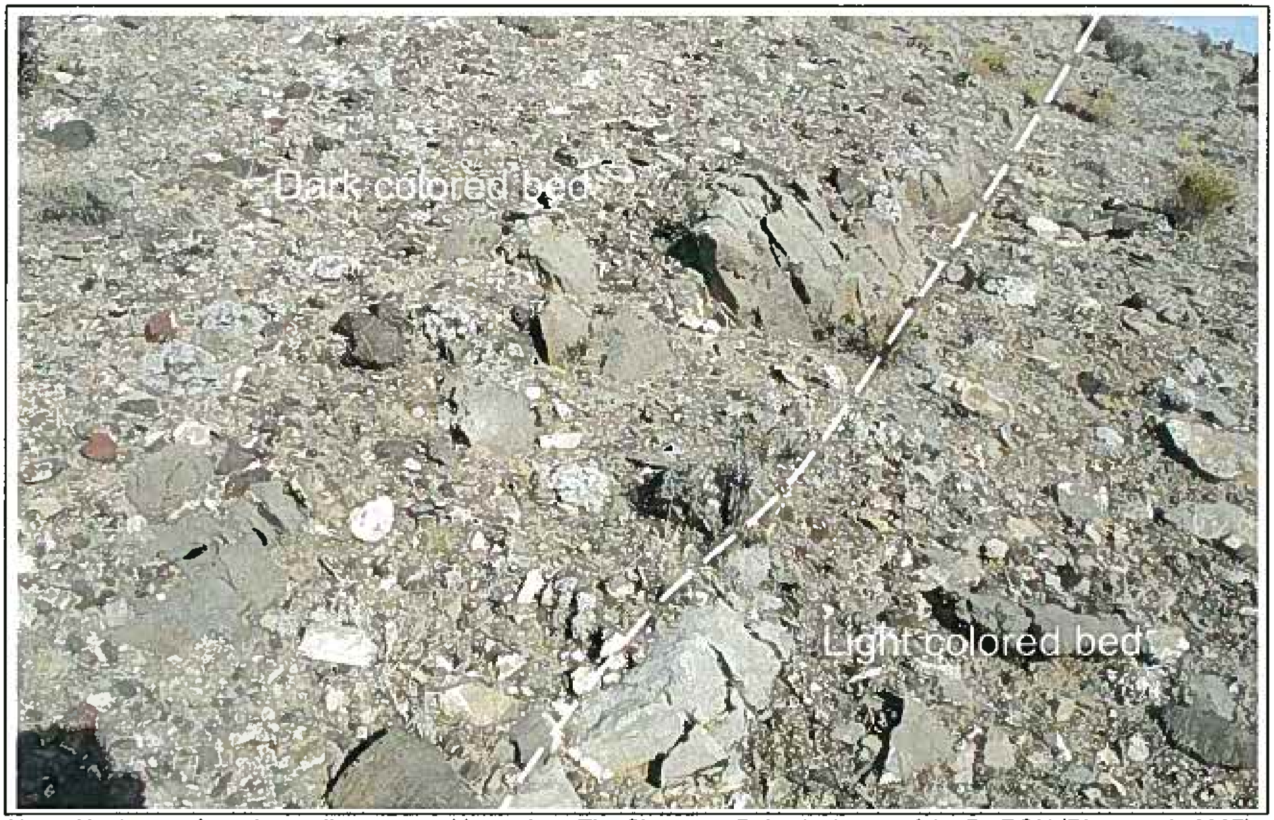
FIGURE 5
OUTCROP OF DOLOMITE OF THE DEVONIAN GUILMETTE FORMATION

Tschanz and Pampeyan (1970, p. 35) and Dixon et al. (2007) report the regional thickness of the Simonson Dolomite as between approximately 900 and 1,200 ft. The Simonson Dolomite consists of four alternating dark and light members. The lowest member is a "light tan coarsely crystalline ... dolomite 160 to 310 ft thick" (Tschanz and Pampeyan, 1970, p. 34). Above that is "the lower alternating member, an alternating sequence of whitish-gray aphanitic ... dolomite and predominantly brown, fine- to medium-grained dolomite." This member is 250 to 400 ft thick. The third member is a brown "massive and fetid...dolomite biostrome" that is 70 to 180 ft thick. The upper member is "the upper alternating member" and is similar to the lower alternating member but with thicker beds. This member is 200 to 460 ft thick (Tschanz and Pampeyan, 1970, p. 34).

In the drill cuttings the darker beds are more common. The presence of the light gray beds alternating with darker beds is a distinguishing characteristic of the Simonson Dolomite. Light and dark beds within the Simonson Dolomite are shown on Figure 6.

2.1.2 GEOLOGIC STRUCTURE AT THE MONITOR WELL SITE

The monitor well site is east of a down-to-the-east range-bounding fault identified in Dixon et al. (2007) that separates the Pahroc Range from Dry Lake Valley and west of at least one smaller fault of opposite movement (Figure 4). These structures form a horst tilted approximately 30 degrees westward that creates the landform of the hill in the background of Figure 3. The large range-bounding fault is covered by alluvium east of the monitor well site. The smaller fault west of the monitor well site cuts Tertiary volcanic rocks and places these volcanics against Paleozoic rocks



Note: Northeast of monitor well, near top of formation. The Simonson Dolomite is part of the Ds RGU (Dixon et al., 2007).

FIGURE 6
LIGHT AND DARK BEDS WITHIN THE UPPER MEMBER OF THE SIMONSON DOLOMITE

(Figure 4). Additional lesser-magnitude faults are shown in Swadley et al. (1994) and were observed north of the monitor well site. Fracturing evident in the monitor well is related to these structures.

2.2 MONITOR WELL 181M-1

Monitor Well 181M-1 was drilled in a single pass. Two initial boreholes were drilled near the completed monitor well and are considered in this report to provide additional details, but the primary focus of this section is on the completed well. For this report, the well cuttings were logged and the geology encountered is discussed.

2.2.1 LITHOLOGY

Lithologic cuttings were collected for Monitor Well 181M-1 at 10-ft intervals during the drilling process using SNWA internal procedures. These cuttings were described to identify the lithologic units encountered by drilling based on descriptions by Tschanz and Pampeyan (1970) and Swadley et al. (1994). A summary of the lithologic log is included in Table 1.

Drill cuttings were collected in the completed monitor well from 80 to 1,500 ft bgs, beginning below the conductor casing. Additional information was provided by drill cuttings from two initial boreholes drilled about 50 ft north of the completed well and to depths of 620 and 1,430 ft bgs,

Table 1
Lithology of Monitor Well 181M-1
(Page 1 of 2)

Interval Top to Base (ft bgs)	Geologic Unit	General Lithology	Description of Cuttings
0 to 80	Dg Guilmette Formation	Dolomite	No cuttings available from the monitor well. Cuttings from nearby initial boreholes are of dark to med olive-gray, microcrystalline to sucrosic dolomite.
80 to 90	Dg	Dolomite	Dark to med olive-gray, microcrystalline to sucrosic dolomite, dolomitic limestone, and limy dolomite.
90 to 100	Dg	Sandstone	Yellow to red, very fine-grained to silty sandstone.
100 to 170	Dg	Dolomite	Dark gray, microcrystalline dolomite. Approximately 5% of the frags are red, tan, and dark gray sandstone and quartzite. Most abundant, approximately 20%, between 110 and 120 ft bgs.
170 to 230	Dg	Dolomite	Med gray to lt tan, microcrystalline, limy dolomite to dolomitic limestone with calcite vlts on fractures, with minor red staining and vlts. Frags are coated with lt brown clay and are up to 3/4-in. between 200 and 230 ft bgs.
230 to 330	Dg	Dolomite	Med gray to lt tan, microcrystalline, limy dolomite and dolomitic limestone with calcite vlts on fractures. Clasts are larger, up to 1/2 in. and coated with lt brown clay between 250 and 300 ft bgs. About 30% of this interval is dolomitic limestone.
330 to 370	Dg	Limestone	Dark to med gray, microcrystalline, dolomitic limestone with irregular calcite grains that partly include unidentifiable fossil hash and minor calcite vlts. Lt brown clay coating is very calcareous.
370 to 540	Dg	Dolomite	Dark to med gray, med crystalline dolomite with calcite vlts. Fine, crystalline dolomite with med sized allochems. Clay is occ present on fractures, particularly from 490 to 500 ft bgs.
540 to 660	Dg	Dolomite	Med gray to olive drab, thinly laminated, fine and med crystalline dolomite with med sized allochems. Yellow clay and white calcite on fractures. Yellow clay is most abundant from 540 to 550 ft bgs and 630 to 640 ft bgs.
660 to 700	Dg	Dolomite	Dark gray to black, fine crystalline, limy dolomite with minor yellow and very minor red calcareous FeOx on fractures.
700 to 750	Dg	Dolomite	Dark gray to black, fine crystalline, limy dolomite with minor yellow and very minor red calcareous FeOx on fracture surfaces with slightly more lt brown clay.
750 to 800	Dg	Dolomite	Dark to med gray and olive and reddish gray, fine crystalline, limy dolomite with med to coarse sized allochems, fossil fragments, and abundant red hematitic clay.
800 to 820	Dg	Dolomite	Dark to med gray, fine crystalline dolomite with med to coarse sized allochems and fossil fragments, and minor lt brown calcareous clay.
820 to 850	Dg	Dolomite	Med to lt gray and reddish gray dolomite, fine cuttings, limy dolomite from 840 to 850 ft bgs. Red FeOx on fractures.
850 to 890	Dg	Dolomite	Med to lt gray, slightly olive, fine crystalline dolomite with minor red FeOx on fractures, calcite vlts slightly more abundant from 870 to 890 ft bgs.
890 to 920	Dg	Limestone	Med to lt gray and olive-gray, fine crystalline, dolomitic limestone with minor red FeOx on fractures and calcite vlts.
920 to 960	Dg	Dolomite	Dark to med gray, slightly reddish brown, fine crystalline dolomite with calcite vlts and minor red FeOx on fractures.
960 to 1,000	Dsi Simonson Dolomite (Ds)	Dolomite	Med to lt gray, med crystalline dolomite with moderate red FeOx and calcite vlts.

Table 1
Lithology of Monitor Well 181M-1
(Page 2 of 2)

Interval Top to Base (ft bgs)	Geologic Unit	General Lithology	Description of Cuttings
1,000 to 1,020	Dsi (Ds)	Dolomite	Med gray, micritic to sucrosic, mottled dolomite with minor red FeOx on fractures and with calcite vlts.
1,020 to 1,030	Dsi (Ds)	Dolomite and Limestone	Med gray, micritic to sucrosic, mottled dolomite and micritic limestone with minor red FeOx on fractures and with more abundant calcite vlts.
1,030 to 1,060	Dsi (Ds)	Dolomite	Med gray, med crystalline to mottled dolomite with minor red FeOx on fractures and with calcite vlts. Rare black stained calcite.
1,060 to 1,070	Dsi (Ds)	Dolomite	Dark to med gray, med to fine crystalline dolomite with red to black FeOx and MnOx on fractures. Calcite vlts are red to blk.
1,060 to 1,190	Dsi (Ds)	Dolomite	Med gray, fine to med crystalline dolomite with minor red FeOx on fractures and minor calcite and quartz vlts.
1,190 to 1,210	Dsi (Ds)	Dolomite	Dark gray, fine crystalline dolomite with very minor red FeOx on fractures and very minor calcite vlts.
1,210 to 1,230	Dsi (Ds)	Dolomite	Med gray, fine crystalline dolomite with red FeOx on fractures and very minor calcite vlts.
1,230 to 1,360	Dsi (Ds)	Dolomite	Med gray, fine crystalline dolomite with very minor red FeOx on fractures and minor calcite vlts.
1,360 to 1,380	Dsi (Ds)	Dolomite	Med gray, fine crystalline dolomite with red FeOx on fractures and minor calcite vlts.
1,380 to 1,500	Dsi (Ds)	Dolomite	Dark gray to black, fine crystalline dolomite with calcite vlts and very minor red FeOx on fractures. Frags have a conchoidal fracture.

Common abbreviations for the above table:
FeOx - iron oxides; red FeOx is generally hematite, and yellow or orange FeOx is generally limonite
frags - fragments
lt - light
med - medium
MnOx - manganese oxide(s)
occ - occasionally
vlts - veinlets

Dg - Devonian Guilmette Formation, the Silverhorn Dolomite facies.
Dsi - Devonian Simonson Dolomite.
Where the unit is a subunit of a RGU, the RGU designation is given in parentheses
The RGUs are defined in Dixon et al. (2007)

respectively. The cuttings from these initial boreholes had similar lithology as those of the completed well.

The first 330 ft of the monitor well was drilled in the upper part of the Devonian Guilmette Formation based on the occurrence of sandstone and quartzite units therein. The middle unit of the Guilmette Formation extends from 330 to 540 ft bgs in the borehole and is of dolomitic limestone and dolomite. The lower unit of the Guilmette Formation extends from 540 to 960 ft bgs in the borehole and is primarily of dolomite with occasional dolomitic limestone beds up to 30 ft thick. Abundant calcite veinlets and hematitic iron oxides between 750 and 800 ft bgs and 820 and 850 ft bgs indicate fracture zones at these depths.

The formation boundary between the Guilmette Formation and the underlying Simonson Dolomite was placed at 960 ft bgs based on a change from medium and dark gray dolomite to light gray dolomite. This contact between the two formations is also indicated by the initial borehole cuttings. The "laminated, dusky yellow" unit (Tschanz and Pampeyan, 1970) was not evident in the cuttings near the base of the Guilmette Formation, and the color of this unit at the surface may be due to surficial weathering, not the original color of the rock.

The Devonian Simonson Dolomite is present from 960 to the total depth of 1,500 ft bgs. The alternating upper member of the Simonson Dolomite (Tschanz and Pampeyan, 1970) is represented in the borehole cuttings as alternating light and medium gray dolomites to a depth of 1,380 ft bgs, with a particularly dark interval between 1,190 and 1,210 ft bgs. Abundant calcite veinlets with iron and manganese oxides indicate a fault zone between 1,060 and 1,070 ft bgs.

Between 1,380 and the total depth of 1,500 ft bgs, the Simonson Dolomite is represented by dark gray to black dolomite with occasional calcite veinlets and very occasional iron oxide coatings. This dark unit is the third (brown) member of Tschanz and Pampeyan (1970). Occasional zones of calcite veinlets were observed, though there was little indication of fracturing or of iron oxides in this unit.

In the borehole video and in surface exposures, the dip of bedding is about 30 degrees. Based on this dip, the actual thickness of Guilmette penetrated by the borehole is about 830 ft. Similarly, the actual thickness of the Simonson penetrated is about 460 ft. The thickness of the Guilmette Formation correlates well with the location of the monitor well site, which is near the middle of the Guilmette Formation as depicted on the geologic map of Figure 4.

The thicknesses of the middle and lower units of the Guilmette Formation in the borehole cuttings are 210 and 420 ft, respectively, or 180 and 360 ft perpendicular to bedding. These thicknesses are in approximate agreement with the thicknesses of those units reported in Swadley et al. (1994), 200 and 500 ft, respectively (Section 2.1.1). The smaller thickness of the lower Guilmette could be due to variations in the formation thickness and/or offsets along the fracture zones between 750 and 850 ft bgs.

The thicknesses of the upper alternating and third (brown) members of the Simonson Dolomite in the borehole cuttings are 420 and 120 ft, respectively, or 360 and 100 ft perpendicular to bedding, based on the 30-degree dip for the formation. The thickness of the upper unit is within the range of thicknesses reported in Tschanz and Pampeyan (1970), 200 to 460 ft, and the thickness of the third (brown) member of the Simonson Dolomite is within the range of thicknesses reported in Tschanz and Pampeyan (1970), 70 to 180 ft.

The well lithology is presented graphically on Figure 7.

2.2.2 BOREHOLE GEOPHYSICS

On June 8, 2005, geophysical logging was performed on the second initial borehole to its full depth of 1,430 ft bgs (Stoller, 2005). A borehole video was also taken on June 8, 2005, in which the water level was at 679.5 ft bgs. During geophysical logging the water level in the borehole was at about 673 ft bgs (Stoller, 2006). Due to the proximity of the boreholes and similarity of the geologic

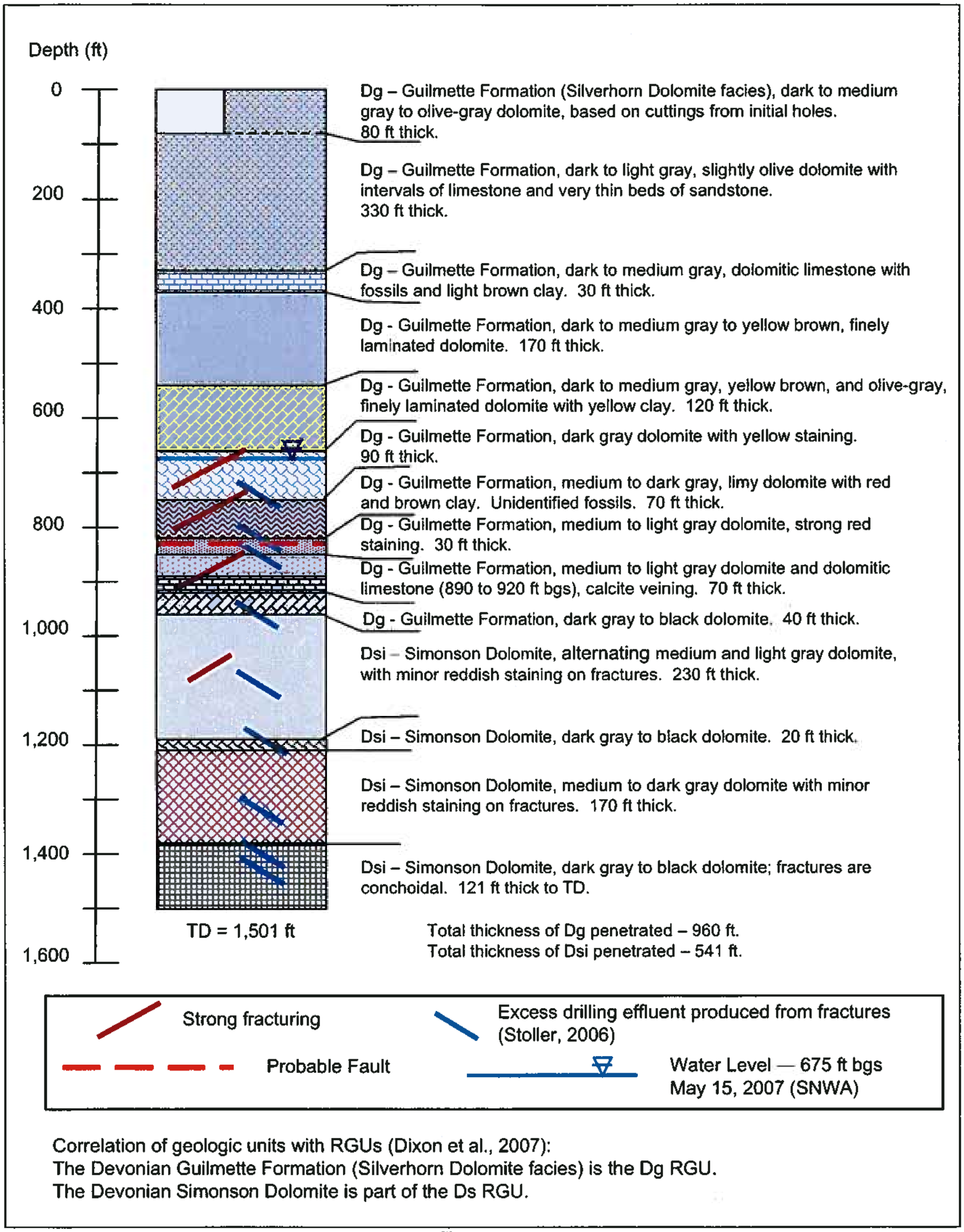


FIGURE 7
BOREHOLE STRATIGRAPHIC COLUMN OF MONITOR WELL 181M-1

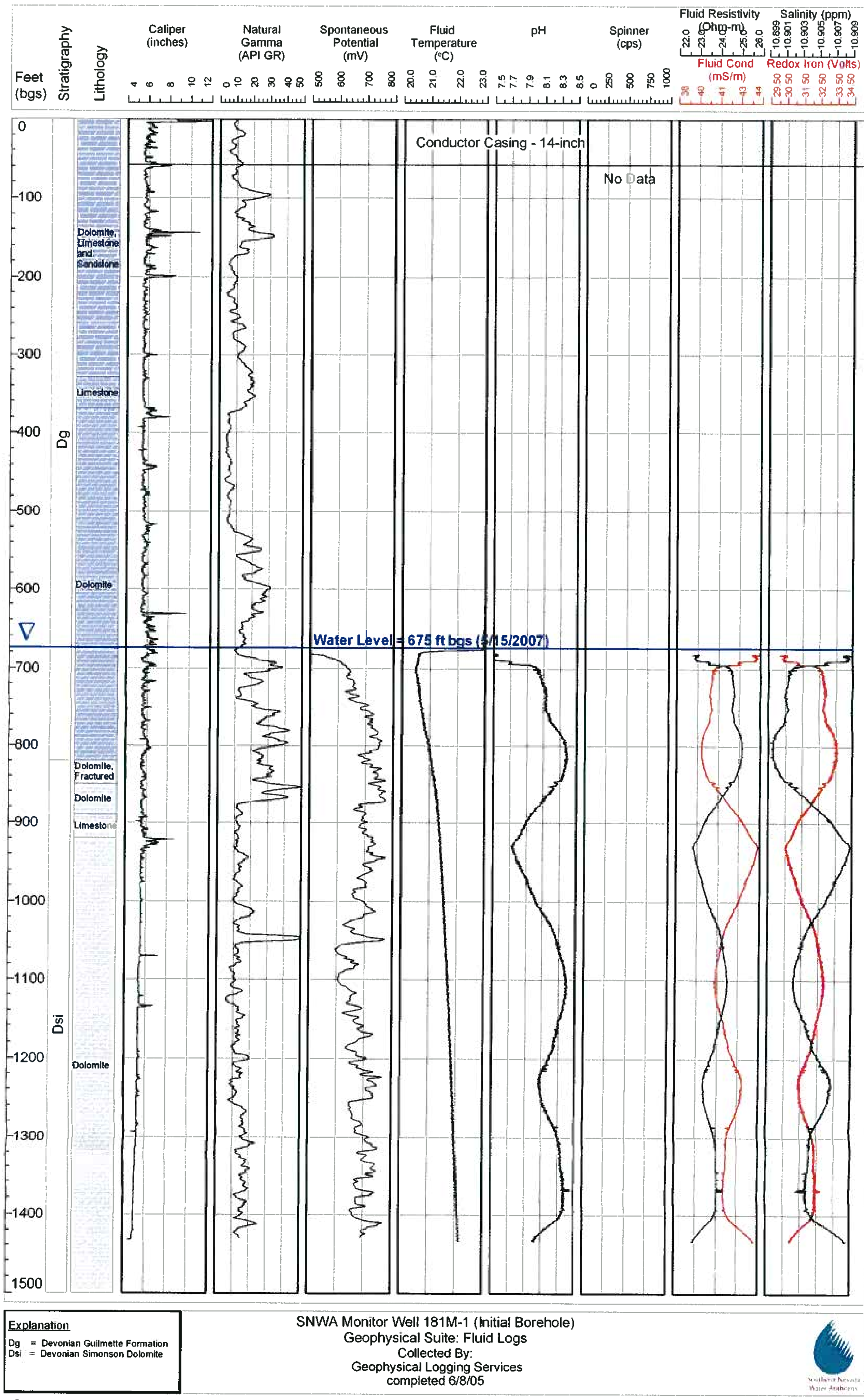
setting, geophysical logs were not performed in the completed monitor well (Stoller, 2006). On August 18, 2005, a partial borehole video was performed (0 to 205 ft bgs), and on October 4, 2005, a deviation survey was performed in the completed and cased monitor well. The following geophysical logs were performed:

- Natural Gamma Ray
- Deep Induction (Resistivity)
- Medium Induction (Resistivity)
- Short Guard
- Medium Guard
- Lateral Resistivity
- Spontaneous Potential
- Spectral Gamma – Potassium, Uranium, and Thorium (KUT)
- Total Spectral
- Neutron
- Density
- Sonic Delta T and Full Wave Sonic
- Fluid Temperature
- Differential Temperature
- Fluid Conductivity
- Fluid Resistivity
- Redox Iron Reduction Volts
- Salinity (NaCl)
- pH
- Spinner Log
- Caliper Log
- Deviation Log
- Pressure (psi).

These geophysical logs are presented on Figures 8 and 9.

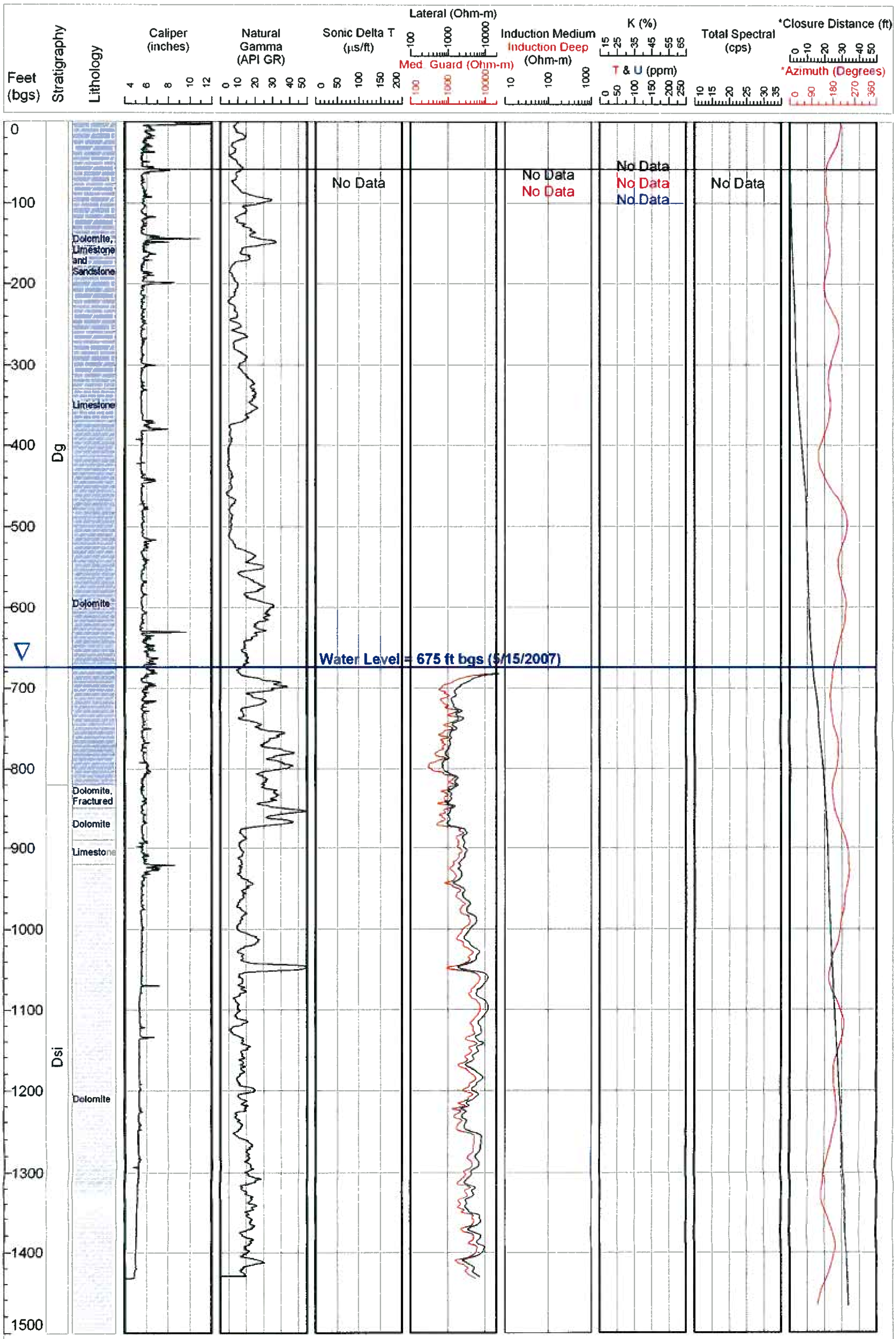
Muller (2007a, b, and c) evaluated the geophysical logs for Monitor Well 181M-1 and indicated that the more reliable logs are Natural Gamma Ray (Gamma), Lateral Resistivity, Medium Guard, Spontaneous Potential, Fluid Temperature, Fluid Conductivity, Fluid Resistivity, Salinity, pH, and Deviation. All other logs, including the Spectral Gamma (KUT), Sonic, and Spinner logs, were considered as probably invalid. The Lateral and Guard logs are generally conformable and are discussed in subsequent paragraphs as Electric logs. The Induction logs are also Electric logs; however, Muller (2007a and b) indicated that these logs were not responding properly and hence not valid.

The Electric, Gamma, and Spontaneous Potential logs show a response at about 870 to 880 ft bgs in a zone of dolomite in the Guilmette Formation. In the Electric logs (Lateral and Guard), this depth marks a change to a more resistive interval, perhaps due to an increase in calcite veinlets. A slightly higher resistivity from 810 to 830 ft bgs is in and just above a fractured zone with hematite on fractures. Below 890 ft bgs, the resistivity has a slight drop at 950 ft bgs, and it increases from 960 to 1,060 ft bgs. The slight drop is at the base of the Guilmette in a dark gray dolomite with calcite veinlets and minor hematite, below which is the lighter gray Simonson Dolomite, which appears to be



Note: Correlation with RGUs (Dixon et al., 2007): The Guilmette Formation is part of the Dg RGU, and the Simonson Dolomite is part of the Ds RGU. Logs plotted by SNWA.

Figure 8
Monitor Well 181M-1 Geophysical Fluid Logs



Explanation
Dg = Devonian Guilmette Formation
Dsi = Devonian Simonson Dolomite

SNWA Monitor Well 181M-1 (Initial Borehole)
Geophysical Suite: Formation Logs
Collected By: Geophysical Logging Services
completed 6/8/05
*Closure Data logged in the Completed Cased Well on October 4, 2005

Note: Correlation with RGUs (Dixon et al., 2007): The Guilmette Formation is part of the Dg RGU, and the Simonson Dolomite is part of the Ds RGU. Logs plotted by SNWA.

Figure 9
Monitor Well 181M-1 Geophysical Formation Logs

more resistive than the Guilmette. The resistivity decreases slightly from 1,210 to 1,250 ft bgs, a zone of dolomite with occasional hematite on fractures.

The Gamma log, as well as the other logs, was run in an open borehole with no surface casing. The two spikes in the Gamma logs between 80 and 180 ft bgs are at the same depths as yellow and red sandstone and quartzite observed in the drill cuttings. The variation in the Gamma counts between 180 and 320 ft bgs is due to sparse, thin sandstone and quartzite units in the dolomite. The higher Gamma counts between 320 and 370 ft bgs include a limestone interval. The low Gamma counts between 370 to 530 ft bgs represent a dolomite with a small amount of brown clay. The higher Gamma counts from 530 to 870 ft bgs are from a clayey or shaly dolomite.

The lower part of the monitor well, from 870 to 1,430 ft bgs, is nearly exclusively dolomite with minimal clay, which is consistent with the generally low Gamma values, averaging less than 20 gru. The lone spike in the Gamma at 1,040 ft bgs is in an interval with numerous calcite veinlets in dolomite and limestone. This spike is associated with a drop in resistivity. A smaller increase in Gamma at 1,000 to 1,020 ft bgs is also associated with a drop in resistivity, though less pronounced. Calcite veinlets are also common in this interval. A small Gamma peak at 1,200 ft bgs is associated with a dark gray dolomite. The Gamma counts increase slightly between 1,260 and 1,420 ft bgs in medium to dark gray dolomite. Carbonaceous material in the dolomite may be responsible for this slight increase, including the small peak at 1,200 ft bgs.

The Spontaneous Potential log has a very similar shape to the Gamma log. There is a prominent decrease at 870 ft bgs and prominent spike at 1,040 to 1,050 ft bgs. The drilling fluid consisted of groundwater with limited additives to maintain circulation and to facilitate capture of the cuttings. Because of this method, the total dissolved solids (TDS) measurement for the drilling fluids was similar to that of the groundwater. Since Spontaneous Potential log interpretation depends on a difference between the two (Keys and MacCary, 1971), the Spontaneous Potential log for this initial well cannot be interpreted with any certainty.

The Fluid Temperature log shows a steady increase with depth to a maximum of approximately 22.1°C, which was very close to the groundwater temperature of 22.5°C measured during pumping for a geochemical sample on May 31, 2006 (Acheampong et al., 2007). The steady increase in temperature indicates that groundwater was mixing with the borehole fluid and/or there is a steady increase in the groundwater temperature with depth.

Logs of pH, Fluid Resistivity, Fluid Conductivity, Salinity, and Redox Iron were all derived from an Idronaut Water Quality Probe. The strong similarity of the logs indicates that they were all derived from one sensor (Muller, 2007c), so only the Fluid Conductivity log will be considered.

The Fluid Conductivity log shows noticeable variation with depth, first decreasing to a low at 820 ft bgs, then increasing to a high at 930 ft bgs, then decreasing to a low again at 1,100 ft bgs, next to a high again at 1,240 ft bgs, and then lower but steady between 1,300 and 1,400 ft bgs, finally increasing to the bottom of the borehole (Figure 8). These variations suggest groundwater interaction with the borehole. The electrical conductance of the groundwater was 47 mS/m on May 31, 2005 (Acheampong et al., 2007), which is slightly higher than the Fluid Conductance log values of 40 to 44 mS/m. This difference indicates that the drilling fluid had a slightly lower TDS than the groundwater. The correlation of the Fluid Conductivity log with zones of groundwater interaction with the borehole is discussed in Section 2.3.

The Caliper log shows multiple small caved zones throughout the entire initial well, usually associated with fractured bedrock. Most of the caved zones are located in the intervals 0 to 200 ft bgs and 640 to 940 ft bgs in the initial hole. Specific zones include 60, 145 to 155, 195 to 203, 370 to 380, 930 to 940, and several caved intervals between 640 and 720 ft bgs. Most of these intervals are evident in the borehole video. No Caliper log was performed in the completed monitor well.

The borehole video provides a view of the borehole wall above the water level in the initial well. In this section, bedding was evident with a dip of approximately 25 to 30 degrees. Between the water level at 679.5 ft bgs and 850 ft bgs and below 1,139 ft bgs, the borehole fluid was too turbid to view the hole wall. Groundwater interaction with the borehole assisted in improving the visibility between 850 and 1,139 ft bgs, suggesting that the primary zone of such interaction occurred in this interval. However, there could be additional groundwater interaction below this interval, evidence of which is masked by the high volume of particulates settling through the borehole fluid. In the less turbid zone above 1,139 ft bgs, the dip of the bedding was about 30 to 35 degrees.

The Deviation (Closure Distance) log indicates that the borehole deviates approximately 73.1 ft due south in the initial hole and 33.8 ft S3W in the completed well (Figure 9). The large deviations reflect the hard dolomites through which the boreholes were drilled. The direction of the deviations is most likely caused by roughly north-south faulting as shown in Swadley et al. (1994).

2.2.3 Drilling Parameters

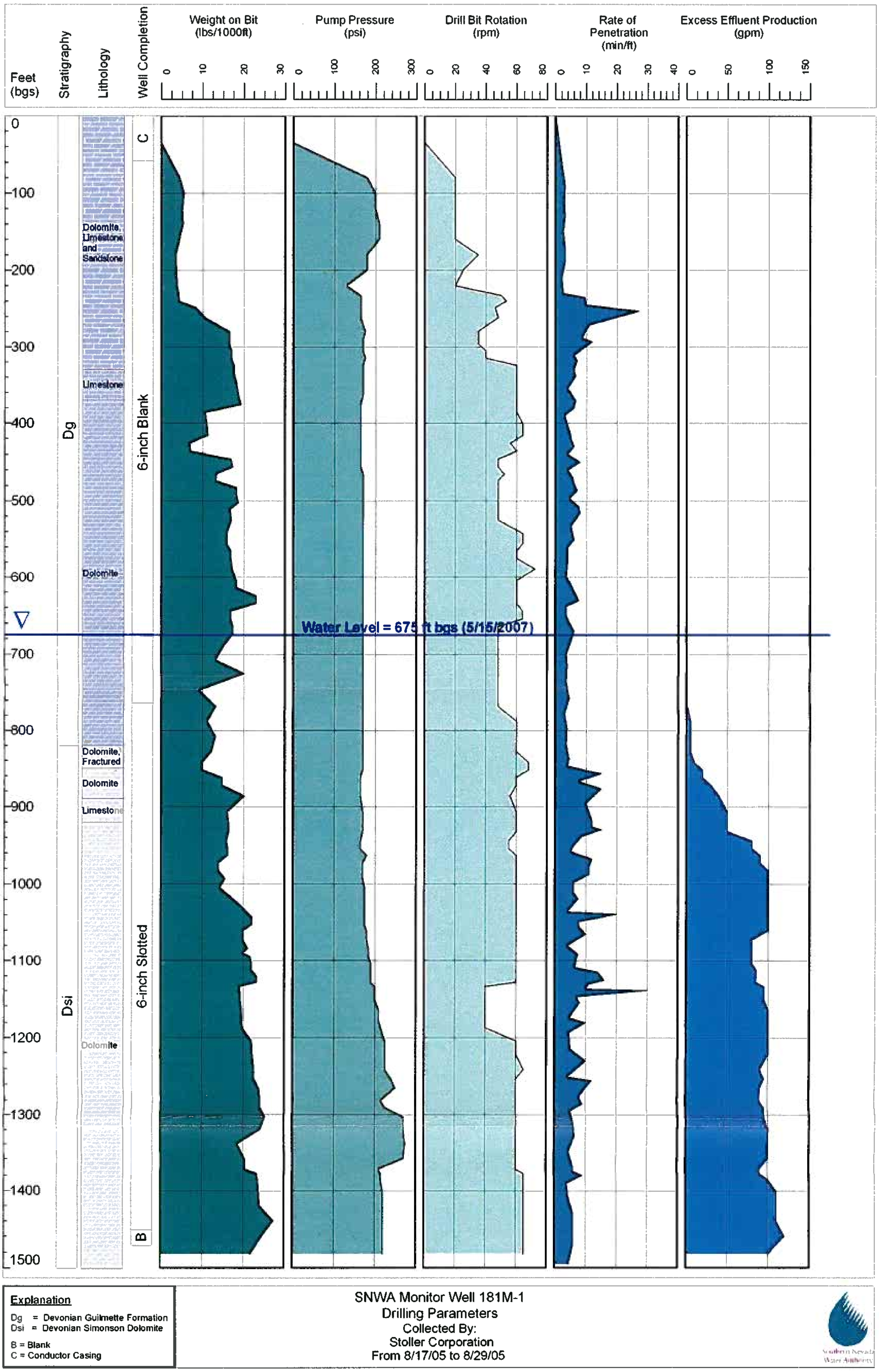
Stoller (2006) provided data on the drilling parameters as follows:

- Weight on Bit
- Pump Pressure
- Drill Bit Rotation
- Rate of Penetration
- Water Production.

These drilling parameters are for the completed monitor well and are presented on Figure 10.

A prominent decrease in the penetration rate occurred at approximately 250 ft bgs. Stoller (2005) describes multiple equipment failures that occurred above and below this interval, from approximately 230 to 275 ft bgs. This information, combined with the low weight on bit, indicates the slowdown in drilling rate may be related more to malfunctions of the drilling equipment and hole condition rather than geologic variation.

Another reduction in drilling rate occurred at approximately 850 ft bgs at the base of the heavily iron-stained, fractured dolomite described in Table 1. The decreased penetration rate suggests a variably harder or more massive dolomite below this depth. The estimated excess drilling effluent production also noticeably increased at this depth (Figure 10). At 1,040 ft bgs, the spike in penetration rate correlates with an increase in the Weight on Bit and with a zone of fracturing and calcite veinlets. At 1,135 ft bgs, a spike in the penetration rate correlates with a decrease in Weight on Bit and Drill Bit Rotation.



Note: Correlation with RGUs (Dixon et al., 2007): The Guilmette Formation is part of the Dg RGU, and the Simonson Dolomite is part of the Ds RGU. Logs plotted by SNWA.

FIGURE 10
MONITOR WELL 181M-1 DRILLING PARAMETERS

2.3 HYDROGEOLOGY

Monitor Well 181M-1 is completed (screened) within the Devonian Guilmette Formation and Simonson Dolomite on the west side of Dry Lake Valley. During drilling operations, excess drilling effluent was first noticed at about 725 ft bgs (Stoller, 2005). This excess effluent increased below the fracture zone noted at 820 to 850 ft bgs. At 910 ft bgs, a flow rate of 50 gpm was estimated from excess drilling effluent production, and at this depth, the driller converted to using only formation water as the foam was interfering with water level measurements (Stoller, 2005). Shortly after this, the drilling method was changed to flooded reverse circulation.

At 960 ft bgs, the excess flow volume reached about 100 gpm with minimal variation to the bottom of the borehole (Figure 10). The increasing flow volume below 850 ft bgs indicates that a large portion of the flow is entering the monitor well in the interval between 850 to 960 ft bgs. This interval is represented by a peak in the Fluid Conductance log (Figure 8), which provides evidence that the groundwater conductance is greater than the borehole fluid conductance. This difference affirms the relative values of fluid conductance between those shown in Figure 8 and that provided during the pumping event on May 31, 2006 (Acheampong et al., 2007). The zone in which excess drilling effluent increased also corresponds to the zone where turbidity of the borehole fluid was reduced.

Another zone of elevated Fluid Conductance occurs between 1,200 and 1,280 ft bgs. This zone does not correspond to an increase in the production of drilling effluent. However, there is a further increase in the turbidity of the borehole fluid, as viewed in the borehole video, below about 1,300 ft bgs.

A depth-to-water level of 677.89 ft bgs was taken at 12:11 on January 9, 2006, by SNWA (Stoller, 2006). The surface elevation at the well is approximately 4,970 ft amsl, which gives a groundwater elevation of approximately 4,292 ft amsl. This site has not been professionally surveyed. Six water level readings have been taken since May 2006 ranging from 675.19 to 675.59 ft bgs, a range of only 0.4 ft. A complete set of water level measurements is provided in Table 2.

2.4 SUMMARY

Monitor Well 181M-1 was drilled and completed in August 2005 for the purpose of collecting geologic, hydrologic, and geochemical data. This monitor well is located in western Dry Lake Valley and was drilled to a total depth of 1,501 ft bgs with a slotted interval from 764.6 to 1,451.4 ft bgs.

The monitor well encountered 960 ft of the Silverhorn Dolomite facies of the Devonian Guilmette Formation and 540 ft of the Devonian Simonson Dolomite. The upper 330 ft of the borehole is in a dolomite with several interbedded sandstone and quartzite layers, which is indicative of the upper Guilmette Formation. From 330 to 960 ft bgs, the middle and lower units of the Guilmette Formation were represented. The borehole encountered a dark gray to black dolomite at 940 to 960 ft bgs, representing the base of the Guilmette Formation, below which is the alternating member of the Devonian Simonson Dolomite. A dark gray to black dolomite below 1,380 ft bgs represents the third (brown) member of the Simonson Dolomite.

Geophysical logs and drilling parameters provided additional data for analysis. These logs assisted in defining geologic contacts and structural features, including fracture zones, and zones of clayey material. The Gamma log correlates with beds of sandstone and shale- or clay-bearing dolomite. The

TABLE 2
WATER LEVEL MEASUREMENTS FOR MONITOR WELL 181M-1

Date	Time	Depth (ft bgs)	Elevation (ft amsl)	Data Collected By
6/8/2005	–	682	4,288	GLS, electric logs
6/8/2005	22:00	678.5	4,292	GLS, borehole video
8/23/2005	12:40	676	4,294	Stoller (2005, 2006), partially drilled monitor well at 941 ft bgs
8/26/2005	23:30	676	4,294	Stoller (2005, 2006), partially drilled monitor well at 1,360 ft bgs
8/30/2005	22:45	676	4,294	Stoller (2005, 2006), monitor well at TD
1/9/2006	12:11	677.89	4,292	Stoller (2006), completed monitor well
5/31/2006	13:30	680	4,290	Layne Christensen Co. (Yermo, CA) (SNWA, 2006)
10/24/2006	13:42	675.19	4,295	SNWA
12/8/2006	11:10	675.30	4,295	SNWA
1/22/2007	16:47	675.59	4,294	SNWA
2/26/2007	13:50	675.31	4,295	SNWA
4/3/2007	12:50	675.54	4,295	SNWA
5/15/2007	14:02	675.44	4,295	SNWA

Note: GLS = Geophysical Logging Services (Prescott, AZ).
Groundwater elevations are rounded to the nearest foot to reflect the uncertainty in the surface elevation of the well and the variability of water level measurement procedures.

Gamma, Electric, and Spontaneous Potential logs show a shift in values at approximately 870 ft bgs. The lithology does not change at this depth, but there is an increase in calcite veinlets, and there was an increase in drilling effluent production.

The static water level was about 676 ft bgs, and the water elevation was about 4,295 ft amsl. Groundwater interaction with the borehole was most noticeable between 850 and 960 ft bgs, but based on the Fluid Temperature and Fluid Conductance logs, other deeper fractures also can contribute groundwater to the borehole.

References

Acheampong, S.Y., Eastman, H.S., and Cansdale, M.G., 2007, Chemical and Radiochemical Constituents of Selected Wells and Springs in Parts of Clark, Lincoln, and White Pine Counties, Nevada: SNWA, unpublished.

BLM, see Bureau of Land Management.

Bureau of Land Management, 2006, "Surface Land Ownership" files nv_landowner.e00.zip and nv_landowner_shp.zip, accessed at website http://www.nv.blm.gov.gis/geospatial_data.htm.

Dixon, G.L., Rowley, P.D., Burns, A.G., Watrus, J.M., and Ekren, E.B., 2007, Geology of White Pine and Lincoln Counties and Adjacent Areas, Nevada and Utah—The Geologic Framework of Regional Groundwater Flow Systems: Doc. No. HAM-ED-0001 Southern Nevada Water Authority, Las Vegas, Nevada.

Fenneman, N.M., 1931, Physiography of the Western United States, Chapter 8 – Basin and Range Province: McGraw-Hill.

Keys, W.S., and MacCary, L.M., 1971, Application of borehole geophysics to water-resources investigations (Chapter E1), U.S. Geological Survey Techniques of Water-Resources Investigations, Book 2—Collection of environmental data, 126 p.

Muller, D., 2007a, Evaluation of SNWA Well Log Data: SNWA, unpublished.

Muller, D., 2007b, Personal communication to D. Donovan (SNWA) regarding geophysical data for Well 181M-1, January through April 2007.

Muller, D., 2007c, Email to R. Schuth (SNWA) regarding Monitor Well 181M-1 and the similarity of certain logs and geophysical logs for other wells, 3 May.

Rowley, P.D., and Dixon, G.L., 2001, The Cenozoic Evolution of the Great Basin Area, U.S.A. – New Interpretations Based on Regional Geologic Mapping: Utah Geol. Soc. Publ. 30 – Pacific Section Amer. Assoc. of Petr. Geol. Publ. GB78.

S.M. Stoller Corporation, 2005, Drilling Morning Reports—Well 181M-1: SNWA, unpublished.

S.M. Stoller Corporation, 2006, 181M-1, Well Data Report: SNWA, unpublished.

SNWA, see Southern Nevada Water Authority.

Southern Nevada Water Authority, 2006, Notes from geochemical sampling for Monitor Well 181M-1 on 31 May, unpublished.

Swadley, W.C., Page, W.R., and Scott, R.B., 1994, Preliminary geologic map of the Deadman Spring NE quadrangle, Lincoln County, Nevada: U.S. Geological Survey Open-File Report 94-283, 14 p., scale 1:24,000.

Tschanz, C.M., and Pampeyan, E.H., 1970, Geology and Mineral Deposits of Lincoln County, Nevada: Nevada Bureau of Mines and Geology Bulletin 73, 188 p.