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Southern Nevada Water Authority

Geologic Data Analysis Report for Monitor Well 209M-1 in Pahranagat Valley

October 2007

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SOUTHERN NEVADA
WATER AUTHORITY

Geologic Data Analysis Report for Monitor Well 209M-1 in PahranagatValley

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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
HA	hydrographic area
RGU	regional geologic unit
SNWA	Southern Nevada Water Authority
TD	total depth
USGS	U.S. Geological Survey

ABBREVIATIONS

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

1.0

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 209M-1 is located on the eastern margin of the Pahranagat Valley hydrographic area (HA 209), at the south end of the North Pahroc Range, at an elevation of approximately 5,120 ft amsl. The site is located approximately 21 mi east of Ash Springs in central Lincoln County about 2 mi north of U.S. Highway 93 (Figure 2).

1.1 PURPOSE AND SCOPE

The purpose of this report is to describe the geologic, geophysical, and hydrologic data collected for Monitor Well 209M-1. The scope involves evaluation and comparison of borehole cuttings, drilling statistics, borehole geophysical logs, and hydraulic properties of the monitor 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 monitor well, and geologic units and structure that control 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 the 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.

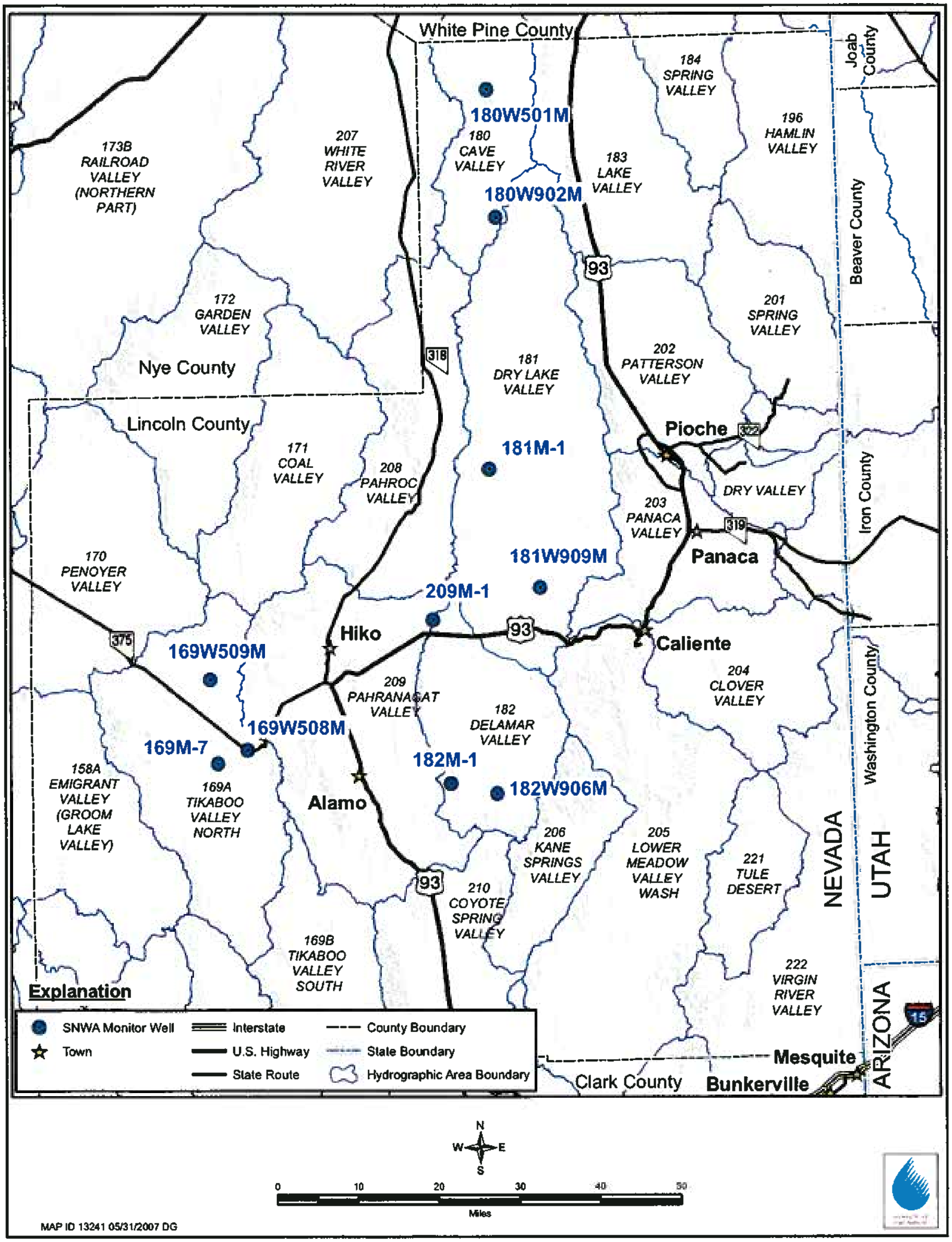
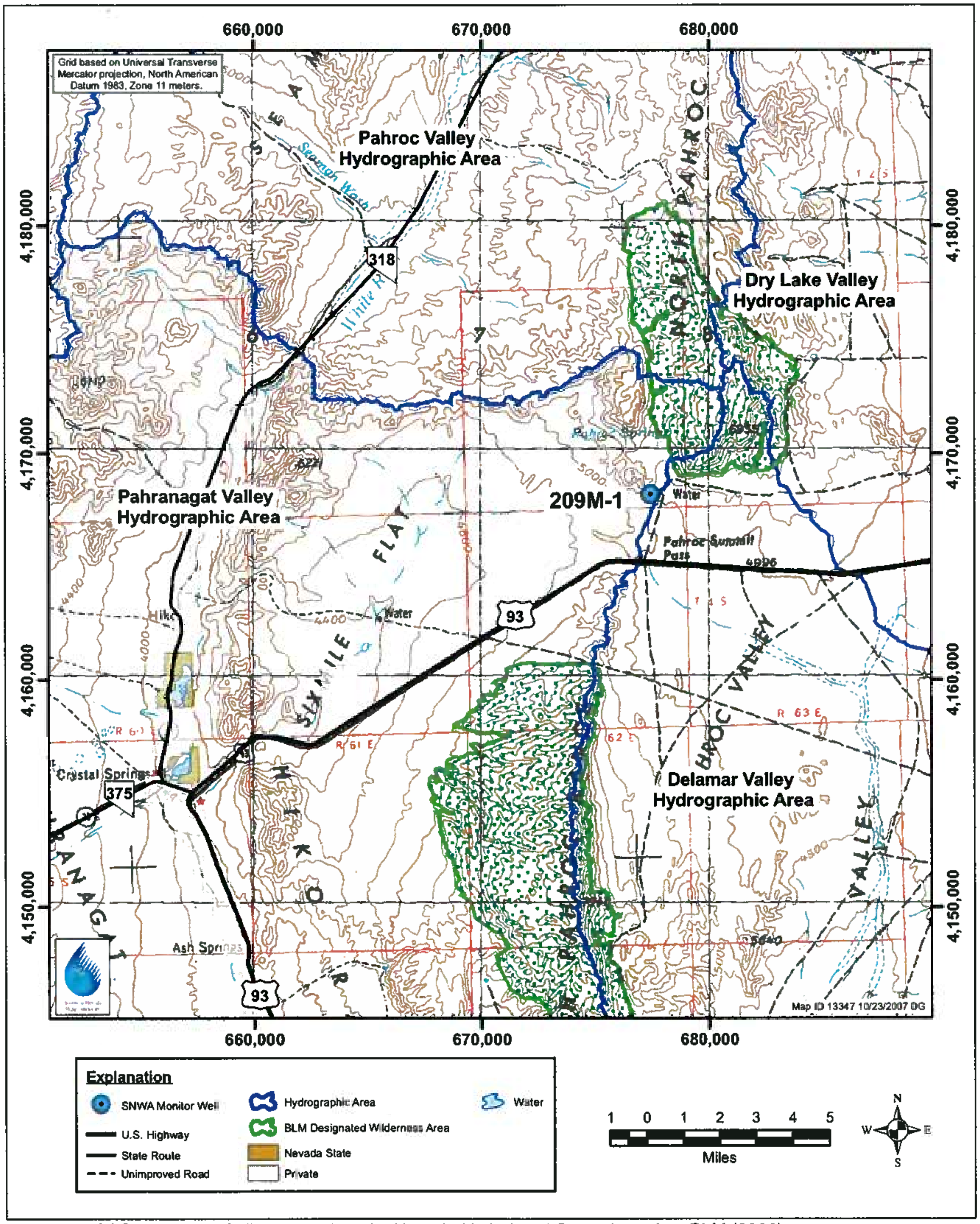


Figure 1
SNWA Monitor Well Locations, Lincoln County, Nevada



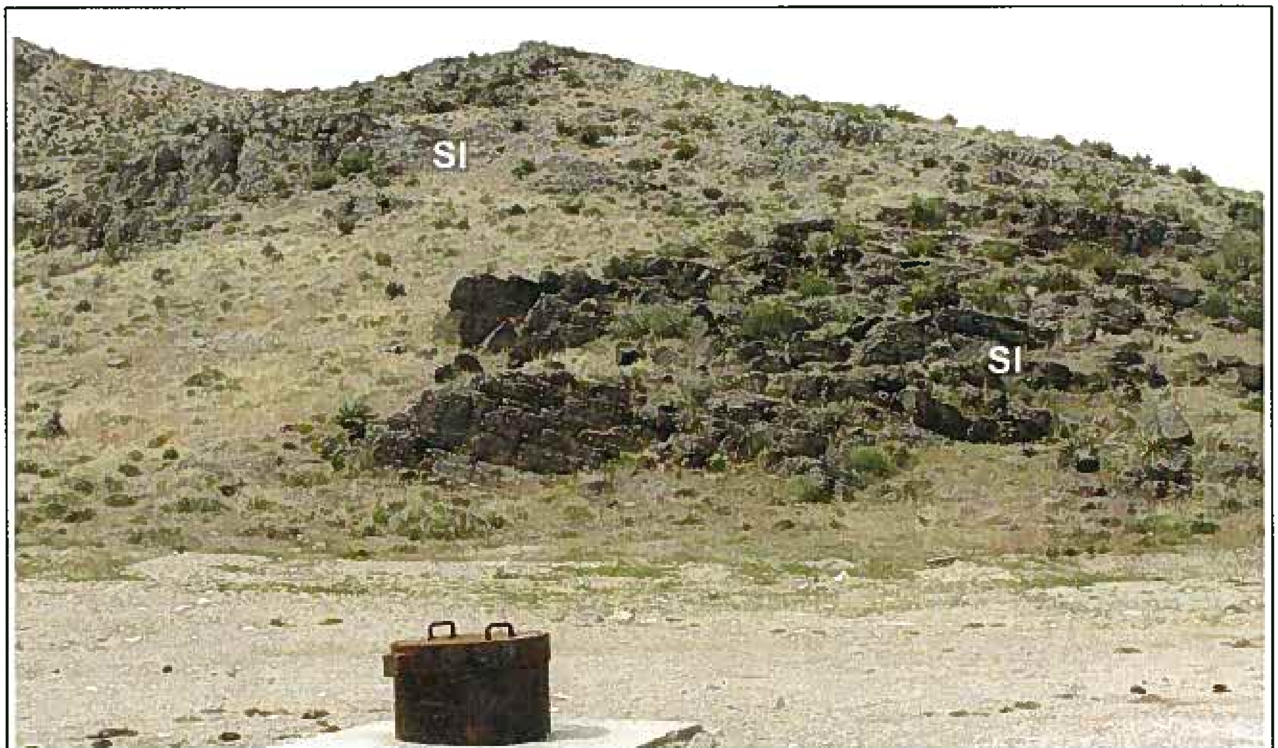
Source: USGS 1:250,000 Caliente quadrangle, Nevada-Utah; Land Status based on BLM (2006).

FIGURE 2
LOCATION OF MONITOR WELL 209M-1, LINCOLN COUNTY, NEVADA

1.3 SUMMARY OF MONITOR WELL CONSTRUCTION

Monitor Well 209M-1 was completed in two stages. An initial (pilot) hole was completed on April 5, 2005, to a total depth of 940 ft bgs, to a total depth of 940 ft bgs as a 5.875-in. borehole inside 9.875-in. O.D. temporary surface casing. This hole was abandoned at a later date. The final monitor well was drilled and completed from July 14 to August 4, 2005, to a depth of 1,616 ft bgs. The monitor well was completed with 14-in. O.D. conductor casing to 50 ft bgs and 6.625-in. O.D. well casing from 1.5 ft above ground surface to 1,615.5 ft bgs with a slotted interval from 1,273.5 to 1,595 ft bgs. The monitor well was drilled using multiple drilling methods, which included conventional air-foam and flooded reverse circulation, primarily with a borehole diameter of 13.5 in.

Figure 3 is a photograph of the completed monitor well, at the toe of an outcrop of Silurian Laketown Dolomite. For additional information on the well construction, refer to Stoller (2006).



Note: Silurian Laketown Dolomite (Sl) just north of the monitor well, which is collared in Quaternary alluvium. The Laketown Dolomite is part of the SOu RGU (Dixon et al., 2007).

FIGURE 3
VIEW OF MONITOR WELL 209M-1 SITE, LOOKING NORTH

2.0

DATA ANALYSIS

This section analyzes the lithology, geophysical logs, and drilling statistics to evaluate the geology encountered in Monitor Well 209M-1.

2.1 GEOLOGIC SETTING

Pahranagat Valley is a basin within the Great Basin subprovince (Fenneman, 1931) formed during the regional extension during the late Tertiary Period (Rowley and Dixon, 2001). Monitor Well 209M-1 is close to the topographic divide of Pahranagat Valley (HA 209) and Delamar Valley (HA 182) and is near the boundaries of the Dry Lake (HA 181) and Pahroc Valley (HA 208) hydrographic areas (Figure 2).

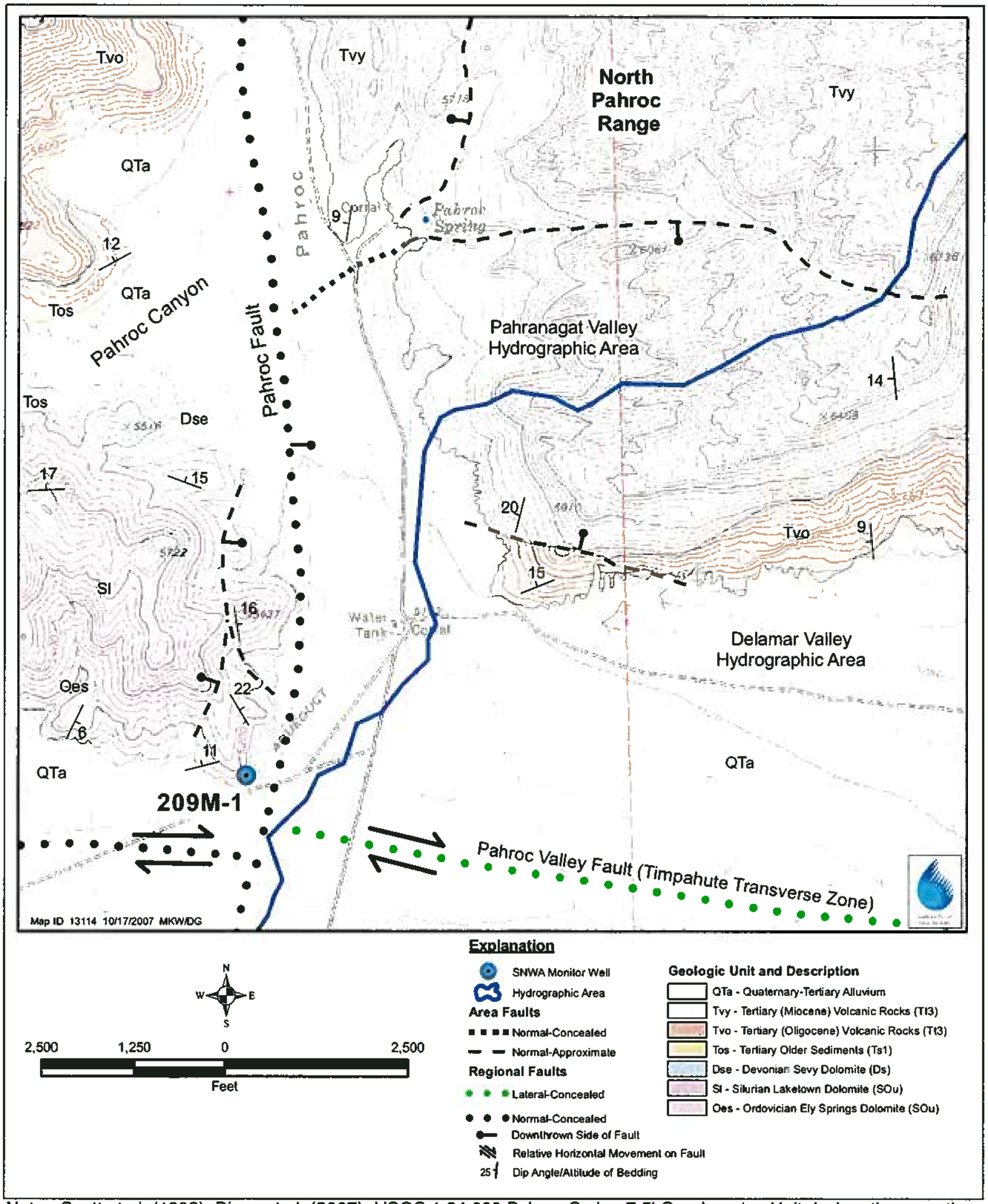
The monitor well is located at the southern end of the North Pahroc Range, less than 100 ft south of an outcrop that is the basal part of the Silurian Laketown Dolomite (Tschanz and Pampeyan, 1970; Scott et al., 1992). The rocks encountered in the monitor well are older than and underlie the adjacent exposed bedrock. Dixon et al. (2007) indicates that most of the North Pahroc Range is covered by approximately 2,000 ft of Tertiary volcanic rocks, underlain by Paleozoic rocks. The monitor well site is located in a window of Paleozoic rock surrounded by younger volcanic rocks and alluvium. The surface geology is displayed on Figure 4. The positions of the regional north-south and east-west faults, which are covered by alluvium, were taken from the regional geologic map of Dixon et al. (2007).

2.1.1 GEOLOGIC UNITS ENCOUNTERED AT THE MONITOR WELL

The geologic units encountered in Monitor Well 209M-1 consist of alluvium Silurian Laketown Dolomite, Ordovician Ely Springs Dolomite, Ordovician Eureka Quartzite, and the upper part of the Ordovician Pogonip Group. The alluvium consists of a thin veneer of carbonate and volcanic detritus eroded from the surrounding hills. This material is part of the "surficial alluvium and basin fill" (QTa) regional geologic unit (RGU) (Dixon et al., 2007). The Silurian Laketown Dolomite and Ordovician Ely Springs Dolomite are part of the "Silurian and Ordovician, Upper part" (SOu) RGU. The Ordovician Eureka Quartzite and the Ordovician Pogonip Group are combined into the "Ordovician, Lower part" (Ol) RGU.

Alluvium is less than 10 ft thick at the monitor well site. The Laketown Dolomite is distinctive as being composed of a dark gray upper dolomite section, a light gray to yellowish brown dolomite middle section, and a dark gray lower dolomite section (Tschanz and Pampeyan, 1970, p. 30). Scott et al. (1992, p. 12) report a local thickness of approximately 820 ft (250 m) of Laketown Dolomite and mapped this unit immediately north of the monitor well site (Figure 3).

The Ely Springs Dolomite is lithologically similar to the Laketown Dolomite (Dixon et al., 2007); however, the most distinctive part of the unit is darker and contains more chert. In the Pahranagat and Delamar ranges the unit is between 276 and 527 ft thick, and in the Southern Egan and Ely Springs ranges, the formation is 495 to 525 ft thick (Tschanz and Pampeyan, 1970, p. 28). About 200 ft (60 m) of this formation is locally exposed (Scott et al., 1992, p. 12).



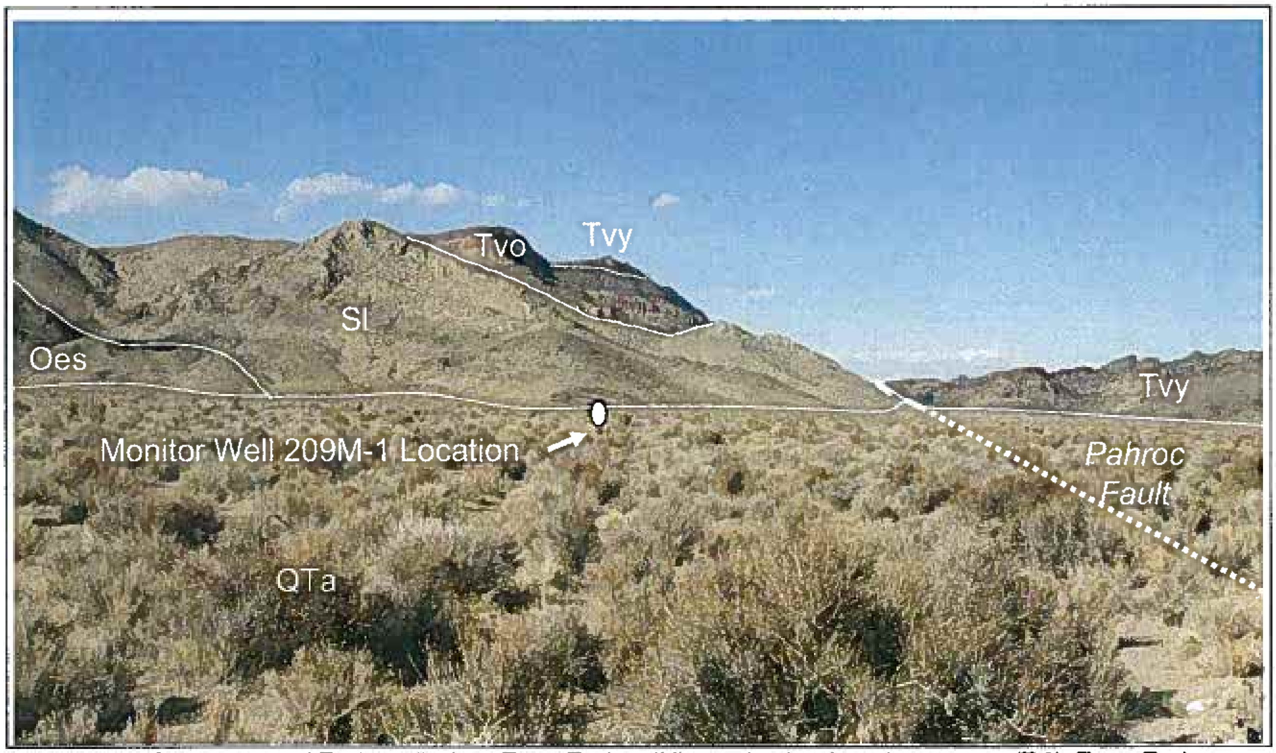
Note: Scott et al. (1992); Dixon et al. (2007); USGS 1:24,000 Pahroc Spring 7.5' Quadrangle. Unit designations are the RGUs defined in Dixon et al. (2007).

FIGURE 4
PRELIMINARY GEOLOGIC MAP OF MONITOR WELL 209M-1

The Eureka Quartzite is a white to light gray, fine to medium grained, massive quartzite. The unit is not exposed locally, but it is approximately 500 ft thick in a large part of Lincoln County (Tschanz and Pampeyan, 1970).

The Pogonip Group, which is not exposed near the monitor well site, is characterized as a thick- and thin-bedded grayish to brownish limestone and silty and shaly limestone (Tschanz and Pampeyan, 1970, p. 24–25) and is of nearly uniform thickness, approximately 3,000 ft, throughout most of Lincoln County. The uppermost unit is designated the Antelope Valley Limestone in areas where the geologic group is divided.

Figure 5 is a photograph, taken January 4, 2007, of the structural block containing the monitor well site from about the location of the Pahroc Valley Fault. Figure 6 is a photograph from the monitor well site to the east across location of the Pahroc Fault.

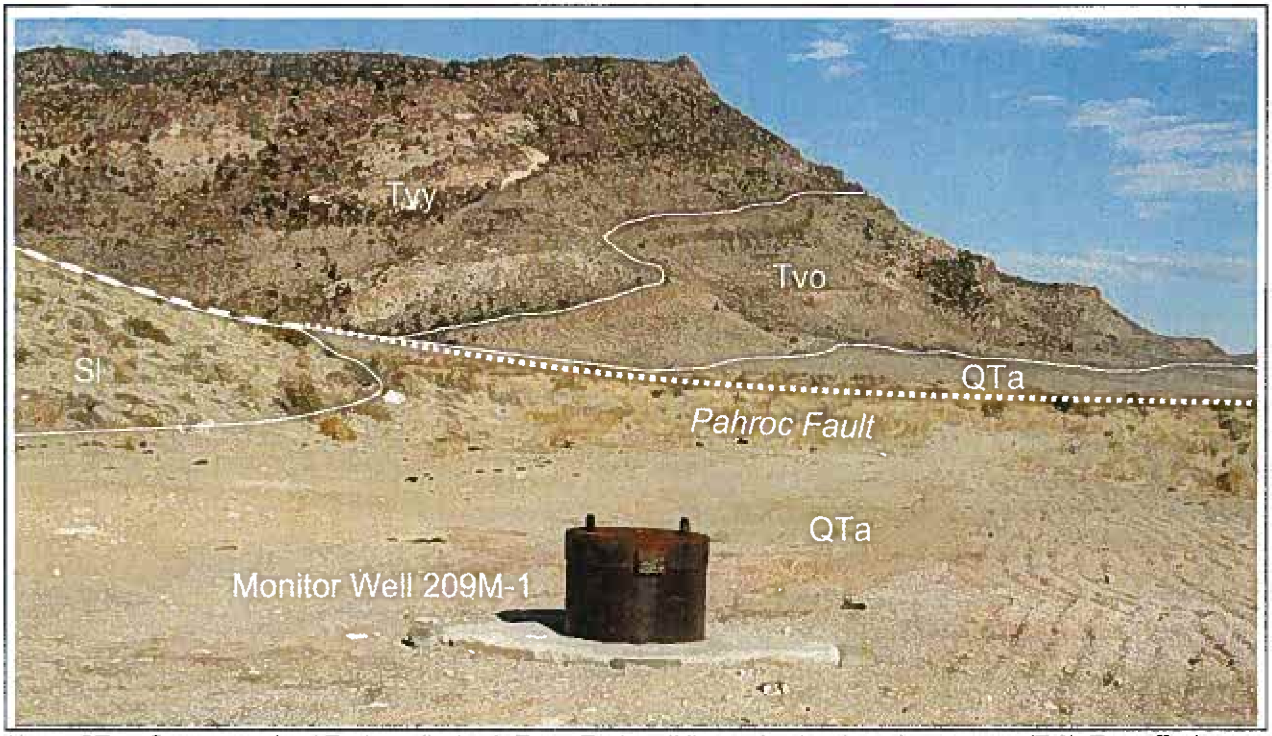


Note: QTa = Quaternary and Tertiary alluvium, Tvy = Tertiary (Miocene) volcanic rocks, younger (Tt3), Tvo = Tertiary (Oligocene) volcanic rocks, older (Tt3), Sl = Silurian Laketown Dolomite (SOu), Oes = Ordovician Ely Springs Dolomite (SOu). Photograph shows westward dip of beds and offset of Pahroc Fault. Regional geologic units of Dixon et al. (2007) in parentheses.

FIGURE 5
VIEW OF THE STRUCTURAL BLOCK CONTAINING MONITOR WELL 209M-1 FROM PAHROC VALLEY FAULT, LOOKING NORTH

2.1.2 GEOLOGIC STRUCTURE AT THE MONITOR WELL SITE

The monitor well site is on the west side of Pahroc Canyon, a topographic feature created by the north-south, down-to-the-east, normal Pahroc Fault. The Pahroc Fault cuts the Pahroc Valley Fault south of the monitor well site (Figures 4, 5, and 6) (Dixon et al., 2007). These features are covered by alluvium east and south of the monitor well site.



Note: QTa = Quaternary (and Tertiary alluvium), Tvy = Tertiary (Miocene) volcanic rocks, younger (Tt3), Tvo = Tertiary (Oligocene) volcanic rocks, older (Tt3), Sl = Silurian Laketown Dolomite (SOu), Oes = Ordovician Ely Springs Dolomite (SOu).

FIGURE 6
VIEW OF MONITOR WELL 209M-1 SITE, LOOKING EAST ACROSS THE PAHROC FAULT

2.2 MONITOR WELL 209M-1

Monitor Well 209M-1 was drilled in a single pass. 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 209M-1 at 10-ft intervals during the drilling process using SNWA internal procedures. These cuttings were described and the lithologic units encountered by drilling were identified based on descriptions by Tschanz and Pampeyan (1970) and Scott et al. (1992). A summary of the lithologic log is included in Table 1.

The cuttings indicate 7 to 10 ft of alluvium, generally sands and gravels of dolomite and volcanic fragments. Beneath the alluvium is the lower portion of the Silurian Laketown Dolomite, a generally dark gray to black dolomite with occasional chert or white silica. Beneath the Laketown Dolomite is the Ordovician Ely Springs Dolomite, which tends to be a darker gray dolomite than the overlying Laketown Dolomite. The identification of the contact of the Ely Springs and Laketown dolomites was based on a change to a darker color in the Ely Springs Dolomite, though the precise depth of the contact is uncertain due to the similarity of units above and below the contact. The thickness encountered of the Ely Springs Dolomite is about 405 ft. This thickness is less than that indicated for the southern Egan and Ely Springs ranges.

TABLE 1
LITHOLOGY OF MONITOR WELL 209M-1
(PAGE 1 OF 3)

Interval Top to Base (ft bgs)	Geologic Unit	General Lithology	Description of Cuttings
0 to 10[a]	QTa	Alluvium	Sand with gravel; poorly sorted silt, sand, and gravel, primarily dolomite with lesser Tertiary volcanic tuffs with sanidine, quartz, and biotite. Subrounded to angular clasts (Stoller, 2006). No cuttings preserved from either initial or completed well.
10 to 50[a]	SI Silurian Laketown Dolomite (SOu)	Dolomite	Lt gray to dark gray, very fine- to med-grained microcrystalline to sucrosic dolomite and limy dolomite, commonly with a very fine-grained sandy appearance. Occ lt gray fossil frags, minor irregular chert frags and occ calcite vlts (Stoller, 2006).
50 to 60	SI (SOu)	Dolomite	Dark gray to brownish gray, fine-grained microcrystalline to sucrosic dolomite and dolomitic limestone, commonly with a very fine-grained sandy appearance. Extensive white to brown calcite veining and FeOx (red) on fractures. Occ red and black chert.
60 to 70	SI (SOu)	Dolomite	Lt gray, gray to black, mod to well indurated, micritic to microcrystalline dolomite with abundant white, orange, and clear calcite and dolomite on fractures; red-orange FeOx on fractures. Occ microcrystalline quartz (agate).
70 to 80	SI (SOu)	Dolomite	Dark gray, mod to well indurated, microcystalline dolomite and limy dolomite, often with a very fine-grained sandy appearance. Minor red-orange FeOx on fractures. Occ tan, microcrystalline and fossiliferous limestone. Fossils are crinoid-like.
80 to 100	Oes Ordovician Ely Springs Dolomite (SOu)	Dolomite	Very dark gray, mod to well indurated, microcrystalline to sucrosic dolomite, with partially dolomitized, tan, sucrosic limestone, commonly with a very fine-grained sandy appearance. Occ white-orange fracture fill and minor clay-FeOx on fractures; minor red to reddish-gray chert, 1% to 5%.
100 to 120	Oes (SOu)	Dolomite	Gray to very dark gray, well indurated, microcrystalline dolomite and limy dolomite. Limy dolomite with a very fine-grained sandy appearance. Minor FeOx and brown clay on fractures; approximately 10% lt gray chert.
120 to 170	Oes (SOu)	Dolomite	Very dark gray, well indurated, microcrystalline to sucrosic dolomite and limy dolomite, commonly with a very fine-grained sandy appearance. Minor FeOx on fractures.
170 to 210	Oes (SOu)	Dolomite	Very dark gray, mod indurated, microcrystalline to sucrosic dolomite. Occ calcite vlts, trace FeOx on fractures.
210 to 220	Oes (SOu)	Dolomite	Very dark gray, mod indurated, microcrystalline to sucrosic dolomite, with some reddish-gray chert. Occ calcite and dolomite vlts and white silica. Occ brown-gray clay.
220 to 260	Oes (SOu)	Dolomite	Dark gray to very dark gray, mod indurated, microcrystalline to sucrosic dolomite, often with a very fine-grained sandy appearance. Trace FeOx on fractures and white calcite vlts and calcite on healed microfractures. Small crinoid-like fossil at 240 to 250 ft bgs.
260 to 310	Oes (SOu)	Dolomite	Gray to dark gray, mod to well indurated, microcrystalline to sucrosic dolomite, with minor FeOx on fractures, white calcite vlts.
310 to 410	Oes (SOu)	Dolomite	Gray to very dark gray, mod to well indurated, sucrosic to microcrystalline dolomite, with some microfracture healing. Occ chert, particularly at 340 to 350 ft bgs.

TABLE 1
LITHOLOGY OF MONITOR WELL 209M-1
(PAGE 2 OF 3)

Interval Top to Base (ft bgs)	Geologic Unit	General Lithology	Description of Cuttings
410 to 440	Oes (SOu)	Dolomite	Gray to very dark gray, mod indurated, microcrystalline to sucrosic dolomite, with abundant white orange fracture fill and minor red-orange FeOx on fractures.
440 to 480	Oes (SOu)	Dolomite Sandstone	Gray to very dark gray, mod to well indurated, microcrystalline to sucrosic dolomite, with red-orange on fractures and white microfracture healing. Tan, lt gray to gray sandstone increasing in abundance with depth from about 30% to 80%. Well rounded, well sorted, often quartzitic, often limy, and often with red to orange FeOx. Tan to lt brown limy argillite, up to 20%.
480 to 490	Oe Ordovician Eureka Quartzite (Ol)	Sandstone, and Quartzite	Tan-orange, mod indurated sandstone, as above, often with FeOx. Pink, orange, white to gray quartzite with sutured grain contacts. Quartzite has recrystallized to a very hard or indurated material in this and subsequent intervals and as is typical of the Eureka Quartzite.
490 to 500	Oe (Ol)	Quartzite	Lt gray to gray quartzite with yellow to orange FeOx-clay on surfaces[b], with some red-orange FeOx on fractures.
500 to 550	Oe (Ol)	Quartzite	White to lt gray quartzite, occ tan to reddish, pinkish gray, less red-orange FeOx on fractures than in 490 to 500.
550 to 560	Oe (Ol)	Quartzite	White to yellow-orange quartzite, abundant red-orange FeOx on fractures.
560 to 580	Oe (Ol)	Quartzite	White to yellow-orange quartzite with less red-orange FeOx on fractures than above.
580 to 610	–	–	No samples collected due to lost circulation.
610 to 620	Oe (Ol)	Quartzite	White, yellow to orange quartzite with occ hematite on fractures.
620 to 650	Oe (Ol)	Quartzite	White, yellow to orange quartzite with abundant red, hematitic FeOx on fractures.
650 to 720	Oe (Ol)	Quartzite	White, orange, red, reddish gray quartzite with abundant red FeOx on fractures.
720 to 740	Oe (Ol)	Quartzite	White to lt gray, yellow to orange quartzite with occ FeOx on fractures.
740 to 820	Oe (Ol)	Quartzite	White to lt gray, yellow to orange quartzite with abundant red, some orange, FeOx on fractures.
820 to 850	Oe (Ol)	Quartzite	White to lt gray, yellow, orange quartzite with abundant FeOx on fractures, mostly yellow to orange limonite, minor hematite.
850 to 900	Oe (Ol)	Quartzite	White to lt gray, orange, red quartzite with abundant FeOx on fractures, mostly hematite.
900 to 910	Oe (Ol)	Quartzite	White to lt gray, orange, red quartzite with abundant red FeOx (hematite) on fractures; minor amounts of dark red hematitic clay.
910 to 930	Oe (Ol)	Quartzite	White to lt gray, occ yellow quartzite with red FeOx (hematite) on fractures.
930 to 950	Oe (Ol)	Quartzite Limestone	White to lt gray, yellow to orange quartzite with some red FeOx (hematite) on fractures. Approx 10% dark gray limestone.

TABLE 1
LITHOLOGY OF MONITOR WELL 209M-1
(PAGE 3 OF 3)

Interval Top to Base (ft bgs)	Geologic Unit	General Lithology	Description of Cuttings
950 to 960	Ordovician Pogonip Group (Ol)	Limestone	Dark gray to very dark gray microcrystalline to sucrosic limestone; commonly orangish or brownish gray. 10% to 20% quartzite slough.
960 to 1,000	Op (Ol)	Limestone	Dark to very dark gray microcrystalline to crystalline limestone, occ dark brownish gray with some red to orange FeOx on fractures. Occ dark red (hematitic) argillaceous clay. White to lt gray quartzite slough, approx 10% to 20%, with occ red FeOx on fractures.
1,000 to 1,100	Op (Ol)	Limestone	Med to dark gray microcrystalline to sucrosic limestone; limonite-hematite (orange-red) on fractures, calcite vlts common.
1,010 to 1,610	–	–	No samples collected due to lost circulation
1,610 to 1,616	Op (Ol)	Limestone	Gray to dark gray, mod indurated, microcrystalline limestone with white microfracture calcite healing and calcite vlts. A portion to all of this material may be slough, much of which is from zone of lost circulation.

[a]No cuttings 0 to 50 ft in completed well. The geology in the initial hole is offset about 50 ft so that this section is also not represented in that hole.
[b]Clay and FeOx that are commonly on surfaces of quartzite frags are often from fractures and have been smeared on the quartzite frags by the drilling process.

Common abbreviations for the above table:
approx - approximately
FeOx - iron oxides, limonite or hematite
frags - fragments
lt - light
med - medium
mod - moderate or moderately
occ - occasional or occasionally
vlts - veinlets

Sl - Silurian Laketown Dolomite
Oes - Ordovician Ely Springs Dolomite
Oe - Ordovician Eureka Quartzite
Op - Ordovician Pogonip Group
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).

The fine- to very fine-grained sandy-appearing dolomite and limy dolomite disappears toward the base of the Ely Springs Dolomite. At the base, there are beds of fine-grained sandstone within the dolomite. These sands are well rounded, well sorted, and occasionally tinged with limonite. This zone is about 40 ft thick, beginning at about 440 ft bgs and extending to 480 ft bgs. Also within this zone are beds of limy argillite, indicating shale deposition.

The Ordovician Eureka Quartzite was first encountered at a depth 480 ft bgs. Except for the interval from 580 to 610 ft bgs where cuttings were not collected due to lost circulation, the entire interval was of quartzite. The entire quartzite interval was collected in the initial hole, such that the missing interval is known to be similar to the material above and below. The Eureka Quartzite, present in Monitor Well 209M-1, is white to light gray, commonly with yellow, orange, or red iron oxides on fractures and on the surfaces of quartzite fragments. The quartzite is noncalcareous except where veined by calcite. Primary variations in the Eureka Quartzite are variations in iron oxides on fractures and the extent of fracturing. The quartzite is otherwise relatively uniform.

The Ordovician Pogonip Group was first encountered at 950 ft bgs, indicating a 470-ft thickness for the Eureka Quartzite. This thickness is only slightly less than the approximately 500 ft of Eureka Quartzite noted in Tschanz and Pampeyan (1970). Due to lost circulation, cuttings were not collected for most of the Pogonip Group encountered by drilling, particularly between 1,010 and 1,610 ft bgs. A small amount of cuttings was obtained from 1,610 to 1,616 ft bgs, but these cuttings may be slough from the overlying Pogonip Group limestone. However, it is unlikely that the missing material was anything but Pogonip Group limestone as the total thickness of the formation is over 2,000 ft (Tschanz and Pampeyan, 1970) and thus much greater than the 666 ft of borehole below the top of the formation.

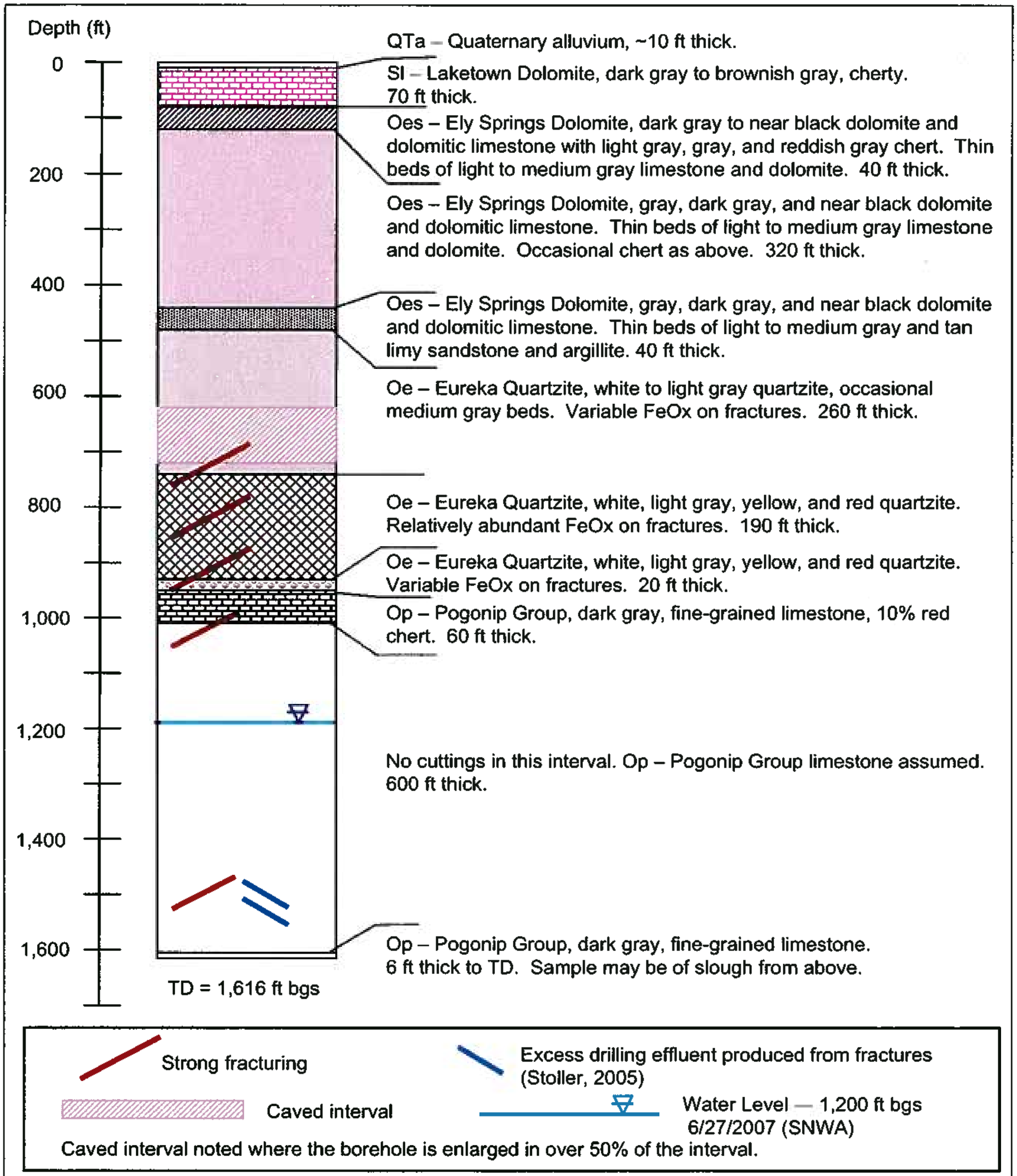
The well lithology is presented graphically on Figure 7.

2.2.2 BOREHOLE GEOPHYSICS

On August 2 and 3, 2005, following the completion of drilling, a full suite of geophysical logs was performed to the full depth of the borehole (Stoller, 2006). During the geophysical logging, the water level in the well was approximately 1,205 ft bgs. On August 3, 2005, a borehole video was taken of the uncased hole to the full depth of the borehole. The following geophysical logs were performed:

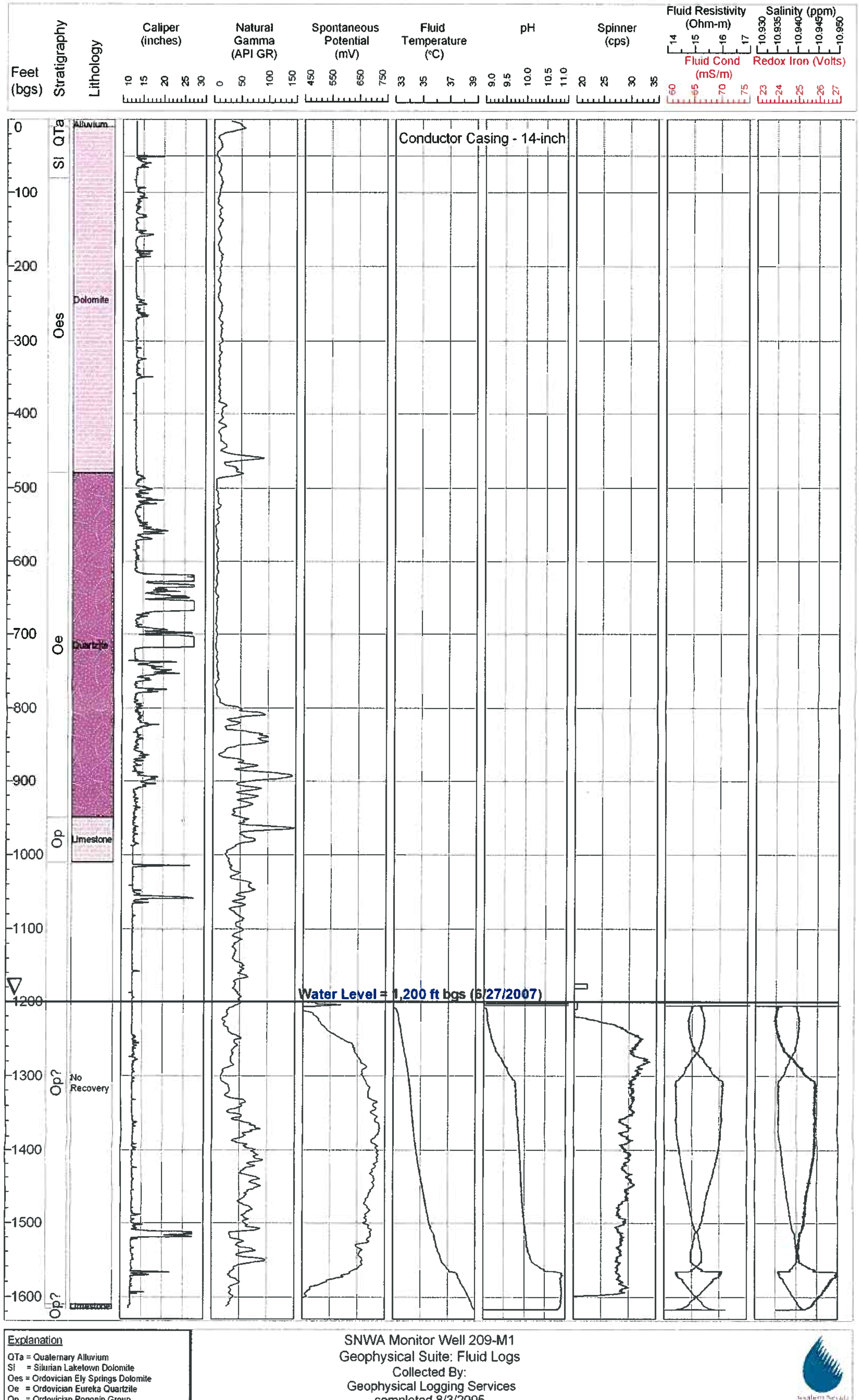
- Natural Gamma Ray
- Deep Induction (Resistivity)
- Medium Induction (Resistivity)
- Short Guard
- Long Guard
- Lateral Resistivity
- Spontaneous Potential
- Spectral Gamma – Potassium, Uranium, and Thorium (KUT)
- Total Spectral
- Neutron
- Density
- Sonic Delta T and Full Wave Sonic
- Fluid Temperature
- 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.



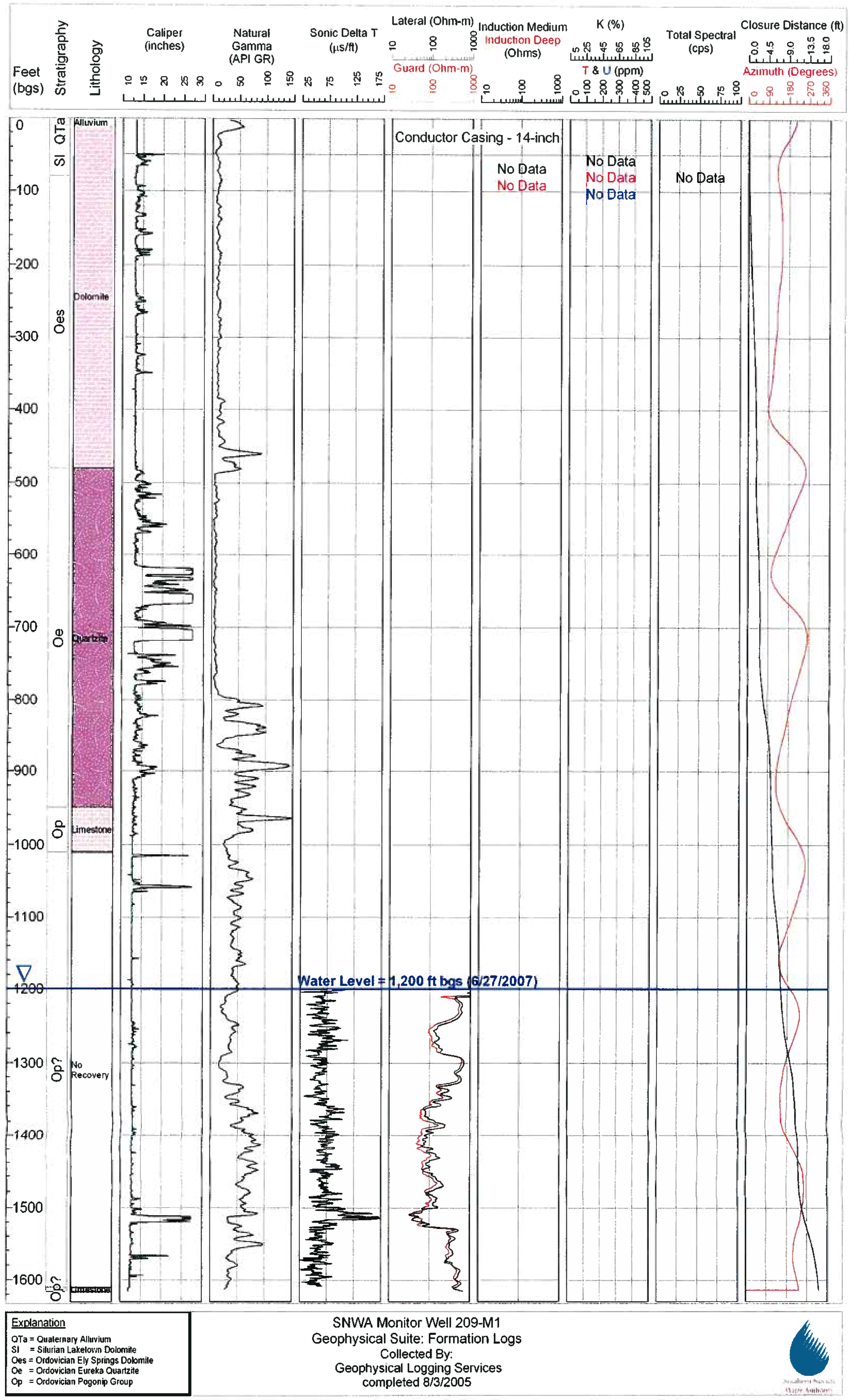
Correlation of geologic units with regional geologic units (RGUs) (Dixon et al., 2007):
The surficial alluvium is part of the QTa RGU.
The Silurian Laketown Dolomite (Sl) and the Ely Springs Dolomite (Oes) are part of the SOu RGU.
The Eureka Quartzite (Oe) and the Pogonip Group (Op) are part of the Ol RGU.

Figure 7
Borehole Stratigraphic Column of Monitor Well 209M-1



Note: Correlation with Regional Geologic Units (Dixon et al., 2007): The Silurian Laketown Dolomite and Ordovician Ely Springs Dolomite are part of the SOu RGU, and the Ordovician Eureka Quartzite and the Ordovician Pogonip Group are part of the OI RGU. Logs plotted by SNWA.

FIGURE 8
MONITOR WELL 209M-1 GEOPHYSICAL FLUID LOGS



Note: Correlation with RGUs (Dixon et al., 2007): The Silurian Laketown Dolomite and Ordovician Ely Springs Dolomite are part of the SOu RGU, and the Ordovician Eureka Quartzite and the Ordovician Pogonip Group are part of the OI RGU. Logs plotted by SNWA.

Figure 9
Monitor Well 209M-1 Geophysical Formation Logs

Muller (2007a, b, and c) evaluated the geophysical logs for Monitor Well 209M-1. The more reliable logs for this well include Resistivity logs (except the Induction logs), Spontaneous Potential, Fluid Temperature, Fluid Conductivity, Fluid Resistivity, Salinity, pH, Deviation, and Pressure. The Spontaneous Potential and Spinner logs are of questionable value, and the Natural Gamma Ray (Gamma) does not appear to correlate with the lithology. The Spectral, KUT, Density, Neutron, and Sonic Delta T logs do not appear to be valid.

The Gamma log indicates higher Gamma counts within the alluvium declining to about 10 gru within the dolomite. A slight increase in Gamma was noted beneath the surface casing, as was expected. An additional slight increase in Gamma from about 10 to 15 or 20 gru was noted at 385 ft bgs, continuing to 450 ft bgs. A zone of relatively high Gamma counts is present from 450 to 480 ft bgs, to a maximum of about 80 gru. This zone is of dolomite with sandstone, argillite, and quartzite beds.

Very low Gamma was noted within the upper 60 percent of the Eureka Quartzite, generally about 4 to 10 gru, to a depth of about 800 ft bgs. Below this depth, Gamma counts within the Eureka Quartzite were variable, from about 20 to 90 gru with several peaks up to 130 gru. The quartzite lithology is not particularly different within the low Gamma and higher Gamma zones, and this fact led Muller (2007a) to question the validity of the Gamma log. There is no correlation between the high Gamma and zones of higher iron oxides on fractures.

The contact of the Eureka Quartzite with the underlying Pogonip Group is marked by a slight increase in Gamma counts with a spike to nearly 150 gru about 15 ft below the contact, between 960 and 970 ft bgs. Gamma counts are variable within the Pogonip Group limestone, from about 20 to 90 gru, which is consistent with shaly units within the formation. Much of the Pogonip Group cuttings were not recovered, but the presence of shales is expected based on descriptions of the unit by Tschanz and Pampeyan (1970).

The Lateral and Guard logs are generally conformable and are discussed in this and subsequent paragraphs as Electric logs. These Electric logs indicate fairly resistant rock units with a slightly lower resistivity from 1,250 to 1,280 ft bgs and from 1,330 to 1,525 ft bgs. These intervals coincide with intervals of higher Gamma, higher than the higher-resistivity material above and below these zones. The coincidence of higher Gamma with lower resistivity is an indication of shale layers within the Pogonip Group. The low point on the Electric logs at 1,510 to 1,530 ft bgs corresponds to a caved interval, reduced Gamma, and a spike in the Sonic log. The variation in geophysical responses is probably due to the caved interval, but a change in the lithology or more likely a zone of fracturing may have resulted in the caving.

The Spontaneous Potential log has the form of a dome of high values between 1,250 and 1,570 ft bgs, with maximum values between 1,330 and 1,460 ft bgs. There are no spikes or drops in the Spontaneous Potential data except for a slight drop at 1,525 ft bgs, at the base of a 15-ft caved interval. The Spontaneous Potential drops at the same depth as a sharp rise in Fluid Temperature, at 1,570 ft bgs.

The Caliper log shows that the hole is variably caved in the interval from 480 to 950 ft bgs, with the largest caved interval occurring in several zones between approximately 625 and 725 ft bgs. Additional caved intervals are present to a depth of 775 ft bgs. The caved intervals indicate fracture zones within the Eureka Quartzite and spalling of the hole wall into the borehole. Further indications of these fracture zones are represented in the lithology as intervals with abundant iron oxides on fractures, particularly between 620 and 720 ft bgs, the zone of maximum caving of the borehole. The high degree of caving also explains the presence of up to 20 percent quartzite in the cuttings of limestone below the base of the Eureka Quartzite.

Short caved intervals occur at approximately 1,010 ft bgs and 1,050 ft bgs in the Caliper log. This caving coincides with the loss of circulation and lack of recovered samples below the depth of 1,010 ft bgs and a description of tight hole conditions at the same depth (Stoller, 2005). Important fracture zones appear to have been intersected at these depths.

The Fluid Temperature log increases from 33°C to 39°C from the water level to the base of the borehole. The rate of increase varies, slowing after 1,280 ft bgs, and increasing again below 1,400 ft bgs. A minor inflection occurs at 1,510 ft bgs, and a sharper inflection occurs at 1,570 ft bgs. These inflections represent fracture zones with probable groundwater interaction with the borehole. The lower temperatures are indicative of the borehole fluid, and the increasing temperature with depth is indicative of increasing percentages of groundwater with depth from zones of groundwater influx. On June 7, 2006, the monitor well was pumped for a geochemical sample, and the groundwater temperature at that time was 39.6°C (Acheampong et al., 2007). This value is coincident with the maximum value obtained from the Fluid Temperature log, a further indication of increasing mixing of groundwater with drilling fluid with depth. Much of the groundwater enters at the points of temperature inflection, particularly at 1,280, 1,510, and 1,570 ft bgs.

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

The Fluid Conductivity decreased from about 67 mS/m to 62 mS/m from 1,270 to 1,300 ft bgs, further indication of groundwater interaction within this interval diluting the drilling fluid. Below 1,300 ft bgs, the Fluid Conductivity increased steadily back to 67 mS/m, with a slight inflection at 1,510 ft bgs. A sharp reduction in Fluid Conductivity occurred at 1,570 ft bgs, emphasizing the interaction of groundwater at this depth as the drilling fluid is diluted. The increase in Fluid Conductivity below 1,570 ft bgs indicates reduced dilution of the drilling fluid. On June 7, 2006, the Electrical Conductance, which is equivalent to Fluid Conductivity, was 48.7 mS/m (Acheampong et al., 2007), lower than that of the Fluid Conductivity log. This lower conductance of the groundwater emphasizes that the decreases in the Fluid Conductance are indicative of groundwater interaction with the borehole fluid.

The Spinner log is relatively unvarying and suggests little or no upward or downward flow within the borehole. As indicated by Muller (2007a, p. 9), the Spinner log was collected using a micro electric tool that "does not appear to be responding to formation hydrologic flow properties" and therefore may not be valid.

The well video indicates a water level of about 1,205 ft bgs. Above the water table, harsh lighting and debris on the camera lens obscured most of the features of the borehole. Additionally, turbid water and harsh lighting conditions obscured visibility in some intervals below the water table, most notably below 1,570 ft bgs. The video was sufficient to observe several large caved intervals, including at 1,015 ft bgs, and that calcite veining was common. Additionally, light and dark gray-colored bands (beds) of rock were observed, especially at 1,376 ft bgs. This feature is reported in published descriptions of Pogonip Group (Tschanz and Pampeyan, 1970), confirming the assumption that the lower 605 ft of the monitor well was drilled in this geologic unit.

The Deviation (Closure Distance) log indicates that the borehole deviates approximately 16.1 ft S22W. An inflection in the curve of the hole deviation begins at 770 ft bgs. This depth represents the base of a zone of caved intervals and fracture zones within the Eureka Quartzite. Unfractured quartzite was likely more difficult to drill and, therefore, caused the increase in hole deviation. As the borehole was being drilled with a hammer bit, the greater hardness of the formation had little effect on the drilling parameters (Section 2.2.3).

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

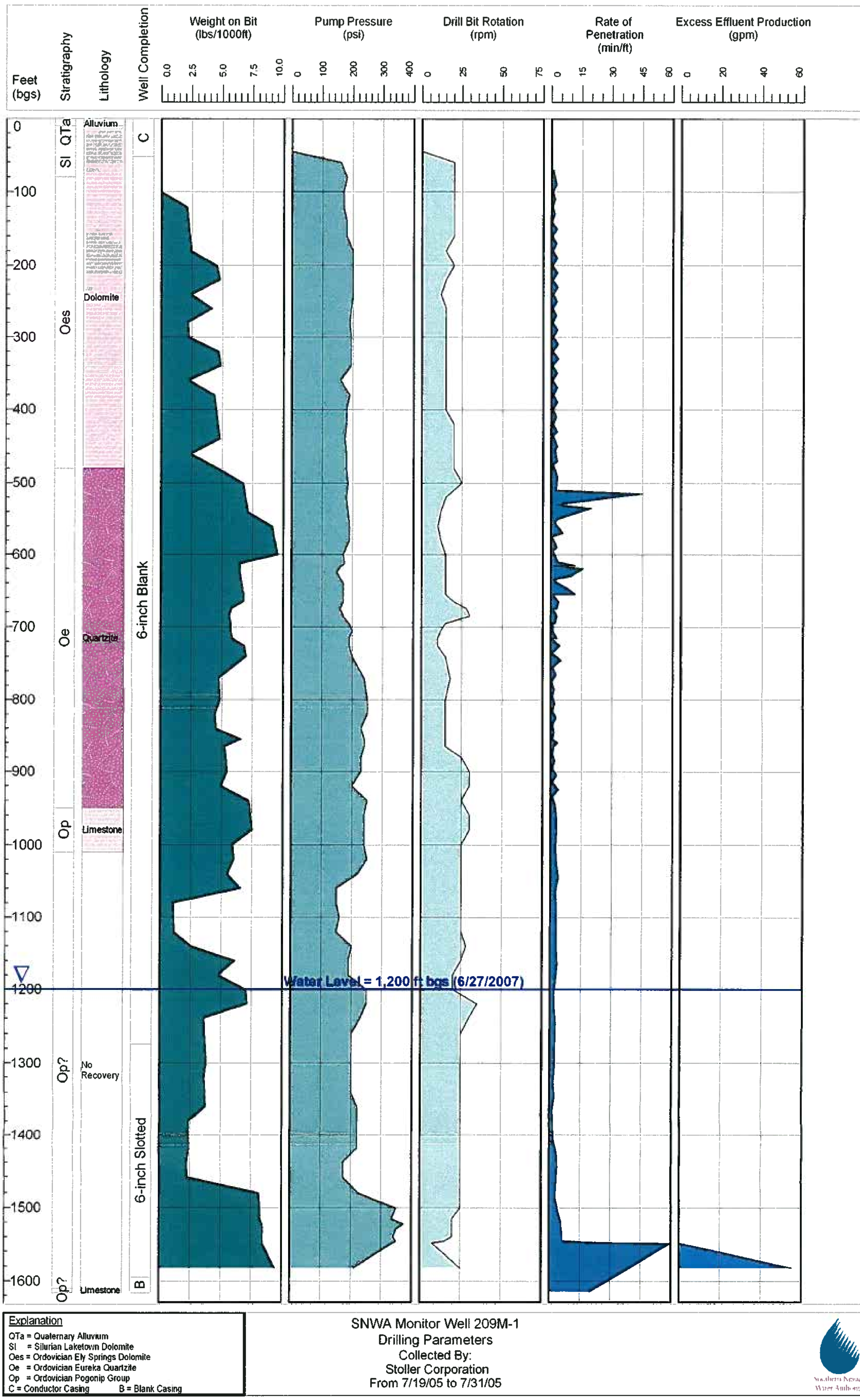
These drilling parameters are presented on Figure 10.

Except for specific intervals, the penetration rate was in the range of 1 to 5 min/ft. Low penetration rates were encountered between 510 and 545 ft bgs and to a lesser extent between 610 and 650 ft bgs. These low penetration rates are due to drilling in very hard, relatively unfractured Eureka Quartzite beneath the overlying Ely Springs Dolomite. The penetration rate was also low between 1,540 ft bgs and the total depth of the borehole. This low rate was apparently due to a worn-out bit (Stoller, 2005) and may have been compounded by caving at 1,510 ft bgs that may have interfered with the drilling.

The contact between the Eureka Quartzite and the overlying Ely Springs Dolomite at 480 ft bgs is also indicated by an increase in the Weight on Bit, and at 510 ft bgs there was a decrease in the Drill Bit Rotation. The decreased Drill Bit Rotation may be due to tight hole conditions in combination with hole caving commonly encountered within the Eureka Quartzite. A short interval of increased Drill Bit Rotation from 570 to 590 ft bgs corresponds to an uncaved portion of the quartzite. Drill Bit Rotation increased in the Pogonip Group limestone beneath the Eureka Quartzite.

The weight on the bit decreased sharply at 1,070 ft bgs and continued at a low weight to 1,130 ft bgs. This zone is most likely a lithology that was easily drilled by the hammer bit in use at the time. The drilling contractor may have increased the weight on the bit at 1,140 to 1,230 ft bgs in response to zones of more difficult drilling. There is no correlation of these changes in the Weight on Bit with the lithology indicated by the geophysical logs, but greater induration of the carbonates may not show a geophysical response.

The Weight on Bit and the Pump Pressure logs illustrate elevated values in the interval from 1,470 ft bgs to the total depth, corresponding first to a small and then a sharp decrease in penetration rate, the latter at 1,550 ft bgs. The high pump pressure corresponds to tight hole conditions indicated by Stoller (2005) in this interval. The higher weight on the bit may have been the contractor's response to a slight decrease in penetration rate. This depth also corresponds closely to a slight change in the



Note: Correlation with RGUs (Dixon et al., 2007): The Silurian Laketown Dolomite and Ordovician Ely Springs Dolomite are part of the SOu RGU, and the Ordovician Eureka Quartzite and the Ordovician Pogonip Group are part of the OI RGU. Logs plotted by SNWA.

FIGURE 10
MONITOR WELL 209M-1 DRILLING PARAMETERS

downhole assembly (Stoller, 2005). The drill bit rotation has little correlation with the penetration rate except for the interval from 1,550 to 1,560 ft bgs, where a clay zone may have slowed down the bit rotation.

2.3 HYDROGEOLOGY

Monitor Well 209M-1 was completed (screened) within the Ordovician Pogonip Group. A large portion of the flow to the monitor well is from fractures at the depth of approximately 1,565 ft bgs, approximately 300 ft below the static water level. This depth corresponds to a reduction in Gamma and an increase in the resistivity shown by the Electric logs. These changes indicate a decrease in the shale content of the Pogonip Group limestone and an increase in formation permeability as discussed in Section 2.2.2. Most of the increased drilling effluent was reported by Stoller (2006) to occur below 1,550 ft bgs (Figure 10).

A depth to water level of 1,200.92 ft bgs was taken on January 13, 2006, by SNWA (Stoller, 2006). The surface elevation at the well is approximately 5,120 ft amsl, which gives a groundwater elevation of approximately 3,919 ft amsl. This site has not been professionally surveyed. In addition, seven water level readings have been taken since June 2006, ranging from 1,199.8 to 1,200.2 ft bgs. All of the readings vary by less than 1.0 ft from the average measurement taken after hole completion, except the June 2006 reading, which was taken with an airline and therefore with a lower level of accuracy. Table 2 summarizes the water level measurement collected at the monitor well.

TABLE 2
WATER LEVEL MEASUREMENTS FOR MONITOR WELL 209M-1

Date	Time	Depth (ft bgs)	Elevation (ft amsl)	Data Collected By
7/26/2005	8:20	1,205.0	3,915	Stoller (2006) Incomplete hole
7/26/2005	23:20	1,214.0	3,906	Stoller (2006) Incomplete hole
8/1/2005	16:00	1,204.0	3,916	Stoller (2006) Incomplete hole
1/13/2006	NP	1,200.92	3,919	SNWA
6/7/2006	12:00	1,203	3,917	Layne Christensen Co. (Yermo, CA) (SNWA, 2006)
10/24/2006	15:01	1,199.86	3,920	SNWA
12/11/2006	11:05	1,200.02	3,920	SNWA
1/22/2007	14:53	1,200.12	3,920	SNWA
2/26/2007	11:40	1,199.84	3,920	SNWA
4/2/2007	11:48	1,199.97	3,920	SNWA
5/14/2007	12:28	1,200.05	3,920	SNWA
6/20/2007	13:30	1,200.18	3,920	SNWA
6/27/2007	16:36	1,200.08	3,920	SNWA

Note: Groundwater elevations in the above table are rounded to the nearest foot to reflect the uncertainty in the surface elevation of the well and the variability of the water level measurement procedures.
NP - Not Provided.

2.4 SUMMARY

Monitor Well 209M-1 was drilled in July and August 2005 for the purpose of collecting geologic, hydrologic, and geochemical data. This monitor well is located in Pahranagat Valley near the hydrologic divide of four hydrographic areas (HAs 209, 182, 181, and 208) and was drilled to total depth of 1,616 ft bgs, with a slotted interval from 1,273.5 to 1,595 ft bgs.

The monitor well encountered 10 ft of alluvium, below which are Silurian Laketown Dolomite and Ordovician Ely Springs Dolomite, which are partially exposed locally, and Ordovician Eureka Quartzite and limestone of the Pogonip Group, which are not exposed locally. Only the lowermost 70 ft of the Laketown Dolomite was penetrated; this interval corresponds to the dark gray lower portion of Tschanz and Pampeyan (1970). The apparent thickness of Ely Springs Dolomite is 400 ft and the apparent thickness of the Eureka Quartzite is 470 ft. The thicknesses of these units are somewhat consistent with those given by Tschanz and Pampeyan (1970), though the Ely Springs Dolomite is about 100 ft thinner than other published thicknesses.

The geologic data and borehole video indicated that the rocks are fractured and veined, with some fractures healed with calcite. Iron oxides are common on fractures within the Eureka Quartzite. No large fault was observed within the monitor well, which is consistent with the published geologic literature of the area (Tschanz and Pampeyan, 1970; Scott et al., 1992; Dixon et al., 2007).

Geophysical logs and drilling parameters provided additional data for analysis. The geophysical and drilling parameter data assisted in confirming the geologic contacts indicated in the cuttings and in further defining the geology within the intervals in which no cuttings were available. The geophysical logs also indicated zones of groundwater interaction with the borehole and were consistent with published reports of shales within the Ordovician Pogonip Group between 1,320 and 1,530 ft bgs.

Water-level measurements indicate a water-level elevation of approximately 3,920 ft bgs. The majority of the groundwater flow appears to be below the shale-bearing section of the Ordovician Pogonip Group limestone that extends to about 1,530 ft bgs.

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