Doc No. RDS-ED-0004

Southern Nevada Water Authority

Geologic Data Analysis Report for Monitor Well 180W501M in Cave Valley

October 2007

Doc No. RDS-ED-0004

SOUTHERN NEVADA WATER AUTHORITY

Geologic Data Analysis Report for Monitor Well 180W501M in Cave Valley

Prepared by: Harvey S. Eastman

November 2007

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

Contents

FIGURES

TABLES

ACRONYMS

API GR	American Petroleum Institute gamma ray unit
ASTM	American Society for Testing and Materials
BLM	Bureau of Land Management
RGU	regional geologic unit
SNWA	Southern Nevada Water Authority
TD	total depth
TDS	total dissolved solids
USCS	Unified Soil Classification System
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

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 180W501M is located in western Cave Valley in Section 31, T9N, R64E, at an elevation of approximately 6,445 ft amsl (Figure 2). The site is approximately 46 mi south of Ely, Nevada, and 20 mi south-southeast of Lund, Nevada. It is 11 mi east of Nevada State Route 318 through Shingle Pass. The site can also be accessed from Ely, Nevada, by a gravel road to Cave Valley from U.S. Highway 93 in Steptoe Valley.

1.1 PURPOSE AND SCOPE

The purpose of this report is to describe the geologic, geophysical, and hydrologic data collected for Monitor Well 180W501M. 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.

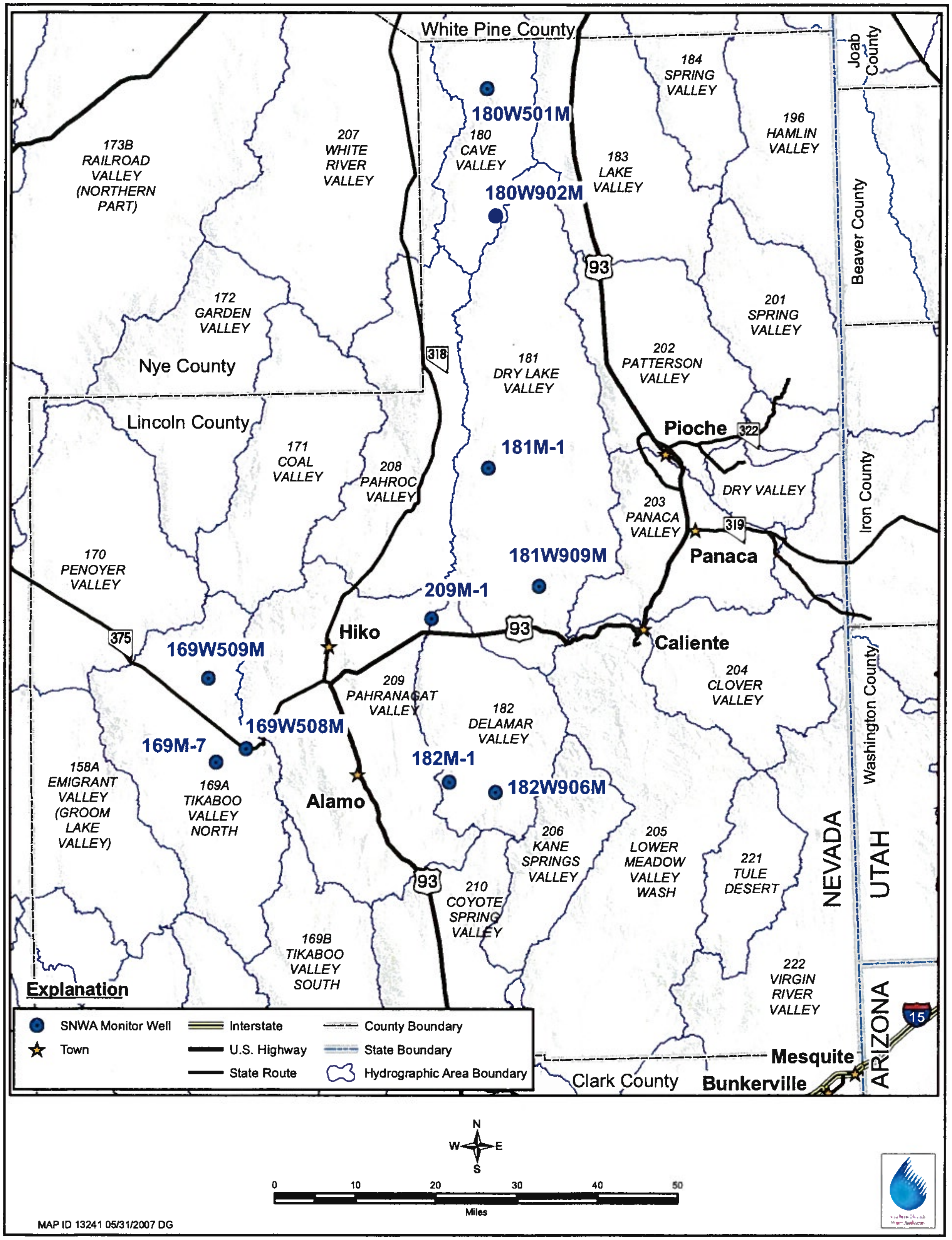
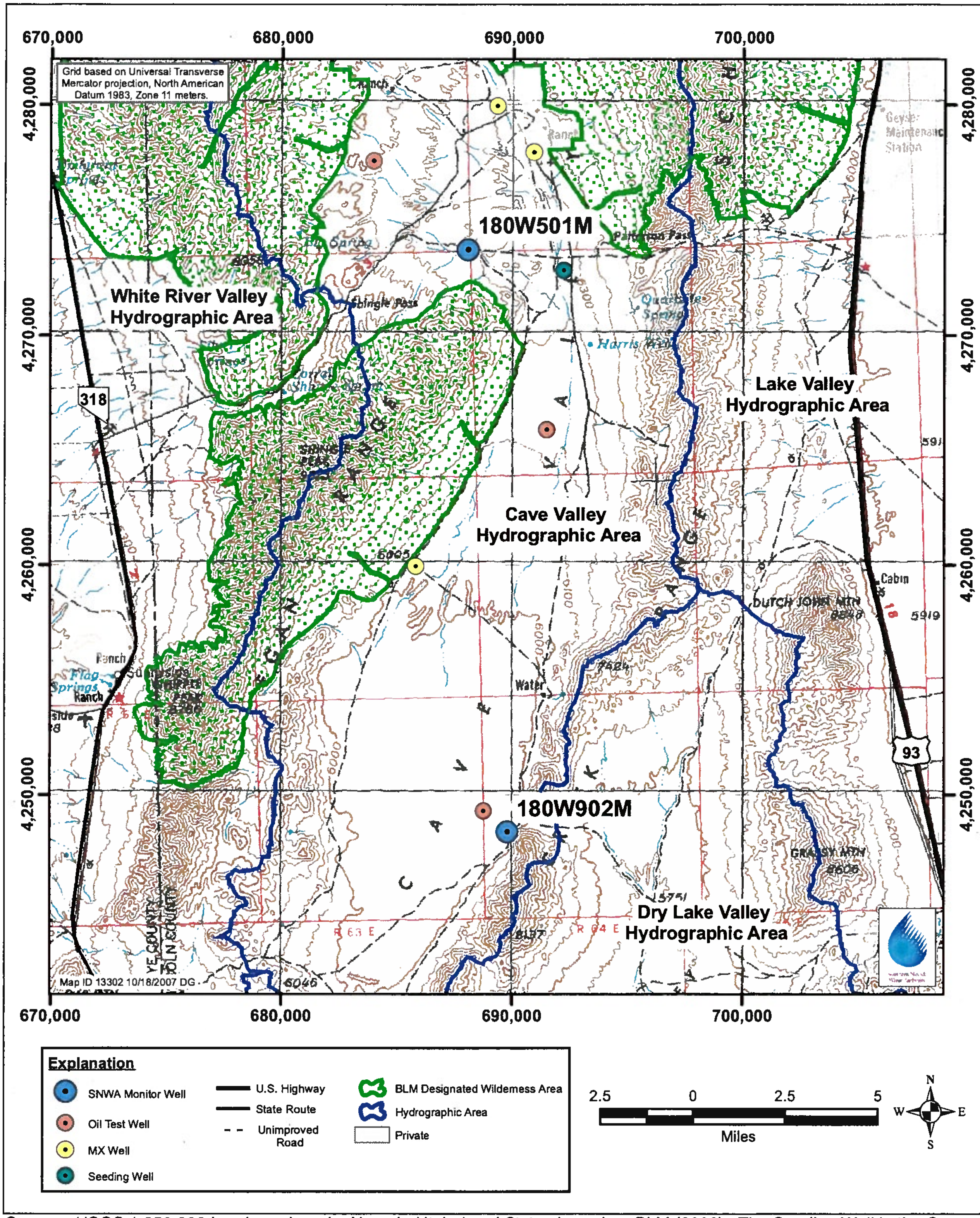


Figure 1
SNWA Monitor Well Locations, Lincoln County, Nevada



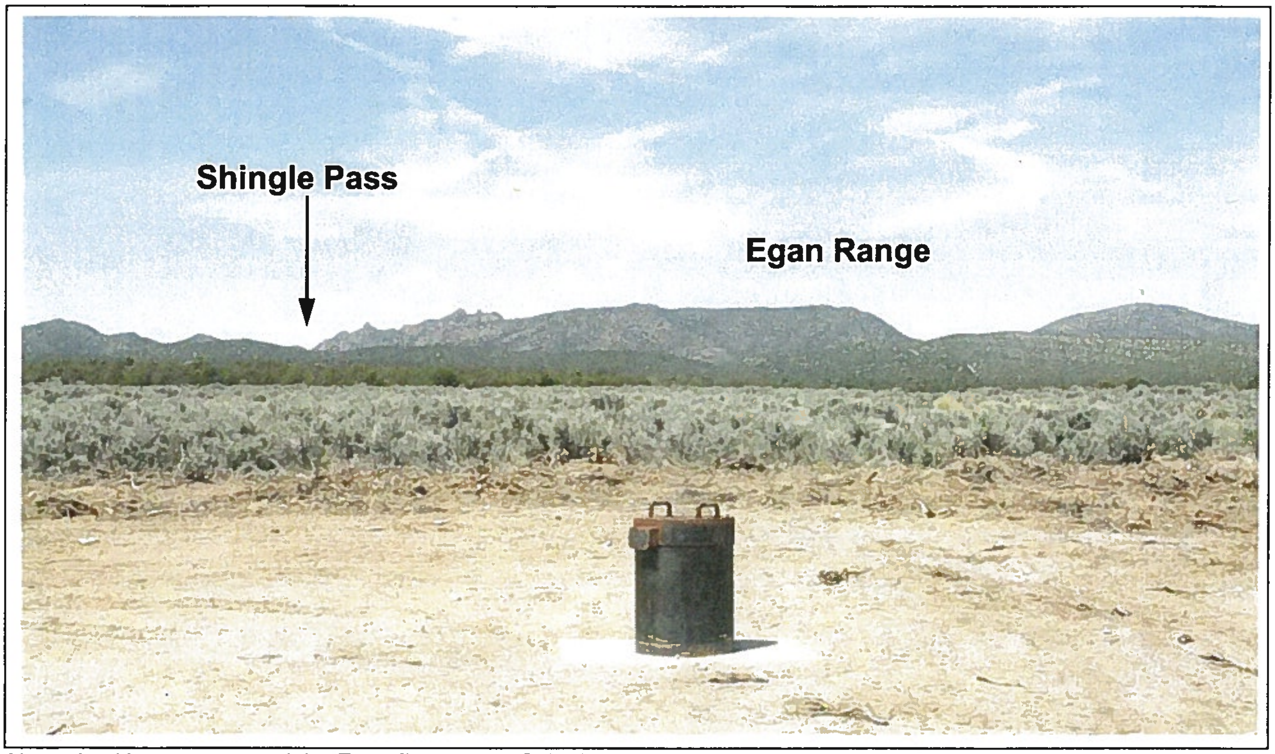
Source: USGS 1:250,000 Lund quadrangle, Nevada-Utah; Land Status based on BLM (2006). The Seeding Well is the Cave Valley Seeding Well, the nearest water well to Monitor Well 180W501M.

FIGURE 2
LOCATION OF MONITOR WELL 180W501M, LINCOLN COUNTY, NEVADA

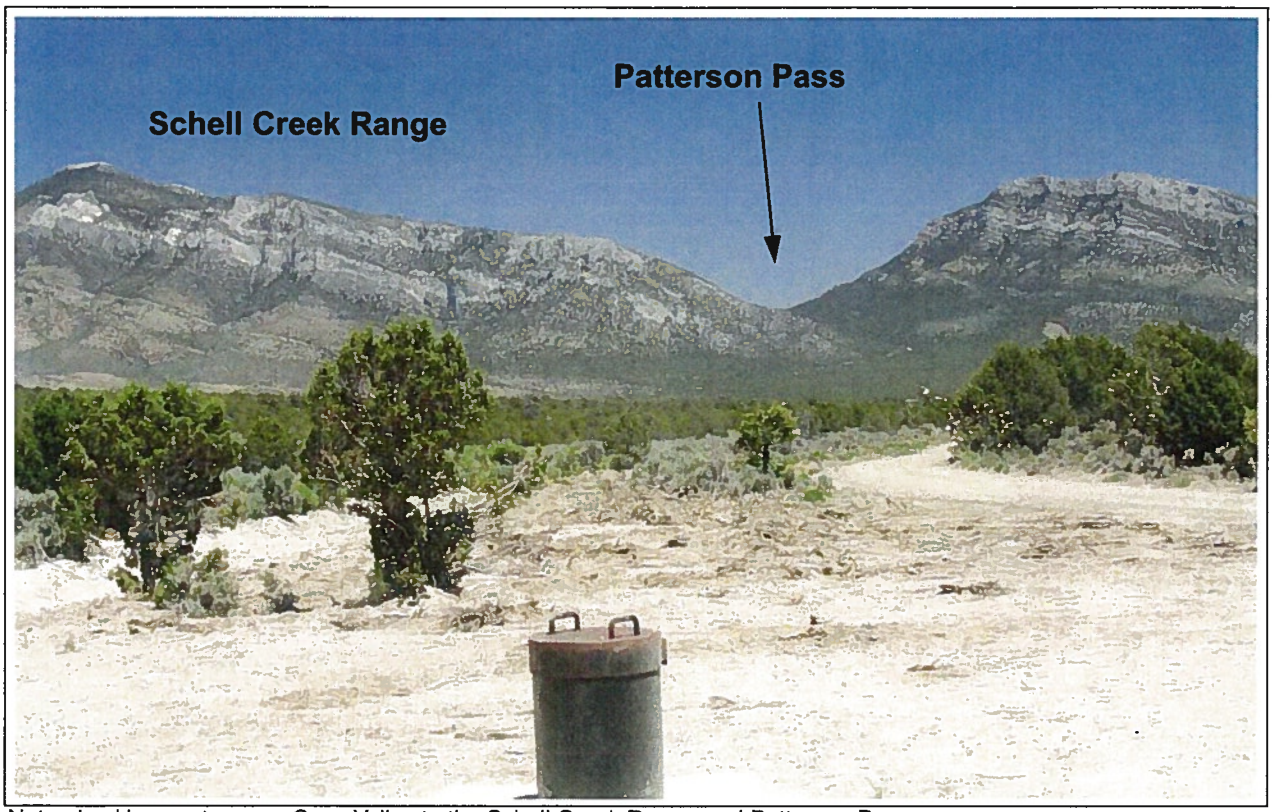
1.3 SUMMARY OF MONITOR WELL CONSTRUCTION

Monitor Well 180W501M was drilled and completed from September 17 to September 23, 2005, to a depth of 1,215 ft bgs. The monitor well was completed with 14-in. O.D. conductor casing to 54 ft bgs and 6.625-in. O.D. (6-in. I.D.) well casing from 3.0 ft above land surface to 1,212.0 ft bgs with a slotted interval from 787.8 to 1,191.8 ft bgs. The completion borehole was drilled using air-foam and flooded reverse circulation drilling techniques with a borehole diameter of 12.25 in.

Figure 3 presents photographs of the well site taken on May 11 (top) and June 19 (bottom), 2007. For additional information on the well construction refer to Stoller (2006).



Note: Looking west toward the Egan Range and Shingle Pass.



Note: Looking east across Cave Valley to the Schell Creek Range and Patterson Pass.

FIGURE 3
TWO VIEWS OF MONITOR WELL 180W501M SITE

2.0

DATA ANALYSIS

This section analyzes the lithology, geophysical logs, and drilling statistics to evaluate the geology encountered in Monitor Well 180W501M.

2.1 GEOLOGIC SETTING

Cave 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, west of Monitor Well 180W501M, is marked by a north-trending shear that is associated with the extensional tectonics.

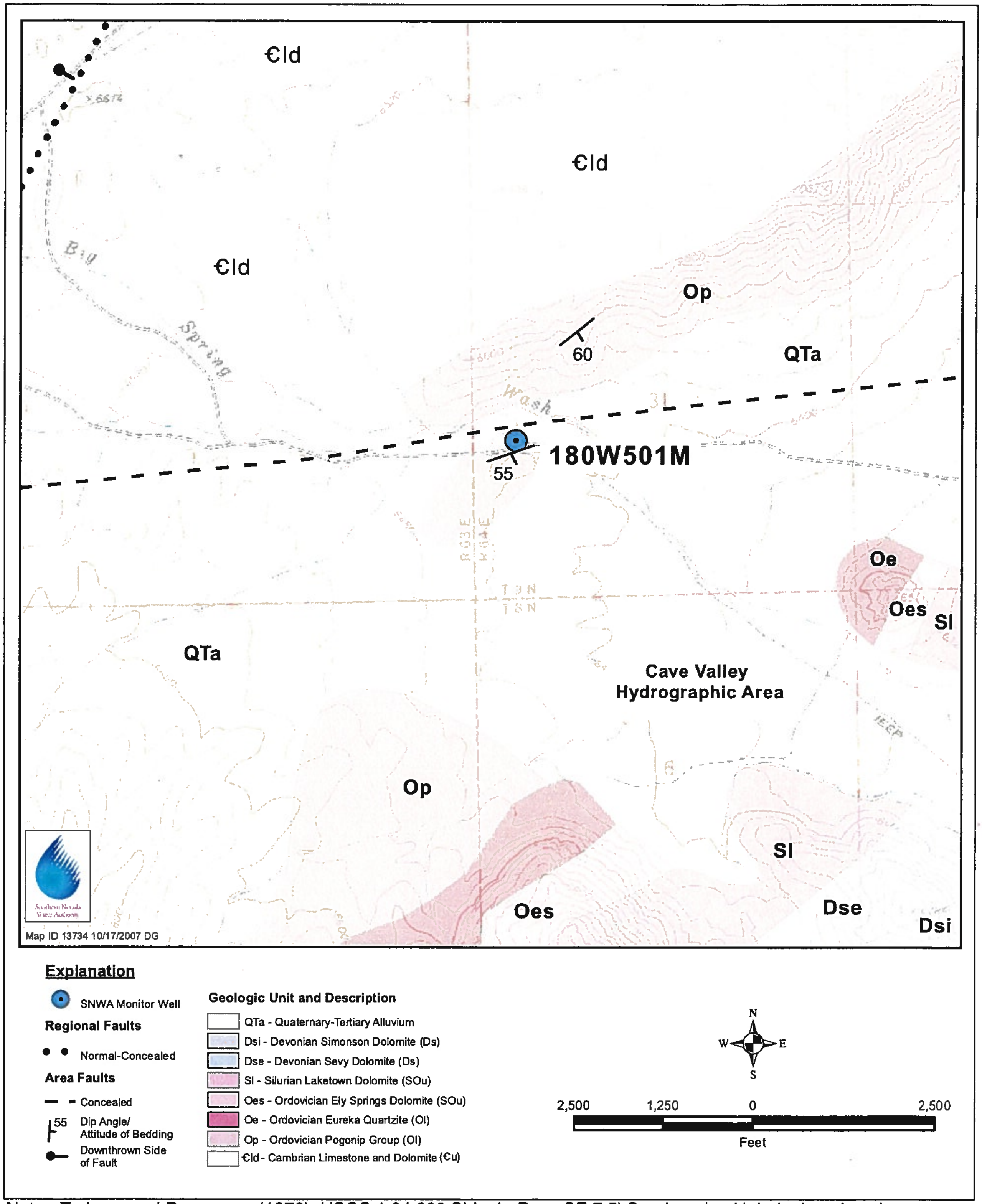
Monitor Well 180W501M is situated on the west side of the Cave Valley Hydrographic Area (Figure 2). The surface geology at the well site is of Quaternary alluvium overlying Ordovician and Cambrian carbonate rocks. Based on the geomorphology of the area and the borehole cuttings, a roughly east-west fault is inferred to traverse the area near the monitor well site. The surface geology is shown on Figure 4.

2.1.1 GEOLOGIC UNITS ENCOUNTERED AT THE MONITOR WELL

The geologic units encountered in Monitor Well 180W501M consist of alluvium, the Ordovician Pogonip Group, and upper Cambrian limestone and dolomite. 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 Ordovician Pogonip Group is part of the Lower Ordovician (Ol) RGU, and the Cambrian limestone and dolomite unit is part of the upper Cambrian (Ꞓu) RGU (Dixon et al., 2007).

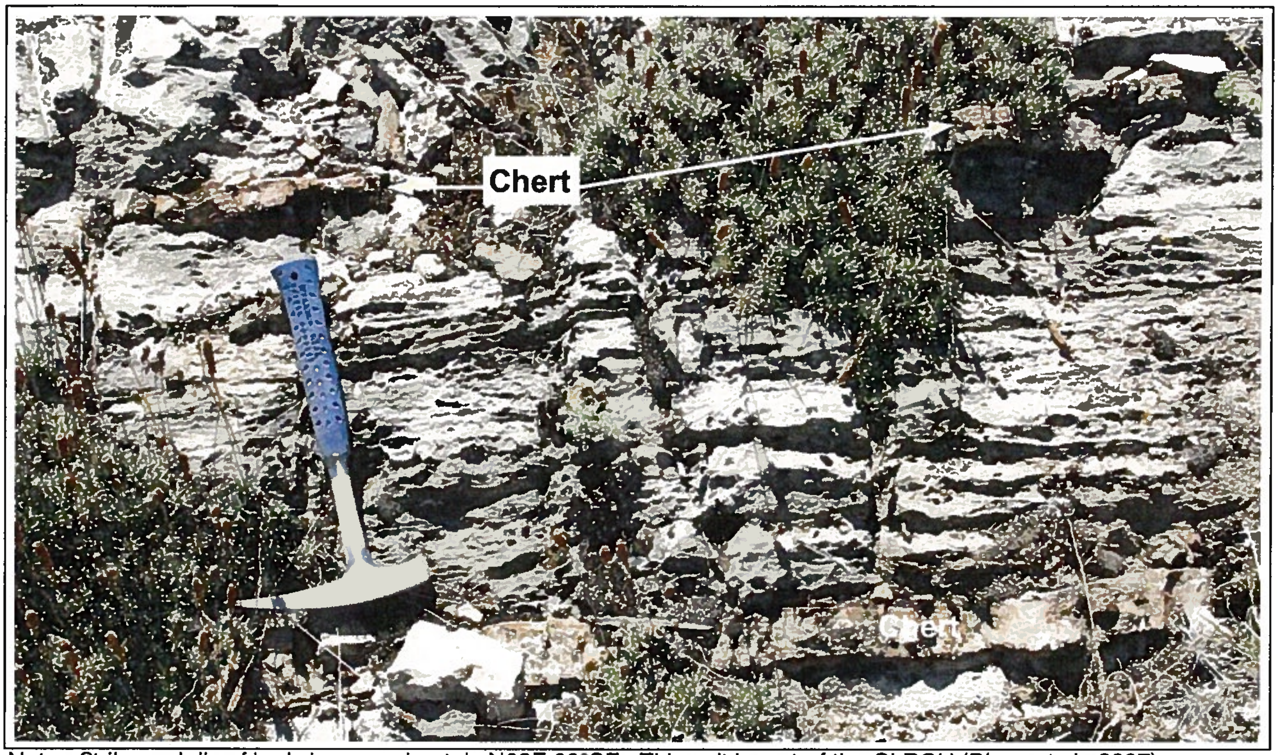
The Pogonip Group is dominated by a sequence of limestone units with common silt and shale layers, which can be up to 260 ft thick (Tschanz and Pampeyan, 1970; Kellogg, 1963). The Pogonip Group is often fossiliferous and cherty. The base of the Pogonip Group is indistinct but is marked by a change from predominantly limestone beds to predominantly dolomite beds of the underlying unit (Tschanz and Pampeyan, 1970). The total thickness of the Pogonip Group is about 3,390 ft in the southern Egan Range (Tschanz and Pampeyan, 1970). Kellogg (1963) noted that the chert content increases above the lower contact to as much as 70 percent chert at 150 to 200 ft above the base of the formation (Figure 5).

Below the Pogonip Group is an unnamed sequence of Cambrian limestone and dolomite, of which the upper portion is represented in Monitor Well 180W501M. The Cambrian carbonate sequence is dominantly of dolomite, generally banded, with limestone beds within the upper part of the sequence (Tschanz and Pampeyan, 1970; Kellogg, 1963). Kellogg (1963) placed the contact with the Ordovician Pogonip Group at the top of the uppermost dolomite in the Cambrian unit, above which is cherty limestone (Figure 5). This contact was noted in the field and is shown on Figure 6. The total thickness of the Cambrian limestone and dolomite unit ranges from 1,624 to 1,883 ft in the southern Egan Range (Kellogg, 1963).



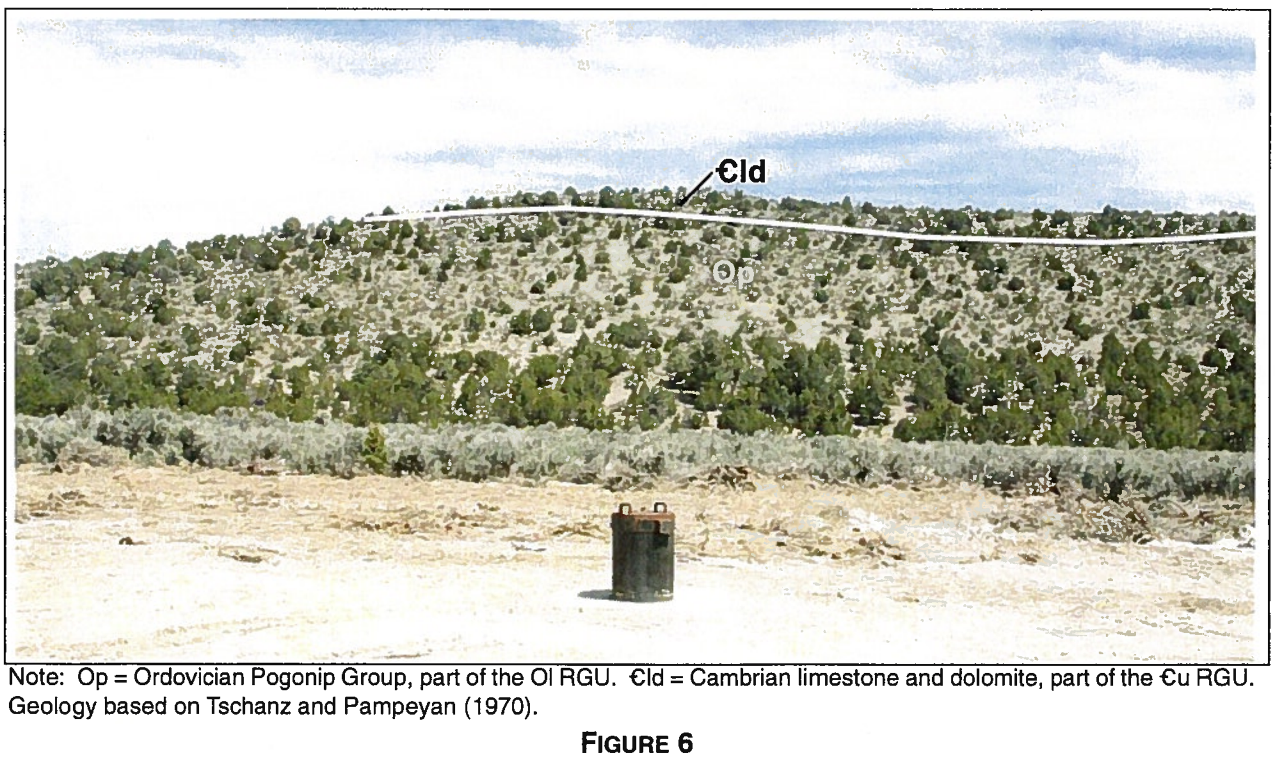
Note: Tschanz and Pampeyan (1970); USGS 1:24,000 Shingle Pass SE 7.5' Quadrangle. Unit designations in parentheses are the RGUs defined in Dixon et al. (2007).

FIGURE 4
GEOLOGIC MAP AROUND MONITOR WELL 180W501M, WESTERN CAVE VALLEY



Note: Strike and dip of beds is approximately N63E 60°SE. This unit is part of the Ol RGU (Dixon et al., 2007).

FIGURE 5
CHERTY LIMESTONE OF THE ORDOVICIAN POGONIP GROUP, SOUTH OF MONITOR WELL 180W501M

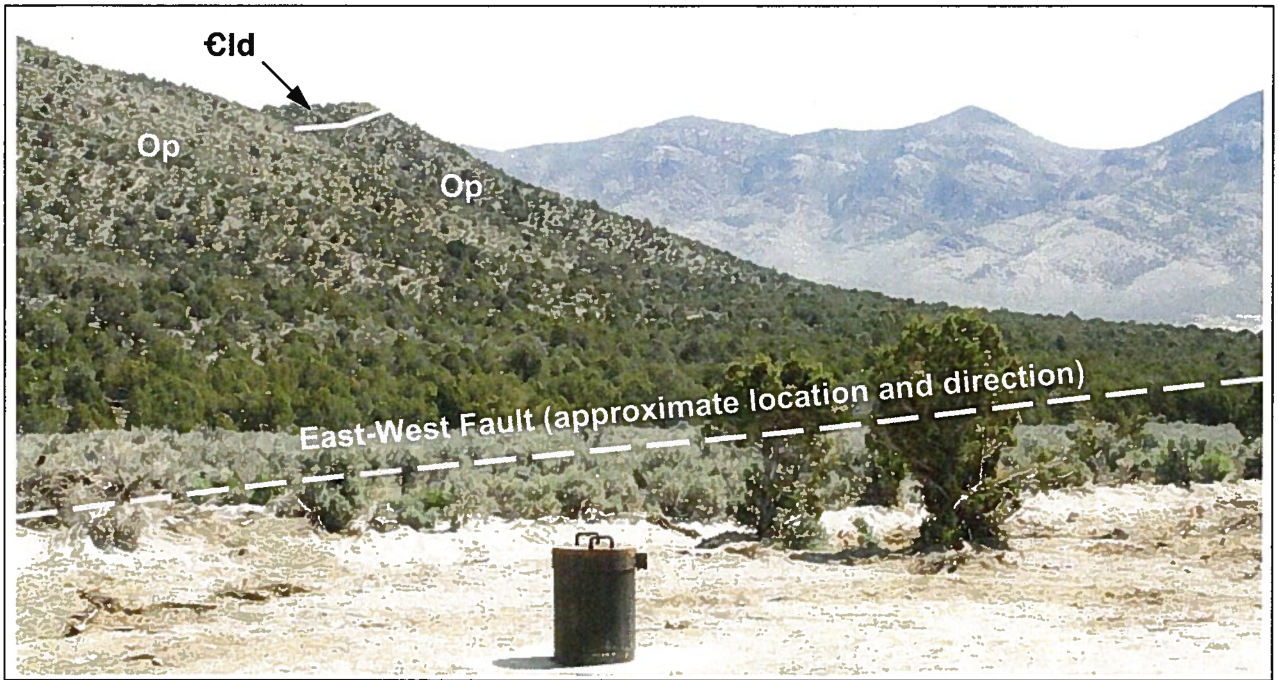


Note: Op = Ordovician Pogonip Group, part of the Ol RGU. €ld = Cambrian limestone and dolomite, part of the €u RGU. Geology based on Tschanz and Pampeyan (1970).

FIGURE 6
OUTCROP OF ORDOVICIAN POGONIP GROUP AND CAMBRIAN CARBONATES, LOOKING NORTH FROM MONITOR WELL 180W501M TOWARD HILL

2.1.2 GEOLOGIC STRUCTURE AT THE MONITOR WELL SITE

To the west of the monitor well site is a shear zone that passes through Shingle Pass and then northward along the east side of the Egan Range. No structures are noted in the vicinity of the well site, but the geomorphology and the field and borehole evidence of bedding offsets suggest a roughly east-west or east-northeast structure along Big Spring Wash, the drainage just north of the monitor well (dashed structure across center of Figure 4 and Figure 7). Other features include calcite vein-filled fractures striking N35E and N5W with a near-vertical dip (Figure 8). The Ordovician and Cambrian carbonates are commonly fractured at about N75E to N85E with a dip of 53° to 75°NW, roughly parallel to the east-west to east-northeast structure indicated above and shown in Figure 7.



Note: Op = Ordovician Pogonip Group limestone, part of the Ol RGU. €ld = Cambrian limestone and dolomite, part of the €u RGU (Dixon et al., 2007). The fault may parallel N75E to N85E fracturing commonly found in the Paleozoic carbonates.

FIGURE 7
APPROXIMATE LOCATION OF AN EAST-WEST OR EAST-NORTHEAST FAULT, LOOKING NORTHEAST FROM MONITOR WELL 180W501M

2.2 MONITOR WELL 180W501M

Monitor Well 180W501M 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 180W501M 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 field observations and descriptions by Tschanz and Pampeyan (1970) and Kellogg (1963). A summary of the lithologic log is included in Table 1.

Note: Op - ls = Pogonip Group limestone, part of the OI RGU (Dixon et al., 2007). View is to the northeast.

FIGURE 8
CALCITE-FILLED FRACTURE IN THE ORDOVICIAN POGONIP GROUP, NORTH OF MONITOR WELL 180W501M

The lithology encountered during drilling includes three rock types: alluvium, limestone, and dolomite. Cuttings from the first 60 ft of the well were not preserved, but according to Stoller (2006), this interval was of alluvium and Ordovician Pogonip Group limestone. The alluvium was encountered from the surface to about 15 ft bgs (Stoller, 2006).

Below the top 15 ft, Stoller (2006) reported bedrock of Ordovician Pogonip Group limestone. This limestone extends to a fault at about 130 to 140 ft bgs, where the rock is a fault gouge of calcareous clay with silt and sand-sized calcite crystals and limestone fragments. Below 140 ft bgs, the rock is a mixture of limestone and dolomite. Below 340 ft bgs, the rock is almost all dolomite and is considered to be the upper Cambrian limestone and dolomite of Tschanz and Pampeyan (1970).

Between 540 and 620 ft bgs, circulation was lost and no cuttings were returned. From 620 to 670 ft bgs the cuttings are of calcareous clay, silt, and sand-sized particles, primarily of calcite and limestone fragments. This zone is inferred to be a fault zone of sheared limestone and minor dolomite. Below this zone is a cherty limestone that extends to 870 ft bgs. The chert content decreases below 780 ft bgs, and dolomite intervals are present. Below 870 ft bgs, the rock is dominated by a mottled dolomite to the bottom of the hole. The cherty limestone is of the Ordovician Pogonip Group, and the dolomite is of the Cambrian limestone and dolomite of Tschanz and Pampeyan (1970). The variation in chert, increasing upward, fits with Kellogg's (1963) description indicating an increasing amount of chert up section in the Ordovician Pogonip Group. The sequence of dolomite and limestone fits with field evidence across the Ordovician-Cambrian boundary and Tschanz and Pampeyan's (1970) observation that the Cambrian limestone and dolomite unit is dominated by dolomite but has some limestone beds near the top of the formation.

Table 1
Lithology of Monitor Well 180W501M
(Page 1 of 2)

Interval Top to Base (ft bgs)	Geologic Unit	General Lithology	Description of Cuttings
0 to 15	QTa	Alluvium SW	Well graded sand with gravel and minor silt, mod yellowish brown, sand is poorly sorted, sub-rounded to angular. Carbonates, conglomerate, and mafics (Stoller, 2006). No samples were collected.
15 to 60	Op (Ol)	Limestone	Limestone (Stoller, 2006). No samples collected.
60 to 130	Op (Ol)	Limestone	Med to dark gray limestone. Fine to med grained, sucrosic texture. Occ calcite vlts or banding.
130 to 140	Fault	Calcareous clay	Lt to med gray calcite and limestone frags as silt-sand mixed with an off-white calcareous clay.
140 to 360	Op (Ol)	Limestone dolomite	Lt to dark gray limestone and dolomite about 70% limestone and 30% dolomite; white calcite and dolomite vlts or recrystallized bands. Med to coarse sucrosic texture. Occ limonite, as coatings and often after pyrite.
360 to 520	€ld (€u)	Dolomite	Lt to dark gray dolomite with white dolomite vlts or recrystallized bands. Matrix is generally mod to coarsely crystalline between white "bands" of coarsely crystalline dolomite. This rock appears to have been recrystallized from the original material. The nature of the coarsely crystalline white dolomite is not clear from the cuttings. They could be vlts, veins, bands, lenses, or some other form[a].
520 to 540	€ld (€u)	Dolomite	Lt to dark gray dolomite with white dolomite vlts or recrystallized bands, as above. White dolomite veins slightly more abundant.
540 to 620	--	--	No samples collected due to lost circulation.
620 to 670	Fault	Calcareous gouge	Lt to med gray calcite and limestone frags as silt-sand mixed with an off-white calcareous clay. Trace limonite.
670 to 780	Op (Ol)	Cherty Limestone	Lt to dark gray cherty limestone, chert as small nodules to 1/2-in. band in cuttings. Limestone generally fine to coarse sucrosic. Occ calcareous sandstone frags. Occ dolomitic bands or vlts.
780 to 870	Op (Ol)	Limestone	Limestone as above with less chert, and dolomite. Dolomite is sucrosic and mod to coarsely crystalline with dolomite bands or vlts. Limestone is fine sucrosic. Calcareous sandstone or sandy limestone 0% to 15%, often weakly limonitic or hematitic.
870 to 1,050	€ld (€u)	Dolomite	Mottled lt gray to dark gray dolomite, sucrosic and mod to coarsely crystalline. Dolomite vlts and veining or banding is common. Occ limestone beds, typically micro-sucrosic.
1,050 to 1,060	€ld (€u)	Dolomite	Mottled lt gray to dark gray dolomite as above. Abundant calcite veins.
1,060 to 1,100	€ld (€u)	Dolomite	Mottled lt gray to dark gray dolomite, sucrosic and mod to coarsely crystalline. Dolomite vlts and veining or banding is common.
1,100 to 1,110	€ld (€u)	Dolomite - Limestone	Mottled lt gray to dark gray dolomite and limestone. Sucrosic and mod to coarsely crystalline dolomite and fine to med sucrosic limestone.
1,110 to 1,160	€ld (€u)	Dolomite	Lt gray to dark gray dolomite, sucrosic and mod to coarsely crystalline. Dolomite vlts and veining or banding is common. Occ limestone, <15%, and calcite. Occ limonite on fractures.
1,160 to 1,170	€ld (€u)	Cherty Dolomite	Lt gray to dark gray, greenish gray, and brownish gray dolomite with limy chert. Dolomite med to coarse crystalline. Occ vugs and dolomite vlts.

Table 1
Lithology of Monitor Well 180W501M
(Page 2 of 2)

Interval Top to Base (ft bgs)	Geologic Unit	General Lithology	Description of Cuttings
1,170 to 1,210	€ld (€u)	Dolomite	Lt gray to dark gray mottled dolomite, sucrosic and mod to coarsely crystalline. Dolomite vlts and veining or banding is common. Occ limestone, <15%, and calcite. Occ limonite on fractures.
1,210 to 1,215	€ld (€u)	--	Slough

[a]The borehole video is unclear at this depth, but at 1,040 to 1,070 ft bgs, dolomite vlts and veining are evident, along with crystalline dolomite banding along fractures, joints, and/or bedding. Vlts are thin and veins are often discontinuous.

Common abbreviations for the above table:
frags - fragments
lt - light
med - medium
mod - moderate, moderately
occ - occasionally
SW - Symbology from the Unified Soil Classification System (USCS) (ASTM D 2487-83)
vlts - veinlets

Op - Ordovician Pogonip Group
€ld - upper Cambrian limestone and dolomite
Where the unit is a subunit of a RGU, the RGU designations are given in parentheses:
The RGUs are defined in Dixon et al. (2007).

Cherty dolomite was noted between 1,160 to 1,170 ft bgs. This cherty dolomite is consistent with field evidence of cherty dolomite present north of the monitor well site within the Cambrian limestone and dolomite unit.

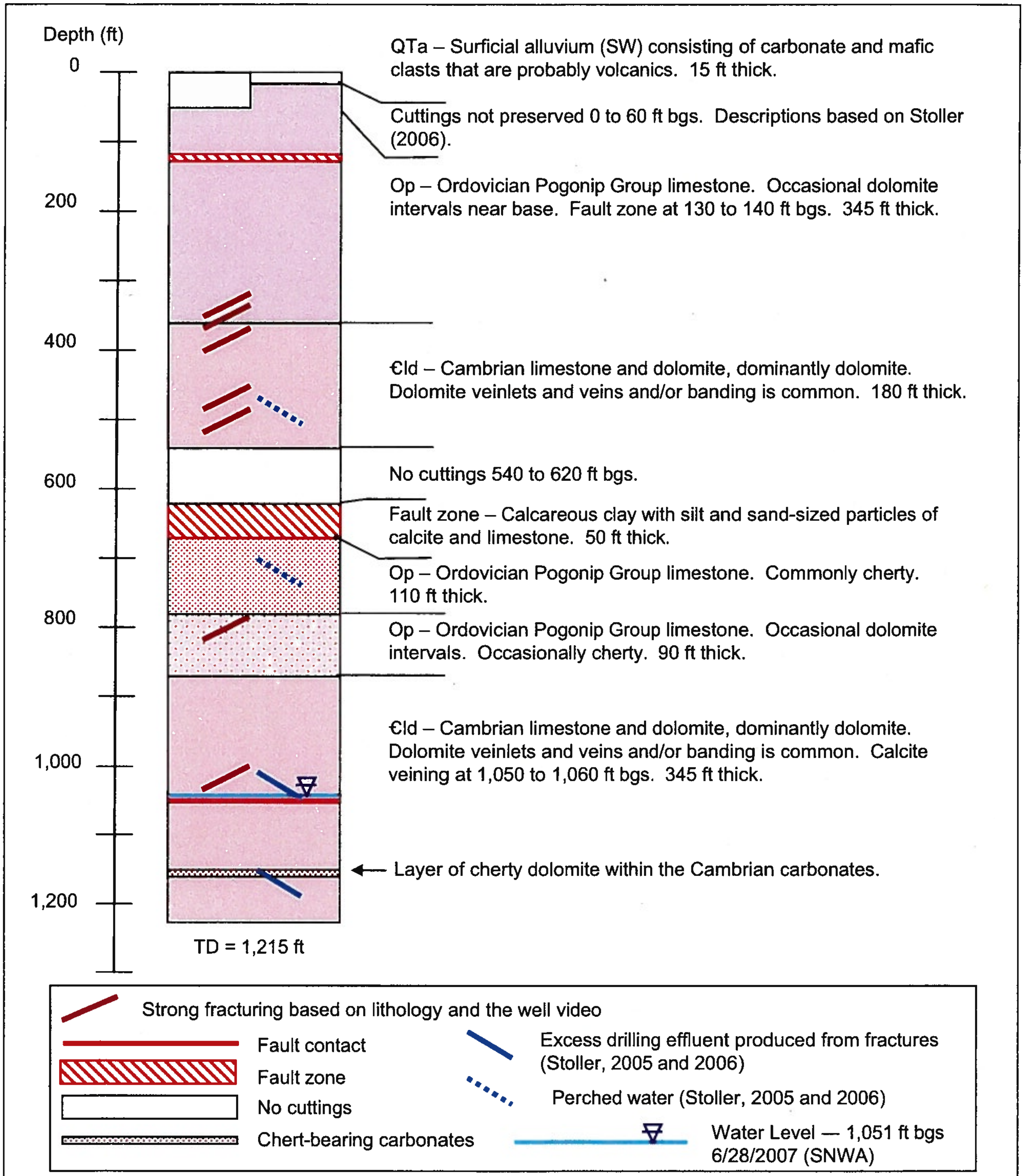
The fault represented in the cuttings between 620 and 670 ft bgs appears to have caused a repeat of the carbonate sequence and is related to a roughly east-west fault in the vicinity of the monitor well (Figure 6). Calcite veining is present at 1,050 to 1,060 ft bgs, and this veining is prominent in the borehole video as nearly vertical anastomosing veins and veinlets. This veining is associated with faulting within the borehole.

The carbonate rocks dip approximately 60 to 65 degrees based on the dip of banding in the borehole video. This dip corresponds to the dip of beds in outcrops near the monitor well site (Figure 4). At a dip of 60 degrees, the 1,200 ft of carbonate in the hole would represent 600 ft of carbonate thickness perpendicular to bedding. Based on the repetition of beds in the borehole, a somewhat thinner section of the Ordovician and Cambrian section is represented in the hole.

The well lithology is presented graphically on Figure 9.

2.2.2 BOREHOLE GEOPHYSICS

On September 23, 2005, a full suite of geophysical logs was performed to the full depth of the borehole (Stoller, 2005). During the geophysical logging, the water level in the borehole varied from about 1,060 to 1,100 ft bgs. On September 23, 2005, a borehole video was taken of the uncased hole to the full depth of the borehole. The following geophysical logs were performed:



Correlation of geologic units with RGUs (Dixon et al., 2007):
The surficial alluvium is part of the QTa RGU.
The Ordovician Pogonip Group is part of the Ol RGU.
The Cambrian limestone and dolomite unit is part of the €u RGU.

FIGURE 9
BOREHOLE STRATIGRAPHIC COLUMN OF MONITOR WELL 180W501M

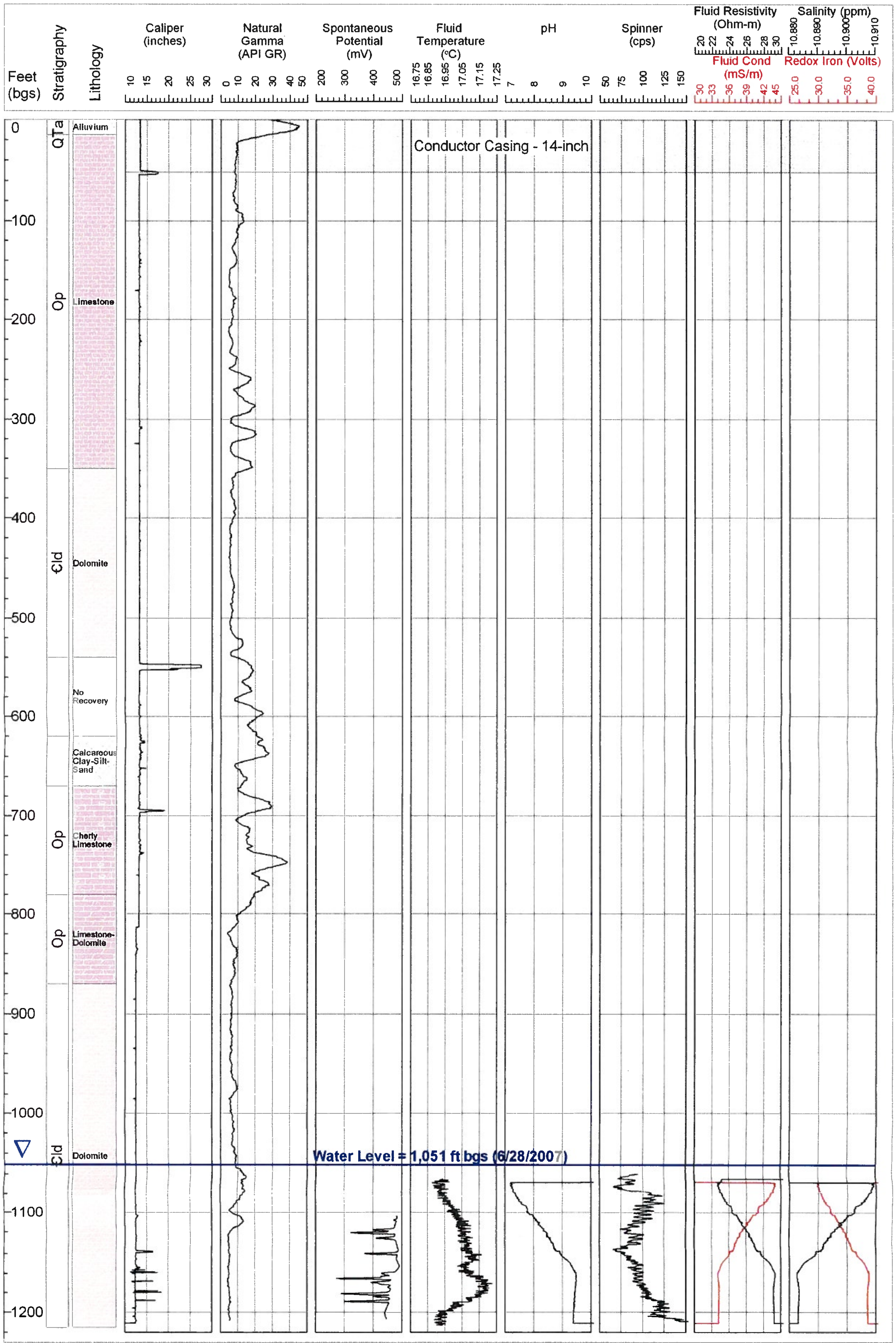
- Natural Gamma Ray
- Deep Induction (Resistivity)
- Medium Induction (Resistivity)
- Short Guard
- Long Guard
- Lateral Resistivity
- Spontaneous Potential
- Spectral Gamma – Potassium, Uranium, and Thorium (KUT)
- Total Spectral
- Neutron
- Density
- Sonic Delta T and Full Wave Sonic
- Fluid Temperature
- Differential Temperature
- Fluid Conductivity
- Fluid Resistivity
- Redox Iron Reduction Volts
- Salinity (NaCl)
- pH
- Spinner Log
- Caliper Log (to 885 ft bgs)
- Deviation Log
- Pressure (psi).

These geophysical logs are presented on Figures 10 and 11.

Muller (2007a, c, and d) evaluated the geophysical logs for Monitor Well 180W501M. The more reliable logs for this well include Natural Gamma Ray (Gamma), Lateral Resistivity, Guard, Spontaneous Potential, Fluid Temperature, Fluid Conductivity, Fluid Resistivity, Salinity, pH, Deviation, and Pressure. The Sonic log may be valid, the Spinner and Spectral (KUT) logs are questionable, and the Induction, Density, and Neutron logs do not appear to be valid. Based on the formation and fluid logs, the water level in the well had not stabilized to a static level prior to logging the hole. The borehole video was taken first with a water level of 1,030 ft bgs. Water levels for the subsequent logs varied from about 1,060 to at least 1,100 ft bgs.

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 at 1,130 to 1,150 ft bgs. The cuttings had about 10 to 15 percent limestone and calcite in this interval.

The Gamma log indicates a high count rate from the surface to about 15 ft bgs due to the presence of volcanic material in the surficial alluvium. There is no change in the Gamma reading at the base of the conductor casing probably due to the low Gamma readings in the carbonates. Below the conductor casing, the Gamma count rate is about 5 to 10 gru, with four 15- to 20-ft zones with a count rate of about 20 gru between 250 and 360 ft bgs. These zones may represent shale, silt, and/or chert within the Ordovician Pogonip Group limestone present in this interval. The Gamma count rate is fairly uniform at less than 10 gru within the Cambrian dolomite, indicating a lack of clastic material.



Explanation

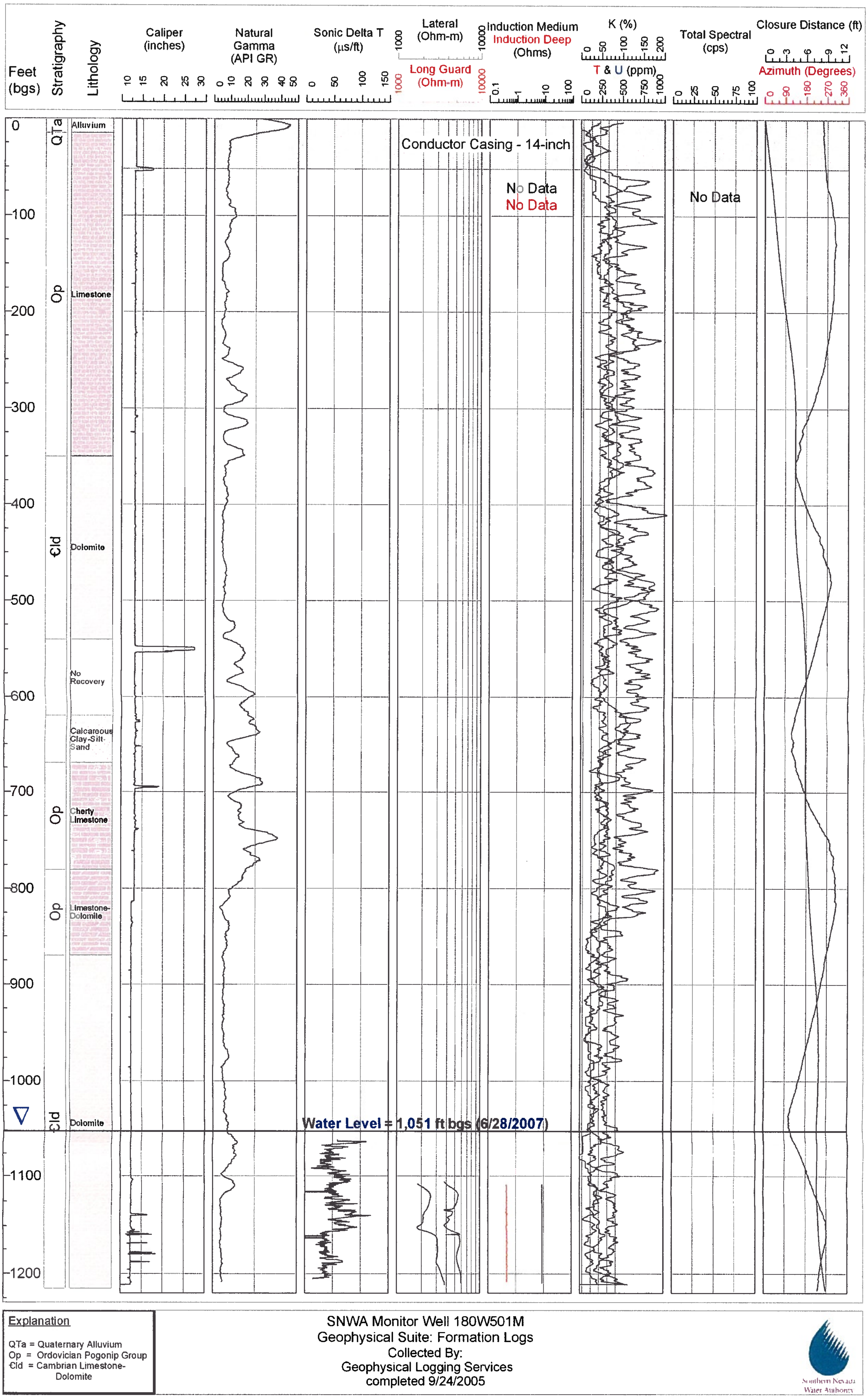
QTa = Quaternary Alluvium
Op = Ordovician Pogonip Group
€ld = Cambrian Limestone-Dolomite

SNWA Monitor Well 180W501M
Geophysical Suite: Fluid Logs
Collected By:
Geophysical Logging Services
completed 9/24/05

Southern Nevada Water Authority

Note: Correlation with regional geologic units (Dixon et al., 2007): The Ordovician Pogonip Group is part of the OI RGU, and the Cambrian limestone and dolomite unit is part of the €u RGU. Logs plotted by SNWA.

Figure 10
Monitor Well 180W501M Geophysical Fluid Logs



Note: Correlation with regional geologic units (Dixon et al., 2007): The Ordovician Pogonip Group is part of the OI RGU, and the Cambrian limestone and dolomite unit is part of the Ꞓu RGU. Logs plotted by SNWA.

FIGURE 11
MONITOR WELL 180W501M GEOPHYSICAL FORMATION LOGS

The count rate varies from 10 to about 40 gru between 520 and 800 ft bgs. The interval between 580 and 640 ft bgs, 20 to 25 gru, suggests that the fault zone indicated by the cuttings in the 620 to 670 ft bgs interval actually starts at about 580 ft bgs. The cuttings indicate fracturing beginning at 520 ft bgs.

Below 670 ft bgs, the higher Gamma readings reflect the presence of chert and probable of shaly limestone within Ordovician Pogonip Group limestone. Below 780 ft bgs, the amount of chert and shaly material within the limestone decreases, dolomite becomes increasingly abundant, and the Gamma readings are generally less than 10 gru. Slightly higher Gamma counts are present between 1,055 and 1,115 ft bgs. Between 1,050 and 1,060 ft bgs, the dolomite is heavily fractured with calcite veins and calcite and dolomite veinlets along a fault or fractured zone. Between 1,100 and 1,110 ft bgs, the cuttings are about 30 percent limestone, possibly slightly shaly.

The KUT log differs markedly from the Gamma log within this well, and Muller (2007a) questioned the relatively high KUT readings within the carbonate units. Because of this difference, the KUT logs are not considered valid and will not be discussed further.

The Spontaneous Potential log is very noisy with a definable potential curve from which spikes depart, all in a negative direction. The reported potential from the curve is 480 mV from 1,110 to 1,160 ft bgs and is 440 to 450 mV below 1,160 ft bgs. The spikes drop to 280 to 410 mV, lower in the deeper interval. The drop in the potential curve probably represents a slight increase in total dissolved solids (TDS) down hole. The reasons for the spikes are not known.

The Fluid Temperature log indicates an increase in fluid temperature from 16.9°C to 17.2°C from 1,070 to 1,175 ft bgs and then a decline to 16.9°C at the bottom of the hole. This variation may indicate an influx of groundwater into the drilling fluid at about 1,150 to 1,175 ft bgs based on the shape of the curve, cooler drilling fluid being replaced with warmer groundwater. The groundwater temperature was determined to be 18.5°C on May 17, 2006 (Acheampong et al., 2007).

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, 2007b), so only the Fluid Conductivity log will be considered.

Fluid Conductivity decreased from about 44 mS/m near the water table to about 33 mS/m between the water level at 1,075 ft bgs and 1,160 ft bgs. Below 1,160 ft bgs, the Fluid Conductivity remains constant. The decrease shows that the TDS in the borehole fluid is decreasing with depth, indicating that groundwater, with a lower TDS content than the drilling fluid, is entering the borehole and mixing with the borehole fluid. The zone of constant fluid conductance below 1,160 ft bgs indicates a lack of fluid flow into the monitor well, which is consistent with the Fluid Temperature data.

The Sonic log was variable from 1,075 to 1,160 ft bgs, and this interval may be a dolomite with occasional limestone beds. Below 1,160 ft bgs, the delta T of the Sonic log decreases to a lower value. This decrease may indicate all dolomite as opposed to dolomite with some interbedded limestone, and/or the decrease may indicate an increase in porosity (Keys and MacCary, 1971, p. 90).

The Spinner log was made using a micro electric tool that "does not appear to be responding to formation hydrologic flow properties" (Muller, 2007a) and therefore may not be valid.

The Caliper log illustrates zones where the borehole was caved or partially caved. Caving occurred above or within a fault zone at 550 ft bgs. Thin caved intervals occurred between 1,140 and 1,190 ft bgs. The Caliper log also indicates the depth at which the drillers switched from a hammer bit to a rotary bit, at 811 ft bgs (Stoller, 2005, September 20, 2005), at which point the hole diameter decreases slightly.

The borehole video provides limited information on the well, as only a portion of the borehole is visible in this video. The interval between 505 ft bgs and the water level at 1,030 ft bgs was filled with foam at the time the video was taken. Below 1,070 ft bgs, the fluid in the well was too turbid to see the hole wall. The hole wall was visible only in the intervals between the bottom of the casing (51 ft bgs) and 505 ft bgs and between the water level (1,030 ft bgs) and about 1,070 ft bgs. Fracturing and calcite or dolomite veinlets were observed between 330 and 500 ft bgs where mud from drilling did not obscure the hole wall. Abundant calcite veining and dolomite veinlets and banding were noted below the water table to 1,070 ft bgs. The well appeared to be partly caved at 52 ft bgs and between 504 to 505 ft bgs (possibly deeper). Only the upper caved zone was noted in the caliper log.

The Deviation (Closure Distance) log indicates that the borehole deviates approximately 9 ft S77W. The direction is roughly parallel to the direction of the approximately east-west fault discussed in Section 2.1.2 and shown on Figures 4 and 7.

2.2.3 DRILLING PARAMETERS

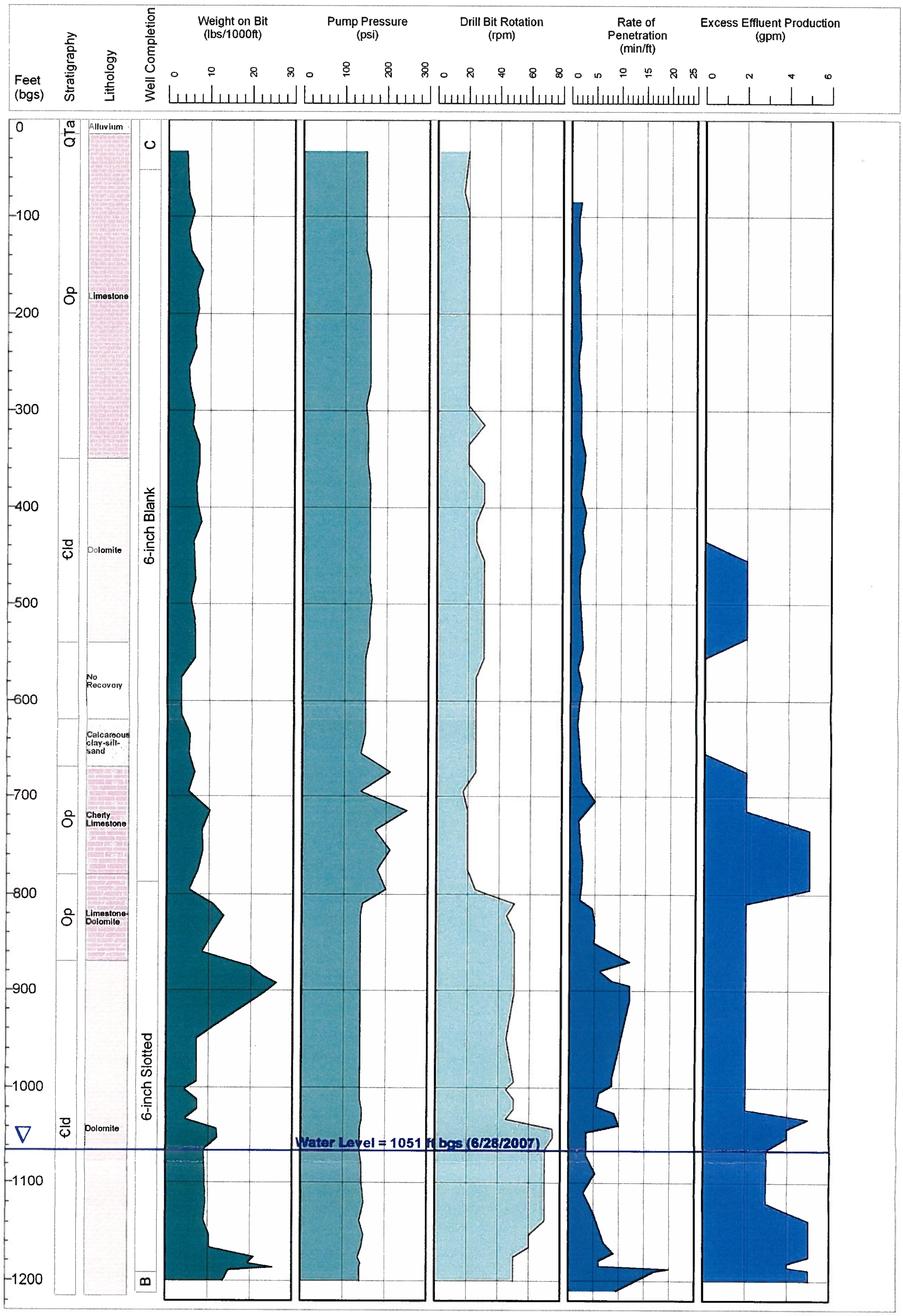
Stoller (2006) provided data on the drilling parameters as follows:

- Weight on bit
- Pump pressure
- Drill bit rotation
- Rate of Penetration
- Water Production.

These drilling parameters are presented on Figure 12.

The rate of penetration was nearly constant from near the surface to about 810 ft bgs based on the parameter graph on Figure 12. As indicated in the discussion of the Caliper log in Section 2.2.2, the drilling contractor switched from a hammer bit to a rotary bit at 811 ft bgs, and after that depth, the rate of penetration varied at a generally reduced rate to about 1,040 ft bgs. The switch from reverse circulation drilling to air-foam drilling at 860 ft bgs resulted in a reduced penetration rate. This reduced penetration rate was temporarily increased by increasing the weight on the bit. The rate of penetration was higher from 1,040 to 1,120 ft bgs, decreasing to a relatively low rate for the last 35 ft of drilling.

The rate of penetration for this monitor well is most likely affected by the induration and degree of fracturing of the carbonate units. Cherty limestone may have caused the small decrease in penetration rate with the hammer bit at 700 to 710 ft bgs. The high degree of fracturing present below 1,040 ft bgs probably facilitated drilling resulting in a higher penetration rate.



Explanation
QTa = Quaternary Alluvium
Op = Ordovician Pogonip Group
Cld = Cambrian Limestone-Dolomite
B = Blank Casing
C = Conductor Casing

SNWA Monitor Well 180W501M
Drilling Parameters
Collected By:
Stoller Corporation
From 9/17/05 to 9/23/05

Southern Nevada Water Authority

Note: Correlation with regional geologic units (Dixon et al., 2007): The Ordovician Pogonip Group is part of the OI RGU, and the Cambrian limestone and dolomite unit is part of the Cu RGU. Logs plotted by SNWA.

FIGURE 12
MONITOR WELL 180W501M DRILLING PARAMETERS

The extent of fracturing declined below about 1,120 ft bgs, which resulted in a reduced penetration rate. An increase in the weight on the bit seemed to offset the reduction in penetration rate at 1,170 ft bgs, but this effect was short-lived. The sharply reduced penetration rate from 1,185 to 1,210 ft bgs is most likely due to relatively unfractured, hard dolomite, based on a comment in Stoller (2005, September 23, 2005).

The pump pressure was higher from 660 to 810 ft bgs. The higher pressure from 660 to 680 ft bgs may be related to the fault zone that ended at 670 ft bgs. The higher pressure from 700 to 810 ft bgs is probably related to the switch from air-foam drilling to reverse circulation drilling with a hammer bit. The pump pressure declined when the hammer bit was replaced with a rotary bit. The switch from reverse circulation back to air-foam drilling did not have any effect on pump pressure.

2.3 HYDROGEOLOGY

Monitor Well 180W501M is completed (screened) within upper Cambrian limestone and dolomite. During drilling operations, excess drilling effluent was first encountered at about 470 ft bgs (Stoller, 2005, September 18, 2005). The hole became dry again at 540 ft bgs, indicating that the regional water table had yet to be encountered. Excess drilling effluent was also encountered at about 660 ft bgs (Figure 12). Because of the small flow amounts, Stoller (2006) believed that this apparent flow was from variations in the discharge of drilling fluid rather than actual groundwater flow. However, it is possible that perched water was present at these elevations.

Excess drilling effluent, estimated at 3 to 5 gpm, was encountered below 1,035 ft bgs (Stoller, 2005, September 22, 2005; Stoller, 2006). No static water level was reported at this time.

A depth to water level of 1,049.89 ft bgs was taken at 21:02 on December 22, 2005, by SNWA (Stoller, 2006). The surface elevation at the well is approximately 6,445 ft amsl, which gives a groundwater elevation of approximately 5,395 ft amsl. This site has not been professionally surveyed. Seven additional water level readings have been taken since May 2006, ranging from 1,049.65 to 1,050.81 ft bgs, or approximately 5,395 ft amsl. These readings are within a foot of the reading taken on December 22, 2005. A complete set of water level measurements is provided in Table 2.

For comparison, the water level in the Cave Valley Seeding Well (Seeding Well) was at an elevation of 6,089 ft amsl on May 9, 2007 (USGS, 2007), about 680 ft higher than that of Monitor Well 180W501M. The first water encountered in Monitor Well 180W501M was perched water at 470 ft bgs, at an elevation of approximately 5,975 ft amsl, or 110 ft lower than that of the Seeding Well. The Seeding Well is the nearest existing water well to Monitor Well 180W501M and is approximately 14,200 ft (4,330 m or 2.7 mi) east of the monitor well site (Figure 2). The Seeding Well is completed in Quaternary and Tertiary alluvial sediments.

2.4 SUMMARY

Monitor Well 180W501M was drilled in October 2005 for the purpose of collecting geologic, hydrologic, and geochemical data. This monitor well is located in western Cave Valley and was drilled to a total depth of 1,215 ft bgs with a slotted interval from 787.8 to 1,191.8 ft bgs.

Table 2
Water Level Measurements for Monitor Well 180W501M

Date	Time	Depth (ft bgs)	Elevation (ft amsl)	Data Collected By
9/23/2005	14:45	1,030	5,415	GLS, borehole video
9/23/2005	17:45	1,069	5,376	From the Fluid logs[a] (Stoller, 2006)
9/23/2005	17:45	1,100	5,345	GLS, from the Electric logs[b]
9/23/2005	20:15	1,069	5,376	From the Density log[c] (Stoller, 2006)
9/24/2005	22:00	1,066	5,379	Stoller (2006), following casing installation[d]
12/22/2005	20:00	1,049.89	5,395	SNWA
10/23/2006	15:51	1,049.65	5,395	SNWA
12/5/2006	16:00	1,049.88	5,395	SNWA
1/23/2007	12:10	1,050.11	5,395	SNWA
2/26/2007	16:15	1,050.01	5,395	SNWA
4/2/2007	10:45	1,050.39	5,395	SNWA
5/15/2007	11:40	1,050.65	5,394	SNWA
6/28/2007	9:35	1,050.81	5,394	SNWA

[a]Corresponds with the Fluid Conductivity and Fluid Temperature logs (GLS).
[b]Taken directly from the Resistivity and Spontaneous Potential logs (rounded).
[c]A deflection in the Density log occurs at about this depth, though the density data is not considered valid (Muller, 2007a). This depth was verified by the Fluid Temperature and Fluid Conductivity logs (GLS).
[d]Stoller (2006) was unable to verify this reading due to foam fouling the water level probe.

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.

The monitor well encountered 15 ft of alluvium, below which are two repeated sections of carbonates separated by a fault zone. The first section consists of 345 ft of the Ordovician Pogonip Group and 180 ft of the Cambrian dolomite to a depth of 540 ft bgs, after which cuttings are missing for 80 ft. From 620 to 670 ft bgs there appears to be a clayey fault zone. Below this fault zone, a second section consists of 200 ft of Ordovician Pogonip Group limestone and cherty limestone, below which 345 ft of the Cambrian limestone and dolomite unit is present. This fault was expected based on the surface geology and geomorphology, though it was not previously mapped.

Geophysical logs and drilling parameters provided additional data for analysis. These logs verified the presence of chert and indicated shaly units within the Ordovician Pogonip Group. Electric logs indicated variations in permeability, and the Sonic log indicated differences between dolomite and limestone-dolomite intervals. The borehole video and the cuttings indicated calcite veining at 1,050 to 1,060 ft bgs.

Water level measurements indicate a water-level elevation of approximately 5,395 ft amsl. The groundwater flow is from fractures and faults below the water level. Geophysical evidence indicates groundwater interaction with the borehole in the intervals 1,050 to 1,070 ft bgs and 1,150 to 1,160 ft bgs.

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.

ASTM D 2487-83, 1985, Classification of Soils for Engineering Purposes—Annual Book of ASTM Standards, Vol. 04.08, American Society for Testing and Materials, p. 395-408.

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.

Kellogg, H.E., 1963, Paleozoic Stratigraphy of the Southern Egan Range, Nevada: Geological Society of America Bulletin v. 74, p. 685-708.

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, Email to R. Schuth (SNWA) regarding the similarity of certain logs and geophysical logs for other wells, 3 May.

Muller, D., 2007c, Email to R. Schuth (SNWA) regarding geophysical logs for Well 180W501M and other wells, 12 May.

Muller, D., 2007d, Personal communication with and subsequent email to H. Eastman (SNWA) regarding the validity of spinner logs, 24 October.

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 American Association of Petroleum Geologists Publ. GB78.

S.M. Stoller Corporation, 2005, Drilling Morning Reports—Well 180W501M.

S.M. Stoller Corporation, 2006, Well 180W501M Well Data Report.

SNWA, see Southern Nevada Water Authority.

Southern Nevada Water Authority, 2006, Notes from geochemical sampling for Monitor Well 180W501M on 17 May, unpublished.

Stoller, see S.M. Stoller Corporation.

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

U.S. Geological Survey, National Water Information System, 2007, Groundwater Levels for Nevada, accessed at website http://nwis.waterdata.usgs.gov/nv/nwis/gwlevels.