Doc No. RDS-ED-0003

Southern Nevada Water Authority

Geologic Data Analysis Report for Monitor Well 180W902M in Cave Valley

October 2007

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SOUTHERN NEVADA
WATER AUTHORITY

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Prepared by: Harvey S. Eastman

November 2007

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

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ACRONYMS

AMT	audiomagnetotelluric
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	rotations 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 180W902M is located in southeastern Cave Valley in Section 19, T6N, R64E, at an elevation of approximately 5,988 ft amsl (Figure 2). The site is 11 mi west of U.S. Highway 93 and can be accessed from that highway through Sidehill Pass. It is 12 mi east of Nevada State Route 318 and can be accessed from that highway by the Silver King Pass road. The site can also be accessed from Ely, Nevada, by the Cave Valley road that departs 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 180W902M. 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.

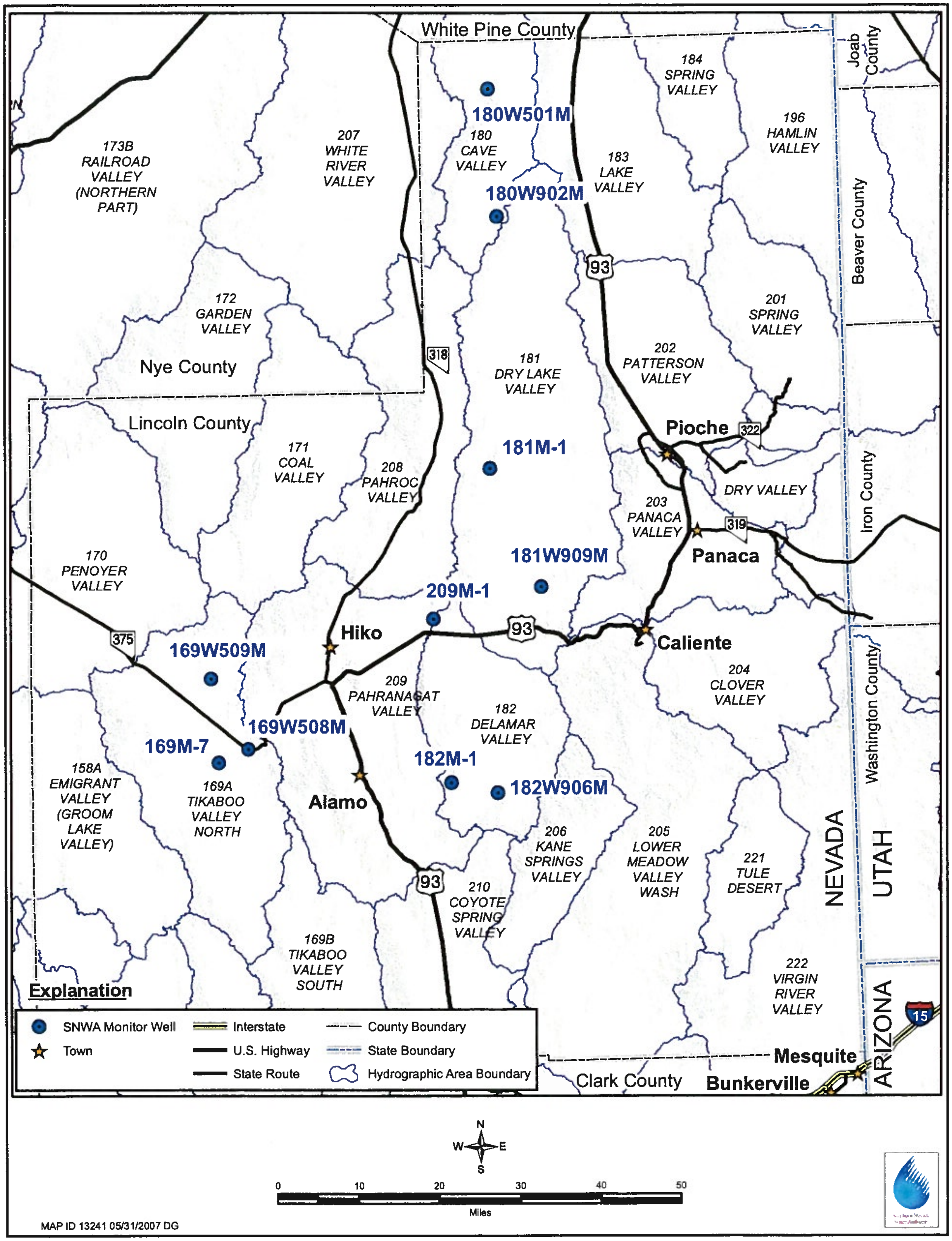
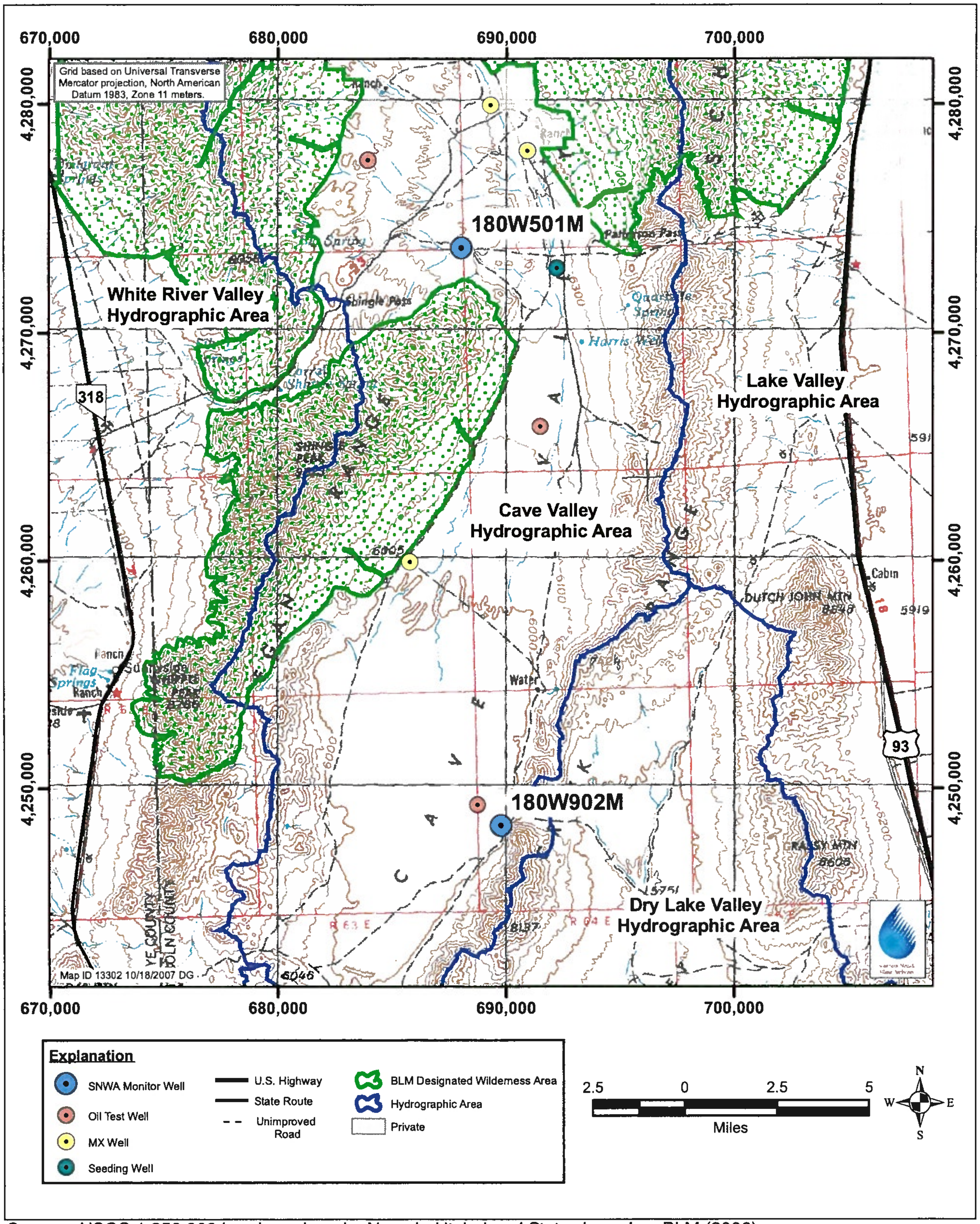


Figure 1
SNWA Monitor Well Locations, Lincoln County, Nevada



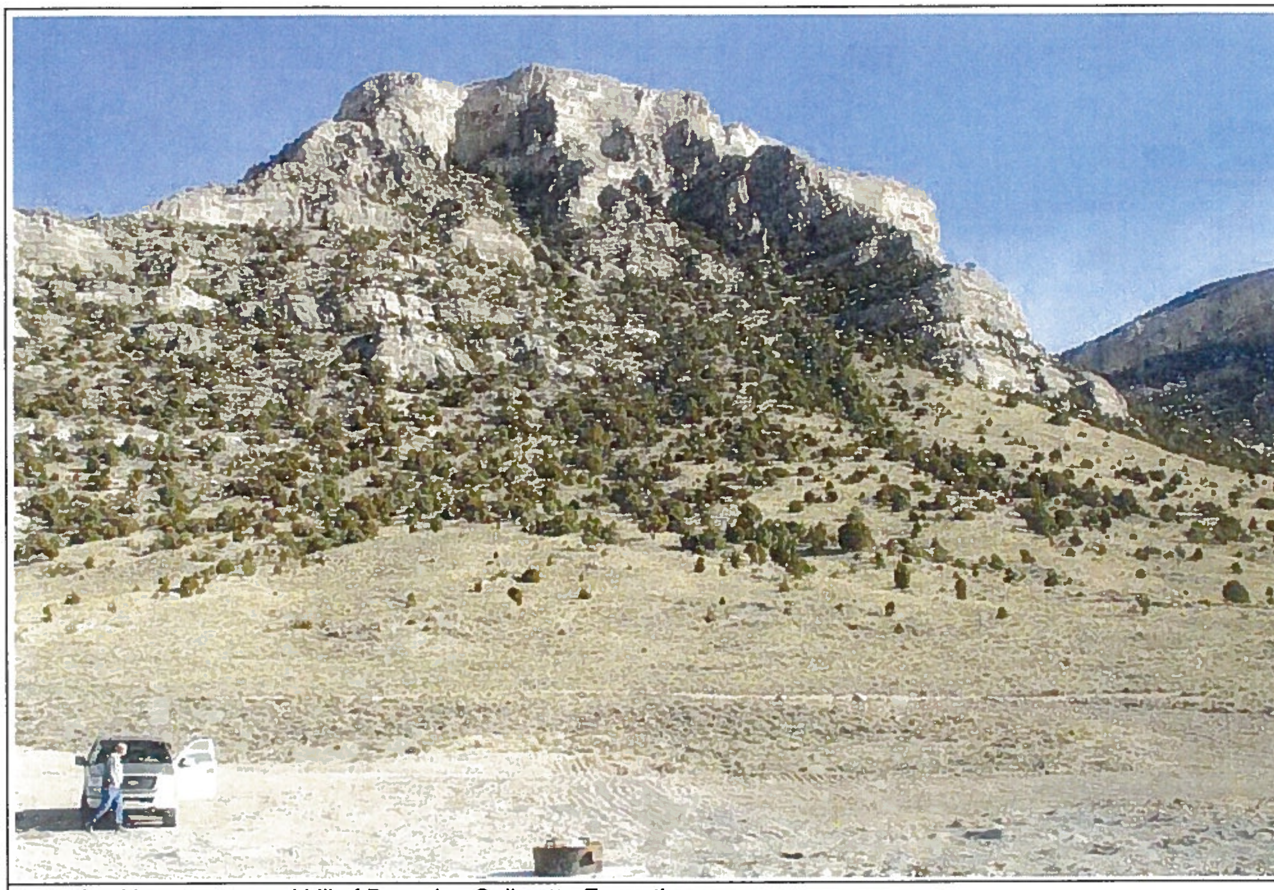
Source: USGS 1:250,000 Lund quadrangle, Nevada-Utah; Land Status based on BLM (2006).

FIGURE 2
LOCATION OF MONITOR WELL 180W902M, LINCOLN COUNTY, NEVADA

1.3 SUMMARY OF MONITOR WELL CONSTRUCTION

Monitor Well 180W902M was drilled and completed from October 9 to October 19, 2005, to a depth of 917 ft bgs. The monitor well was completed with 24-in. O.D. conductor casing to 77 ft bgs and 12.75-in. O.D. (12-in. I.D.) well casing from 3.3 ft above land surface to 903.2 ft bgs with a slotted interval from 195 to 882 ft bgs. The completion borehole was drilled using air-foam and flooded reverse circulation drilling techniques with a borehole diameter of 17.5 in.

Figure 3 presents photographs of the well site taken on February 6, 2007. For additional information on the well construction, refer to Stoller (2006).



Note: Looking east toward hill of Devonian Guilmette Formation.

Note: Looking north toward the gap between southern and northern Cave Valley. The southern Egan Range is on the left and the southern Schell Creek Range is on the right.

Figure 3
Two Views of Monitor Well 180W902M Site

2.0

DATA ANALYSIS

This section analyzes the lithology, geophysical logs, and drilling statistics to evaluate the geology encountered in Monitor Well 180W902M.

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 eastern margin of the valley is marked by a north-trending Cave Valley Fault that was formed by extension within the Great Basin region.

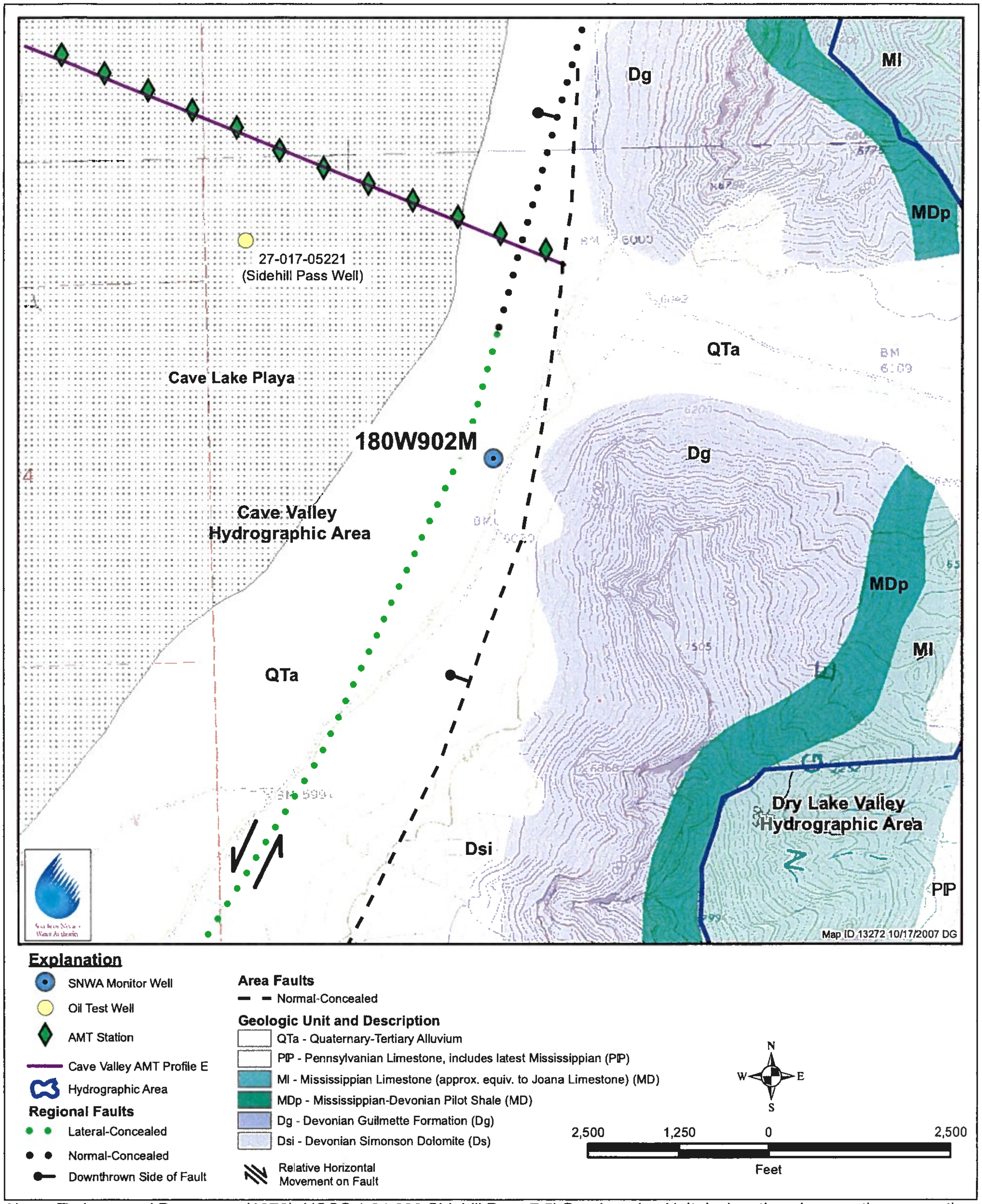
Monitor Well 180W902M is situated near the southern end of the Cave Valley Hydrographic Area near the southeastern margin of the alluvial basin (Figure 2). The surface geology at the well site is of Quaternary alluvium. A major north-south structure, the Cave Valley Fault, crosses through the area near the well site. The surface geology is displayed on Figure 4.

2.1.1 GEOLOGIC UNITS ENCOUNTERED AT THE MONITOR WELL

The geologic units encountered in Monitor Well 180W902M consist of alluvial material, the Devonian Guilmette Formation, and the Devonian Simonson Dolomite. The alluvial material consists dominantly of carbonate detritus eroded from the carbonate rocks to the east. This material is part of the "surficial alluvium and basin fill" (QTa) regional geologic unit (RGU) (Dixon et al., 2007). The Guilmette Formation is the Guilmette Formation (Dg) RGU, and the Simonson Dolomite is part of the Simonson and Sevy Dolomite (Ds) RGU (Dixon et al., 2007).

The Devonian Guilmette Formation is primarily a limestone unit that includes sedimentary reef breccias up to 100 ft thick (Tschanz and Pampeyan, 1970). The lower member is primarily a thick massive limestone unit up to 660 ft thick. The upper member is of alternating massive limestone and brown silty dolomite layers (Kellogg, 1963). The Guilmette Formation is distinguished by a basal unit of yellowish gray dolomite, a thin-bedded, grayish to dusky yellow silty dolomite 50 to 70 ft thick (Tschanz and Pampeyan, 1970). The total thickness of the Guilmette is about 2,000 ft in the southern Egan Range west of the well site (Kellogg, 1963) and 2,750 ft at Grassy Mountain to the east (Tschanz and Pampeyan, 1970).

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 "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). The total thickness of the Simonson Dolomite is approximately 1,200 ft (Kellogg, 1963; Tschanz and Pampeyan, 1970). The primary difference between the Guilmette Formation and the Simonson Dolomite is that the Guilmette is dominantly a limestone with relatively thin dolomite sequences between thick limestone sections, whereas the Simonson Dolomite is almost entirely of dolomite



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

FIGURE 4
GEOLOGIC MAP AROUND MONITOR WELL 180W902M, SOUTHEASTERN CAVE VALLEY

(Tschanz and Pampeyan, 1970). The Guilmette Formation and the Simonson Dolomite commonly contain beds with a spaghetti texture within dark horizons (Figure 5) (Tschanz and Pampeyan, 1970). Light and dark beds within the Simonson Dolomite are presented on Figure 6.

Note: The Simonson Dolomite, Dsi, is part of the Ds RGU (Dixon et al., 2007). Top of pen bottom left.

FIGURE 5
SPAGHETTI DOLOMITE IN THE BROWN CLIFF MEMBER OF THE SIMONSON DOLOMITE, SOUTH OF MONITOR WELL 180W902M

2.1.2 GEOLOGIC STRUCTURE AT THE MONITOR WELL SITE

The Cave Valley Fault Zone is a major north-south structural feature (Figures 4 and 7) with a relative vertical displacement of Paleozoic sediments of over 9,000 ft downward toward Cave Valley.

The range-front fault is in two or more parts, the first of which crops out south of the well site where the Guilmette Formation is downdropped against the Simonson Dolomite. The fault outcrop is south of the map area (Figure 8). This fault continues northward between the well site and the Guilmette outcrop, though the offset near the well site is not more than about 600 ft and probably somewhat less.

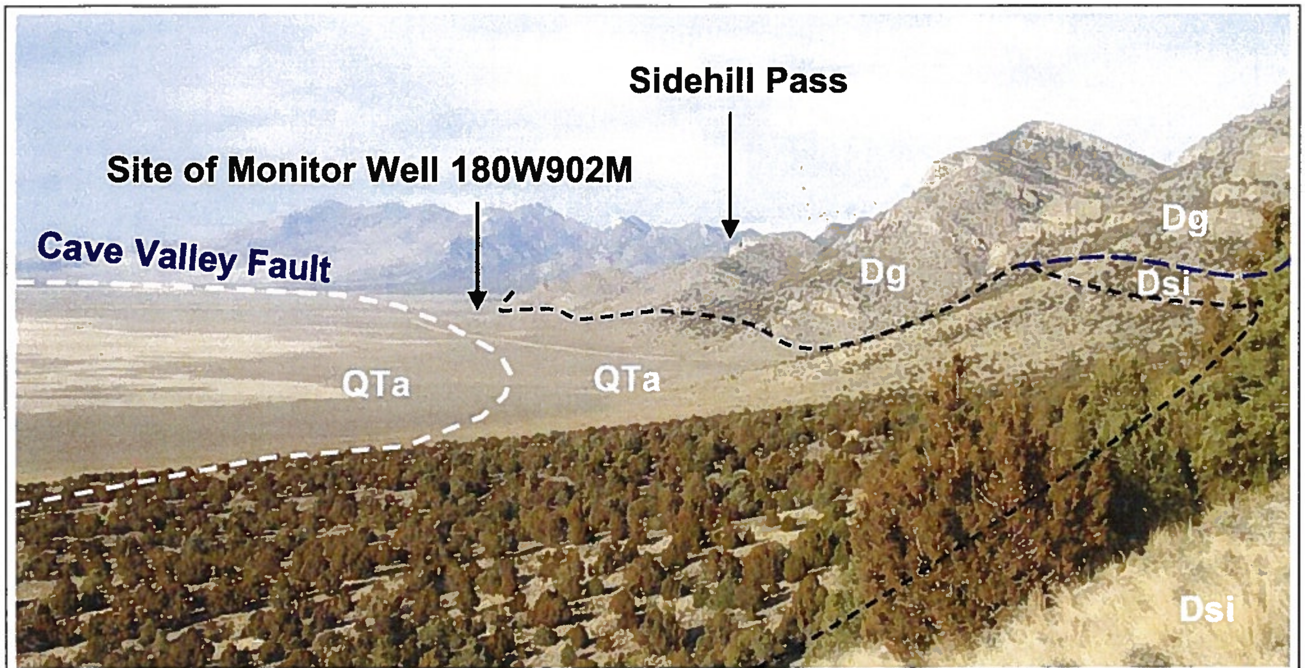
2.2 GEOPHYSICAL SETTING

2.2.1 AUDIOMAGNETOTELLURIC

An audiomagnetotelluric (AMT) survey was performed in Cave Valley just north of the monitor well location (McPhee et al., 2006a and b, and 2007). This survey provides more detailed information regarding the subsurface within about 2,600 to 3,300 ft (800 to 1,000 m) of the surface. The

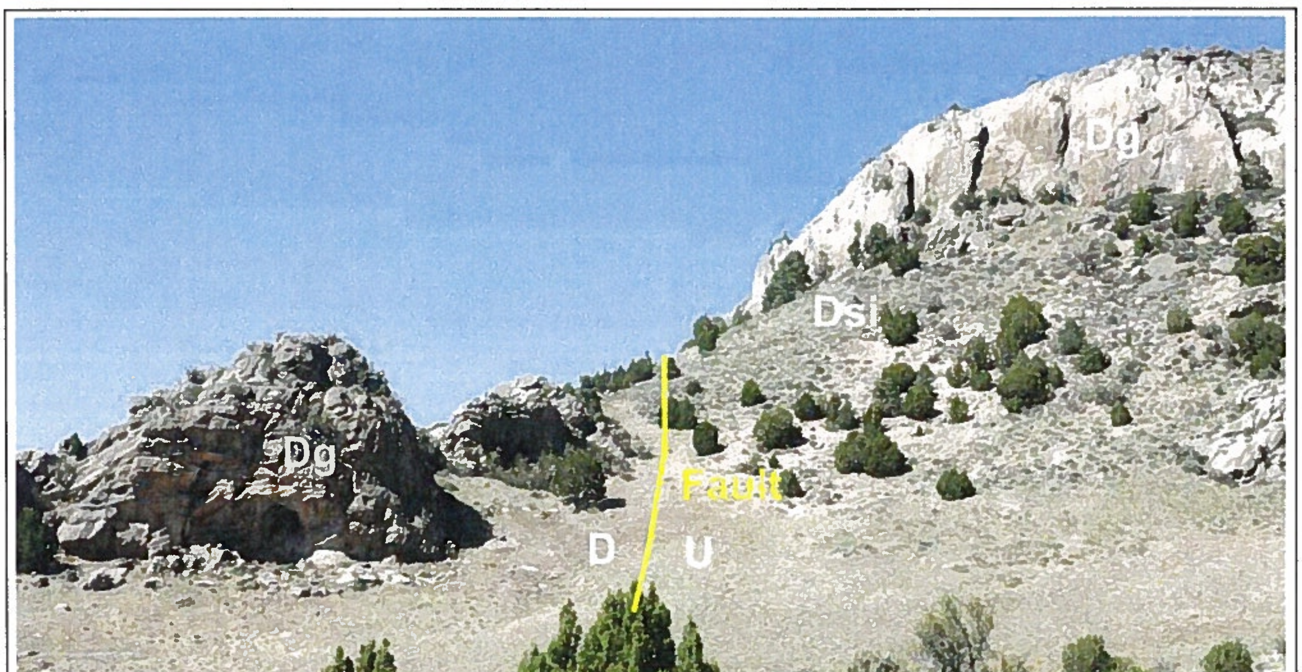
Note: Top view is of lighter gray Simonson Dolomite; bottom view is of bedded dark gray Simonson Dolomite in a bed approximately 15 ft thick, above and below which is lighter gray dolomite as in the upper picture. The Simonson Dolomite is part of the Ds RGU (Dixon et al., 2007).

Figure 6
Simonson Dolomite, South of Monitor Well 180W902M



Note: QTa = includes playa, alluvium, and colluvium. Dg = Guilmette Formation, Dsi = Simonson Dolomite. Fault curvature enhanced by angle of view. QTa and Dg are their own RGUs, and Dsi is part of the Ds RGU (Dixon et al., 2007). Geology based on Tschanz and Pampeyan (1970).

FIGURE 7
VIEW OF RANGE FRONT ON THE WEST SIDE OF THE SOUTHERN SCHELL CREEK RANGE, ILLUSTRATING THE CAVE VALLEY FAULT AND SURFACE GEOLOGY, LOOKING NORTH



Note: Dg = Guilmette Formation. Dsi = Simonson Dolomite. The Guilmette Formation, Dg, is its own RGU, and the Simonson Dolomite is part of the Ds RGU (Dixon et al., 2007). Fault extends northward toward monitor well site (Figure 4).

FIGURE 8
DOWNDROPPED BLOCK OF GUILMETTE TO WEST OF SIMONSON DOLOMITE, SOUTH OF MONITOR WELL 180W902M, LOOKING NORTH

interpretation of this survey given by McPhee et al. (2006a) is presented on Figure 9. In this figure, the approximate locations (projected to the line of Profile E of Figure 4) of both the monitor well and an oil test well, also known as the Sidehill Pass Well, have been added.

Monitor Well 180W902M projects to near the east end of the AMT profile, where the alluvium is relatively shallow compared to the alluvial basin to the west. The uppermost 400 ft of the section at the monitor well is relatively resistive limestone conglomerate and breccia, as indicated in Section 2.3.1. The dominance of limestone cobbles and breccia fragments, bound together with calcareous clay and silt, contributed to the resistive nature of the unit. Alluvial sediments more distant from the range front have a greater percentage of volcanic fragments, as was noted in the lithologic log of the Sidehill Pass Well (Mountain States Well Logging Company, 1996).

The carbonate units were more resistive than the calcareous alluvium as noted on Figure 9 by the pink colors at the monitor well site. The resolution is imprecise but the resistivity effectively illustrates the relatively shallow bedrock on the east margin of Cave Valley. The deeper bedrock in the cross section, about 750 ft (230 m) versus 420 ft (125 m) at the monitor well site, is most likely due to the variation in the bedrock surface between the AMT line and the monitor well.

2.3 MONITOR WELL 180W902M

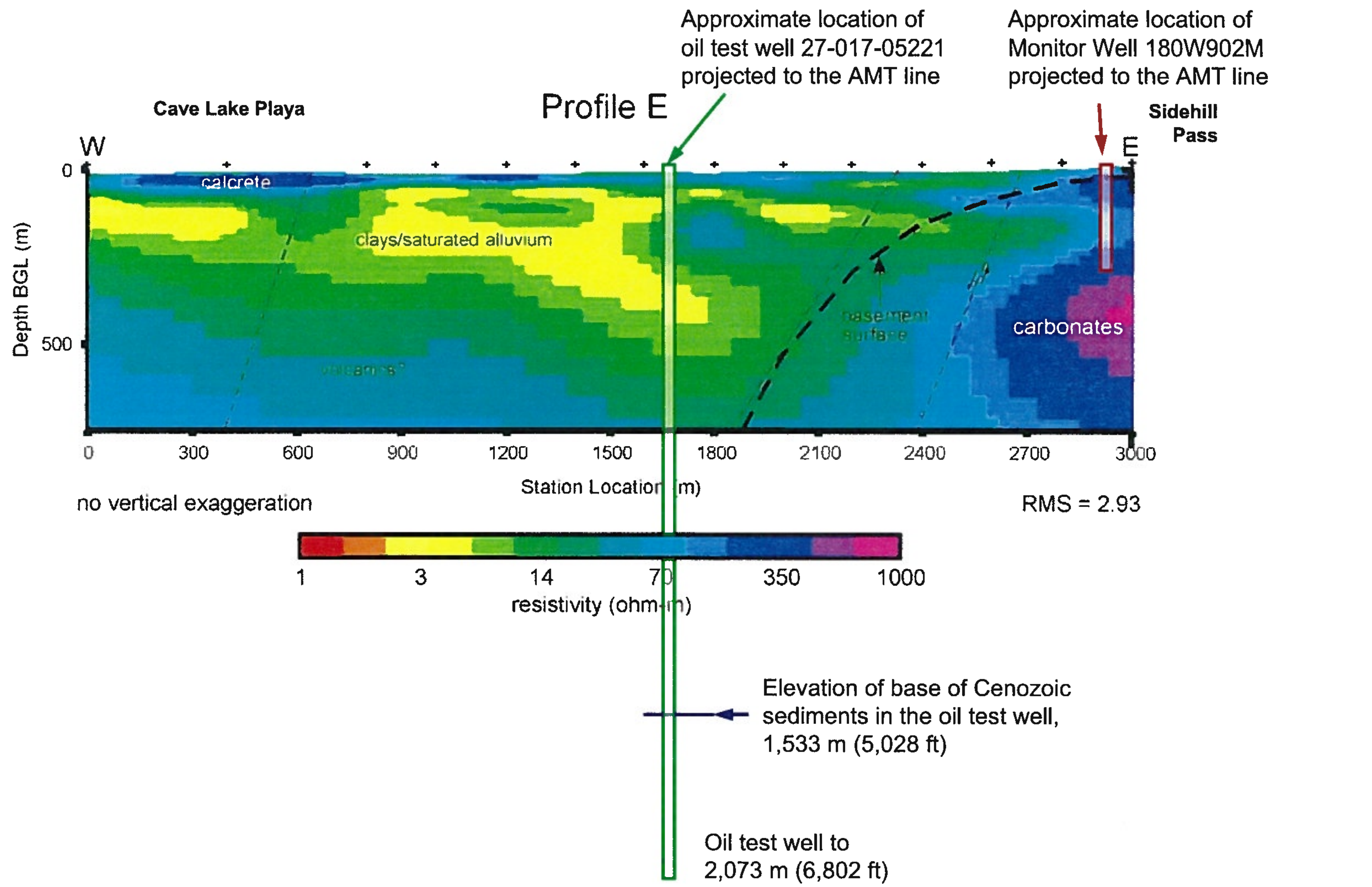
Monitor Well 180W902M was drilled in a single pass. For this report, the well cuttings were logged and the geology encountered is discussed.

2.3.1 LITHOLOGY

Lithologic cuttings were collected for Monitor Well 180W902M 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 Kellogg (1963). A summary of the lithologic log is included in Table 1.

The lithology encountered in drilling includes three rock types: alluvium, limestone, and dolomite. Alluvium was encountered from the surface to about 420 ft bgs, in part evidenced by a borehole video taken at the time of geophysical logging of the well. Cuttings were poor for the first 60 ft of drilling, but the cuttings contain a combination of limestone, dolomite, and volcanic fragments in the first 15 ft (Stoller, 2005). The volcanic fragments contain chatoyant sanidine feldspar most likely derived from Tertiary rhyolitic ash-flow tuffs.

Below the top 15 ft is limestone conglomerate with some dolomite cobbles. The character of this unit is not evident in the cuttings, as the cuttings are comprised entirely of carbonate fragments with little evidence of interstitial material. However, the borehole video clearly indicates rounded to subrounded cobbles to the water table. The thickness of conglomerate is uncertain, as the borehole video was not able to discern the hole wall between the water table at 138 ft bgs to about 303 ft bgs. Below 303 ft bgs, the borehole video indicates that the limestone fragments in the alluvium are much more angular, and this alluvial material is herein defined as an alluvial breccia. A significant amount of interstitial caliche-like material was noted between the breccia fragments, though very little of this caliche is present in the cuttings. This breccia extends to a depth of 420 ft bgs, below which is carbonate bedrock.



Note: Figure 4 from McPhee et al. (2006a). BGL = below ground level; RMS = root mean square. Thick black line shows depth-to-basement estimate derived from gravity data (courtesy of Dan Scheirer, USGS) (McPhee et al., 2006a). Oil test well geology from Mountain States Well Logging Company (1996). Approximate projections of Monitor Well 180W902M and the oil test well API 27-017-05221.

FIGURE 9

TWO-DIMENSIONAL AMT INVERSE MODEL AND INTERPRETATION ALONG PROFILE E (Figure 4) ACROSS CAVE VALLEY NORTH OF MONITOR WELL 180W902M

TABLE 1
LITHOLOGY OF MONITOR WELL 180W902M

Interval Top to Base (ft bgs)	Geologic Unit	General Lithology	Description of Cuttings
0 to 15	QTa	Alluvium	Limestone gravel and conglomerate with sanidine-bearing volcanic fragments. Well graded (Stoller, 2006). Limited volume of cuttings.
15 to 140	QTa	Limestone conglomerate	Lt to med to dark gray limestone cobbles. Fragments are commonly coated with calcium carbonate.
140 to 260	QTa	Limestone conglomerate ± breccia	Lt to med to dark brownish gray limestone cobbles, often coated with calcium carbonate. May include highly angular breccia fragments.
260 to 400	QTa	Limestone breccia (sedimentary)	Lt to med to dark brownish gray to honey brown limestone fragments commonly highly angular. Abundant white to cream and yellowish white frags indicative of calcium carbonate coatings on limestone frags.
400 to 420	QTa	Limestone breccia as above	As above but calcium carbonate coatings more prevalent. Calcite vlts abundant within the frags. Base of alluvial sediments.
420 to 440	Dg Guilmette Formation	Limestone and Dolomite	Med gray to brown-gray or honey brown-gray sucrosic limestone and dolomite, commonly banded, occ dark; onyx-like coatings and frags (fracture filling).
440 to 620	Dsi Simonson Dolomite (Ds)	Dolomite	Med-gray to brown-gray or honey brown-gray sucrosic dolomite, commonly banded, occ calcite on fx.
620 to 670	Dsi Simonson Dolomite (Ds)	Dolomite	Med brown-gray to gray dolomite, sucrosic, with calcite vlts. White to cream frags common, calcareous. Occ red or yellow coating on frags. Strong fracture zone 630 to 650 ft bgs.
670 to 770	Dsi Simonson Dolomite (Ds)	Dolomite	Lt to med to dark gray dolomite, commonly brown-gray, sucrosic to micro-sucrosic. Nearly black 710 to 720 ft bgs, lt brown-gray 720 to 730 ft bgs. Occ yellow coating on fx, calcite on fx.
770 to 880	Dsi Simonson Dolomite (Ds)	Dolomite	Dark gray to black dolomite, sucrosic to micro-sucrosic. Occ FeOx (red) or calcite on fx.
880 to 910	Dsi Simonson Dolomite (Ds)	Dolomite	Dark gray, brown-gray, and med gray sucrosic to micro-sucrosic. Calcite on fx. 900 to 910 ft bgs frags of spaghetti dolomite.
910 to 917	Dsi Simonson Dolomite (Ds)	Fault zone in Dolomite	White calcareous clay with frags of dolomite (gray). Clay from 915 to 917 ft bgs, completely dissolves in acid (Stoller, 2006).

Common abbreviations for the above table:
acid - 10% hydrochloric acid
frags - fragments
fx - fracture(s)
lt - light
med - medium
occ - occasionally
vlts - veinlets

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 upper 20 ft of carbonate bedrock is interbedded limestone and dolomite of the Guilmette Formation, well fractured and with calcite and caliche veinlets. The upper unit of the Simonson Dolomite is present from 440 to 770 ft bgs, dominantly a medium gray dolomite. The medium gray color varies from a light gray to a dark gray, commonly brownish, typical of the upper alternating member described by Tschanz and Pampeyan (1970). The fracturing and calcite and caliche veinlets of the overlying material continue to about 460 ft bgs. A dark gray to black dolomite was noted from 770 to 880 ft bgs and clasts of spaghetti-like dolomite are present below 900 ft bgs. This dark gray to black interval most likely represents the third member described in Tschanz and Pampeyan (1970). Field investigations confirmed the alternating character of the upper Simonson member (Figure 6), including beds of dark brownish gray dolomite with a spaghetti texture.

Marker horizons at the base of the Guilmette and the top of the Simonson could not be specifically identified in the cuttings. The dusky yellow color of the "laminated, dusky yellow" unit (Tschanz and Pampeyan, 1970) may be due to surficial weathering, not the original color of the rock, and field investigations indicate that fossils within the Simonson are too poorly preserved to see in the cuttings.

In the borehole video, the dip of bedding is about 30 degrees. This dip creates an apparent thickness of 1.15 times the actual thickness, the thickness perpendicular to bedding. The actual thickness would be 0.866 times the apparent thickness, such that the approximately 500 ft of carbonate bedrock penetrated represents about 435 ft of actual thickness. This thickness fits well with the thicknesses of units reported by Tschanz and Pampeyan (1970) (Section 2.1.1).

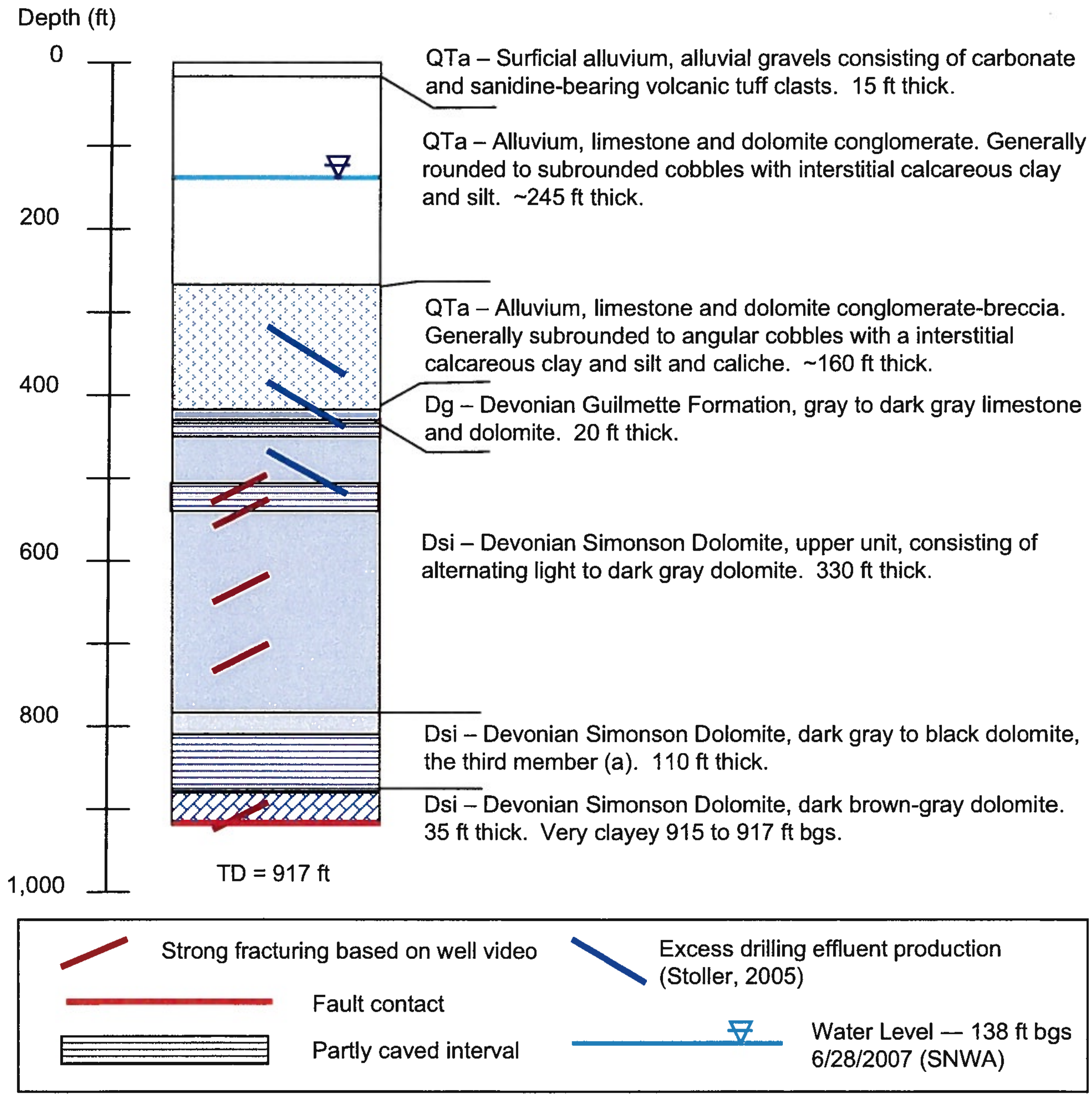
The presence of Guilmette Formation in the borehole indicates a fault between the well site and the Guilmette Formation to the east. The thickness of alluvium is further evidence of a fault that has displaced the valley floor downward between the outcrop to the east and the well site. This fault is probably related to a fault between Simonson Dolomite and the Guilmette Formation south of the well site, where the Guilmette has been faulted down-to-the-west (Figure 8) (Tschanz and Pampeyan, 1970).

The well lithology is presented graphically on Figure 10.

2.3.2 BOREHOLE GEOPHYSICS

On October 17 and 18, 2005, following the completion of drilling, a full suite of geophysical logs was performed to the full depth of the monitor well (Stoller, 2005). During the geophysical logging, the water level in the monitor well was at about 138 ft bgs. On October 17, 2005, a borehole video was taken of the uncased hole to the full depth of the monitor well. 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



Correlation of geologic units with RGUs (Dixon et al., 2007):
The surficial alluvium and older alluvium are part of the QTa RGU.
The Devonian Guilmette Formation is the Dg RGU.
The Devonian Simonson Dolomite is part of the Ds RGU.

(a) Tschanz and Pampeyan, 1970, p. 34.

FIGURE 10
BOREHOLE STRATIGRAPHIC COLUMN OF MONITOR WELL 180W902M

- 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).

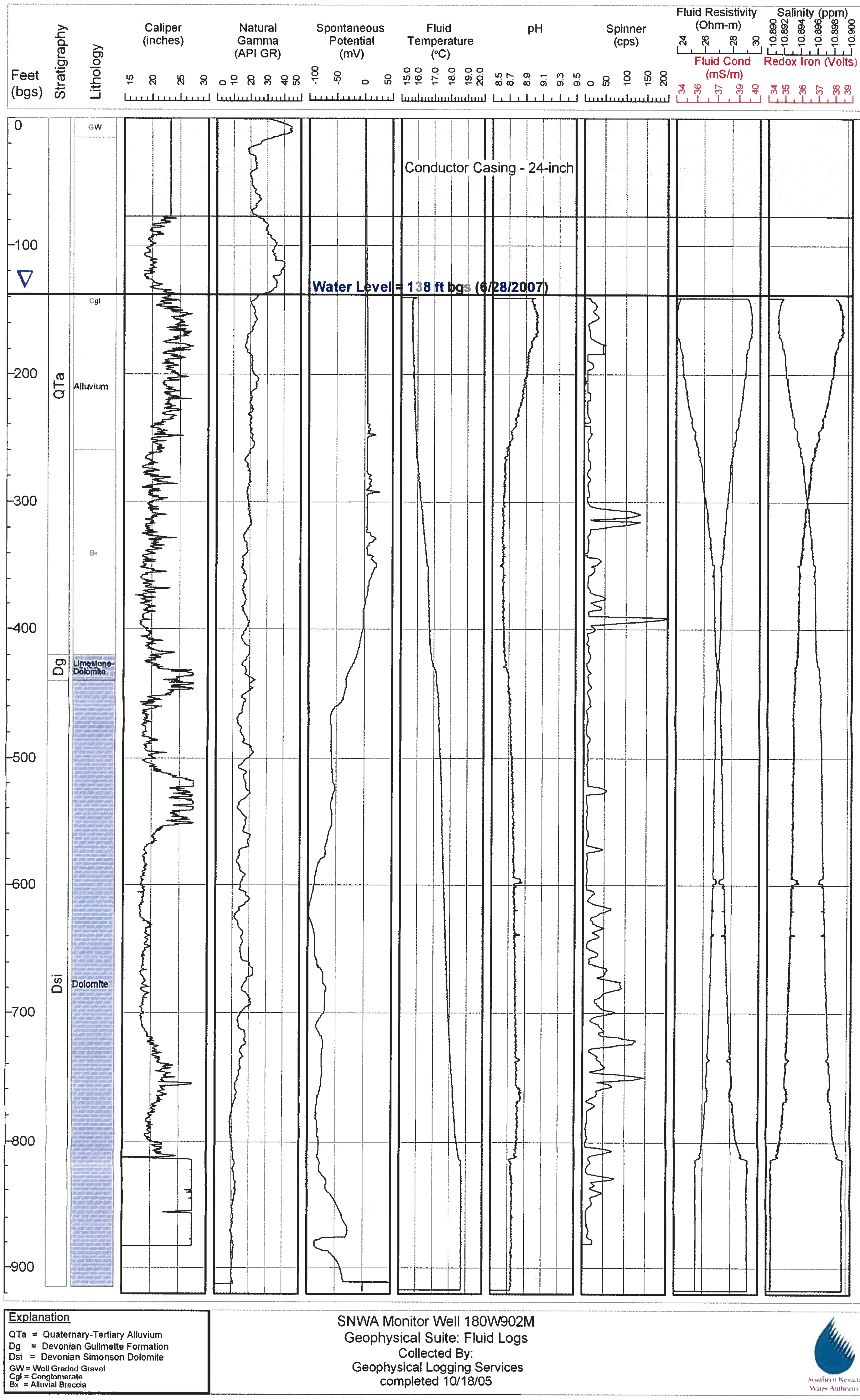
These geophysical logs are presented on Figures 11 and 12.

Muller (2007a and b) evaluated the geophysical logs for Monitor Well 180W902M. The more reliable logs for this well include Natural Gamma Ray (Gamma), resistivity logs (except the Induction log), Spontaneous Potential, Fluid Temperature, Fluid Conductivity, Fluid Resistivity, Salinity, pH, Deviation, and Pressure. Muller (2007b, 2007c) indicated that the Spinner and Sonic logs seem reasonable, but the Spinner log does not show correspondence with the Temperature log. Meanwhile, the Spectral (KUT) log does not appear to be valid.

The Lateral, Guard, and Induction logs are generally conformable and are discussed in this and subsequent paragraphs as the Electric logs. These Electric logs all indicate a change in response to a slightly more resistive material at about 260 ft bgs. Lacking better evidence, this change is chosen as the base of the limestone conglomerate and the top of the limestone breccia. A stronger change to more resistive material is seen at about 425 ft bgs. This change corresponds to the base of the alluvial breccia noted in the borehole video and also to the resistive material in the nearby AMT profile.

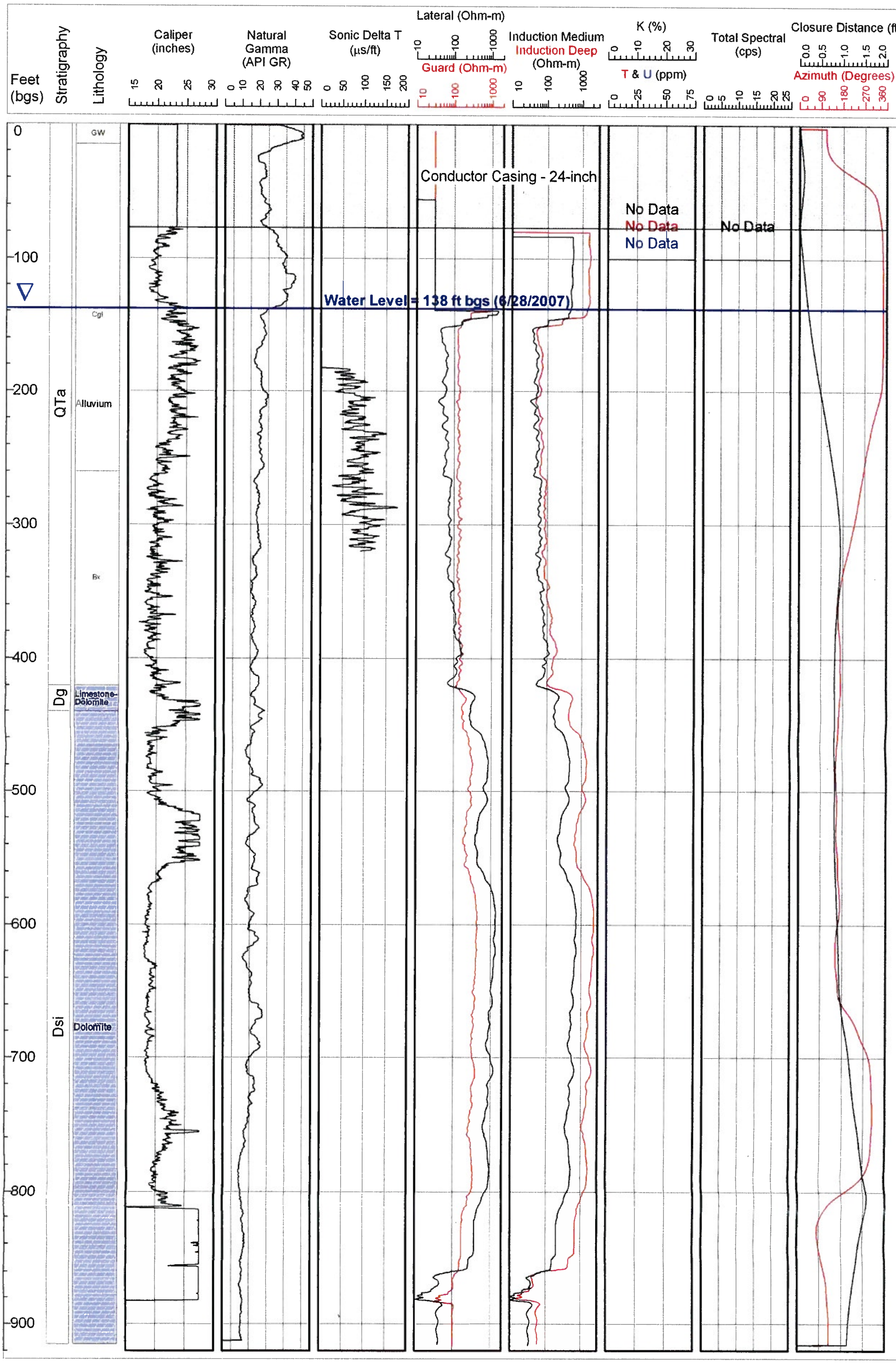
The dolomite appears to be slightly more resistive in the Electric logs than the interbedded limestone and dolomite, with the change at about 450 ft bgs. Below 855 ft bgs, the rock becomes more conductive, possibly indicative of a less permeable zone within the dolomite at the base of the dark gray to black material. This material contains organic carbon, which may contribute to the conductivity of the material. Other changes in the Electric logs appear to correspond to washed-out zones within the borehole, as between 430 and 450 ft bgs, 520 and 550 ft bgs, and between 815 and 880 ft bgs, the total depth of the Caliper log.

The Natural Gamma Ray (Gamma) log indicates a high count rate from the surface to about 20 ft bgs, probably due to the presence of sanidine-bearing (potassic) volcanic material in the surficial alluvium. Beneath this surficial high, the Gamma count rate is fairly low to the bottom of the hole, averaging about 20 gru below the water table. There is a very slight drop in the Gamma counts at 260 ft bgs, corresponding to a small change in the Electric logs. The less resistant zone indicated in the Electric logs at 860 to 880 ft bgs has no corresponding change in the Gamma log. The lower resistance is most likely related to the organic carbon content of the dolomite.



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 11
Monitor Well 180W902M Geophysical Fluid Logs



Explanation
QTa = Quaternary-Tertiary Alluvium
Dg = Devonian Guilmette Formation
Dsi = Devonian Simonson Dolomite
GW = Well Graded Gravel
Cgl = Conglomerate
Bx = Alluvial Breccia

SNWA Monitor Well 180W902M
Geophysical Suite: Formation Logs
Collected By:
Geophysical Logging Services
completed 10/18/05

Southern Nevada Water Authority

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 12
Monitor Well 180W902M Geophysical Formation Logs

The Spontaneous Potential log is constant from the water level to about 400 ft bgs, where the potential appears to decrease steadily within the carbonates to a low at about 625 ft bgs. The flat line to about 350 ft bgs may indicate a problem with the instrument. The subsequent decrease indicates a lower permeability of the carbonate unit relative to the alluvial material. There is an increase in Spontaneous Potential between 840 and 880 ft bgs within the dark gray to black dolomite interval. This interval may represent a more permeable fracture zone within the dolomite. Below this interval, the Spontaneous Potential drops again, corresponding to the increase in conductivity (decrease in resistivity) noted in the Electric logs.

The Fluid Temperature log indicates a steady increase in fluid temperature from the water table to 820 ft bgs, becoming constant below 820 ft bgs at 18.8°C. The constant temperature below 820 ft bgs suggests the effect of infiltration of groundwater from the carbonate bedrock. The groundwater influx is probably at and below 820 ft bgs. An inflection of the temperature curve at approximately 430 to 440 ft bgs suggests the influence of cooler groundwater at this level in the hole. This level corresponds to a zone of fractured limestone and dolomite of the Guilmette Formation. Another inflection at approximately 350 ft bgs indicates an additional interaction of groundwater with the borehole fluid, again, slightly cooler than the deeper groundwater. The fluid temperature continued to decline toward the surface, indicating a steady increase in influence of the drilling fluid. The range of temperature from 16.7°C to 18.8°C is consistent with that obtained on May 18, 2006, of 18.2°C (Acheampong et al., 2007).

The Spinner log is very spiky above a baseline of approximately 10 cps, with spikes going up to 200 cps. Based on Keys and MacCary (1971), this situation would indicate upward groundwater flow except at the spikes where groundwater flow would either be stagnant or downward, depending on the height of the spike. Muller (2007b) indicated that the Spinner log seems reasonable, but that he would be more confident if there was a correlation with the temperature log. Other evidence, particularly the borehole video and Fluid Temperature and Fluid Conductivity logs, indicates zones of stagnant water above about 330 ft bgs and below about 850 ft bgs. This evidence suggests that the upward flow indicated by the Spinner log in these intervals is very unlikely.

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 indicate that they were all derived from one sensor (Muller, 2007b), so only the Fluid Conductivity log will be considered.

Fluid Conductivity increased from about 34 mS/m near the water table to about 39.5 mS/m at 820 ft bgs. Below 820 ft bgs, the Fluid Conductivity remains constant. The increase suggests that the borehole fluid is becoming more saline with depth. This change may be due to a lower total dissolved solids (TDS) content of water used for drilling versus groundwater influx. It also may indicate a lower TDS of groundwater within alluvial sediments relative to the groundwater in the carbonates. The zone of constant fluid conductance suggests a consistent salinity of groundwater entering below 820 ft bgs. The sudden drop at 820 ft bgs appears to indicate a zone of less saline groundwater interacting with the borehole.

The borehole video also provides information on groundwater flux as groundwater interaction with the borehole improves clarity of the borehole fluid. Turbid water between the water level at 138 ft bgs and 303 ft bgs suggests a lack of groundwater flow to the wellbore in this interval. Improved visibility below 303 ft bgs suggests some groundwater flux fairly close to this depth. A groundwater flux at 330 ft bgs, as is indicated by Stoller (2005), could cause the improvement in visibility in the borehole fluid. Poor visibility in the borehole video below about 850 ft bgs indicates a lack of groundwater interaction with the hole below that depth.

The Sonic log was considered valid between about 180 and 320 ft bgs (Muller, 2007c). The Sonic log may indicate a slight increase in porosity over the interval, though there is a lot of signal noise and there could be other reasons for the slight increase. This short segment, which is entirely within alluvium, was not adequate to provide information regarding the geology at the monitor well.

The Caliper log indicates zones where the borehole was caved or partially caved. These zones are noted on the Borehole Stratigraphic Column (Figure 10) and in the Caliper log (Figure 11). There was some widening of the borehole between about 130 and 260 ft bgs within the limestone conglomerate. Within the caved zones at 430 to 450 ft bgs and 520 to 550 ft bgs, there was no indication of excessive fracturing in the borehole video. The lowermost caved interval, between 815 and 880 ft bgs, was visible in the borehole video to a depth of 852 ft bgs and appears to contain intervals of fractured dolomite. The fracturing may be a source of groundwater flux between 815 and 850 ft bgs, as indicated in the Fluid Temperature and Fluid Conductivity logs. Below about 855 ft bgs the borehole fluid was too turbid to view the hole wall, and interaction between the borehole fluid and the groundwater is unlikely.

The Deviation (Closure Distance) log indicates that the borehole deviates approximately 1.1 ft S40W.

2.3.3 DRILLING PARAMETERS

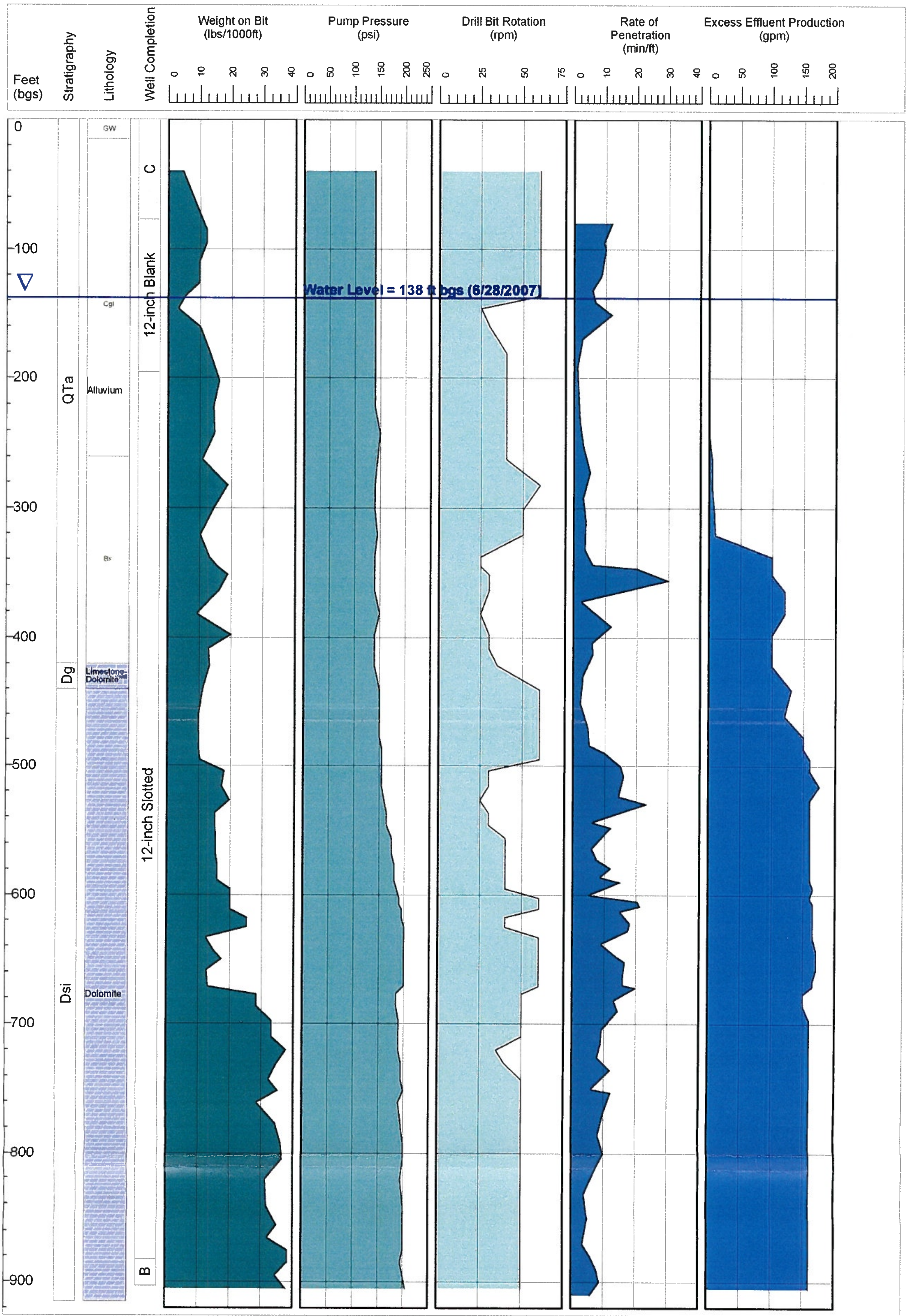
Stoller (2006) provided data on the drilling parameters as follows:

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

These drilling parameters are presented on Figure 13.

The Rate of Penetration log indicates a generally lower rate of penetration in the carbonates than the alluvium. The higher rate of penetration within much of the alluvium indicates that the calcareous interstitial material between cobbles and breccia fragments in the alluvium was either not cemented or weakly cemented. Further evidence of this lack of cementation is noted by the Caliper log, which showed an erratic hole wall, generally wider than the drill bit, in the zone of the highest penetration rate, 1 to 2 min/ft between 160 and 260 ft bgs. The lack of a gamma response in this material indicated that this material was primarily of calcium carbonate. The penetration rate was lower above 150 ft bgs. This lower penetration rate is probably due to caliche within the conglomerate, which was often noted on limestone clasts in the cuttings.

A low penetration rate also occurred between 350 to 365 ft bgs, which may indicate a clayey or caliche zone within the alluvial breccia. Caliche may be associated with a zone of groundwater flow, and caliche was noted coating some of the limestone fragments at about this depth. In addition, the drilling method was converted from air-foam drilling to flooded reverse circulation at 334 ft bgs after



Explanation

QTa = Quaternary-Tertiary Alluvium
Dg = Devonian Guilmette Formation
Dsi = Devonian Simonson Dolomite

C = Conductor Casing
B = Blank Casing

GW = Well Graded Gravel
Cgl = Conglomerate
Bx = Alluvial Breccia

SNWA Monitor Well 180W902M
Drilling Parameters
Collected By:
Stoller Corporation
From 10/9/05 to 10/17/05

Southern Nevada Water Authority

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 13
Monitor Well 180W902M Drilling Parameters

water was encountered. This change may have contributed to the lower penetration rate. Higher penetration rates near the bottom of the hole correspond with a higher weight on the bit, particularly below about 674 ft bgs, at which depth additional drill collars were added to the drill string (Stoller, 2005). Some of the variation in penetration rate is probably due to variations in the induration and fracturing of the dolomite.

2.4 HYDROGEOLOGY

Monitor Well 180W902M was completed (screened) within the saturated alluvial and carbonate rocks, particularly the Devonian Simonson Dolomite, in southeastern Cave Valley. During drilling operations, a noticeable increase in drilling effluent was first encountered at about 332 ft bgs, at which depth excess effluent discharge was estimated at 40 to 50 gpm (Stoller, 2005). Below that depth, during drilling operations, excess effluent flow increased to 100 gpm and was about 160 to 175 gpm near the base of the well (Figure 13) (Stoller, 2006).

A depth-to-water level of 137.99 ft bgs was taken at 21:02 on December 22, 2005, by SNWA (Stoller, 2006). The surface elevation at the well is approximately 5,988 ft amsl, which gives a groundwater elevation of approximately 5,852 ft amsl. This site has not been professionally surveyed. Seven additional water level readings have been taken since May 2006 ranging from 136.94 to 137.89 ft bgs, or approximately 5,850 ft amsl. These readings are essentially equivalent to the readings taken previously. A complete set of water level measurements is provided in Table 2.

TABLE 2
WATER LEVEL MEASUREMENTS FOR MONITOR WELL 180W902M

Date	Time	Depth (ft bgs)	Elevation (ft amsl)	Data Collected By
10/11/2005	12:10	140	5,848	Stoller (2006), on first clear indication of groundwater
10/14/2005	21:30	140	5,848	Stoller (2006), on completion of drilling
12/22/2005	21:02	137.99	5,850	SNWA
5/18/2006	13:00	137.6	5,850	Layne Christensen Co. (Yermo, CA) (SNWA, 2006)
10/23/2006	14:54	136.94	5,851	SNWA
12/05/2006	14:57	137.11	5,851	SNWA
1/23/2007	13:04	137.41	5,851	SNWA
2/26/2007	NP	137.25	5,851	SNWA
4/02/2007	11:25	137.67	5,850	SNWA
5/15/2007	12:20	137.76	5,850	SNWA
6/28/2007	10:16	137.89	5,850	SNWA

Note: Groundwater elevations are rounded to the nearest foot to reflect the uncertainty in the surface elevation of the well.
NP = Not Provided.

For comparison, the water level in the Sidehill Pass Well is at an elevation of 5,816 ft amsl (USGS, 2006), about 35 ft lower than that of Monitor Well 180W902M. The Sidehill Pass Well is approximately 4,600 ft (1,400 m) northwest of the monitor well site and is currently completed in Quaternary and Tertiary alluvial sediments. The Sidehill Pass Well was originally drilled as an oil test well to a depth of 6,802 ft bgs (Hess et al., 2004).

2.5 SUMMARY

Monitor Well 180W902M was drilled in October 2005 for the purpose of collecting geologic, hydrologic, and geochemical data. This monitor well is located in southeastern Cave Valley and was drilled to a total depth of 917 ft bgs with a slotted interval from 195 to 882 ft bgs.

The monitor well encountered 420 ft of alluvium, 20 ft of the Devonian Guilmette Formation, and 475 ft of the Simonson Dolomite. The hole penetrated a section of dark gray to black dolomite between 770 to 880 ft bgs, the brown (third) member of the Simonson Dolomite, above which is the uppermost, fourth member. Calcareous clay at the bottom of the borehole is indicative of a fault zone.

Geophysical logs and drilling parameters provided additional data for analysis. These logs assisted in defining geologic contacts and structural features. Zones of strong fracturing were noted in the borehole video that often corresponded to calcite veinlets in the cuttings, changes in the geophysical logs, and changes in the drilling parameters. The geophysical logs and the borehole video also indicate zones of groundwater interaction with the borehole and zones of relatively stagnant water.

Water level measurements indicate a water-level elevation of approximately 5,850 ft amsl. The groundwater flow was indicative of relatively porous alluvium above the carbonate bedrock and some contribution from fractures within the limestone and dolomite.

3.0

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.

Hess, R.H., Fitch, S.P., and Warren, S.N., 2004. Nevada Oil and Gas Well Database, Nevada Bureau of Mines and Geology, OFR 2004-1.

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.

McPhee, D.K., Pellerin, L., Chuchel, B.A., Tilden, J.E., and Dixon, G.L., 2006a, Resistivity Imaging in Eastern Nevada using the Audiomagnetotelluric Method for Hydrogeologic Framework Studies: in Proceedings of the 19th Annual Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP), Seattle, Washington, April 2-6.

McPhee, D.K., Chuchel, B.A., and Pellerin, L., 2006b, Audiomagnetotelluric data from Spring, Cave, and Coyote Spring Valleys, Nevada: U.S. Geological Survey OFR 2006-1164.

McPhee, D.K., Chuchel, B.A., and Pellerin, L., 2007, Audiomagnetotelluric profile SVNE, from presentation to Southern Nevada Water Authority on 24 January.

Mountain States Well Logging Company, 1996, Lithologic and Drilling Log for Well SHP FED 18-13 (API 27-017-05221) for Conley P. Smith Operating Company: Mountain States Well Logging Company, Aztec, New Mexico.

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

Muller, D., 2007b, Email to R. Schuth (SNWA) regarding geophysical logs for Well 180W902M and other wells, 3 May.

Muller, D., 2007c, Email to R. Schuth (SNWA) regarding the Sonic log for Well 180W902M, 14 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 American Association of Petroleum Geologists Publ. GB78.

S.M. Stoller Corporation, 2005, Drilling Morning Reports—Well 180W902M.

S.M. Stoller Corporation, 2006, Well 180W902M Well Data Report.

SNWA, see Southern Nevada Water Authority.

Southern Nevada Water Authority, 2006, Notes from geochemical sampling for Monitor Well 180W902M on 18 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, 2006, Groundwater Levels for Nevada, accessed at website http://nwis.waterdata.usgs.gov/nv/nwis/gwlevels.