NEW UTAH GEOTHERMAL DATA ACQUISITION —
A PROJECT SUPPORTING
THE NATIONAL GEOTHERMAL DATA SYSTEM

Prepared for:
Arizona Geological Survey
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National Geothermal Data System

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CONVERSION FACTORS

Length:	1 centimeter (cm) = 0.3937 inch (in.) 1 meter (m) = 3.281 feet (ft) 1 kilometer (km) = 0.6214 mile (mi)
Area:	1 m^2 = 10.76 ft^2 1 km^2 = 0.3861 mi^2
Volume:	1 liter (L) = 0.2642 gallon (gal) 1 km^3 = 0.2399 mi^3
Mass:	1 kilogram (kg) = 2.205 pounds (lb)
Flow Rate:	1 liter per minute (L/min) = 0.26417 gallon per minute (gpm) 1 ft^3/second (cfs) = 1,699 liters per minute (L/min)
Temperature:	degrees Celsius (°C) = (5/9) · (degrees Fahrenheit [°F] - 32) Kelvin (K) = °C + 273.15
Temperature gradient:	1°C/km = 0.05486°F/100 ft
Energy:	1 joule (J) = 0.2390 calorie (cal) 1 J = 9.485×10^{-4} British thermal unit (Btu) 1 J = 2.777×10^{-4} watt-hour (W·hr) 10^{18} J = 0.9485 quad (10^{15} Btu)
Power or work:	1 watt (W) = 1 J/s 1 megawatt (MW) = 3.154×10^{13} J/yr
Heat flow:	1 mW/m^2 = 2.390×10^{-8} cal/cm·s 1 mW/m^2 = 2.390×10^{-2} heat-flow unit (HFU)
Thermal conductivity:	1 W/m · K = 2.390 mcal/cm · s · °C

(Source: Reed, 1982)

ABSTRACT

The Utah Geological Survey, in support of the National Geothermal Data System, managed through the Arizona Geological Survey, gathered new geothermal-related data over a two-year period from May 2011 to May 2013. The data were obtained mainly from thermal-gradient drilling and sampling in various western Utah valleys. The majority of efforts focused on the collection of temperature-depth data from the Black Rock and Sevier Desert regions of Millard and Juab Counties that resulted from the completion of 10 temperature-gradient wells (seven drilled from project funding, three completed previously). Temperature-depth data were also collected from six existing wells near Sevier Lake in Millard County, from five existing wells near the Bonneville Salt Flats of western Tooele County, from two new wells near the north arm of Great Salt Lake, and one new well in the Salt Valley anticline region of Grand County in eastern Utah. Thermal conductivity was measured using a needle probe and divided bar apparatus on 676 cutting and core samples collected from the new drilling. Archived samples from five oil and gas exploratory wells in the Sevier-Black Rock Desert region were also used to measure 262 thermal conductivities. Twenty-six water analyses were obtained from thermal wells and springs, mostly as a result of leveraging other water sampling efforts in western Tooele, Juab, and Millard Counties. Six technical papers and reports were written either directly or indirectly as a result of this data gathering effort.

INTRODUCTION

In May 2011, the Utah Geological Survey (UGS) entered into a contract (UT-EE0002850) with the Arizona Geological Survey (AZGS) to collect new geothermal/scientific data, mainly in western Utah over a two-year time frame. This work was in support of the joint efforts of the Association of American State Geologists (AASG) and U.S. Department of Energy to develop the National Geothermal Data System (NGDS). The UGS proposed to study three areas in west-central Utah that, at the time, were part of UGS-sponsored geophysical investigations (magnetotelluric and gravity surveys). The areas included the western part of the Black Mountains (Escalante Desert, north-central Iron County), the central part of the Black Rock Desert (Meadow to Pavant Butte in Millard County), and the northern Sevier Desert, surrounding Fumarole Butte/Crater Bench (Crater Springs) in south-central Juab County. The primary activity was to drill several shallow, thermal-gradient test wells throughout the region to better define thermal signatures and to further investigate geothermal development potential. The proposal included drilling up to eight new exploratory/scientific boreholes for thermal-gradient studies. Data obtained from the seven completed exploratory wells included temperature-depth information, thermal-conductivity of material penetrated, lithology, and geophysical logs. Other efforts included gathering additional temperature-depth data and fluid chemistry data from existing "wells of opportunity." Gwynn and others (in preparation) provide details regarding the thermal-gradient well drilling and results. This report provides an overall review and presents data from the entire contracted data-gathering effort.

The UGS subcontracted with the U.S. Geological Survey's (USGS) Western Region Research Drilling program to drill seven approximately 152-m-deep, thermal-gradient wells as the centerpiece of its effort. Originally, we had proposed to drill three to eight boreholes in the three sub areas (Black Mountains, Meadow-Pavant Butte, and Crater Bench). Permitting and environmental complications at the Black Mountains site, however, resulted in dropping that location.

Prior to entering into the contract with AZGS, UGS began thermal-gradient and geophysical studies in the region using both internal and ARRA[1] funding. During the spring of 2011, UGS contracted with the USGS Western Research Drilling Program to complete two thermal-gradient boreholes near Crater Bench in the northern part of the Sevier Desert (well CS-4) and southeast of Pavant Butte in Black Rock Desert (well P-2A). The wells were each drilled to 244 m depth and completed by installing a sealed, 5-cm diameter PVC liner. Cutting samples were collected for lithology and thermal-conductivity measurements. In addition, UGS was able to take advantage of a newly drilled, but unproductive water supply well drilled by the Utah Division of Wildlife Resources in the Clear Lake Wildlife Management Area (well CL-1) during winter 2011. The UGS funded the completion of the well as a thermal-gradient well similar to CS-4 and P-2A. However, completed depth for CL-1 was much shallower (146 m). High-precision temperature measurements were later recorded at 2-m intervals in all three wells following establishment of thermal equilibrium in each well.

We also gathered thermal data from 16 available "wells of opportunity." Several of these wells are within the Sevier and Black Rock Deserts. Most, though, are located in other areas of

[1] ARRA refers to the American Recovery and Reinvestment Act of 2009

western Utah (Snake Valley-Sevier Lake, Bonneville Salt Flats, and northern Great Salt Lake regions) with one thermal-gradient well located in eastern Utah (Salt Anticline region). Well data from all drilling and sampling can be accessed through the appendices to this report and Internet links provided in those appendices.

A parallel effort (Hardwick and Chapman, 2011, 2012) included gathering additional magneto-telluric and gravity data to guide the placement of well drilling sites and to help assess the potential deep geothermal resources.

We collected fluid samples for chemical analyses from six wells and eight springs. We also leveraged 12 water analyses that were gathered as part of the UGS's Western Utah Groundwater Monitoring program (Kirby and Hurlow, 2005).

THERMAL STUDIES — SEVIER-BLACK ROCK DESERTS MILLARD COUNTY, UTAH

Summary

Gwynn and others (2013) and Allis and others (2011, 2012), summarized below, describe ongoing investigations of the deep geothermal potential beneath the Sevier-Black Rock Deserts of west-central Utah (figures 1 and 2). The study region is located in a 6000 km² basin at the northern end of what is informally known as the Sevier thermal anomaly along the eastern boundary of the Great Basin (Mabey and Budding, 1987). The basin is subdivided into the Black Rock Desert to the south and the Sevier Desert to the north, but as there is no distinct bounding feature, the name Sevier-Black Rock Desert (SBRD) is used to refer to the basin as a whole.

The UGS, in cooperation with the USGS Research Drilling Division, drilled and completed 10 temperature gradient wells in the SBRD. These wells, drilled as part of contracted efforts, and four others drilled in the 1970s, delineate a possible geothermal resource where temperatures of more than 150°C may extend beneath an area of about 350 km² at a depth of 3 km. This coincides with the axis of an actively extending basin containing late Tertiary to Quaternary sediments of similar thickness overlying Middle to Late Cambrian carbonate bedrock. An area of approximately 60 km² appears to have temperatures above 200°C at 3 km depth indicated by an abandoned oil exploration well with temperatures of 230°C at 3.3 km depth in the center of this thermal anomaly. Geothermal reservoirs may be contained in the near-horizontal carbonate stratigraphy between 3 and 4 km depth below the SBRD. These same units are exposed in the adjacent Cricket Mountains west of the SBRD. If these carbonate bedrock formations are sufficiently permeable, a substantial geothermal resource may exist in this region.

Twelve oil and gas exploration and test wells were drilled in the SBRD study area between 1957 and 2010. All of these wells were eventually plugged and abandoned. Most bottom-hole temperature (BHT) data obtained from well logs and corrected to minimize depressed temperatures caused by the drilling typically revealed geothermal gradients around 30-45°C/km. However, the Pavant Butte 1 well, drilled to 3290 m by Arco Oil and Gas Co. in 1981 revealed a corrected BHT of 230±10°C, equating to a geothermal gradient of about 66°C/km. The Pavant

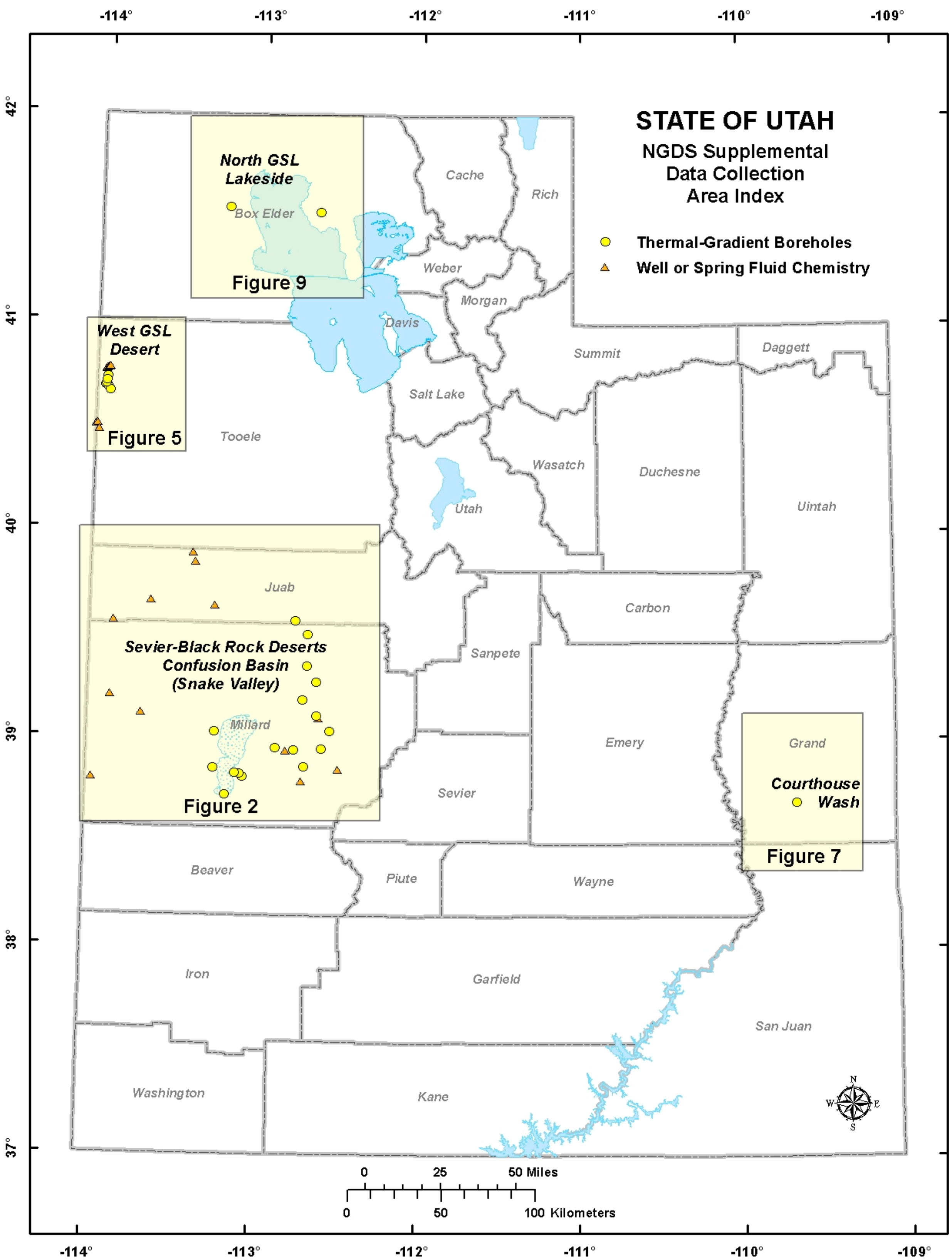

Figure 1. Index of Utah NGDS Supplemental Data.

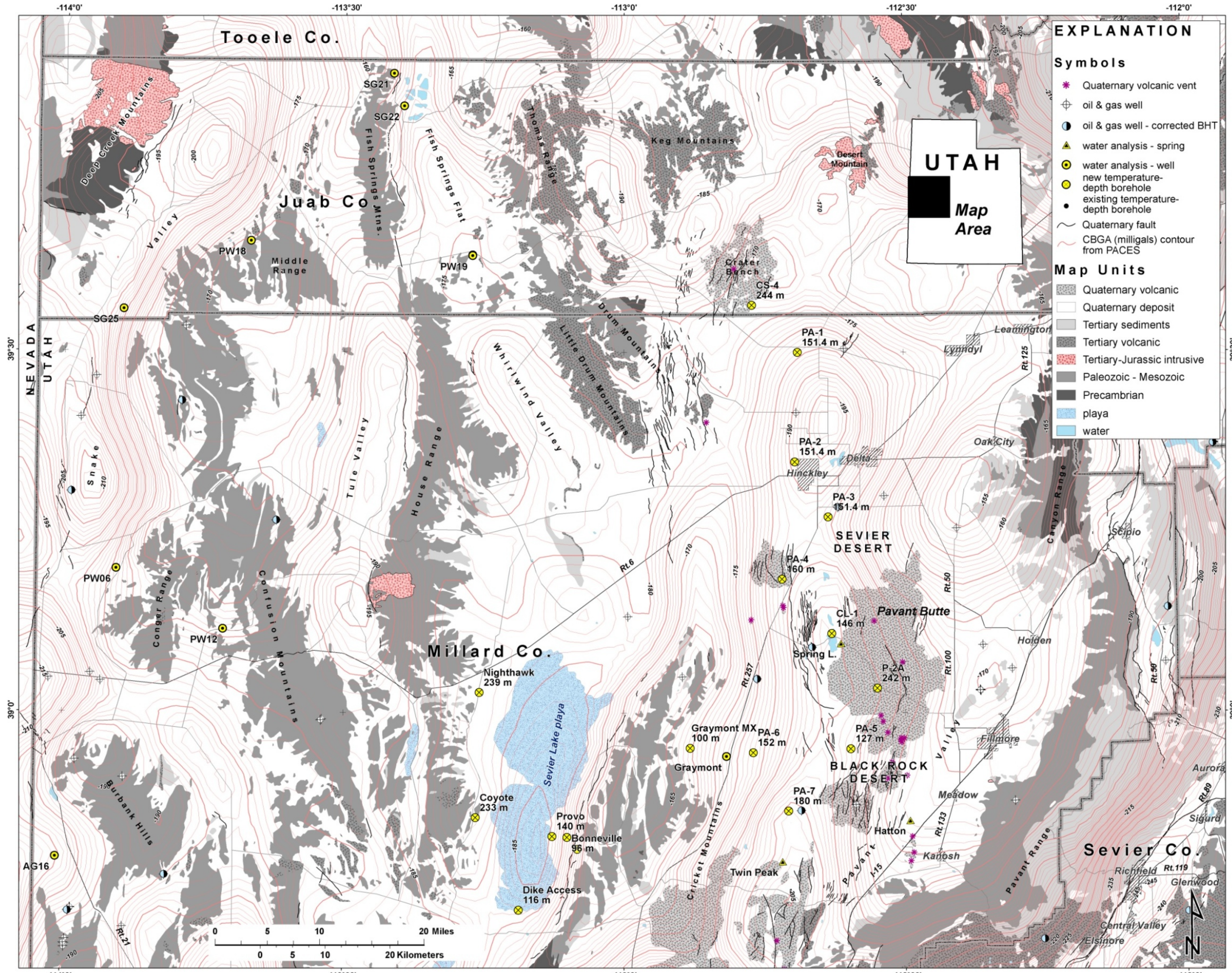

Figure 2. General geology, locations of thermal gradient wells, sampled wells and springs, oil and gas wells in the SBRD and Confusion Basin study regions, Millard and Juab Counties, Utah. Geology from Hintze and others (2000). Gravity contours from UTEP (2013).

Butte 1 well is located 3.5 km west of Pavant Butte, a volcano that last erupted about 15,000 years ago and is roughly centered in the basin containing the SBRD (Oviatt, 1989, 1991). The anomalously high BHT and gradient at the Pavant Butte 1 well became the impetus for further study in the area, ultimately leading to the drilling of 10 thermal-gradient wells in 2011-2012.

Over 80 shallow thermal-gradient wells have been drilled near the southern and west-central margins of the SBRD and in the adjacent ranges as part of previous geothermal exploration programs. These wells range in depth from 32 to 522 m, but about 80 percent are less than 100 m deep. The temperature profiles in many of these wells, from all depths, appear to be disturbed or convective and gradients fluctuate widely. The data from many of these wells are questionable and many occur in the bedrock associated with the surrounding ranges. As a result, only a few of these wells are considered useful with respect to thermal gradient studies within the SBRD (Gwynn and others, 2013).

New Thermal Gradient Wells

The effort here focused on installing 10 new thermal gradient boreholes distributed around the deeper parts (> 3 km) of the SBRD basin to allow refinement of the thermal regime suggested by existing wells (Gwynn and others, 2013). Gravity data (Hardwick and Chapman, 2012) were used to define the basin geometry and depth.

The new thermal gradient wells were drilled between April 2011 and September 2012 (Gwynn and others, in preparation). These wells range in depth from 130 to 244 m and were each completed with a string of 5-cm diameter, schedule 80, PVC pipe, sealed at the bottom and filled with fresh water, to facilitate precision temperature measurements. Bentonite grout (30 percent solids) fills the annulus between the PVC and wellbore.

Clear Lake-1 (CL-1) was drilled as a groundwater supply test well for the Utah Division of Wildlife Resources in the Clear Lake Wildlife Management Area. The well was drilled to a total depth of 420 m, but permeability was insufficient for water supply. Rather than simply plugging and abandoning the well, we completed CL-1 as a thermal-gradient well. Unfortunately, caving within the well bore prevented the PVC string from being inserted below 145 m. The remaining thermal-gradient wells, Crater Springs-4 (CS-4), Pavant-2A (P-2A), and Pavant Area-1 to Pavant Area-7A (PA-1 to PA-7A), were drilled by the USGS Western Region Research Drilling Program using mud-rotary and direct-air techniques (P-2A only). The CL-1 well is approximately 2.7 km southwest of the Pavant Butte 1 well and exhibited the highest geothermal gradient, 105°C/km, of all 10 thermal-gradient wells drilled during this investigation. Thermal gradients in the other wells ranged from 42 to 70°C/km.

Drill cuttings were collected for each 3-m interval in all of the UGS/USGS-drilled wells. The samples were rinsed in fresh water to remove as much drilling mud as possible and, with the exception of the CS-4 well, were then sealed in plastic bags to preserve the moisture content of the clay. The CS-4 and CL-1 samples were inadequately preserved and could not be used for thermal conductivity measurements. Samples from the remaining eight wells were preserved adequately for thermal conductivity, X-ray diffraction, and other studies. Samples from all 10 of the wells are predominantly hydrated clays with minor quantities of sand and gravel. Basalt flows up to about 50 m thick were penetrated in three of the wells (P-2A, PA-4, and PA-5A).

Temperature-depth profiles were recorded on several occasions at each well using high-precision temperature logging equipment. The equipment consists of a thermistor probe attached to reel-mounted four-conductor cable and the measurement accuracy is ±0.01°C. A summary of gradient wells is provided in table 1. Temperature-depth profile graphs are shown in figures 3, 4, 6, 8 and 10. Internet links for individual temperature-depth data logs are included in appendix A.

Temperature-Depth Data – Wells of Opportunity

Several wells of opportunity for gathering additional temperature-depth data were found along the western side of the study area near the Cricket Mountains and Sevier Lake (figure 2). At the Graymont lime plant, just east of the Cricket Mountains, we identified a well drilled as part of the MX Missile program during the early 1980s. This well was open to 116 m and was dry. Although not ideally located near the east flank of the Cricket Range and not ideally completed (> 15.2 cm diameter, dry hole) for thermal gradient studies, this well yielded an approximate gradient of 73°C/km.

Peak Minerals is assessing saline resources of brine at Sevier Lake. Their assessment includes monitoring of groundwater surrounding the lake through numerous shallow (< 30 m) and several deeper (> 125 m) monitoring wells. We accessed six of these deeper wells (Nighthawk, Coyote, Monument Point, Dike Access, Bonneville, and Provo) for thermal profiling (figures 2 and 4, table 1). Driller's logs were unavailable except for the Nighthawk well.

The Monument Point well was drilled to a depth of 370 m and completed with a string of 12.7-cm diameter, schedule 80, PVC pipe slotted from 369 m to 314 m. Peak Minerals reported static water level at 90 m depth. The thermal profile of the well (figure 4) lies close to an average Basin and Range (bedrock) geothermal gradient[2] from about 100 m to 285 m at 35°C/km. The geothermal gradient in this well decreases from 290 m to 355 m to 20°C/km. The differences in gradients within this well likely reflect changes in thermal conductivity of the material penetrated. Hintze and Davis (2003) show the well spudded in undifferentiated lacustrine and alluvial deposits (Qla), usually up to about 3.7 m thick. Below this surficial material is probably a thick section (more than 1219 m) of Cambrian Prospect Mountain Quartzite (Cpm).

The Coyote well was drilled to a depth of 233 m and completed with a string of 12.7-cm diameter, schedule 80, PVC pipe slotted from 232 to 171 m. Peak Minerals reported the static water level at 105 m depth. The thermal profile of the well (figure 4) approaches isothermal conditions from about 110 to 233 m. Hintze and Davis (2003) show the well spudded in Quaternary lacustrine and alluvial deposits (Qlg/Qla), up to about 5.5 m thick. Below this surficial material is likely a thick section (up to 520 m) of the Ordovician-Cambrian Notch Peak Formation (OCn). The near-isothermal gradient exhibited in this well may reflect lateral groundwater flow within the bedrock units.

[2] Determined from regional heat flow values for western Utah (between 85 and 90 mW/m^2) presented in Blackwell and Richards (2004) using an average bedrock thermal conductivity of 2.5 W/m·K.

Region	UWI	Hole Name	County	Location	UTM_E NAD83 Z12	UTM_N NAD83 Z12	Elev (M)	Meas Date	Drill Date	Depth (m)	BHT (°C)	GRAD (°C/KM)
Salt Valley	9901900017	CHW-1	Grand	(D-24-20)25bca	615718	4283983	1353	12/5/2012		268	17.7	13.4
Sevier-Black Rock	9902700234	PA-1	Millard	(C-15-08)24dab	354737	4373633	1396	3/19/2013	8/28/2012	151	18.2	41.6
Sevier-Black Rock	9902700235	PA-2	Millard	(C-17-08)12dca	353958	4356798	1399	3/19/2013	8/8/2012	151	21.9	62.1
Sevier-Black Rock	9902700236	PA-3	Millard	(C-18-07)9aab	358932	4348217	1400	3/19/2013	8/4/2012	151	21.4	60.4
Sevier-Black Rock	9902700237	PA-4	Millard	(C-19-08)02dcc	351622	4338793	1413	3/13/2013	9/9/2012	160	25.7	69.6
Sevier-Black Rock	9902700238	PA-5	Millard	(C-21-07)36bbb	359107	4330260	1423	3/13/2013	9/24/2012	127	17.9	47.0
Sevier-Black Rock	9902700239	PA-6	Millard	(C-21-08)32adc	346622	4312192	1427	3/19/2013	8/22/2012	152	22.4	69.8
Sevier-Black Rock	9902700240	PA-7	Millard	(C-22-08)36bbb	351891	4303080	1452	3/13/2013	9/13/2012	180	22.3	50.8
Sevier-Black Rock	9902700241	CS-4	Millard	(C-14-08)32baa	347844	4381037	1400	7/20/2011	4/11/2011	244	29.2	66.4
Sevier-Black Rock	9902700242	P-2A	Millard	(C-20-06)32acb	365960	4321706	1425	10/10/2012	4/26/2011	242	24.8	58.8
Sevier-Black Rock	9902700243	Graymont MX	Millard	(C-21-09)32aab	336925	4313076	1562	10/25/2012		100	21.2	73.0
Sevier-Black Rock	9902700244	CL-1	Millard	(C-20-07)03bab	359107	4330260	1399	10/25/2012	3/1/2011	146	24.9	104.8
Sevier Lake	9902700245	Coyote	Millard	(C-22-13)36cab	303568	4303130	1456	11/29/2012		233	26.6	ISO
Sevier Lake	9902700246	Monument Point	Millard	(C-23-11)15cbb	319181	4297924	1487	11/29/2012		370	26.0	34.5
Sevier Lake	9902700247	Nighthawk	Millard	(C-20-13)36aca	304603	4322362	1460	11/29/2012		239	20.5	19.7
Sevier Lake	9902700248	Dike Access	Millard	(C-24-12)15bdd	309904	4288747	1393	4/10/2013	Jan-13	116	20.15	63.8
Sevier Lake	9902700249	Bonneville	Millard	(C-23-11)09bcc	317620	4299783	1456	4/10/2013	Feb-13	96	16.95	37.4
Sevier Lake	9902700250	Provo	Millard	(C-23-11)07bdd	315328	4299972	1405	4/10/2013	Feb-13	140	17.7	36.2
Bonneville SF	9904530003	1-2 Harvest	Tooele	(C-01-19)23cbc	248338	4512353	1286	6/22/2011		90	15.0	ISO
Bonneville SF	9904530004	DBW-8	Tooele	(C-02-19)03bcd	246858	4507930	1285	6/23/2011		240	24.2	56.6
Bonneville SF	9904530005	DBW-14A	Tooele	(C-02-19)02ccc	248217	4507176	1285	6/22/2011		200	21.6	41.0
Bonneville SF	9904530006	DBW-17	Tooele	(C-02-19)14adb	249301	4504899	1285	6/22/2011		410	43.9	72.0
Bonneville SF	9904530007	DBW-22	Tooele	(C-01-19)34cdd	247230	4508722	1285	6/23/2011		105	16.4	ISO
Bonneville SF	9904530008	DBW-23	Tooele	(C-01-19)34aba	247728	4510189	1285	6/23/2011		85	15.2	ISO
Great Salt Lake	9900300053	Rozel-1	Box Elder	(B-09-07)04cdd	362021	4598906	1317	3/13/2013	11/18/2012	125	21.7	25.8
Great Salt Lake	9900300054	Matlin-1	Box Elder	(B-10-12)32ada	313807	4602412	1349	3/13/2013	11/25/2012	183	20.3	55.8

ISO – isothermal conditions

Table 1. Summary of temperature-gradient wells measured as part of the supplemental (new) Utah data gathered for inclusion in the NGDS.

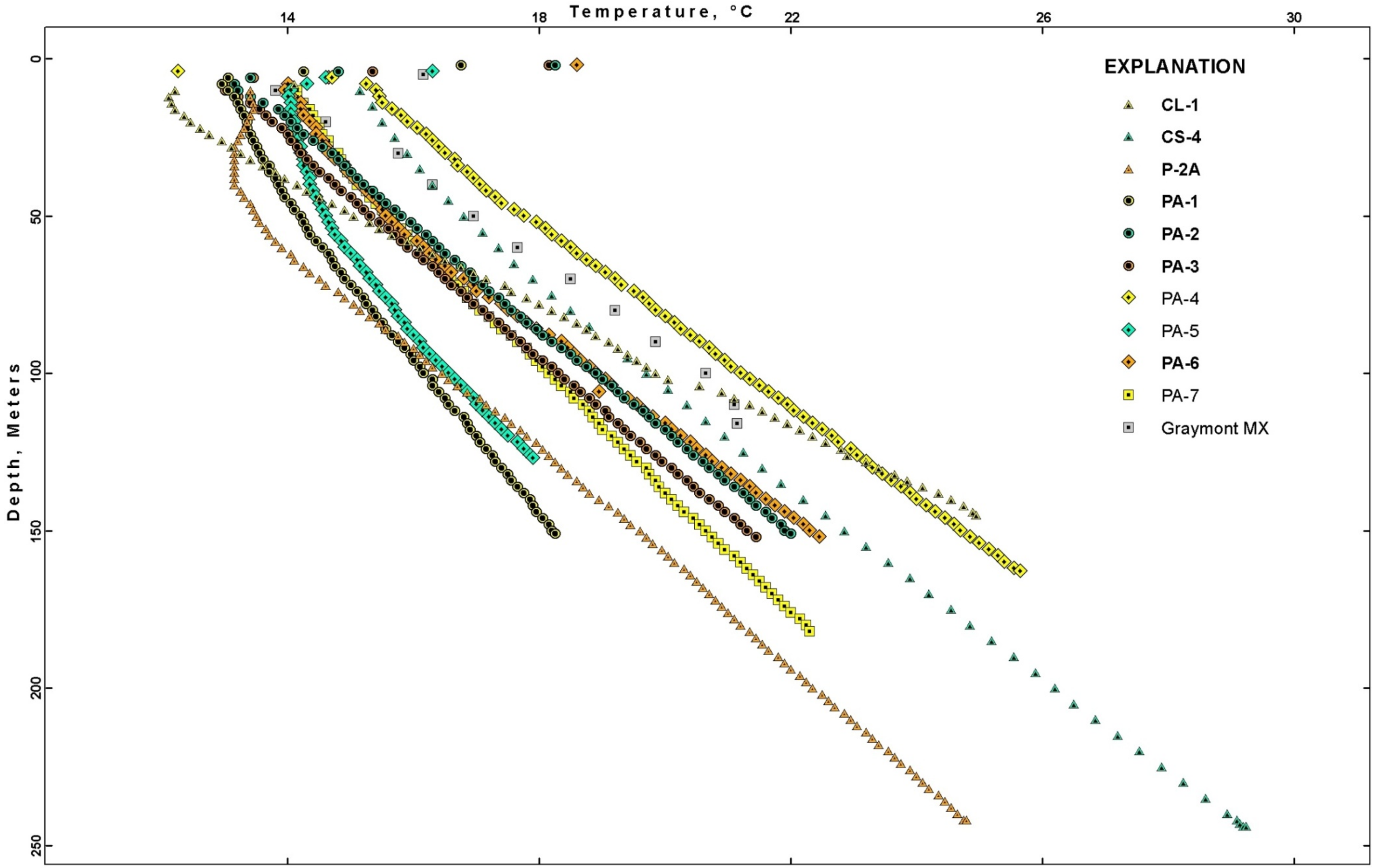

Figure 3. Temperature profiles for thermal gradient wells in the SBRD, Utah project area.

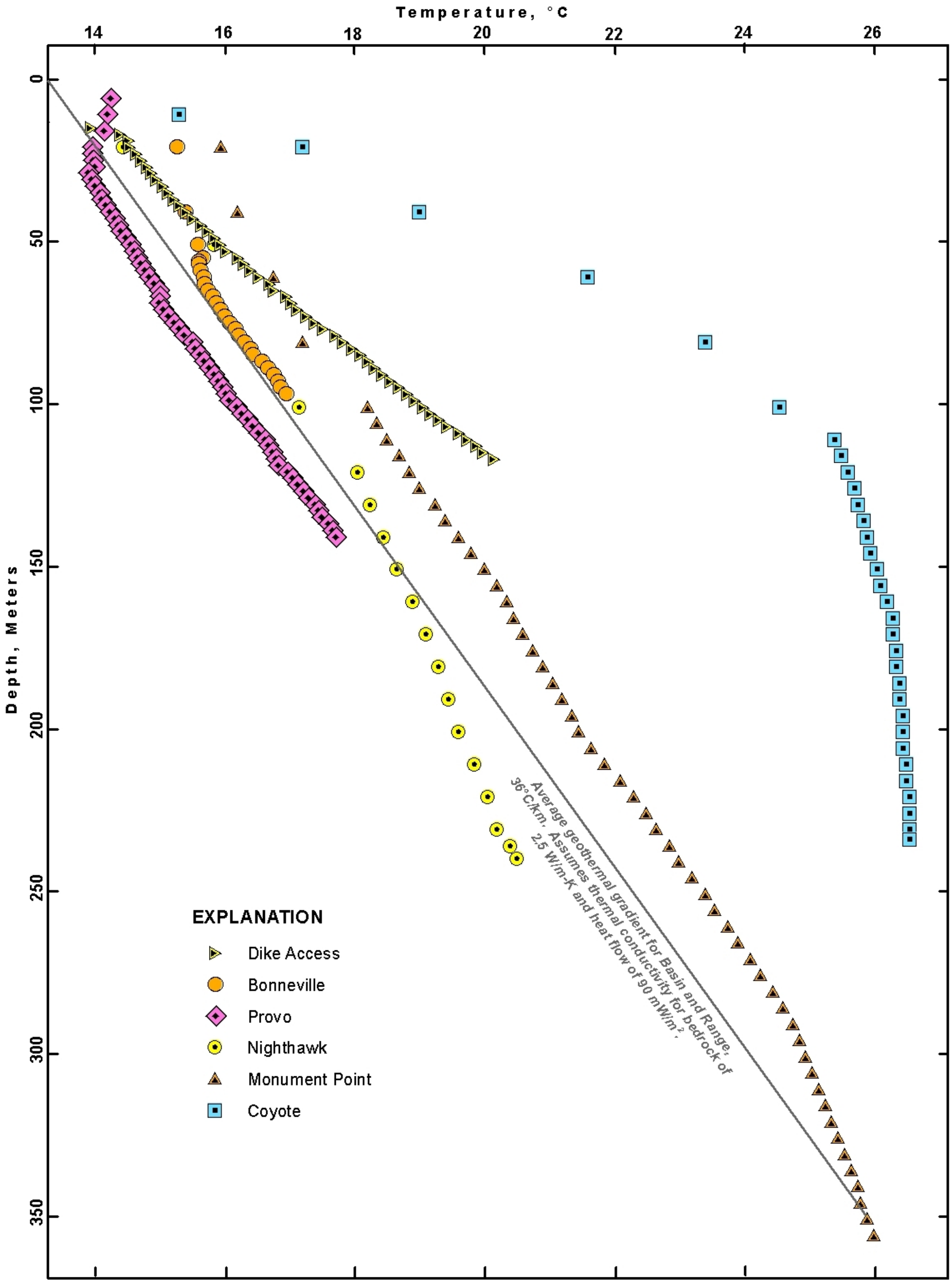

Figure 4. Temperature profiles for selected groundwater monitor wells in the Sevier Lake area, Utah.

The Nighthawk well was drilled to a depth of 239 m and completed with a string of 12.7-cm diameter, schedule 80, PVC pipe slotted from 238 to 177 m. Peak Minerals reported static water level at 110 m depth. The thermal profile is somewhat less than average Basin and Range thermal gradient. From about 120 to 220 m the thermal gradient is 20°C/km. The driller's log indicates the well penetrated 55 m of clay, sand, and gravel, below which the well penetrated bedrock. Bedrock units mapped in the area consist of a thick section (up to 520 m) of the Ordovician-Cambrian Notch Peak Formation (OCn).

The Dike Access well (SEV-12-027), drilled January 2013 near the southern extent of Sevier Lake (figure 2), was completed to 116 m depth with 12.7-cm diameter, schedule 80, PVC pipe slotted from 106 to 116 m. No geology or driller's log is available but the well is probably completed in mixed Quaternary-Tertiary sediment and possibly volcanic units. Peak Minerals classifies this well as an "Interplaya" well. A static water level of 14.7 m below ground level was recorded in April 2013. The temperature profile appears linear with a gradient of about 64°C/km.

The Bonneville well (SEV-12-026), drilled February 2013 through a westward sloping alluvial fan shed from the Cricket Mountains roughly 4 km east of the Sevier Lake shoreline (figure 2), was completed to 96 m depth. The 12.7-cm diameter, schedule 80, PVC liner is reportedly slotted between 64 and 94 m. Peak Minerals classifies this well as an "Interplaya" well. A static water level of 54.3 m below ground level was recorded in April 2013. No geology or driller's log is available but the well is probably completed in mixed Quaternary-Tertiary sediment and possibly volcanic units. Between 60 and 96 m depth interval the temperature profile appears linear (conductive) with a calculated gradient of about 37°C/km. This is a typical thermal gradient for the Basin and Range province.

The Provo well (SEV-12-025), drilled February 2013 about 2 km west of the Bonneville well and through the same alluvial fan described above for the Bonneville well (figure 2), was completed to 140 m depth. A static water level of 21.3 m below ground level was recorded in April 2013. A mostly linear temperature profile at depths between 50 and 140 m yields a thermal gradient of about 36°C/km. This is a typical thermal gradient for the Basin and Range province. No geology or driller's log is available but the well is probably completed in mixed Quaternary-Tertiary sediment and possibly volcanic units.

THERMAL STUDIES — WEST GREAT SALT LAKE DESERT TOOELE COUNTY, UTAH

Researchers from the Idaho National Laboratory organized an assessment of the geothermal potential of the Utah Test and Training Range (UTTR) for the U.S. Department of Defense (Smith and others, 2012). During 2011, geoscientists from the UGS and the University of Utah Energy & Geoscience Institute participated in this study by collecting subsurface temperature data from supply wells for Intrepid Potash's processing plant and water samples for geochemical analyses from other wells and surrounding springs near the town of Wendover, Utah, and the UTTR, Tooele County (figure 5).

UGS Geologists measured down-hole temperatures in six inactive deep brine production wells at the Intrepid Potash facility near Wendover June 22 and 23, 2011 (Blackett and others, 2012). Intrepid produces brine from a number of shallow and deep wells for potash and other salt extraction. The brine produced from the deep wells contains 120,000 to 130,000 mg/L total dissolved solids (TDS). Temperature logging revealed elevated subsurface temperatures, suggesting that hydrothermal fluids circulate to relatively shallow depths, possibly along faults marginal to the Wendover graben (figure 5). Turk (1973) reported a down-hole temperature of 88°C in the (bailed) drilling mud from 499 m in well DBW-3, located less than 5 km west of the southern tract of the UTTR (figure 6). Turk (1973) also reported somewhat lower temperatures in 12 other "deep brine wells" in the area at depths ranging from 326 to 631 m. These temperature data also suggest that temperatures increase southeastward toward the west side of the southern tract of the UTTR. The highest temperature in wells measured as part of our study was a bottom-hole temperature of 43.9°C measured at 410 m depth in well DBW-17 (figure 6). The temperature profile for the depth interval 320 to 385 m in this well yields an approximate thermal gradient of 72°C/km.

Hydrothermal systems indicated by thermal springs and wells are scattered throughout this large, sparsely populated region of Utah. The region extends westward from the Cedar Mountains in central Tooele County across the Bonneville Salt Flats to the Utah-Nevada state line, and then southward into Snake and Tule Valleys of Juab and Millard Counties. Mundorff (1970) included information on thermal springs and general geology for the Great Salt Lake Desert and western Utah as part of his report on major thermal springs in the state. Turk (1973) noted abnormally high geothermal gradients in brackish water wells, several deep brine wells, and two warm springs in the Bonneville Salt Flats area. Blue Lake and Mosquito Willies Springs, located south of the study area in western Tooele County near the Utah-Nevada border, are small lakes and marshes fed by thermal springs. Blue Lake maintains a fairly constant temperature at about 29°C, although we measured a temperature of about 28°C during a water-sampling investigation in September 2011. Whelan and Petersen (1974) focused a brief report on the geothermal potential of the Bonneville Salt Flats, referencing the work of Turk (1973). Goode (1978) also reported on thermal springs in this region as part of an overall study of thermal waters in Utah.

Whelan and Petersen (1974) discussed the relationship of the location and depths of the deep brine wells with respect to the Wendover graben (figure 5). Cook and others (1964), based on gravity surveys, suggested this graben trends southwest-northeast, parallel to the Silver Island Range to the north. The graben is more than 56 km long and about 16 km wide. Beneath the salt crust, the graben is filled with lacustrine sediment underlain by fluvial deposits. At about 366 m, the deep brine wells described by Turk (1973) penetrated "hard rock" or "conglomerate" that Whelan and Petersen (1974) suggested may be volcanic breccia corresponding to volcanic rocks in the Silver Island Range.

Russ Draper of Intrepid Potash's Wendover facility provided UGS geologists with access to the six unused deep-brine wells. Temperature profiles (figure 2, appendix A) were recorded by UGS personnel (Blackett and others, 2012) using a high-precision thermistor probe and temperature

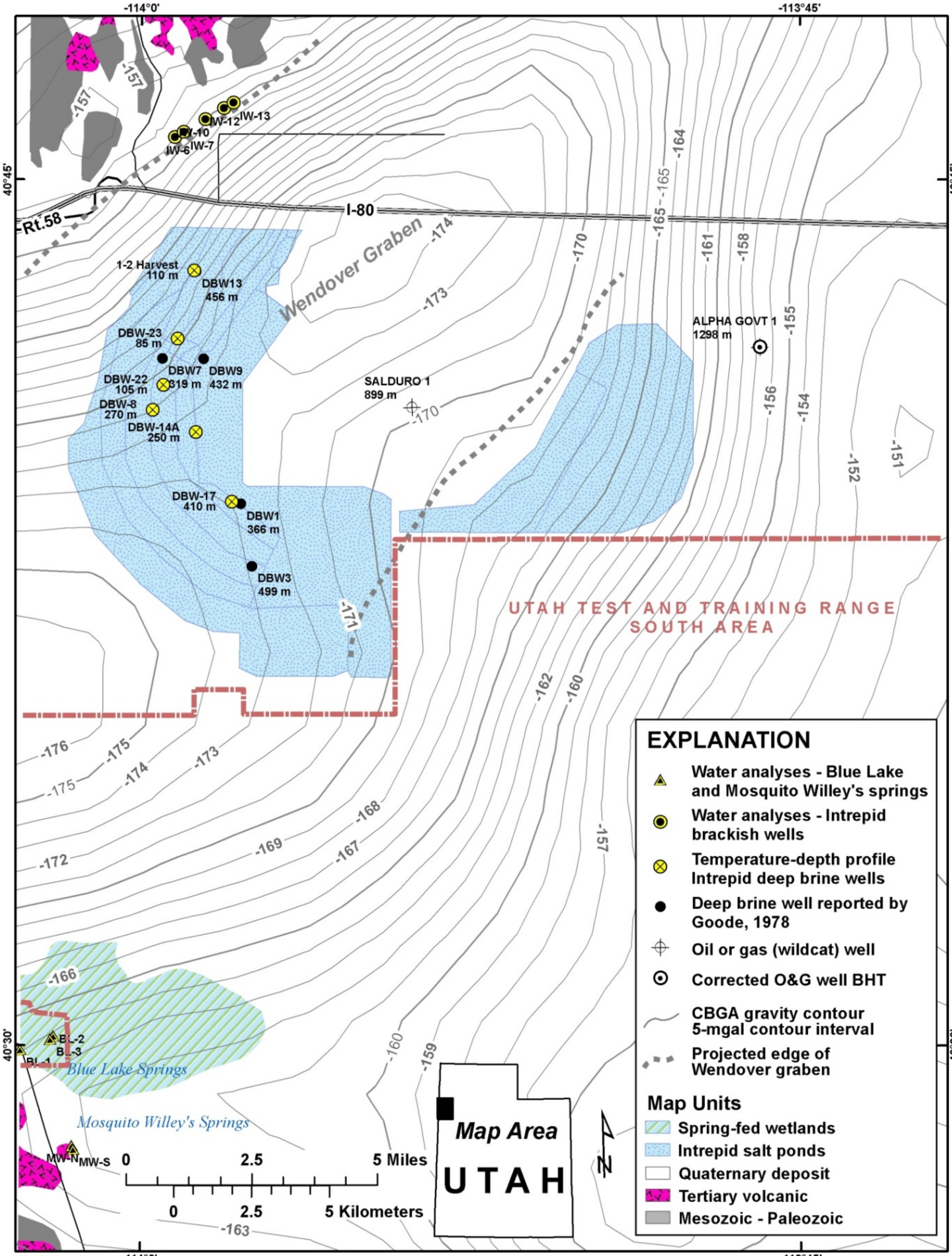

Figure 5.General geology, location of Intrepid Potash wells, oil and gas wells, and gravity data in the western Great Salt Lake Desert study region near Wendover, Tooele County, Utah. Geology from Hintze and others (2000). Gravity contours from UTEP (2013).

logging equipment.[3] Temperatures were recorded at 5-m intervals in the six wells, and a total of 1130 m of borehole length was recorded. BHTs ranged from 15 to 44°C in boreholes ranging from 85 to 410 m depth (table 1, appendix A). All wells were completed with surface casing of approximately 43-cm diameter and production casing of about 18.4-cm diameter. Shallow temperatures recorded above the static water levels (in air) depict negative thermal gradients downward to the static water level in all wells. Below the static-water level, temperature profiles reverse, becoming positive in most cases.

The following paragraphs summarize the temperature logging within Intrepid's deep brine wells. The locations of the wells are shown on figure 5. Temperature-depth plots are shown on figure 6. Russ Draper (Intrepid) reported that he thought that all of the wells were originally completed to about 400 m depth. However, since the wells had not been used in a number of years, we found that only DBW-17 was open to the original total depth of about 410 m.

1-2 Harvest: A blockage was encountered in this well at 90 m depth, stopping the temperature probe. The BHT recorded was 15.0°C. The temperature profile is nearly isothermal within the probed interval. A driller's log was not available for this well. Static water level was 11.7 m depth.

DBW-8: Temperatures in this well were measured to 240 m where a blockage was encountered. The BHT was 24.2°C. The thermal gradient between 100 and 200 m is about 57°C/km. Turk (1973) showed a driller's log for DBW-8 extending to 343 m depth, encountering alternating layers of clay and gypsum to a depth of about 283 m. From this depth to TD, the drillers encountered mainly "gravel" and "conglomerate." Static water level was 14.3 m depth.

DBW-14A: Temperatures were measured in this well to a depth of 200 m where the probe became stuck. The profile reveals a conductive gradient from about 50 m to about 200 m depth where a BHT of 21.6°C was measured. A driller's log was not available for this well. Static water level was 7.25 m depth.

DBW-17: Temperatures were measured in this well to 410 m, where the BHT was 43.9°C. A driller's log was not available for this well; however, DBW-17 is near DBW-1, which was completed in 1943 to a depth of 366 m (Turk, 1973). DBW-1 reportedly encountered mostly clay, gypsum, and sand to 356 m, apparently encountering black volcanic (?) rock below that depth. The static water level in DBW-17 was 26.5 m. The temperature profile for the depth interval 320 to 385 m in this well yields an approximate thermal gradient of 72°C/km. Changes in thermal gradients above the valley-fill/bedrock contact (about 350 m?) may be due to higher thermal-conductivity layers of salt interbedded with lower thermal-conductivity layers of clay and silt.

DBW-22: A blockage was encountered in this well at about 105 m depth where a BHT of 16.4°C was measured. The temperature profile to that depth was nearly isothermal. Static water level was 15.5 m depth.

[3]The thermistor probe is linked to a volt-ohm meter by four-conductor cable on a reel. Probe resistance is read from the volt-ohm meter, manually recorded and converted to temperature using a probe-specific polynomial determined by the manufacturer (Natural Progression Instruments, Olympia, Washington). Instrument characteristics and periodic calibrations result in a temperature measurement precision of 0.01°C.

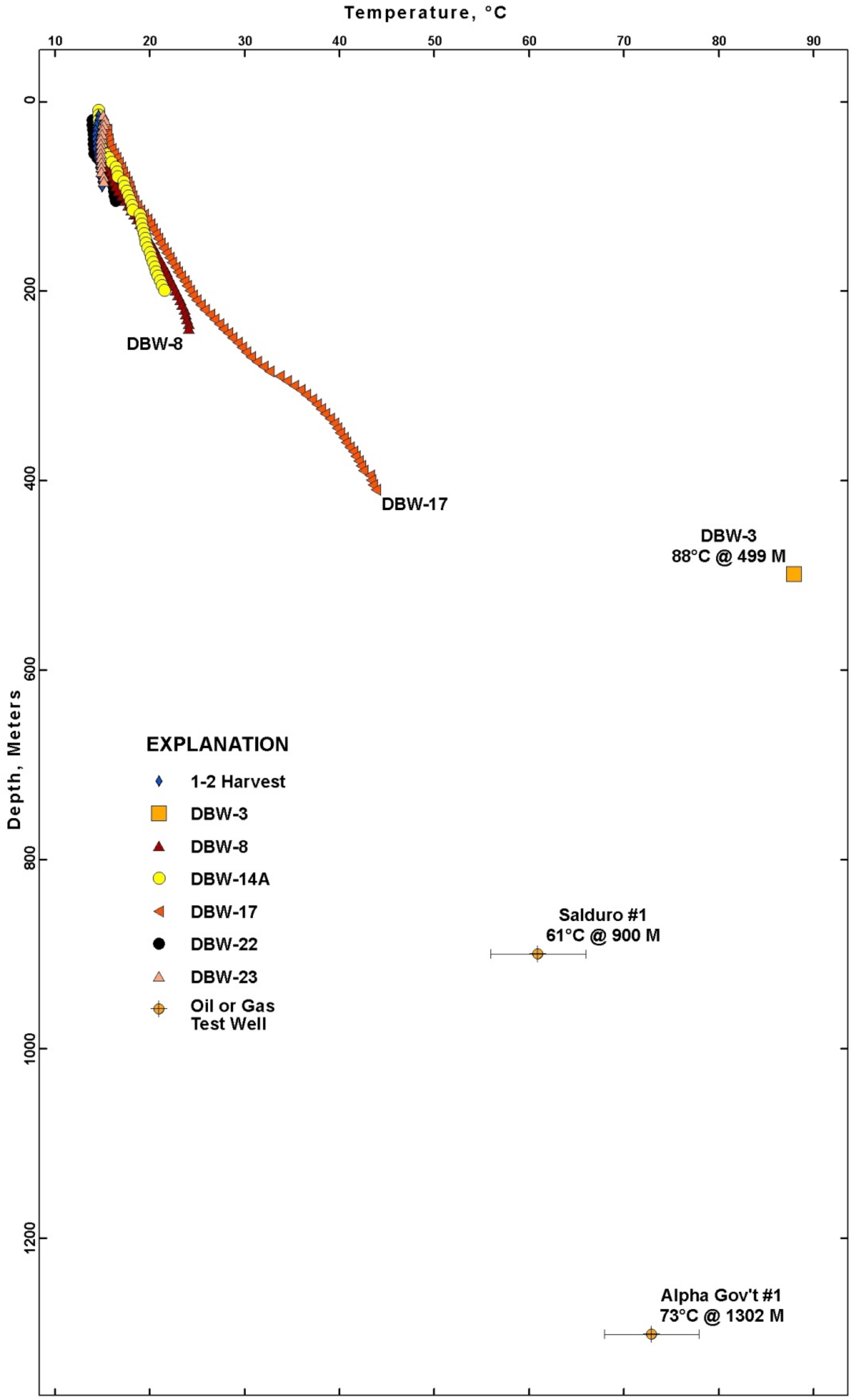

Figure 6. Temperature profiles for Intrepid Potash wells and corrected bottom-hole temperatures for two oil and gas exploratory wells near Wendover, Tooele County, Utah.

DBW-23: A blockage was encountered in this well at about 85 m depth where a BHT of 15.2°C was measured. The temperature profile to that depth was nearly isothermal. Static water level was 8.1 m depth.

Two oil and gas exploratory wells, the Salduro #1 and the Alpha Gov't #1 wells, drilled within the project area provide some insight into the deep geothermal gradient of the study area. Whelan and Petersen (1974) described the lithologies penetrated in the Shell Oil Salduro #1 exploratory well drilled in 1956 (figure 5). The well was drilled to 900 m depth, penetrating typical lacustrine clay, gypsum, and limestone to about 410 m. From this point the well continued through "conglomerate" to 490 m, followed by a sequence of "volcanic breccia" with alternating beds of clay/tuff. The well then entered basalt at about 835 m. "Microgabbro" was described at 863 m and the well was bottomed in dark igneous rock described as "olivine augite diabase." Utah Division of Oil, Gas, and Mining records indicate an uncorrected BHT of 56°C for the Salduro #1 well and 68°C for the Alpha Gov't #1 well. We computed corrected BHTs of 61°C at 899 m and 73°C at 1302 m for the Salduro #1 and Alpha Gov't #1 wells, respectively (see the plotted values on figure 6). Note that these corrected BHTs are rough estimates derived by adding 5°C/km to the uncorrected values, assuming typical conditions. No information about bottom-hole mud circulation times (the time when the temperature measurement was recorded versus the time when circulation stopped) that we use to make more accurate corrections were available on the log headers. We estimate the uncertainty associated with these corrected temperatures is ± 5°C.

THERMAL STUDIES — COURTHOUSE WASH–SALT VALLEY ANTICLINES GRAND COUNTY, UTAH

Kirby and others (2013) describe the Courthouse Wash groundwater monitoring well (CHW-1, table 1, appendix A), completed in February 2012 near Arches National Park in Grand County, Utah. The purpose of the well is to determine the relationship between groundwater that supplies important springs in the park and groundwater beneath the upper part of Courthouse Wash, an area that may experience development in the near future.

The CHW-1 well is situated in the Salt Valley anticline region of the Paradox Basin of the Colorado Plateau physiographic province in eastern Utah along the Courthouse syncline (figure 7) about 16 km northwest of the town of Moab. The region has been subjected to salt tectonism, with several eroded salt anticlines, as a result of salt movement and diapirism originating within the Pennsylvanian Paradox Formation from late Miocene to Pleistocene (?) (Olig and others, 1996). The Moab Fault, also a major salt-tectonic related feature near the CHW-1 well, is described by Foxford and others (1996) as having as much as 950 m of displacement at the surface.

The well was completed with two piezometers to total depth of 268 m and penetrated several Jurassic formations including the Entrada and Navajo regional aquifers. One piezometer is open to the Slick Rock Member of the Entrada Sandstone from 204 and 210 m, while the second piezometer is screened within the Navajo Sandstone from 262 to 268 m. Water levels measured

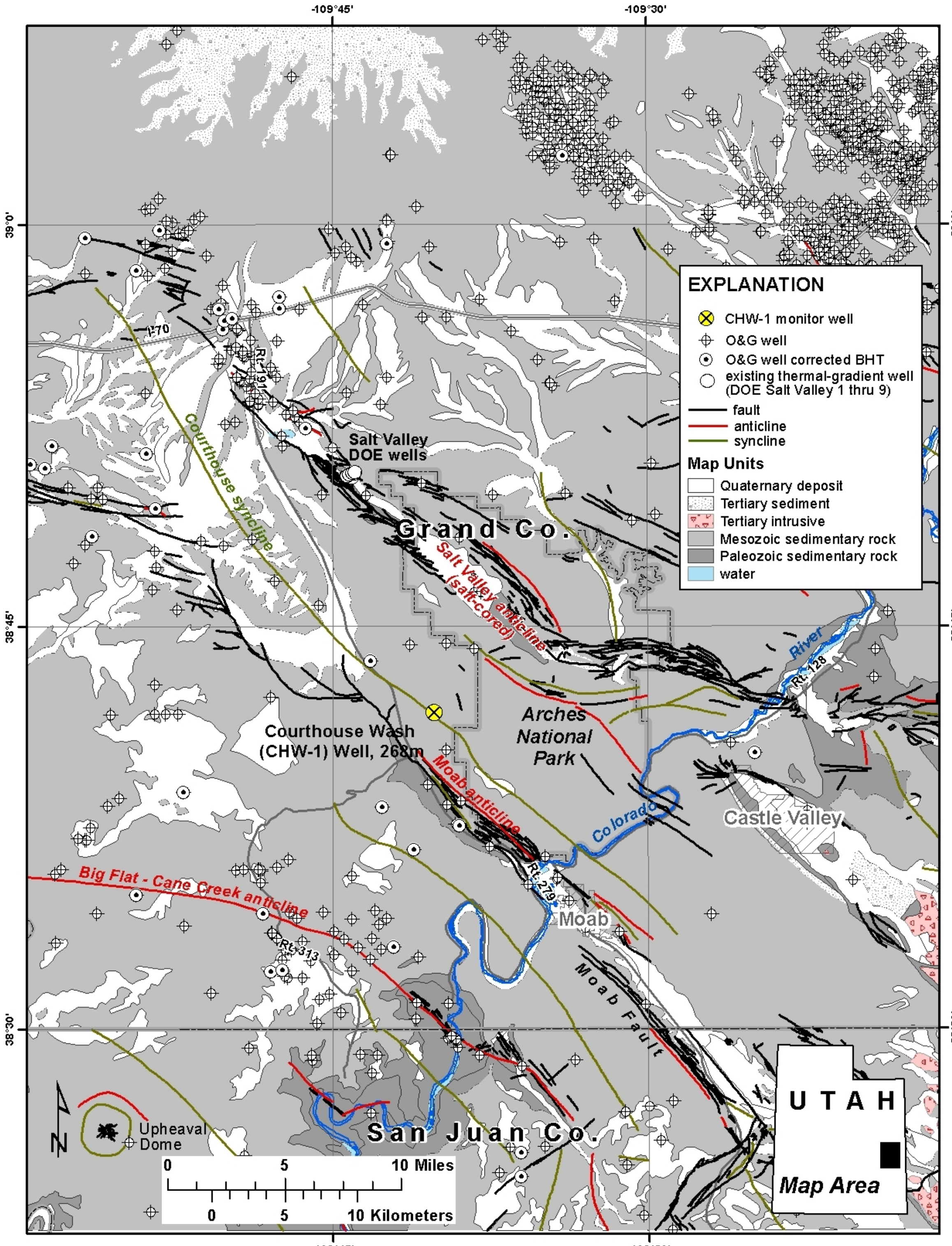

Figure 7. General geology and the location of the Courthouse Wash well (CHW-1) with respect to oil and gas wells and the Salt Valley DOE thermal gradient wells, Grand and San Juan Counties, Utah. Geology from Doelling (2002, 2004).

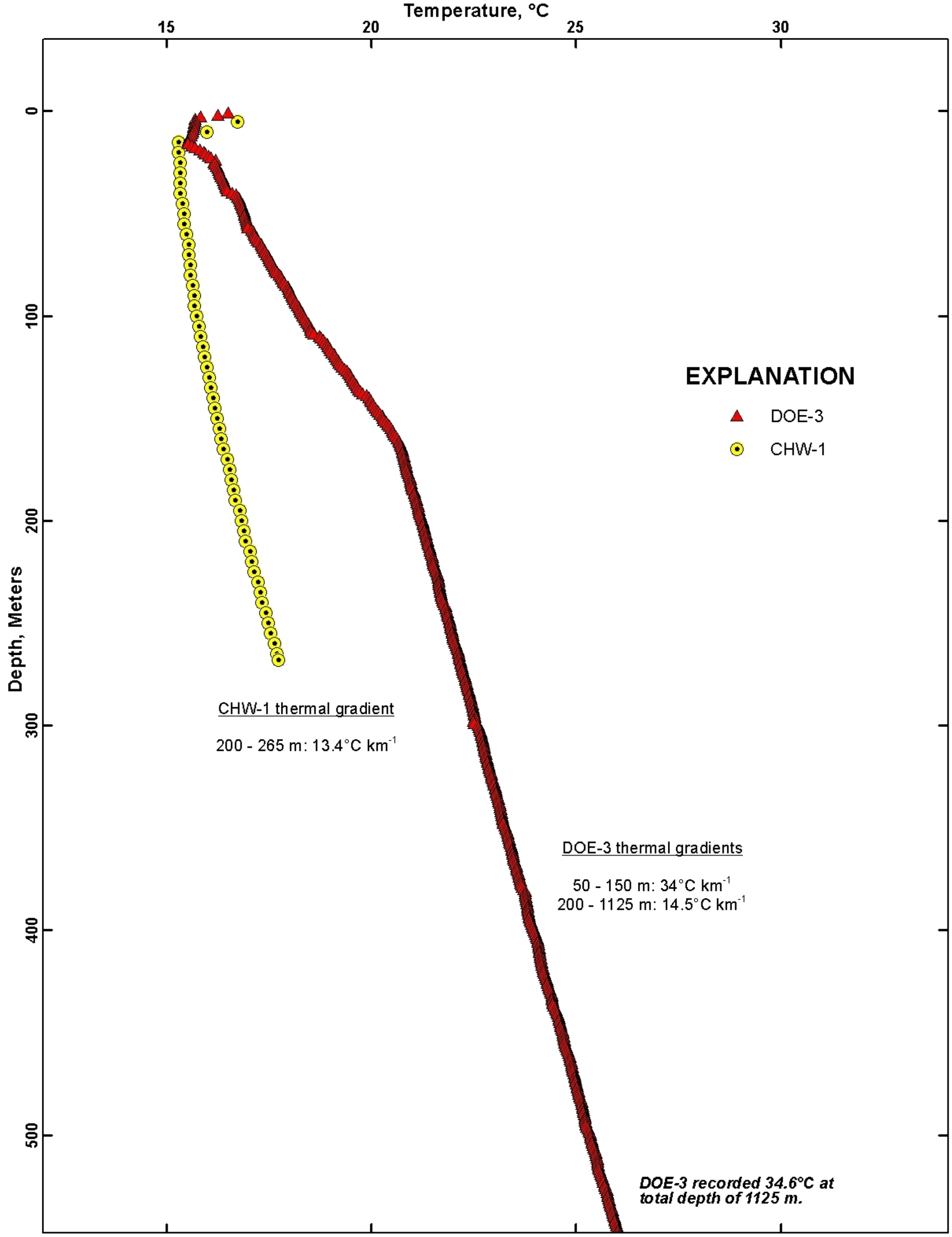

Figure 8. Temperature-depth profiles of the Courthouse Wash well (CHW-1) and the DOE-3 well described by Sass and others (1983).

in the two piezometers range from about 10.7 m below the top of the casing for the Navajo completion to about 2.1 to 3.4 m above the top of the casing for the Entrada completion.

A temperature profile of the CHW-1 well was taken on December 5, 2012 (figure 8). Measurements were recorded at 5-m intervals downward within the deeper piezometer (Navajo completion) to total depth (268 m). The gradient slope of a linear fit between 200 and 265 m for these temperature data is 13.4°C/km.

As part of a thermal study of the Salt Valley anticline, Sass and others (1983) obtained temperature profiles in nine wells (DOE Salt Valley 1 through 9) drilled by the U.S. Department of Energy. They also measured thermal conductivities on ten representative samples of rocks from the deepest well (1125 m). Temperature gradients in four wells near the center of the anticline average about 38°C/km, while two wells along the southwest side of the valley yielded temperature gradients between 25 and 30°C/km. They suggest that the differences could be the result of lateral variation of thermal conductivity, structure, water movement or a combination of these. The temperature profile of well DOE-3, the deepest of these, is shown with the profile for CHW-1 on figure 8.

THERMAL STUDIES — NORTHERN GREAT SALT LAKE BOX ELDER COUNTY, UTAH

The USGS, in cooperation with the UGS, drilled and completed two thermal gradient wells adjacent to the north arm of Great Salt Lake in Box Elder County, Utah, during fall 2012. The wells, named Rozel-1 and Matlin-1, were completed to 186 m and 126 m, respectfully.

The Rozel-1 and Matlin-1 wells are situated on opposite sides of the Great Salt Lake north arm (figure 9). The wells were drilled by the USGS Western Region Research Drilling Program using mud-rotary techniques. Drill cuttings were collected over 3 m intervals, sealed in plastic bags, and preserved for thermal conductivity, X-ray diffraction, and other studies. Samples from Rozel-1 comprised mainly clay and sand with some gravel, and as much as 27 m of basalt between about 119 m and 146 m depth. Samples from Matlin-1 comprised mainly coarse sand, gravel, and some clay. Drilling of Matlin-1 was terminated following total loss of circulation after penetrating fractured, cavernous basalt at about 120 m. Both wells were completed with 5-cm diameter schedule 80 PVC pipe, sealed and filled with fresh water for temperature profiling. Bentonite grout (30 percent solids) fills the annulus between the PVC and wellbore.

Temperature profiles for both wells are shown on figure 10, along with a profile measured in a thermal-gradient well (NF-1) in the Newfoundland Mountains measured by Chapman and others (1978). Well NF-1 is located roughly 40 km south-southwest of the Matlin-1 well (figure 9).

The Rozel-1 temperature profile is largely non-linear and may, in part, be due to varying thermal conductivities of the different basin-fill lithologic units penetrated by the well. However, the deflection at about 35 m likely indicates a subsurface cross flow of slightly warmer water. The similar, but less pronounced, profile at about 135 m may also indicate a cross flow. The profile

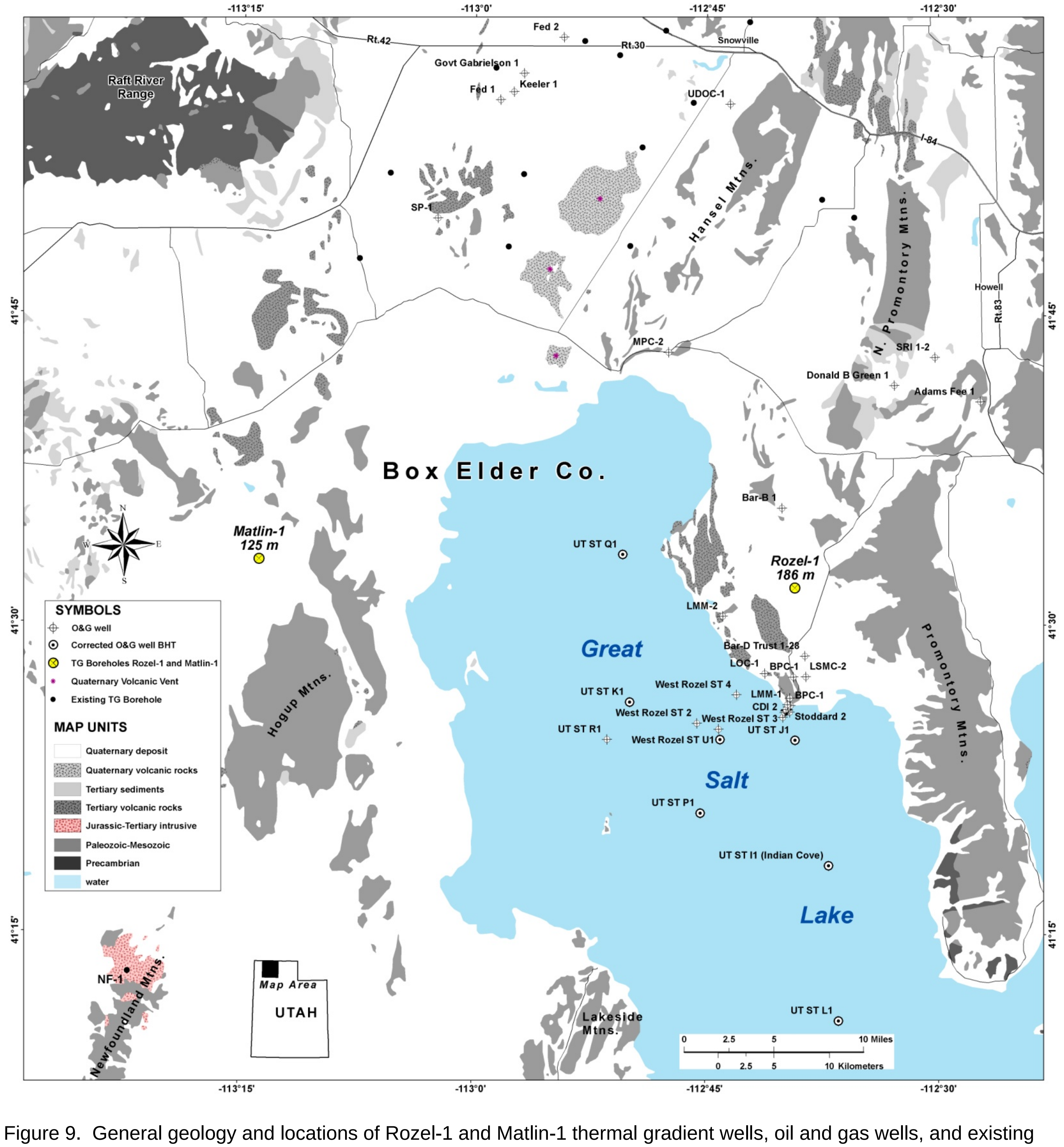

Figure 9. General geology and locations of Rozel-1 and Matlin-1 thermal gradient wells, oil and gas wells, and existing thermal gradient wells in the northern Great Salt Lake study region. Geology from Hintze and others (2000).

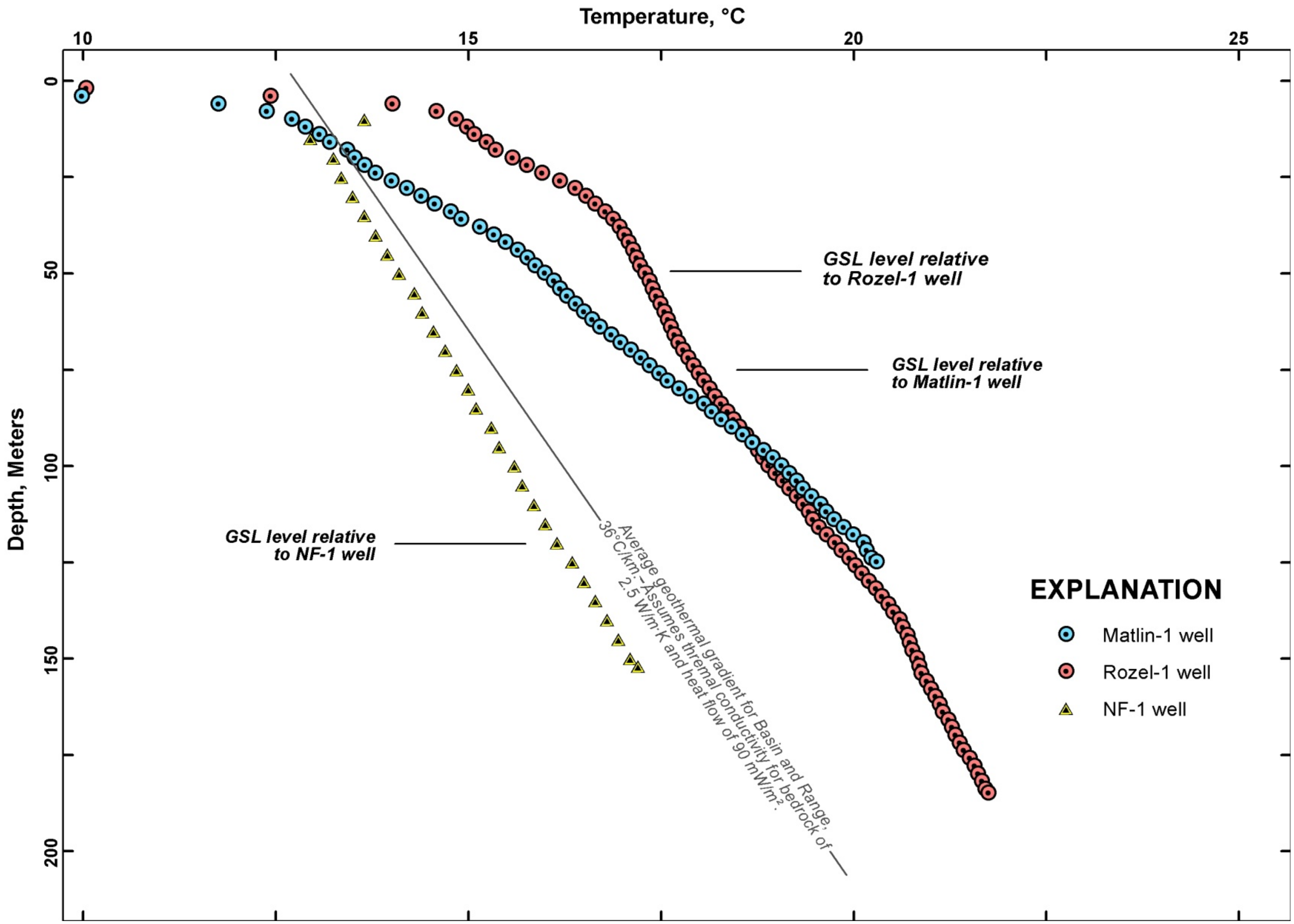

Figure 10. Temperature-depth profiles for thermal-gradient wells Rozel-1 and Matlin-1 located on opposite sides of the north arm of Great Salt Lake. Thermal-gradient well NF-1 (from Chapman and others, 1978), located in the Newfoundland Range to the southwest (figure 8), is shown for comparison.

does appear to somewhat track along with the typical Basin and Range bedrock gradient of 36°C/km.

The Matlin-1 temperature profile is somewhat linear below about 40 m and the gradient calculated from 96 m to total depth at 126 m is about 49°C/km. Material within this interval is valley-fill material consisting mainly of alternating clay, silt, sand, and pea gravel. Basalt was penetrated below about 120 m.

Well NF-1 was apparently drilled into a Late Jurassic age (147 – 158 Ma) quartz monzonite intrusive complex described by Allmendinger and Jordan (1989). The temperature profile is linear with a thermal gradient reported by Chapman and others (1978) of 30°C/km, an average thermal conductivity of 2.38 W/m•K, and a calculated heat flow of 71 mW/m^2.

Wireline geophysical surveys (gamma, electric, and sonic) were acquired by the UGS Groundwater Program in the Rozel-1 and Matlin-1 thermal-gradient wells. The interpreted lithologies from the wireline logs were consistent with those observed in the drill cuttings (appendix D).

NEW WATER ANALYSES
SEVIER-BLACK ROCK DESERT, CONFUSION BASIN, AND WEST GSL DESERT
MILLARD, JUAB, AND TOOELE COUNTIES, UTAH

Overview

Another component of NGDS new data collection effort involved chemical analysis of additional thermal wells and springs in the basins of the Basin and Range province of western Utah. As a result, we have added 26 new water analyses. Eight analyses are thermal spring samples and 18 are from wells of opportunity. Table 3 presents location information and provides concentrations of major cations and anions from these analyses. Figure 11 shows a plot of sodium versus chloride for all samples.

The water analyses are from three general regions — SBRD, the western part of Great Salt Lake Desert, and the Confusion Basin. Fourteen of the 26 analyses were collected by field efforts in the western Great Salt Lake and Black Rock Deserts. The remaining 12 analyses are from ongoing groundwater monitoring as part of the UGS's West Desert Groundwater Monitoring Network (UGS, 2012; see table 2).

Methodology

Temperature and pH were measured at each location during sampling using portable temperature probes and a combined pH/EC (electrical conductivity) meter. Three water samples were collected at each sample location; a 500 ml sample of filtered water; a 25 ml sample of filtered water diluted with 225 ml of distilled water; and a 500 ml sample of unfiltered water. The samples were filtered using a peristaltic pump and 0.45 micrometer filter. Sample locations and

Site Name	Well Name	Depth (ft)	Geo Unit	Screened Interval (ft)	TDS
Davies Ranch Ag	AG16C	317	QTs	c: 305-315	2228
NE Eskdale	PW06A	390	QTs	a: 150-170	360
	PW06C	390	Pa	c: 370-390	490
Little Valley	PW12A	1645	Dg	a: 1593-1633	1218
NW Middle Range	PW18A	1003	Dg	a: 970-990	2970
Table Knoll	PW19A	460	Co	a: 260-280	2520
	PW19C	460	Co	c: 440-460	2736
	PW19B	523	Co	b: 385-405	2600
Fish Springs North	SG21B	39	QTs	b: 33-38	3080
	SG21C	67	Sl?	c: 56-66	2660
Fish Springs Middle	SG22B	75	QTs	b: 56-61	1826
Leland Harris Sprs.	SG25D	60	QTs	d: 40-45	394

QTs - Quaternary-Tertiary valley fill sediments

Pa - Permian Arcturas Formation

Dg - Devonian Guillmette Formation

Sl - Silurian Laketown Dolomite

Co - Cambrian Orr Formation

Table 2. West Desert Groundwater Monitor Network wells, selected water analyses (see table 3) showing well designations, depths, geologic unit screened, screened intervals, and total dissolved solids (TDS) content.

NAME	Temp	Longitude	Latitude	pH	Ca	Mg	Na	K	Li	SiO_2	Cl	SO_4	Fe	HCO_3	TDS
units	°C	DDD.dddddd	DD.dddddd		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
AG16C Well	20.7	-114.009290	38.798615	8.51	21.3	25.9	603	18.5			10.4	1370		410	2228
PW06A Well	18.6	-113.905260	39.198771	8.09	56.7	28.3	31.6	3.4			41.4	55.3		294	360
PW06C Well	18.1	-113.905262	39.198771	7.38	43	26	57	4.2			49	55		274	490
PW12 Well	22.3	-113.714253	39.115626	8.48	199	54.8	53.9	9.71			71.7	668		138	1218
PW18 Well	19.2	-113.668311	39.653758	8.52	242	115	561	9.78			1510	135		125	2970
PW19A Well	30.9	-113.271124	39.634252	8.36	173	53	510	52			745.7	299		548	2520
PW19B Well	33.7	-113.271175	39.635253	8.2	191	54.5	500	52.2			744.33	320		576	2736
PW19C Well	33.5	-113.271124	39.634252	7	210	65	630	70			1000	300		592	2600
SG21B Well	24.4	-113.413394	39.886584	8.07	116	69.8	900	50.3			1430	394		258	3080
SG21C Well	24.7	-113.413340	39.886597	8.53	99.1	59.2	624	40.5			895.95	384		268	2660
SG22B Well	28.2	-113.394549	39.841460	8.12	96.5	52.7	435	39.1			621	277		300	1826
SG25D Well	20.6	-113.895670	39.558599	8.17	43.3	22.2	49.9	3.85			65.9	37.9		260	394
IW-6 Well	32.8	-113.987262	40.762232	6.87	134	88.7	2730	126	1.57	38.7	4350	399		203	8060
IW-7 Well	31.3	-113.983901	40.763625	6.93	143	97.9	2840	139	1.61	41.3	4630	384		199	8480
IW-10 Well	25.8	-113.975693	40.767358	7	195	142	3690	172	1.93	37	6440	460		161	11300
IW-12 Well	27.3	-113.968630	40.770513	7.16	253	193	4160	183	2.16	30.4	7100	477		167	12600
IW-13 Well	26.8	-113.965056	40.772181	7.36	141	107	2620	121	1.52	35.6	4300	308		182	7820
Graymont Well	34.9	-112.817376	38.940111	8	36.8	17.9	775	31.4		26.5	636	471	0.031	576	2278
Hatton Hot Spring	65.7	-112.491354	38.850741	7.39	452	87	1070	143		61.2	1810	1040	0.134	429	5100
Spring Lake Spring	14.0	-112.613029	39.096439	7.62	184	111	513	44.6		37.3	896	568	0.016	253	2610
Twin Peak Spring	29.5	-112.718234	38.794099	7.39	147	46.5	1370	13.1		65.6	2020	395	0.086	229	4280
Blue Lake Spr-1	29.2	-114.045139	40.498739	6.65	156	49.2	1640	109	1.6	25.1	2780	256		313	5144
Blue Lake Spr-2	28.0	-114.032662	40.502625	6.84	158	54.7	1720	115	1.67	26	2810	280		311	5291
Blue Lake Spr-3	27.2	-114.033786	40.501744	6.97	149	47.2	1700	120	1.63	29.9	2840	269		314	5280
Mosquito Willy N	26.9	-114.025634	40.471018	6.38	146	58.9	1400	107	1.49	24.4	2490	283		306	4635
Mosquito Willy S	26.8	-114.025032	40.469949	7.59	149	59.8	1460	113	1.53	27.5	2520	300		305	4752

Table 3. Results of chemical analyses of supplemental water samples.

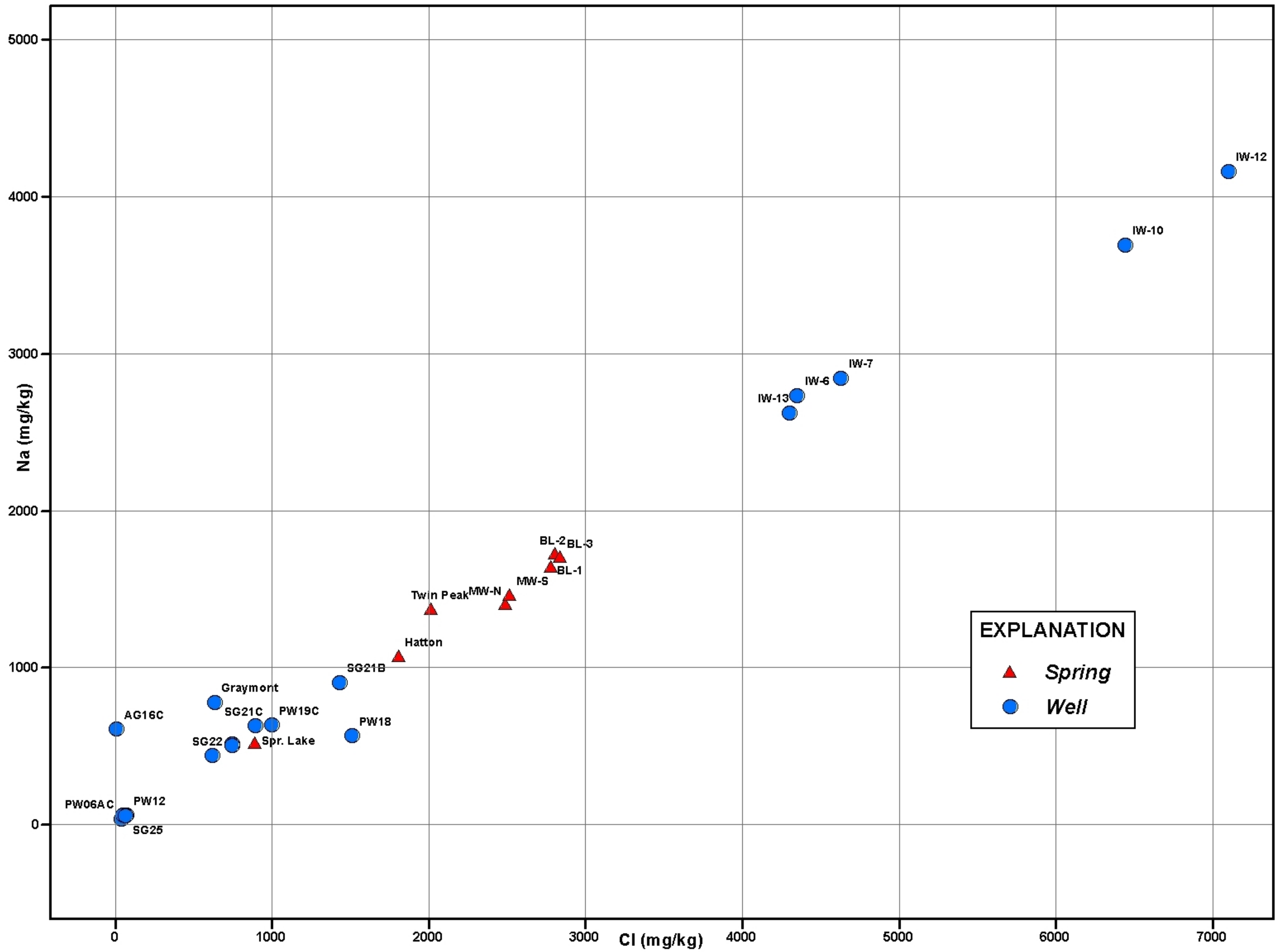

Figure 11.Plot of sodium (Na) versus chloride (Cl) for all water samples.

elevations were determined using a handheld GPS device. The water samples were analyzed byThermochem, Inc. of Santa Rosa, California.

Confusion Basin, Snake Valley Water Analyses

Regionally referred to here as the Confusion Basin, the West Desert Groundwater Monitoring Network extends across a north-south trending hydrologic basin straddling 217 km of the Nevada-Utah state line in the east-central part of the Great Basin (Kirby and Hurlow, 2005). The monitoring network consists of 51 wells containing 68 piezometers installed at 27 sites[4]. Snake Valley is bounded by several north-south trending mountain ranges including the Snake Range and Deep Creek Range on the west, the Confusion Range to the east, and the Burbank Hills to the east-southeast (figure 2). Snake Valley extends northeastward, merging with the Great Salt Lake Desert. Several monitoring wells were also installed northeast of Snake Valley in Tule Valley and Fish Springs Flat.

Temperature profiles made at 23 of these well sites in 2008 and 2009 were included as part of the Utah NGDS thermal-gradient dataset (Blackett, 2011). Selected water samples (above 18°C) collected and analyzed as part of the West Desert Groundwater Monitoring Network are included in this data-gathering effort. These 12 analyses, from eight different well sites, were not previously included in any geothermal data set (Utah Geological Survey, 2012). Multiple analyses per well site indicate samples taken from different piezometers that tap separate aquifers (tables 2 and 3).

The Piper plot for these water analyses (figure 12), coupled with table 3, shows a broad range of water types throughout the project area depending on location and the geologic unit comprising the aquifer, but not necessarily piezometer depth. The higher TDS fluids occur in shallow, alluvial wells at Fish Springs (SG21, SG 22), but also in a deeper, bedrock well (PW19) at Table Knoll south of Fish Springs Flat. These analyses are also closely grouped on the Piper plot suggesting similar sources. Shallow alluvial well SG25, located in northern Snake Valley, appears to have similar chemical characteristics to the deeper, bedrock well PW06, located roughly 40 km to the south along the eastern margin of the valley adjacent to the Conger Range.

West Great Salt Lake Desert Water Analyses

Moore and others (2012) describe sampling, analyses, and results from thermal waters that discharge at several locations along the western boundary of the Great Salt Lake Desert (figure 5, table 3). Nine samples were collected as part of an assessment of geothermal resources on military lands in the area. Four samples were collected from the Blue Lake Springs area and five samples were collected from wells located on the southeast flank of the Silver Island Mountains on September 28, 2011. Samples were also taken from two locations at Mosquito Willey's Springs, located approximately 3.6 km south of Blue Lake, on January 31, 2012.

Although analyses of these waters plot in nearly the same position on a Piper diagram (figure 13), TDS varies considerably between thermal springs and thermal wells. All of the Intrepid

[4] Information and data on the West Desert Monitoring-Well Project can be found online at http://geology.utah.gov/utahgeo/water/

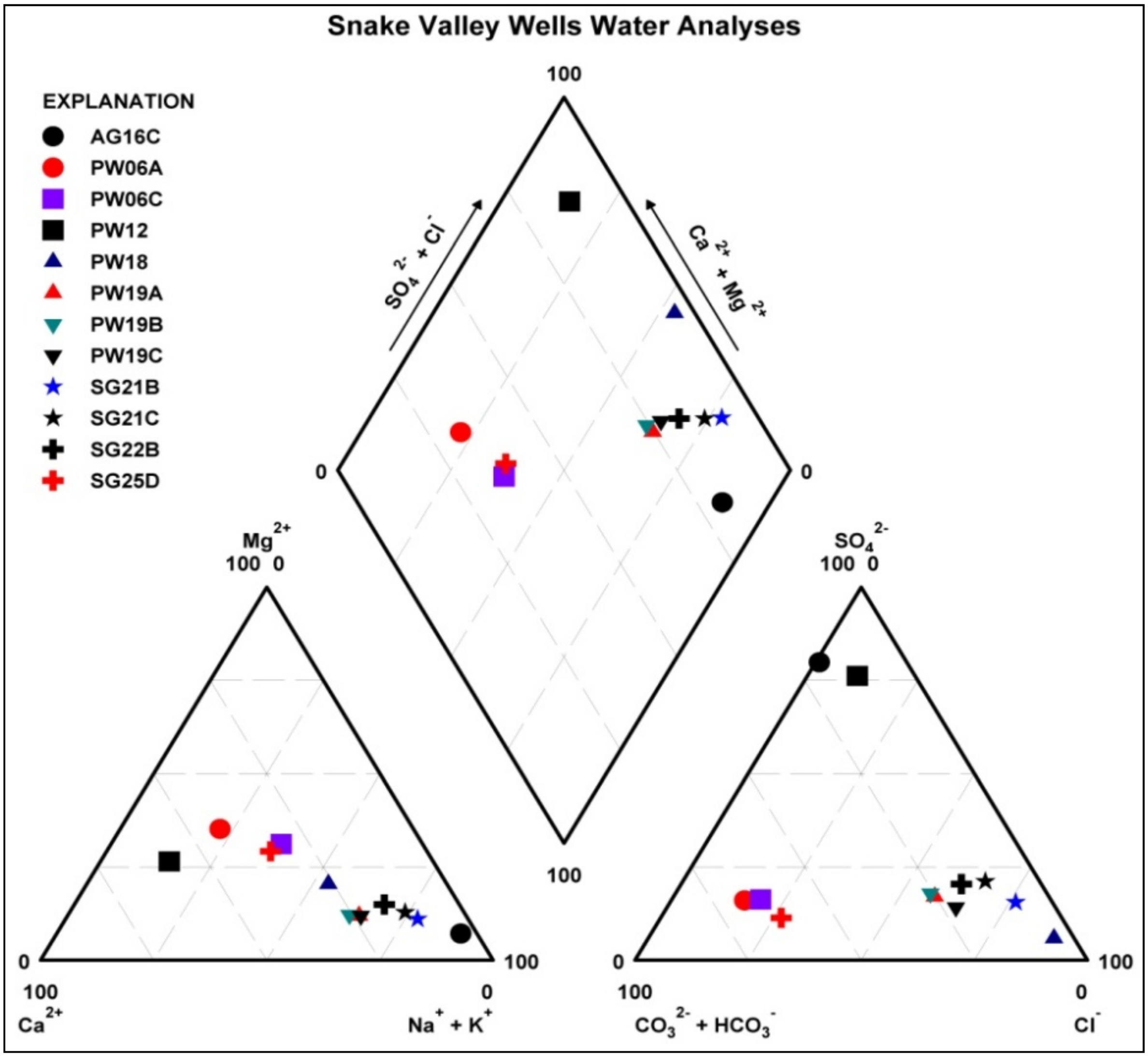

Figure12. Piper plot of Snake Valley wells water analyses.

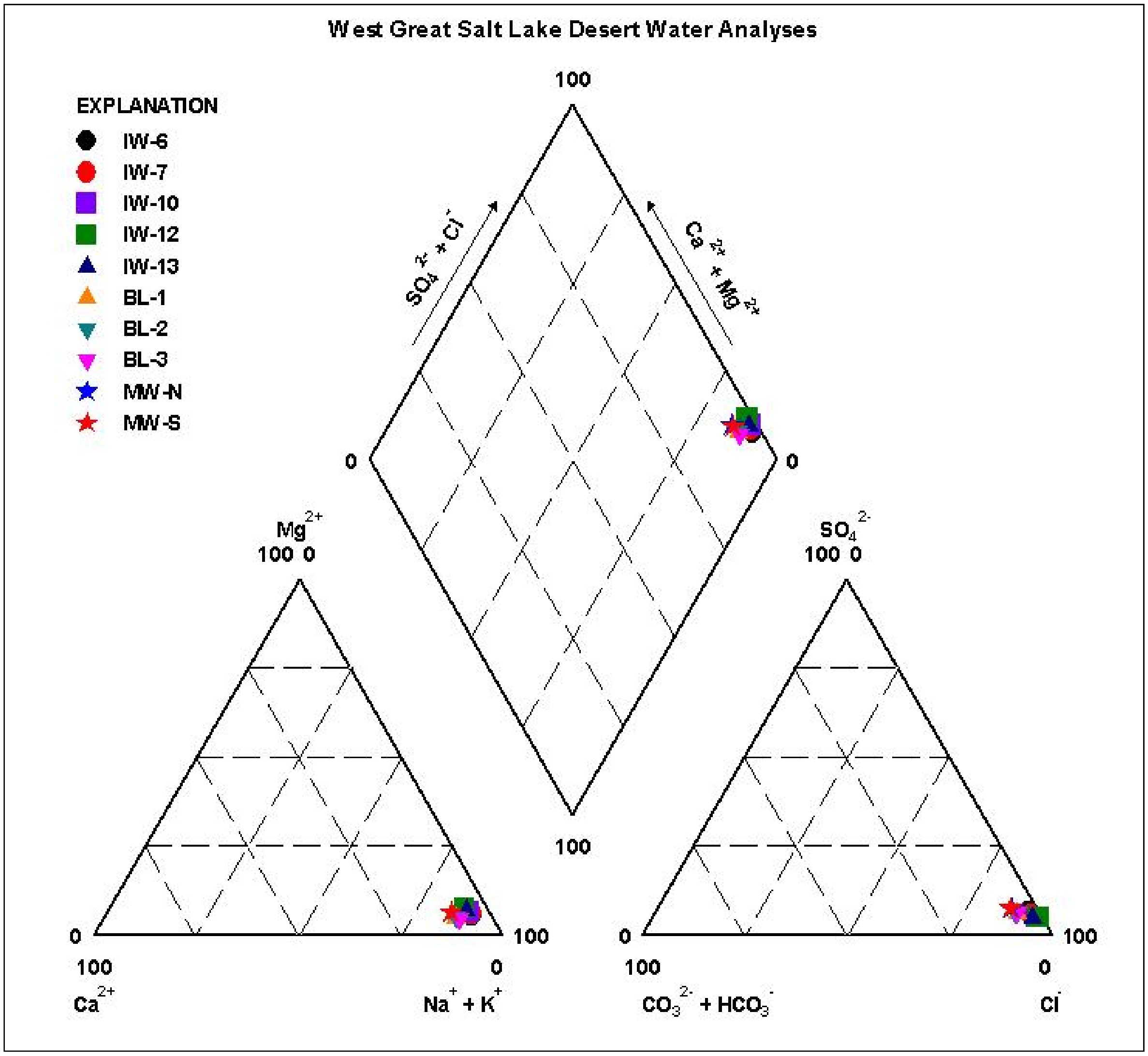

Figure13. Piper plot of west Great Salt Lake area water analyses.

wells produce water with salinities up to four times greater than any other wells in the data set. Wells IW-10 and IW-12 contain by far the highest salinities of all wells and springs (table 3; figure 11).

Water samples were collected from five pumped wells located between 2 km and 3.5 km north of Interstate 80 (IW-6, 7, 10, 12, and 13 on figure 5 and table 3) along the southeast flank of the Silver Island Range. These wells, which originally flowed at the surface, produce water with temperatures from 25.8 to 32.8°C and are reported to be 60 m deep (Russ Draper, Intrepid Potash Inc., verbal communication, 2011). The wells produce from fluids that likely discharge into the shallow alluvial aquifer along the Silver Island range-front fault. Static water levels are reported to be approximately 15 to 20 m deep in the wells.

Blue Lake is located about 26 km south of Wendover, Nevada (figure 5). Blue Lake is about 18 m deep and is a spring-fed lake. Springs discharge thermal water along the western edge, but also into the bottom of the lake. Bottom temperatures are approximately 29°C. The area surrounding the lake is characterized by wetlands and ponds of various sizes fed by diffuse thermal springs. Moore and others (2012) report that they were not aware of mineral deposits (e.g., silica or carbonate) related to the discharge of thermal water in this area.

Water samples are reported here from three locations around Blue Lake (figure 5, table 3). Blue Lake Spr-1 was collected directly from a spring orifice discharging into the south end of a large pond, which in-turn discharges into Blue Lake. The sample location is 1 km west-southwest of Blue Lake. Blue Lake Spr-2 was collected on the northern shoreline of Blue Lake. Measured temperatures (28°C) were slightly warmer at the sample location than at other shoreline locations in the vicinity, and a mound below the surface of the water about 2 m from the shoreline suggest that the sample location is near a spring; however, no direct evidence of discharging thermal water was observed. Blue Lake Spr-3 was collected from a floating dock on the west shore of Blue Lake.

Mosquito Willy Springs are located approximately 3.5 km south of Blue Lake in Tooele County, Utah, inside the UTTR (figure 5; table 3). Discharge occurs at two locations separated by about 130 m. The north spring discharges into a shallow pond about 2 m deep, 8 m wide and 25 m long. Water temperature was 26.9°C. The south spring discharges into a reed-filled depression approximately the same size as the north spring pond. Discharge rates at the south spring appear to be significantly lower, however, and temperature was 26.8°C.

Sevier-Black Rock Desert Water Analyses

Water samples were collected at four sites in the SBRD geothermal study area (figure 2). The sites include one well and three springs. Analytical results for these sources are shown on table 3. They include:

- Graymont Supply Well (34.9°C at 489 m)
- Hatton Hot Springs (65.7°C, new orifice)
- Twin Peak Springs (29.5°C, new orifice)
- Spring Lake Springs (14°C, Clear Lake Wildlife Management Area)

The Graymont Supply Well is located at Graymont's Cricket Mountain lime plant roughly 8 km east of the Cricket Mountains and just west of SR-257 (figure 2). According to records available through the Utah Division of Water Rights, the well was completed to a depth of 489 m on October 31, 2003. Slotted casing (41 cm dia.) extends down to 352 m near the contact between overlying valley-fill material and limestone bedrock (Cambrian Notch Peak Fm.?). Water pumped from this well has a temperature of about 35°C. The Piper plot of these springs and Graymont's well suggest that water from the Graymont well has a chemical signature distinct from the sampled springs (figure 14). The well TDS was lowest (2278 mg/L) of all the waters sampled.

The Meadow-Hatton geothermal area (figure 2) consists of a large travertine mound, marshland, and thermal springs located about 16 km southwest of the town of Fillmore on the east side of the SBRD in Millard County. Hatton Hot Spring issues from the southern margin of the travertine and is one of the warmest springs in Utah at about 65°C. The sample was collected from a relatively new, shallow pool excavated by the property owner. Analysis yielded a TDS of 5100 mg/L, and showed the chemistry to be dominated by sodium-chloride/sulphate. The Piper plot (figure 14) suggests that, with the exception of ionic strength, Hatton Hot Spring water has cation-anion ratios similar to the Spring Lake waters (figure 11).

Twin Peak Spring is located near the northeast foot of Twin Peaks in the southern part of the SBRD (figure 2). The sample was collected from the outflow of the spring where the land owner recently enhanced the spring flows by excavating the source. The water temperature at the sampling point was 29.5°C and the TDS of the water appears typical of thermal springs in the region (4280 mg/L). The Piper plot suggests the water chemistry is somewhat distinctive within this sample group.

Surface waters in the Clear Lake Wildlife Management Area are fed mainly by a number of non-thermal springs that form Spring Lake. The springs issue from beneath the edge of a series of broad basalt flows. We sampled this water because thermal gradient well CL-1, which lies about 1.6 km north-northwest of Spring Lake, exhibits thermal gradients in excess of 100°C/km, the highest recorded in any of our temperature-gradient wells. The water temperature at the Spring Lake sampling point was 14°C while TDS was 261 mg/L. The piper and sodium vs. chloride plot suggest that these waters are chemically similar to waters from the carbonate rocks in the Snake Valley region, specifically well PW-18.

To access more specific water chemistry information in the content model (*.xls file) supplied to the NGDS, you can go on-line to:
http://geology.utah.gov/geothermal/ngds/supplemental/water_analyses/UtahAqueousChemistry_Supplemental.xls.

To access a summary of the water chemistry in these wells and springs (*.xls file), you can go on-line to:
http://geology.utah.gov/geothermal/ngds/supplemental/water_analyses/UtahAqueousChemistry_Supplemental_Summary.xls.

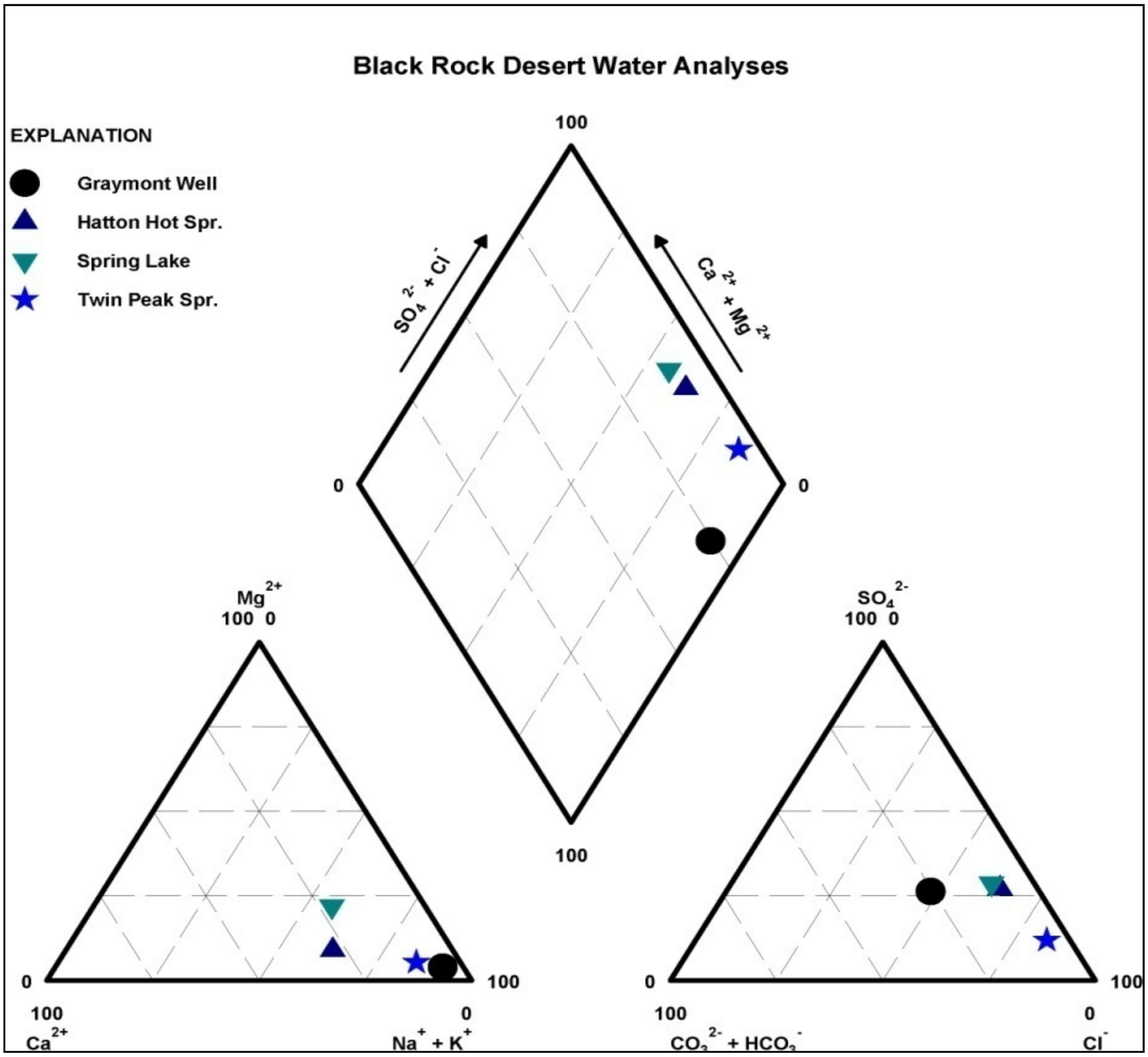

Figure14. Piper plot of SBRD water analyses.

THERMAL CONDUCTIVITY MEASUREMENTS SEVIER-BLACK ROCK DESERTS, GREAT SALT LAKE

Overall, 938 thermal conductivity measurements were performed on samples collected from either thermal-gradient wells or deep exploratory oil and gas wells. Thermal conductivity values include 474 measurements made using a divided bar apparatus at the University of Utah's Thermal Studies Laboratory (UUTSL). Thermal conductivities of 464 samples of clay drill cuttings from the PA-series wells and from P-2A, Matlin-1, and Rozel-1 wells were measured using a Decagon Devices KD2 Pro Thermal Properties Analyzer (needle probe). Needle probe accuracy is ±10 percent, which is about ±0.1 W/m·K for these samples. The overall average thermal conductivity determined for a given well from these measurements was about 1.3 W/m·K with a range of 1.0-1.8 W/m·K (appendix C).

The thermal conductivity of 196 samples from PA-1, PA-3, PA-5A, and PA-6 were also analyzed by the UUTSL using a divided bar apparatus with a calculated accuracy of ±10 percent. A simplified sample preparation procedure was used on most of these samples whereby a quantity of the hydrated-clay cuttings was placed directly into a test cell and measured. Thermal conductivity values between the two instruments varied by as much as 23 percent for a given sample, but most differed by much less than 10 percent and the overall average calculated for each well only differed by 2 percent.

Ten samples from the P-2A well were also analyzed with the divided bar. These samples were prepared using a more traditional and complex procedure that allow the matrix thermal conductivity to be calculated and combined with the estimated porosity to estimate the in situ thermal conductivity. Porosity estimates from a sonic porosity log run in this well were 44-49 percent. Thermal conductivities for nine samples, measured by the two instruments, varied by less than 10 percent. The well average, calculated from the divided bar measurements, was about 7 percent lower than the average determined from the needle probe results. This greater difference is likely due to differences in the number of samples analyzed (10 divided bar vs. 61 needle probe).

Core samples consisting of hydrated clays were recovered from a single interval (≤ 0.9 m) in each of three wells (PA-3, PA-5A, and PA-6). The cores were recovered and left in steel core liners (Shelby tubes) which were later cut into 12.7 cm segments. Thermal conductivities in these cores were measured by inserting the needle probe axially into the core. The results from the PA-3 and PA-5A cores were about 10-15 percent higher than in the cuttings recovered from above and below the cores, suggesting that conductivities derived from cuttings probably represent a minimum value. The results from the PA-6 core suggest that it was subjected to some degree of compression which artificially increased the thermal conductivity.

Thermal conductivity measurements (262) were also done on cutting samples from five deep oil and gas exploratory wells by the UUTSL. The first three of the wells listed below are located in the SBRD region of Millard County. The fourth and fifth listed wells are located in the south arm of Great Salt Lake, Davis and Tooele Counties. For more detailed information, you can access the content model (*.xls file) supplied to NGDS at the following internet address:

http://geology.utah.gov/geothermal/ngds/supplemental/thermal_conductivity/thermal_conductivity_data.xls.

Well Name	Depth (m)	Completion Date
Gronning-1	2457	3/21/1957
Hole-in-Rock-1	3350	5/14/1981
Pavant Butte-1	3393	8/29/1981
Utah State E1	3176	11/22/1979
Utah State N1	2397	6/9/1980

Summary information on wells used for thermal-conductivity measurements is listed in appendix C.

GEOPHYSICAL LOGGING

Downhole wireline geophysical surveys (gamma ray, resistivity/SP, and sonic logs) were acquired by the USGS Western Region Research Drilling Unit and by the UGS Groundwater Program in six of these new thermal-gradient wells (CS-4, P-2A, PA-3, PA-6, Matlin-1, and Rozel-1). The average calculated sonic porosities in these wells were about 46-50 percent. The interpreted lithologies from the wireline logs were consistent with those observed in the drill cuttings. In addition, the UGS Groundwater Program acquired wire-line geophysical logs for a groundwater monitor well (CHW-1) in eastern Utah. For more detailed information and to download the individual E-logs, go to appendix D where internet links to the individual E-logs are given.

SUMMARY

The results of this work supplement the Utah NGDS data package. The UGS either completed or assisted with completion of 12 shallow (125 – 244 m) wells for thermal-gradient studies. Seven of these wells were completed under AZGS/AASG/NGDS funding while five wells were drilled and completed with other funding sources. All data from every well, however, have been added to the NGDS. In addition to these drilled wells, UGS also gathered temperature-depth profiles from 14 wells-of-opportunity located in the Great Salt Lake Desert, SBRD, around Sevier Lake, and near Arches National Park in southeastern Utah. The UGS also compiled lithologic logs for 12 of these wells and geophysical logs for eight of these wells. We also collected water samples for analyses from six wells-of-opportunity and eight springs as part of this effort, plus 12 water analyses from “slightly thermal” wells sampled as part of ongoing groundwater studies in other valleys of western Utah. Cutting samples collected from the active drilling project plus cuttings archived from oil and gas wells in the Sevier Desert and Great Salt Lake led to the addition of 938 thermal-conductivity measurements. Seven technical papers have been completed and presented by the UGS at geothermal meetings and workshops.

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APPENDIX A
Temperature-Depth Data (on-line Excel files)

Region	UWI	Hole Name	County	Well Location	Link Location
Salt Valley	9901900017	CHW-1	Grand	(D-24-20)25bca	http://geology.utah.gov/geothermal/ngds/supplemental/tempdepth_data/CHW-1_UGS2012.xls
Sevier-Black Rock	9902700234	PA-1	Millard	(C-15-08)24dab	http://geology.utah.gov/geothermal/ngds/supplemental/tempdepth_data/PA-1_UGS2012.xls
Sevier-Black Rock	9902700235	PA-2	Millard	(C-17-08)12dca	http://geology.utah.gov/geothermal/ngds/supplemental/tempdepth_data/PA-2_UGS2012.xls
Sevier-Black Rock	9902700236	PA-3	Millard	(C-18-07)9aab	http://geology.utah.gov/geothermal/ngds/supplemental/tempdepth_data/PA-3_UGS2012.xls
Sevier-Black Rock	9902700237	PA-4	Millard	(C-19-08)02dcc	http://geology.utah.gov/geothermal/ngds/supplemental/tempdepth_data/PA-4_UGS2012.xls
Sevier-Black Rock	9902700238	PA-5A	Millard	(C-21-07)36bbb	http://geology.utah.gov/geothermal/ngds/supplemental/tempdepth_data/PA-5_UGS2012.xls
Sevier-Black Rock	9902700239	PA-6	Millard	(C-21-08)32adc	http://geology.utah.gov/geothermal/ngds/supplemental/tempdepth_data/PA-6_UGS2012.xls
Sevier-Black Rock	9902700240	PA-7A	Millard	(C-22-08)36bbb	http://geology.utah.gov/geothermal/ngds/supplemental/tempdepth_data/PA-7_UGS2012.xls
Sevier-Black Rock	9902700241	CS-4	Millard	(C-14-08)32baa	http://geology.utah.gov/geothermal/ngds/supplemental/tempdepth_data/CS-4_UGS2011.xls
Sevier-Black Rock	9902700242	P-2A	Millard	(C-20-06)32acb	http://geology.utah.gov/geothermal/ngds/supplemental/tempdepth_data/P-2A_UGS2011.xls
Sevier-Black Rock	9902700243	Graymont MX	Millard	(C-21-09)32aab	http://geology.utah.gov/geothermal/ngds/supplemental/tempdepth_data/GraymontMX_UGS2012.xls
Sevier-Black Rock	9902700244	CL-1	Millard	(C-20-07)03bab	http://geology.utah.gov/geothermal/ngds/supplemental/tempdepth_data/CL1_UGS2012.xls
Sevier Lake	9902700245	Coyote	Millard	(C-22-13)36cab	http://geology.utah.gov/geothermal/ngds/supplemental/tempdepth_data/PeakCoyote_UGS2012.xls
Sevier Lake	9902700246	Monument Point	Millard	(C-23-11)15cbb	http://geology.utah.gov/geothermal/ngds/supplemental/tempdepth_data/PeakMonumentPoint_UGS2012.xls
Sevier Lake	9902700247	Nighthawk	Millard	(C-20-13)36aca	http://geology.utah.gov/geothermal/ngds/supplemental/tempdepth_data/PeakNighthawk_UGS2012.xls
Bonneville SF	9904530003	1-2 Harvest	Tooele	(C-01-19)23cbc	http://geology.utah.gov/geothermal/ngds/supplemental/tempdepth_data/1-2Harvest_UGS2011.xls
Bonneville SF	9904530004	DBW-8	Tooele	(C-02-19)03bcd	http://geology.utah.gov/geothermal/ngds/supplemental/tempdepth_data/DBW-8_UGS2011.xls
Bonneville SF	9904530005	DBW-14A	Tooele	(C-02-19)02ccc	http://geology.utah.gov/geothermal/ngds/supplemental/tempdepth_data/DBW-14A_UGS2011.xls
Bonneville SF	9904530006	DBW-17	Tooele	(C-02-19)14adb	http://geology.utah.gov/geothermal/ngds/supplemental/tempdepth_data/DBW-17_UGS2011.xls
Bonneville SF	9904530007	DBW-22	Tooele	(C-01-19)34cdd	http://geology.utah.gov/geothermal/ngds/supplemental/tempdepth_data/DBW-22_UGS2011.xls
Bonneville SF	9904530008	DBW-23	Tooele	(C-01-19)34aba	http://geology.utah.gov/geothermal/ngds/supplemental/tempdepth_data/DBW-23_UGS2011.xls
Great Salt Lake	9900300053	Rozel-1	Box Elder	(B-09-07)04cdd	http://geology.utah.gov/geothermal/ngds/supplemental/tempdepth_data/Rozel-1_UGS2012.xls
Great Salt Lake	9900300054	Matlin-1	Box Elder	(B-10-12)32ada	http://geology.utah.gov/geothermal/ngds/supplemental/tempdepth_data/Matlin-1_UGS2012.xls

APPENDIX B

Lithologic Logs (on-line PDF files)

Region	UWI	Well Name	County	Well Location	Link Location
Salt Valley	9901900017	CHW-1	Grand	(D-24-20)25bca	http://geology.utah.gov/geothermal/ngds/supplemental/lith_logs/CHW-1%20Lithologic%20Log.pdf
Sevier-Black Rock	9902700234	PA-1	Millard	(C-15-08)24dab	http://geology.utah.gov/geothermal/ngds/supplemental/lith_logs/PA-1%20Lithologic%20Log.pdf
Sevier-Black Rock	9902700235	PA-2	Millard	(C-17-08)12dca	http://geology.utah.gov/geothermal/ngds/supplemental/lith_logs/PA-2%20Lithologic%20Log.pdf
Sevier-Black Rock	9902700236	PA-3	Millard	(C-18-07)9aab	http://geology.utah.gov/geothermal/ngds/supplemental/lith_logs/PA-3%20Lithologic%20Log.pdf
Sevier-Black Rock	9902700237	PA-4	Millard	(C-19-08)02dcc	http://geology.utah.gov/geothermal/ngds/supplemental/lith_logs/PA-4%20Lithologic%20Log.pdf
Sevier-Black Rock	9902700238	PA-5A	Millard	(C-21-07)36bbb	http://geology.utah.gov/geothermal/ngds/supplemental/lith_logs/PA-5A%20Lithologic%20Log.pdf
Sevier-Black Rock	9902700239	PA-6	Millard	(C-21-08)32adc	http://geology.utah.gov/geothermal/ngds/supplemental/lith_logs/PA-6%20Lithologic%20Log.pdf
Sevier-Black Rock	9902700240	PA-7A	Millard	(C-22-08)36bbb	http://geology.utah.gov/geothermal/ngds/supplemental/lith_logs/PA-7A%20Lithologic%20Log.pdf
Sevier-Black Rock	9902700241	CS-4	Millard	(C-14-08)32baa	http://geology.utah.gov/geothermal/ngds/supplemental/lith_logs/CS-4%20Lithologic%20Log.pdf
Sevier-Black Rock	9902700242	P-2A	Millard	(C-20-06)32acb	http://geology.utah.gov/geothermal/ngds/supplemental/lith_logs/P-2A%20Lithologic%20Log.pdf
Great Salt Lake	9900300053	Rozel-1	Box Elder	(B-09-07)04cdd	http://geology.utah.gov/geothermal/ngds/supplemental/lith_logs/Rozel-1%20Lithologic%20Log.pdf
Great Salt Lake	9900300054	Matlin-1	Box Elder	(B-10-12)32ada	http://geology.utah.gov/geothermal/ngds/supplemental/lith_logs/Matlin-1%20Lithologic%20Log.pdf

Appendix C: Thermal Conductivity Data

Well location and summary data shown below. For measured thermal conductivity go on-line to:
http://geology.utah.gov/geothermal/ngds/supplemental/thermal_conductivity/thermal_conductivity_data.xls

Well Name	Completion Date	API NO	Well Location	Latitude WGS84	Longitude WGS84	Elevation (FT)	Datum*	TD (FT)	TD (M)
Gronning-1	3/21/1957	4302710423	(C-16-08)24aa	39.41664	-112.69226	4590	GR	8061	2457
Hole-in-Rock-1	5/14/1981	4302730019	(C-22-07)30cd	38.86469	-112.68448	4805	KB	10990	3350
Pavant Butte-1	8/29/1981	4302730027	(C-19-07)35ab	39.12415	-112.60442	4606	KB	11133	3393
Utah State E1	11/22/1979	4301130002	(B-03-04)19bc	40.97917	-112.34907	4223	KB	10419	3176
Utah State N1	6/9/1980	4304530010	(C-01-04)04cd	40.75522	-112.30556	4200	GR	7864	2397
Matlin-1	11/25/2012	9900300054	(B-10-12)32ada	41.55171	-113.23256	4426	GR	600	183
Rozel-1	11/18/2012	9900300053	(B-09-07)04cdd	41.52996	-112.65420	4321	GR	410	125
P-2A	4/26/2011	9902700242	(C-20-06)32acb	39.03414	-112.54866	4675	GR	806	246
PA-1	8/28/2012	9902700234	(C-15-08)24dab	39.50005	-112.68947	4579	GR	500	152
PA-2	8/8/2012	9902700235	(C-17-08)12dca	39.34829	-112.69485	4590	GR	500	152
PA-3	8/4/2012	9902700236	(C-18-07)9aab	39.27183	-112.63612	4592	GR	503	153
PA-4	9/9/2012	9902700237	(C-19-08)02dcc	39.18572	-112.71801	4637	GR	540	165
PA-5A	9/24/2012	9902700238	(C-21-07)36bbb	38.95031	-112.59624	4670	GR	426	130
PA-6	8/22/2012	9902700239	(C-21-08)32adc	38.94527	-112.76985	4680	GR	500	152
PA-7A	9/13/2012	9902700240	(C-22-08)36bbb	38.86407	-112.70710	4762	GR	600	183

*GR = Ground Level; KB = Kelly Bushing

APPENDIX D
Geophysical Logs (on-line PDF files)

Region	UWI	Well / Log Name	County	Well Location	Link Location
Salt Valley	9901900017	CHW-1 multi	Grand	(D-24-20)25bca	http://geology.utah.gov/geothermal/ngds/supplemental/geophys_logs/CHW-1%20Multi.pdf
Sevier-Black Rock	9902700236	PA-3 multi	Millard	(C-18-07)9aab	http://geology.utah.gov/geothermal/ngds/supplemental/geophys_logs/PA-3%20multi.pdf
Sevier-Black Rock	9902700236	PA-3 sonic	Millard	(C-18-07)9aab	http://geology.utah.gov/geothermal/ngds/supplemental/geophys_logs/PA-3%20sonic.pdf
Sevier-Black Rock	9902700239	PA-6 multi	Millard	(C-21-08)32adc	http://geology.utah.gov/geothermal/ngds/supplemental/geophys_logs/PA-6%20Multi%20.pdf
Sevier-Black Rock	9902700239	PA-6 sonic	Millard	(C-21-08)32adc	http://geology.utah.gov/geothermal/ngds/supplemental/geophys_logs/PA-6%20Sonic.pdf
Sevier-Black Rock	9902700241	CS-4 multi	Millard	(C-14-08)32baa	http://geology.utah.gov/geothermal/ngds/supplemental/geophys_logs/CS-4%20multi.pdf
Sevier-Black Rock	9902700241	CS-4 sonic	Millard	(C-14-08)32baa	http://geology.utah.gov/geothermal/ngds/supplemental/geophys_logs/CS-4%20sonic.pdf
Sevier-Black Rock	9902700242	P-2A multi	Millard	(C-20-06)32acb	http://geology.utah.gov/geothermal/ngds/supplemental/geophys_logs/P-2A%20multi.pdf
Sevier-Black Rock	9902700242	P-2A sonic	Millard	(C-20-06)32acb	http://geology.utah.gov/geothermal/ngds/supplemental/geophys_logs/P-2A%20sonic.pdf
Great Salt Lake	9900300054	Matlin-1 multi	Box Elder	(B-10-12)32ada	http://geology.utah.gov/geothermal/ngds/supplemental/geophys_logs/Matlin-1%20Multi.pdf
Great Salt Lake	9900300054	Matlin-1 sonic	Box Elder	(B-10-12)32ada	http://geology.utah.gov/geothermal/ngds/supplemental/geophys_logs/Matlin-1%20Sonic.pdf
Great Salt Lake	9900300053	Rozel-1 multi	Box Elder	(B-09-07)04cdd	http://geology.utah.gov/geothermal/ngds/supplemental/geophys_logs/Rozel-1%20Multi.pdf
Great Salt Lake	9900300053	Rozel-1 sonic	Box Elder	(B-09-07)04cdd	http://geology.utah.gov/geothermal/ngds/supplemental/geophys_logs/Rozel-1%20Sonic.pdf