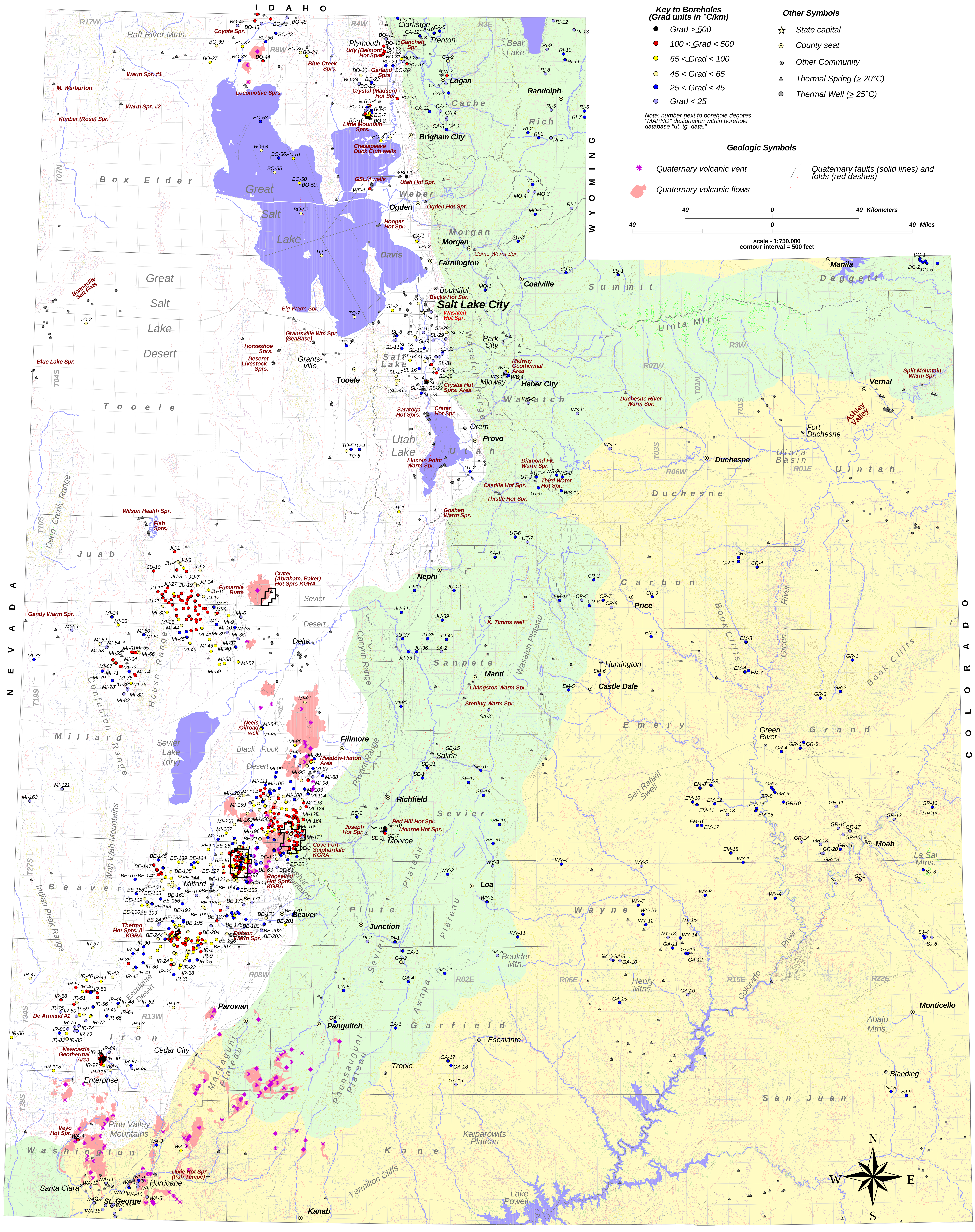
Geothermal Resources of Utah

Temperature-Gradient Boreholes



EXPLANATION

Key to Boreholes (Grad units in °C/km)

- Grad > 500
- 100 < Grad < 500
- 65 < Grad < 100
- 45 < Grad < 65
- 25 < Grad < 45
- Grad < 25

Note: number next to borehole denotes "MAPNO" designation within borehole database "ut_tg_data."

Other Symbols

- State capital
- County seat
- Other Community
- Thermal Spring (≥ 20°C)
- Thermal Well (≥ 25°C)

Geologic Symbols

- Quaternary volcanic vent
- Quaternary volcanic flows
- Quaternary faults (solid lines) and folds (red dashes)

40 0 40 Kilometers

40 0 40 Miles

scale - 1:750,000
contour interval = 500 feet

Geologic Provinces

- Basin & Range
- Middle Rocky Mountains and Transition Zone
- Colorado Plateau

UTAH GEOLOGICAL SURVEY

GEOTHERMAL RESOURCES OF UTAH
A Digital Atlas of Utah's Geothermal Resources

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Utah Geological Survey
a division of
Utah Department of Natural Resources

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 (gal/min) 1 ft^3/second (cfs) = 1,699 liters per minute (L/min)
Temperature:	degrees Celsius (°C) = 5/9 (degrees Fahrenheit [°F]-32) Kelvins (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

ABSTRACT

Many researchers have studied geothermal resources in Utah over the past few decades, largely the result of federal and state cooperative projects. Because no summary from these efforts had been compiled since the publication of a state geothermal resources map in 1980, the Utah Department of Natural Resources and the Utah Department of Community and Economic Development jointly sponsored a project to prepare a statewide review-summary of geothermal resources. The summary is presented as an interactive computer-driven product employing geographic information system technology and other computer software to present detailed, spatially related data on all known geothermal resource areas in Utah. In this report, we review the nature of geothermal systems throughout the four principal physiographic regions of Utah and the relationship to geologic setting, recent faulting, and young igneous rocks. A technical database, UTAHGEO.dbf, contains nearly 3,000 records pertaining to more than 1,100 thermal wells and springs in Utah and is included as part of the GIS data. Descriptions of all known thermal areas in Utah are presented. Crustal heat-flow in Utah, included as a companion report, is also presented.

ACKNOWLEDGMENTS

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INTRODUCTION

As part of a U.S. Department of Energy, state-cooperative geothermal program in the late 1970s, the Utah Geological Survey (UGS) compiled a geothermal resources map of Utah (Utah Geological and Mineral Survey, 1980). Published in 1980, the "Geothermal Resources of Utah" map was compiled using geothermal and water-resource data from existing publications and other data sets. The information presented on the map was of a general nature; however, the map was very useful because it showed locations of thermal wells and springs and listed individual source temperatures, water-quality data, and flow rates. The map also outlined areas of prospective value for geothermal resources, and provided descriptive information about individual geothermal areas. It was published through the U.S. National Oceanic and Atmospheric Administration and was made widely available free of charge. As a result, stores of the map quickly dwindled. Presently, the 1980 map is available only through libraries.

Since the publication of the Utah geothermal resources map in 1980, various workers completed a number of geothermal-related studies, the result of federal, state, and privately funded research. In addition to regional and statewide resource assessments, such as reported in Blackett (1994), Budding and Bugden (1986), and Mabey and Budding (1987), the projects also involved detailed analyses of individual geothermal areas. Due to the recent increase in economic and environmental interest in geothermal systems, the Utah Department of Natural Resources (Utah Geological Survey and the Office of Energy and Resource Planning) and the Utah Department of Community and Economic Development initiated a cooperative project to produce a new, interactive, digital map and report using geographic information system (GIS) technology to be published on compact disk (CD-ROM). The information on this CD-ROM contains technical data on geothermal resources in Utah for scientists and engineers, based on all of the past federal- and state-funded, geothermal-related efforts. It also contains this interactive report for the general user.

Various GIS themes, or coverages, are included at a statewide scale of 1:500,000 although some themes were compiled at more detailed scales. The CD-ROM includes software to view, manipulate, and print the various GIS themes, and also includes a user-guide along with interactive documents. Among other items, these documents contain the GIS-generated geothermal map of Utah with links to supporting text, database, and image files.

OVERVIEW OF GEOTHERMAL RESOURCES

Nature of Geothermal Energy

As described in Wright and others (1990), geothermal energy is the heat that originates within the earth. The earth is an active thermal engine. Many of the large-scale geological processes that have helped to form the earth's surface features are powered by the flow of heat from inner regions of higher temperature to outer regions of lower temperature. The mean value of the surface heat flow for the earth is 1.32 x 10^{13} J/yr (42 million megawatts [MW]) (Williams and Von Herzen, 1974), which represents heat that comes to the surface and is lost by radiation into space. Generation of new oceanic crust at spreading centers such as the mid-Atlantic ridge, motion of the great lithosphere plates, uplifting of mountain ranges, release of stored strain energy by earthquakes and eruption of volcanoes are all powered by the outward transport of internal heat. Plastic, partially molten rock at estimated temperatures between 600°C and 1,200°C (1,100°F and 2,200°F) is postulated to exist everywhere beneath the earth's surface at depths of 100 km (60 mi) or less. By comparison, using present technology applied under favorable circumstances, holes can be drilled to depths of about 10 km (6.2 mi), where temperatures range upward from about 150°C (300°F) in average areas to perhaps 600°C (1,100°F) in exceptional areas.

Exploitable geothermal resources originate from transport of heat to the surface through several geological and hydrological processes. Geothermal resources commonly have three components: 1) a heat source, 2) relatively high permeability reservoir rock, and 3) water to transfer the heat. In general, the heat source for most of the high-temperature resources (>150°C [300°F]) appears to be a molten or recently solidified intrusion, whereas many of the low-temperature (<100°C [212°F]) and moderate-temperature (between 100° and 150°C [212° and 300°F]) resources seem to result from deep circulation of meteoric water with heating due to the normal increase in temperature with depth. A number of high-temperature resources also occur in the Basin-and-Range province of the western U.S. as the result of deep circulation along major faults in a region of high heat flow. In most geothermal systems, fracture permeability controls water movement, but inter-granular permeability is also important in some systems. Water is, of course, the ideal heat transfer fluid because it has a high heat capacity and high heat of vaporization, and can therefore transport more heat per unit volume that any other common fluid.

Table 1 summarizes the way that geothermal resources are commonly classified. For the most part, only convective hydrothermal resources have been commercially developed. The other resource types will require new technology and/or higher energy prices in order to be more economically viable.

White and others (1971) and Henley and Ellis (1983) have discussed models for high-temperature convective hydrothermal systems. A body of molten, or recently solidified, hot (300°C to

1,200°C [570°F to 2,200°F]) rock presumably underlies higher-temperature hydrothermal resources. Interaction of this hot rock with ground water causes heating of the ground water, which then rises by buoyancy. The bulk of the fluid in hydrothermal systems is derived from meteoric water, with the exception of those few systems where the fluids are derived from seawater or connate brines (Craig, 1963). A free convective circulating system is set up with the heated water ascending in the center of the system along zones of permeability, spreading outward in the shallow subsurface or discharging to the surface, and with cool water descending along the margins and recharging the system. Rapid convection produces nearly uniform temperatures over large volumes of the reservoir. The temperatures and pressures generally lie near the curve of boiling point versus depth for saline water, and sporadic boiling may occur. Whether or not steam actually exists in a hydrothermal resource depends, among other less important variables, on temperature and pressure conditions at depth. Escape of hot fluids at the surface is often minimized by a near-surface, sealed zone or cap-rock formed by precipitation from the geothermal fluids of minerals in fractures and pore spaces (Wright and others, 1990).

Geothermal Resources in the U.S.

Most of the known hydrothermal resources and all of the presently known sites that are capable of electric power generation are in the western half of the U.S. (including Alaska and Hawaii) (figure 1). The majority of thermal springs and other surface manifestations of underlying geothermal resources are also in the west. Large areas underlain by warm waters in sedimentary rocks exist in Montana, North and South Dakota and Wyoming (Madison Group aquifers), but the extent and potential of these resources is poorly understood. Another important large area, much of which is underlain by low-temperature resources, is the north, northeast-trending Balcones-Ouachita structural belt in central Texas. The geopressured resource areas of the Gulf Coast and surrounding states are also shown. Resource areas indicated in the eastern states are speculative because little drilling has taken place to confirm their existence. Low- and intermediate-temperature resources are much more plentiful than are high-temperature resources. There are many thermal springs and wells that have water at temperatures only slightly above mean annual air temperature, the temperature of most non-geothermal shallow ground water (Wright and others, 1990).

Geothermal Use in the U.S.

Nearly all commercial geothermal exploration efforts in the U.S. in the past have been directed at finding high-temperature hydrothermal systems over 200°C (392°F) for the commercial generation of electricity. Current U.S. geothermal electric power generation totals approximately 6.94 x 10^{16} J/yr (2,200 MW), or about the same as four large coal-fired or nuclear power plants. U.S. geothermal power units are located in California, Nevada, Utah, and Hawaii. In recent years, more low- and moderate-temperature systems have been explored for space heating applications in buildings and greenhouses, and for electricity generation using modular, binary power plants. Uses for low and moderate temperature resources can be divided mainly into two categories: direct use and ground-source heat pumps. Moderate-temperature resources, under favorable circumstances, can be used to generate electricity using binary technology.

Direct use, as the name implies, involves using the heat in the water directly (without a heat pump or power plant) for such things as heating of buildings, industrial processes, greenhouses, aquaculture (growing of fish) and resorts. Direct-use projects generally use resource temperatures between 40°C to 150°C (104°F to 302°F). Current U.S. installed capacity of direct-use systems totals 1.48 x 10^{16} J/yr (470 MW) or enough to heat 40,000 average-sized houses.

Ground-source heat pumps use the earth or groundwater as a heat source in winter and a heat sink in summer. Using resource temperatures of 4°C (40°F) to 38°C (100°F), the heat pump, a device, which moves heat from one place to another, transfers heat from the soil to the house in winter and from the house to the soil in summer. Accurate data is not available on the current number of these systems; however, the rate of installation is thought to be between 10,000 and 40,000 per year (Oregon Institute of Technology, Geo-Heat Center, webpage: http://geoheat.oit.edu/whatgeo.htm, February 2000).

TERRESTRIAL HEAT FLOW IN UTAH

The worldwide average conductive heat flow to the earth's surface is about 61 milliwatts per square meter (mW/m^2) for the continents (Williams and Von Herzen, 1974). Considerable variation in heat flow exists in Utah. The area of highest heat flow in Utah is the Basin and Range province, which has typical values in the range 80 to 120 mW/m^2. The Colorado Plateau and the Middle Rocky Mountains provinces in Utah have heat-flow values near the average for the earth's surface (Sass and others, 1976; Sass and Munroe, 1974).

Andrew J. Henrikson and David S. Chapman of the University of Utah Department of Geology and Geophysics compiled and summarized heat-flow data in Utah using bottom-hole temperatures from oil and gas wells and from geothermal exploratory drill holes. The results of their work are presented in digital format as a companion to this report. To view the heat-flow report by Henrikson, and Chapman refer to (Terrestrial Heat-Flow in Utah) included as an Adobe Acrobat (pdf) document on this compact disk.

GEOLOGIC SETTING

Physiographic Regions of Utah

Utah comprises parts of three major physiographic provinces (Fenneman, 1931), each with characteristic landforms and geology. These include the Basin and Range Province, the Middle Rocky Mountains Province, and the Colorado Plateau Province. An overlapping of two of these provinces essentially forms a fourth distinctive physiographic region. The Basin and Range-Colorado Plateau Transition Zone extends through central and southwestern Utah, and contains physiographic and geologic features similar to both the Basin and Range and Colorado Plateau Provinces. The physiographic regions of Utah are shown on figure 2 and are included as a separate layer in the associated GIS coverages.

The Middle Rocky Mountains Province in northeastern Utah consists of mountainous terrain, stream valleys, and alluvial basins. It includes the north-south trending Wasatch Range, comprising mainly pre-Cenozoic sedimentary and Cenozoic silicic plutonic rocks, and the east-west trending Uinta Mountains, comprising mainly Precambrian sedimentary and metamorphic rocks.

The Colorado Plateau is a broad area of regional uplift in southeastern and south-central Utah characterized by essentially flat-lying, Mesozoic and Paleozoic sedimentary rocks. Scattered Tertiary and Quaternary volcanic rocks are present on the western margin of the Colorado Plateau in south-central Utah, and some Tertiary intrusive bodies are present in southeastern Utah. Plateaus, buttes, mesas, and deeply incised canyons exposing flat-lying or gently warped strata distinguish the Colorado Plateau of southeastern Utah. Bedrock units are spectacularly exposed, while surficial deposits are sparse.

The Basin and Range Province is noted for numerous north-south oriented, fault-tilted mountain ranges separated by intervening, broad, sediment filled basins. The mountain ranges are typically 20 to 50 km (12 to 31 mi) apart, 45 to 80 km (28 to 50 mi) long and are bounded on one, or sometimes two sides by high-angle, often listric, normal faults. Typical ranges are asymmetric in cross section, having a steep slope on one side and a gentle slope on the other. The steep slope reflects an erosion-modified fault scarp and the range is a tilted fault block (Hintze, 1988). Rocks within the Basin and Range vary widely in age and composition. Older rocks consist mostly of a variety of Mesozoic and Paleozoic sedimentary units and their metamorphic equivalents. Proterozoic-age rocks have limited exposures in the region. Cenozoic volcanic rocks and valley-fill units generally overlie the sedimentary and metamorphic rocks. Valley-fill deposits consist mostly of late Cenozoic lakebeds and alluvium as much as 3,000 m (10,000 ft) thick.

The Transition Zone is a broad region in central Utah containing structural and stratigraphic characteristics of both the Basin and Range province to the west and the Colorado Plateau province to the east. The boundaries of the Zone are the subject of some disagreement, resulting in various interpretations using different criteria (Stokes, 1988). Essentially, extensional tectonics of the Basin and Range has been superimposed upon the adjacent coeval uplifted blocks of the Colorado Plateau and Middle Rocky Mountains. The result is that block faulting, the principal feature of the Basin and Range, extends tens of kilometers into the adjacent provinces forming a 100-km- (62-mi-) wide zone of transitional tectonics, structure, and physiography (Hecker, 1993).

Late Cenozoic Tectonics in Utah

Comprising essentially the western half of Utah, the Basin and Range province is separated from the Middle Rocky Mountains by the Wasatch fault zone, and from the Colorado Plateau by the Transition Zone (figure 2). Within the Basin and Range and the Transition Zone, east-west structural extension is thought to have taken place over the past 17 million years (Hintze, 1988) creating numerous north-south-oriented, fault-bounded blocks. Prior to Basin and Range extension (during mid-Cenozoic time), voluminous silicic volcanism with associated hydrothermal activity took place within several east-west trending belts (Stewart and others, 1977). Patterns of volcanism changed during the latter stages of Basin and Range development to less-voluminous basalt and rhyolite (bimodal assemblage), spatially controlled by north-south Basin-and-Range faults.

Quaternary Faults

Hecker (1993) presents a detailed review of the Quaternary tectonic activity in Utah and describes the potential for earthquake-related hazards in the state. Utah is in a tectonically active region where the Intermountain seismic belt (ISB), a north-trending zone of historical seismicity, bisects the state (figure 3). The ISB coincides with the broad transitional eastern margin (including the Transition Zone) of the Basin and Range Physiographic Province, extending from southern Nevada, through Utah, southeastern Idaho, western Wyoming, and into central Montana. It includes the major active faults of Utah, such as the Wasatch fault system in northern Utah, and the Hurricane and Sevier faults in southern Utah and northern Arizona. Hecker's work on the Quaternary tectonics of Utah is briefly summarized in the following paragraphs. Mapped Quaternary faults in Utah are included with Hecker's fault database as a separate layer in our associated GIS coverages. The reader should refer to Hecker (1993) for a complete description of this information. Table 2 lists Hecker's Quaternary fault data-fields and descriptions of the values reported in the database.

The Wasatch Front region includes Quaternary tectonic features within a 200-km- (125-mi-) wide zone in northern Utah, centered on the Wasatch fault. The Wasatch fault zone, a normal fault with predominantly vertical movement, is the longest (340 km [210 mi]) and most tectonically active structure in Utah, with abundant evidence of surface-rupturing events during the Holocene. More than two-dozen other faults in the Wasatch Front region show evidence of one or more latest Pleistocene to Holocene surface-rupturing events.

In west-central Utah, latest Pleistocene to Holocene faulting events have been distributed across a series of fault zones spanning about 50 km (30 mi) wide. Based upon the extent and style of this faulting, the west-central Utah source region may extend eastward from Gunnison Lake near Manti to the Joes Valley area near the Emery-Sanpete County line B all eastward from the southern part of the Wasatch fault zone (figure 3).

Quaternary tectonism has been largely absent from eastern Utah, which includes the Uinta Mountains portion of the Middle Rocky Mountains and much of the interior of the Colorado Plateau. In the Paradox Basin, however, late Tertiary to Quaternary dissolution and collapse of large salt anticlines and salt flowage has continued locally into the late Quaternary, creating series of northwest-southeast-aligned fault structures (figure 2). Eastern Utah, like most of the Colorado Plateau, may lie east of the significant extensional forces of the Basin and Range, or may be underlain by more coherent crust.

In southwestern Utah, the Hurricane, Sevier, and Paunsaugunt faults are the dominant Quaternary structural features in the region. The Hurricane fault and its northward continuation, the Cedar City-Parowan monocline and the Paragonah fault, are considered by some workers to represent the boundary between the Basin and Range and Colorado Plateau provinces. Others place this system within the Transition Zone. The Sevier fault lies roughly 50 to 65 km (30 to 40 mi) eastward and subparallel to the Hurricane fault. These two features, along with the smaller Washington and Gunlock faults to the west, are considered by some to be the southern equivalent of the Wasatch Front zone of extension. Whereas long-term slip rates throughout the late Quaternary appear comparable between the two structurally aligned zones, slip rates during the Holocene are markedly different. The Wasatch Front region has experienced a considerable increase in surface faulting during the Holocene, particularly along the central Wasatch fault zone, where slip rates have reportedly increased by a factor of ten over longer term (late Quaternary) rates. In contrast, evidence of surface faulting along the Hurricane and Sevier faults during the Holocene in southwestern Utah is sparse.

Tectonically active regions typically have abundant active geothermal systems as fault movement fractures bedrock, thereby opening potential fluid pathways. In areas of active tectonism, meteoric water has more opportunity to circulate deep and absorb thermal energy from the surrounding rocks.

Quaternary Volcanic Rocks

Recent igneous activity may provide local, high-level, heat sources for geothermal systems. As a result, the distribution and timing of volcanic events is important for assessing the geothermal potential of a region. Hecker (1993) summarizes previous work (Best and others, 1980; Hoover, 1974; Clark, 1977; Lipman and others, 1978; Nash, 1986; Anderson, 1988; and Anderson and Christenson, 1989) to describe the distribution and timing of Quaternary volcanic rocks in Utah. The mapped distribution of Quaternary volcanic rocks is included with Hecker's database as a separate layer in our associated GIS coverages. The reader should refer to Hecker (1993) for a complete description of this information. Table 3 lists Hecker's Quaternary volcanic flows and vents data-fields and provides descriptions of the values reported in the two databases.

Clusters of young volcanic rocks (generally less than 2 Ma) extend from northwestern Arizona through southwestern and west-central Utah. These units consist of a bimodal assemblage of mainly basaltic rocks and less voluminous rhyolitic rocks. In southwestern Utah, several clusters of mostly basaltic rocks are oriented northeast-southwest, subparallel to the Basin and Range-Transition Zone margin. This package of volcanic rocks consists of series of basaltic flows and vents that do not seem to coincide with mapped faults. Rather, some vents lie adjacent to major faults, such as the Hurricane and Sevier faults, localized on the footwall or hanging-wall block, but not appearing to have used the fault as a conduit for magma. Cinder cones and mounds, which generally form alignments parallel to the faults, appear to have formed along steep joints.

In west-central Utah, another cluster of young basaltic rocks, with lesser quantities of rhyolite form a narrow belt generally aligned with the eastern margin of the Basin and Range. This volcanic assemblage formed in an intra-graben area between the Pavant and Tushar Mountains on the east, and the Mineral and Cricket Mountains to the west. The region is referred to as (from south to north) the northern part of the Escalante Desert, the Black Rock Desert, and the southern part of the Sevier Desert (figures 3 and 6). Volcanism here appears to have been concurrent with east-west extension across numerous, small-scale intra-basin faults. Vents and cinder cones mostly lie along high-angle normal faults, suggesting that the faults provided the conduits for movement of magma. Basaltic eruptions began in this region about 2 Ma and have continued intermittently since then. The latest eruptions include those during Lake Bonneville time at Pavant Butte (~15.3 ka) and Tabernacle Hill (~14.5 ka), and the youngest eruption in Utah at Ice Springs (~0.66 ka). This group of volcanic rocks, located in the Black Rock Desert of Millard County, also includes White Mountain, dated at about 400 ka years ago, making the flow the youngest exposure of rhyolite in Utah. A grouping of high-silica rhyolite flows and domes situated along the crest and western flank of the Mineral Mountains in Beaver County were erupted between about 800 and 500 ka; the same time interval that included basaltic eruptions to the northeast near Cove Fort.

A small volcanic field of Pleistocene age is located just north of the Great Salt Lake in the southern Curlew Valley in Box Elder County (figure 3). Basaltic rocks comprise the field and have been dated between about 0.7 and 1.15 Ma. Although the field is aligned generally parallel to basin-and-range faults, it does not appear to be spatially associated with any mapped Quaternary faults.

GEOTHERMAL RESOURCES IN UTAH

Previous Workers

The earliest implied reference to geothermal systems in Utah is by Gilbert (1890), who described Fumarole Butte and the nearby Crater (Abraham) Hot Springs. Stearns and others (1937) and Waring (1965) summarized data for about 60 known thermal occurrences. Mundorff (1970) prepared a comprehensive report on the thermal springs of Utah that included data on individual springs. Swanberg (1974) made estimates of subsurface temperatures using chemical analyses of water samples and employing "geothermometry." The technique called geothermometry is based on chemical equilibria and involves the use of water compositions (from springs or water wells) in mathematical formulas to estimate geothermal reservoir temperatures. Goode (1978) and Rush (1983) both produced summaries of geothermal occurrences in Utah. Goode's data compilation is particularly complete, whereas Rush's geologic descriptions are especially useful. In addition to these references, various authors from the University of Utah Department of Geology and Geophysics, Utah Geological Survey (formerly Utah Geological and Mineral Survey), Utah Office of Energy and Resource Planning (formerly Utah Energy Office), and the University of Utah Energy and Geoscience Institute (formerly University of Utah Research Institute) have published details on geothermal systems and geothermal applications in Utah.

Budding and Bugden (1986) compiled a bibliography of this early work up through the mid-1980s. Since then, several authors (Blackett, 1994; Blackett and Moore, 1994; Blackett and Ross, 1992;) have published more recent compilations and research on geothermal systems in Utah. Mabey and Budding (1987, 1994) compiled detailed geological, geochemical, and geophysical information, including previously unpublished data on seven individual systems within the "Sevier thermal area," an area of central and southwestern Utah containing all of Utah's known high-temperature geothermal systems (figure 5). Budding and Sommer (1986) gathered field data and published a study of low-temperature geothermal resources in the St. George area of southwestern Utah. Wright and others (1990) summarized geothermal resources and developments in Utah up through the 1980s, and discussed how factors such as regional low energy costs resulted in relative low growth of geothermal energy in the state. Blackett and Ross (1992) published the results of geochemical and geophysical studies for geothermal systems within the Escalante Desert of southwestern Utah. Several authors in Blackett and Moore (1994) presented geological summaries and development histories of the state's principal geothermal areas. Blackett (1994) prepared an inventory of thermal wells and springs in Utah as part of a U.S. Department of Energy program to update the geothermal database for all of the western states. We have updated the annotated geothermal bibliography compiled by Budding and Bugden (1986) to include publications related to geothermal studies in Utah from 1987 to 2000, and included it as a separate document on this CD-ROM.

Geothermal Occurrences in Utah

With few exceptions, the higher temperature geothermal areas in Utah occur either in the Basin and Range province or within the Transition Zone (figure 4). In central and western Utah, most thermal areas are located in valleys near the margins of mountain blocks, and are probably controlled by active Basin and Range faults. Other geothermal systems occur in hydrologic discharge zones at the bottoms of valleys. A few thermal areas are situated in mountainous regions.

The most significant known occurrence of geothermal water in eastern Utah is from oil wells of the Ashley Valley oil field, which yield large volumes of nearly fresh water at temperatures between 43°C and 55°C (109°F and 131°F) as a byproduct of oil production. In 1981, the Ashley Valley field yielded 5.42 million m^3 (26.1 million barrels) of water (Goode, 1985).

Using geothermometry and other information, Rush (1983) suggested that six areas in Utah are probably high-temperature geothermal systems with reservoir temperatures above 150°C (302°F). He also suggested that ten other areas could be classified as moderate-temperature geothermal systems with reservoir temperatures between 100°C and 150°C (212°F and 302°F). Known high-temperature systems include the Roosevelt Hot Springs and Cove Fort - Sulphurdale Known Geothermal Resource Areas (KGRA). KGRA is a federal classification pertaining to geothermal areas where federal lands have competing leasing interests. Other potential high-temperature systems are Thermo Hot Springs, Joseph Hot Springs, the Newcastle area, and the Monroe-Red Hill area. Mabey and Budding (1987) compiled detailed information on all of Utah's moderate- to high-temperature geothermal systems and proposed the name "Sevier thermal area" to encompass the region in southwestern Utah in and around the Sevier, Black Rock, and Escalante Deserts (figure 5) where a number of geothermal systems have estimated reservoir temperatures greater than 100°C (212°F).

Geothermal Use in Utah

Presently, electric power is generated at the Roosevelt Hot Springs and the Cove Fort -

Sulphurdale KGRAs. The installed gross capacity for the two areas is about 33 MW (electric). Commercial greenhouses, that use thermal water for space heating, operate at Newcastle in Iron County, and at Crystal Hot Springs near Bluffdale in Salt Lake County. Ten resorts use geothermal water for the heating of swimming pools, small space-heating applications, and therapeutic baths. Two of the newer direct-use geothermal developments consist of commercial SCUBA-diving and aquaculture facilities near Grantsville in Tooele County, and near Plymouth in Box Elder County.

Power Plants

Utah Power, a PacifiCorp company that merged with Scottish Power in 1999, has operated the single-flash, Blundell geothermal power station at the Roosevelt Hot Springs geothermal area near Milford in Beaver County since 1984. Intermountain Geothermal Company, a subsidiary of California Energy Company and the current field developer, produces geothermal brine for the Blundell plant from wells that tap a geothermal resource in fractured, crystalline rock. The resource depths range generally between 640 and 1,830 m (2,100 and 6,000 ft). Resource temperatures are typically between 271 and 316°C (520 and 600°F). Wellhead separators are used to "flash" the geothermal fluid into liquid and vapor phases. The liquid phase, or geothermal brine, is channeled back into the reservoir through gravity-fed injection wells. The vapor phase, or steam fraction, is collected from the production wells and directed into the power plant at temperatures between 177 and 204°C (350 and 400°F) with steam pressure approaching 7.66 kilograms per square centimeter (109 psi). The plant produces 26 MW gross (23 MW net), which equals the energy that would be produced by burning roughly 48,000 cubic meters (300,000 barrels) of oil annually.

At Sulphurdale in Beaver County in 1985, Mother Earth Industries, in cooperation with the City of Provo, installed a geothermal binary-cycle power system and a steam-turbine generator. In 1990, Provo City and the Utah Municipal Power Agency, the current field operator, dedicated the Bonnett geothermal power plant, which became the third geothermal power facility to go on-line at Sulphurdale to provide electricity for Provo City. The estimated net output capacity from the power units is about 10 MW. Because hydrogen sulfide (H_2S) gas is produced, the plant includes a sulfur abatement system designed to extract up to 1.36 metric tons (1.5 short tons) per day of sulfur. Production wells primarily tap a shallow, vapor-dominated part of the geothermal system at depths between 335 and 366 m (1,100 and 1,200 ft). A deeper well, however, reportedly taps the liquid-dominated part of the system. Spent fluid is returned to the reservoir through a deep injection well.

Commercial Greenhouses

Various research organizations and energy companies became interested in the Newcastle area of Iron County in the 1970s after farmers accidentally discovered a relatively shallow hydrothermal system while drilling an irrigation well. The well had encountered a hot-water aquifer with a maximum temperature of 108°C (226°F) between depths of 75 and 94 m (245 and 310 ft). Subsequent studies by the UGS suggest a model of hot water rising along a range-bounding fault and discharging into an aquifer in unconsolidated Quaternary sediments, forming a broad outflow plume. Temperatures within the outflow plume generally range between 82° and 104°C (180° and 220°F). Several commercial greenhouses, covering about 100,000 m^2 (25 acres), use the geothermal fluid from shallow production wells (152 m [~ 500 ft] deep) to produce high-quality flowers, vegetables, and ornamental plants year-round.

Crystal (Bluffdale) Hot Springs is located at the southern end of the Salt Lake Valley where Bluffdale Flower Growers (formerly Utah Roses) operates a geothermal-heated greenhouse complex. The facility covers about 11,700 m^2 (2.9 acres), and produces cut roses as its primary product. Utah Correctional Industries at the nearby Utah State Prison uses thermal water from a well for raising tropical fish commercially. Surface spring temperatures are about 62°C (144°F). Subsurface temperatures of 88°C (190°F) have been reported in one of two 122-m- (400-ft-) deep production wells. The springs normally issue from valley alluvium into several ponds. When production wells are in operation, the surface springs and ponds reportedly dry up.

Therapeutic Baths, Resorts, and Aquaculture

Bonneville SeaBase is a SCUBA-diving facility developed at Grantsville Warm Springs located about 66 km (40 mi) west of Salt Lake City along Interstate Highway 80 in Tooele County. SeaBase consists of several dive pools fed by warm springs and stocked with tropical marine fish. The facility is associated with Neptune Divers of Salt Lake City, a business devoted to SCUBA diving and related-product sales.

At Belmont (Udy) Hot Springs in northeastern Box Elder County, about 50 hot springs and seeps issue along the Malad River at about 52°C (125°F). In addition to a golf course and camping facilities, the resort has therapeutic hot tubs, a swimming pool, and a SCUBA diving pool. The resort also operates a commercial aquaculture facility, raising lobsters and crayfish for distribution out of the local area.

Crystal (Madsen) Hot Springs Resort, near Honeyville along Interstate Highway15 in Box Elder County, uses cold springs and hot springs at the same facility. The springs are situated along the northern extension of the Wasatch fault, which traverses along the western side of the Wellsville Mountains. A cold spring (11°C [52°F]) is used to help fill a 1.1-million-liter- (300,000-gallon-) pool, while hot springs 60°C (140°F) fill therapeutic hot tubs, mineral pools, and also flow into the swimming pool. Pool temperatures range from 29° to 44°C (85° to 112°F).

Thermal springs in and around the community of Midway in Wasatch County issue from several widespread, coalescing travertine mounds covering an area of several square kilometers. Temperatures in the springs generally range from 35° to 46°C (95 to 115°F). Thermal water at Midway probably originates from deep circulation of meteoric water from recharge zones located to the north near Park City. The Mountain Spa Resort uses thermal water for heating a swimming pool and for therapeutic baths. The Homestead, a hotel and resort complex, uses thermal water in a therapeutic bath, and also offers guests SCUBA diving within a 35°C (95°F) thermal pool inside "the old hot pot," a large travertine mound.

The Monroe-Red Hill Hot Spring area is 16 km (10 mi) south of Richfield in Sevier County. The proprietors have named the resort "Mystic Hot Springs" and offer a geothermal-heated swimming pool, therapeutic baths, camping facilities, and tropical fish ponds. The Monroe and Red Hill Hot Springs issue at about 77°C (170°F) near the surface trace of the Sevier fault adjacent to the Sevier Plateau. The area was the focus of U.S. Department of Energy-sponsored geothermal studies in the late 1970s.

Veyo and Pah Tempe Hot Springs resorts in southwestern Utah offer swimming and therapeutic baths. At Veyo Hot Springs Resort, located southeast of the town of Veyo along the Santa Clara River canyon, spring flows are channeled to a swimming pool at a temperature of about 32°C (89°F). At the Pah Tempe Hot Springs Resort springs flow from a number of vents along the Virgin River at about 42°C (108°F) near where the river crosses the Hurricane fault between the towns of Hurricane and La Verkin. The thermal water is channeled into a swimming pool and therapeutic baths.

GEOTHERMAL WELL AND SPRING DATA FOR UTAH B UTAHGEO.dbf

Background

For more than two decades, the UGS has worked with other state and federal agencies to compile data sets and files on thermal wells and springs in Utah. The U.S. Geological Survey (USGS), in cooperation with the U.S. Department of Energy (DOE), compiled the first comprehensive database of geothermal wells and springs in Utah in support of two national geothermal assessments (Muffler, 1979; and Reed, 1983). The data for these assessments were incorporated into GEOTHERM (Bliss and Rapport, 1983), a mainframe computer system of databases and software used to store, locate, and evaluate information on geothermal systems. GEOTHERM received data until it was taken off-line in 1983. The USGS preserved these data and made them available for public use through a series of Open-File reports presenting information on source location, description, and water chemistry.

The UGS (formerly Utah Geological and Mineral Survey) helped with data compilation for GEOTHERM, and eventually published a state geothermal resource map in cooperation with DOE and the National Oceanic and Atmospheric Administration (Utah Geological and Mineral Survey, 1980). Based primarily on the work of Goode (1978), the map listed about 330 wells and springs included in GEOTHERM, showed heat-flow information from the work of Chapman and others (1978, 1981) and Sass and others (1976), and outlined areas of prospective value for geothermal exploration. Since the national geothermal assessments were completed in the early 1980's, no new resource data have been gathered at a regional scale. The map also showed nine Known Geothermal Resource Areas (KGRAs), a classification for federal leasing based on competitive interests and/or geologic criteria. Since 1980, only three of these areas (Cove Fort-Sulphurdale, Roosevelt Hot Springs, and Crater Springs) still maintain the classification of KGRA. The others (Meadow-Hatton, Monroe-Joseph, Thermo, Lund, Newcastle, and Navajo Lake) were declassified because of either a lack of competitive interests or, a lack of an indicated resource.

In 1991, the Geothermal Division of the U.S. Department of Energy (DOE) initiated the Low-Temperature Geothermal Resources and Technology Transfer Program, following a special appropriation by Congress, to encourage wider use of lower-temperature geothermal resources through direct-use, geothermal heat-pump, and binary-cycle power conversion technologies. The Oregon Institute of Technology (OIT), the University of Utah Research Institute (now the Energy and Geoscience Institute), and the Idaho Water Resources Research Institute organized the federally-funded program and enlisted the help of geothermal specialists in ten western states to re-inventory thermal wells and springs, and compiled relevant information on each source. As part of this project, the UGS compiled a database with information on thermal wells and springs in Utah with temperatures of 20°C (68°F) or greater (Blackett, 1994). The database contained 964 records on 792 locations of wells and springs, and it included the location of the well or spring, its temperature, depth, flow-rate, and chemical constituents. The database was developed for use on personal computers to provide users with access to specific geothermal information in Utah. Resource maps of thermal wells and springs, derived from the database, were included in the 1994 open-file report.

Sources of Data

Because the data contained in the 1994 UGS open-file report (Blackett, 1994) pertained mostly to low-temperature geothermal sources, information on deep, exploratory geothermal wells was generally not included. Published data on deep, geothermal exploration wells is included with this report. In addition, an effort was made to include new information generated from the drilling of new wells, or additional data on existing wells that has become available since that time.

Like the 1994 open-file report, well and spring information included here was obtained from the published sources listed in the references, and from the U.S. Geological Survey/Water Resources Division (USGS/WRD). The Utah district office of the USGS/WRD provided location, descriptive, and water-chemistry data on wells and springs in Utah, with measured temperatures of 18°C (64°F) or greater, from the National Water Information System (NWIS) database.

These data were then culled using a cutoff temperature. The general criteria used to determine a cutoff temperature was if a ground-water source surface temperature is greater than 10°C (18°F) above the mean annual ambient temperature, then it is considered "thermal." Ground-water sources with temperatures below the cutoff temperature are not considered thermal and, therefore, are not included. Mean annual ambient temperatures (MAAT) were estimated for all counties using information provided in Greer and others (1981). In general, because the MAAT for most of Utah is near 10°C (50°F), a measured temperature of 20°C (68°F) was used to define the cutoff temperature of thermal sources for most counties. In the case of some of the northern counties, or those at higher elevations, a lower cutoff temperature was used to compensate for a lower MAAT. Table 4 lists the cutoff temperatures used for each county. Since no thermal sources were recorded in Rich and Daggett Counties, they do not appear on the list. In addition, it should be noted that a 20°C (68°F) cutoff was still used in those counties with relatively higher MAATs, in particular Washington County (MAAT = 16°C [61°F]). This was done for consistency with the previous, 1994 assessment.

UTAHGEO Database Format

Thermal well and spring data listed in Appendices A and B and included in the GIS coverage differs somewhat from the previous, 1994 open-file report (Blackett, 1994). The "UTAHGEO" GIS coverage and associated database file contains 2,985 records pertaining to 1,133 sources of "thermal" water in Utah. In nearly all cases, these sources are either springs or water wells; these data are recorded in the "TYPE" field. Sources are coded as oil-field drain (D), mine (M), or a well collector (C) in fewer than ten cases.

Table 5 lists the field name, field contents, and measurement units for the 38 data fields contained in "UTAHGEO.dbf." The information within "UTAHGEO" is organized into two broad categories B *Descriptive Data* and *Fluid-Chemistry Data.* The *Descriptive Data,* listed in Appendix A, presents the location and physical parameters of the source. Included in this category are the GIS-map designation for the source (county code plus number), location of the source in three coordinate systems (latitude-longitude, UTM, and cadastral), physical parameters (temperature, depth of well, and flow-rate), date of measurement, and a short reference citation. The short citation refers to the attached reference list. The *Fluid-Chemistry Data,* listed in Appendix B, presents quantitative chemical analyses of fluid samples from the source, including major cations and anions, pH, conductivity, and total dissolved solids (TDS). Table 6 provides a key to county codes shown as part of the MAPNAME data field.

Limitations of UTAHGEO Database

Data from the 1994 open-file report (Blackett, 1994) were combined with data from the USGS's NWIS to create UTAHGEO. Since many of the records in the 1994 database used information taken from an older USGS database similar to the NWIS, UTAHGEO includes many duplicate records. There are enough subtle differences, however, between the new data and the previous, 1994 data set that we decided to keep both sets of information in the UTAHGEO database. The reader is urged to research records with their referenced source if more detailed information is required, or if the data need verification.

At a minimum, locations, types, temperatures, and references are reported. Many cells within other fields of the database, however, are empty because data were often not available for a particular parameter.

An effort was made to correct more obvious location errors for well-known geothermal sources in Utah. In a number of instances, plotted locations of sources did not obviously conform to the reported cadastral location (well and spring numbering system for Utah). In most cases, further research revealed that the reported cadastral location was correct and the coordinate location was not. In any case, the reader should be aware of location inconsistencies and be prepared to do more research on individual sources as needed.

More information is available on individual sources from the USGS/WRD and the Utah Department of Natural Resources, Division of Water Rights. The USGS/WRD's office in Salt Lake City provides information on ground-water sources in Utah as well as other water-related information.

The address for the USGS/WRD's Internet site is: http://ut.water.usgs.gov/. In addition to providing information regarding water usage and water right ownership, the Division of Water Rights also provides information on individual wells and springs in the state. The Division maintains an Internet website at: http://nrwrt1.nr.state.ut.us/.

Well and Spring Numbering System in Utah

The system of numbering wells and springs in Utah is based on the cadastral land-survey system of the U.S. Government (figure 6). The number designates a location and describes its position in the land net. The land-survey system divides the state into four quadrants with respect to the Salt Lake Base Line and Meridian (origin in Salt Lake City), and these quadrants are designated by uppercase letters as follows: A-northeast, B-northwest; C-southwest; and D-southeast. Numbers designating the township and range (in that order) follow the quadrant letter, and all three are enclosed in parentheses. The number after the parentheses indicates the section and is followed by the three letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section (generally 0.04 km^2 or 10 acres). The quarters of each subdivision are designated by lowercase letters as follows: a, northeast; b, northwest; c, southwest; and d, southeast. For example, the well/spring number "(C-36-15)20bca" describes a location in T.36S., R.15W., in the northeast quarter of the southwest quarter of the northwest quarter of Section 20. The Uinta Special Meridian is a separate land-survey system established for the Uinta Basin in northeastern Utah. Wells and springs located using this system are designated by a preceding "U," for example "U(B-01-08)30ddb." Within the UTAHGEO database, the well/spring number for each record is included under the fieldname "LOCATION."

GEOTHERMAL RESOURCE AREA SUMMARIES

Wasatch and Uinta Mountains

Regional Setting

Comprising the Middle Rocky Mountains Physiographic Province in Utah (figure 2), the Wasatch and Uinta Mountains lie near the boundaries with the Basin and Range Province and the Colorado Plateau Province, respectively. These mountain ranges stand high above the surrounding terrain and are composed of relatively old rock formations that have been subjected to faulting and folding from several, major orogenic events. During the process of deformation, the rock units were faulted, fractured, and folded by tectonic activity, and intruded by igneous masses, thereby creating permeable conduits for fluid movement. These conduits, coupled with abundant recharge mostly from snow-melt, provide the conditions for meteoric water to percolate deep, become heated by the Earth's natural heat, rise through forced convection, and surface at points of low pressure in this "convective hydrothermal" system. Often, thermal waters will mix with shallow meteoric waters, becoming diluted before issuing at the surface or discharging into shallow aquifers. Much of the recharge water in the Wasatch Range eventually reaches systems at the eastern edge of the Basin and Range Province, but a considerable amount of thermal water discharges to springs and aquifers along the eastern slope or the Wasatch Hinterlands (described by Stokes, 1988). Such thermal waters are manifested in high mountain valleys like Cache Valley or Heber Valley (Midway area), or as high-altitude, point-source occurrences like those in Third Water Canyon and at Split Mountain.

Cache Valley

Cache Valley is a narrow, north-trending valley in northern Utah and southern Idaho, which lies on the northeastern edge of the Great Basin (figure 7). The overall structure of the valley is a graben bounded by high-angle normal faults. The structural basin forming Cache Valley is filled by as much as 1.6 km (1 mi) of semi-consolidated and unconsolidated Tertiary and Quaternary strata. De Vries (1982) analyzed the geothermal resource potential of Cache Valley and reported temperature, water chemistry, and thermal-gradient data. For the evaluation, she compiled temperatures and water chemistries from 90 wells, and gathered temperature-depth profiles from 12 wells. The results of her investigation suggest that three areas within the Cache Valley contain anomalously warm water. Geochemical indicators suggest that reservoir temperatures are between 50° and 100°C (122° and 212°F). Chemical mixing models applied to the same analyses indicate that reservoir temperatures may approach 200°C (392°F) (de Vries, 1982).

In the North Logan area, well temperatures ranged up to 25.1°C (77.2°F), although a bottom-hole-temperature of 32.5°C (90.5°F) was recorded in one of the thermal gradient holes (CVG-9). De Vries (1982) suggests that the occurrence of thermal waters is due to increased vertical permeability along an intersection of two segments of the nearby East Cache Valley fault zone. Estimated resource temperatures near North Logan range up to 56.1°C (133.0°F).

Around Benson, de Vries measured well temperatures that ranged up to 23°C (73°F). Geothermometry of water chemistry was ambiguous. De Vries suggests that the thermal water near Benson may have some relationship to the Clarkston fault zone to the west.

Three springs and one well in the Trenton area have temperatures ranging from 22.9° to 50.1°C (73.2° to 122.2°F). Tufa deposits are reportedly associated with the Dayton fault zone in this location. De Vries reports that Cottle's spring had a sulfurous odor and a temperature of 22.9°C (73.2°F). A tufa mound surrounds Gancheff's spring and the spring water has a fairly constant temperature at about 30°C (86°F). Gancheff's spring water has a dissolved solids content of about 4,500 mg/L (note: for dilute solutions, mg/L is essentially equivalent to parts-per-million [ppm]). The highest temperature recorded near Trenton was in an exploratory gas well (Karmis-Brown) where de Vries measured a temperature of 50.1°C. The Karmis-Brown well was drilled to a depth of 1,587 m (5,207 ft).

Midway Area

Midway is a small farming and resort town located about 8 km (5 mi) west of Heber City in Wasatch County. Thermal springs in and around the community issue from several widespread, coalescing travertine mounds covering an area of several square kilometers (Baker, 1968). Temperatures in these springs range from 38°C to 46°C (100°F to 115°F). Kohler (1979) suggested that thermal water at Midway originates from deep circulation of meteoric water from recharge zones located to the north near Park City. Thermal water is contained within fractured, Paleozoic quartzite in a broad antiform structure. Leakage to the surface is expressed as scattered thermal springs and widespread travertine deposits. Chemical geothermometry indicates that the maximum reservoir temperature is about 75°C (167°F).

Thermal water here has been used in pools and spas for several decades. Some new residences in this rapidly growing area reportedly use the geothermal water for space heating. A DOE-funded study (Kohler, 1979) showed that the geothermal system extends for several square kilometers around Midway. Midway's population was 1,554 during the 1990 Census, an increase of 30 percent over the 1980 Census. U.S. Highways 189 and 40 connect Midway with the larger, nearby communities of Provo, Heber, and Park City. The Heber Valley is an agricultural area producing alfalfa, corn, and cattle. At the Mountain Spa Resort, thermal water is used for heating a swimming pool and for therapeutic baths. The Homestead, a hotel and resort complex, uses thermal water in a therapeutic bath, and also offers guests SCUBA diving within a 35°C (95°F) thermal pool inside "the old hot pot," a large travertine mound (see section on geothermal uses).

Third Water Canyon

Third Water Hot Springs, well known to hikers and mountain-bikers, are located in eastern Utah County. They are unusual because they occur at an elevation of 1,890 m (6,200 ft) in the Wasatch Mountains. The springs were known only to recreational enthusiasts and were not reported in previous geothermal or water-resource publications. Third Water Hot Springs issue from multiple vents along Third Water Creek, about 5 km (3 mi) east of Three Forks Campground in Diamond Fork Canyon. Access to the springs is by hiking, mountain biking, or on horseback. The springs occur over a distance of about 0.5 km (0.3 mi) in and along the stream course, with many vents located below a 6 m (20 ft) waterfall. Abundant vertical fractures are apparent with some evidence of offset. Bedrock consists mostly of pebble and cobble conglomerate, probably of upper Cretaceous (Price River Formation) or lower Tertiary (North Horn Formation) age.

Spring temperatures range from tepid to a maximum of 55.5°C (131.9°F) at a vent located just below the waterfall. The springs give off a pervasive sulfurous odor, and deposit both white and black mineral coatings on the stream bottom. A pH of 7.03 was measured at the sampled vent, and analyses of a water sample yielded a TDS content of 932 mg/L. Geothermometry suggests equilibration temperatures between 65°C and 97°C (149°F and 207°F). Results of the laboratory analysis (included in the database) indicate a sodium bicarbonate, chloride, sulfate type water.

Castilla and Thistle Hot Springs

Klauk and Davis (1984) presented thermal and chemical data on Castilla Hot Springs (two springs) located about 13 km (8 mi) southeast of Spanish Fork in Spanish Fork Canyon, along the north side of U.S. Highway 6/89 in Utah County (figure 8). Temperature at both springs was 36°C (97°F).

They also presented data on another spring located about 5 km (3 mi) southeast of Castilla exposed in the bed of the Spanish Fork River near the massive Thistle earthflow. At the time of Klauk and Davis' (1984) study, the earthflow had dammed the Spanish Fork River, exposing the riverbed. They reported the temperature of this spring as 50°C (122°F). They also reported that small seeps, ranging in temperature from 7.2 to 26.7°C (45° to 80°F), were also noted in the streambed from Thistle Hot Spring to the confluence with Diamond Fork Creek, a distance of 2.7 km (1.7 mi). It is not known if Thistle Hot Spring or the other seeps are evident at present.

Diamond Fork

Diamond Fork Warm Springs are about 27 km (17 mi) east of Spanish Fork in Utah County in SE¼, section 14, T.8S., R.5 E (figure 8). The springs issue from Cretaceous conglomerate rocks along Diamond Fork, a tributary to the Spanish Fork River, at 20°C (68°F). TDS content is 837 mg/L, and there is a pervasive hydrogen sulfide odor associated with the springs. The water type is calcium-sodium-sulfate, and Mundorff (1970) reported a discharge range from 1,300 to 2,700 L/min (350 to 700 gpm).

Split Mountain Warm Springs and Duchesne River Springs

A few thermal springs issue from fault and fracture zones along the south flank of the Uinta Mountains. At Split Mountain Warm Springs (figure 4), within Dinosaur National Monument, water issues from fractured Mississippian-age rocks along the crest of the Split Mountain anticline at 30°C (86°F). Goode (1978) reported a flow of 10,200 L/min (2,700 gpm) and TDS of 942 mg/L at Split Mountain, and reported that the water issues from several spring orifices. Goode also described a group of warm springs in the Duchesne River valley near Hanna that flow about 8,517 L/min (2,250 gpm) of low-TDS water at a temperature of 26°C.

Uinta Basin

Regional Setting

The Uinta Basin in northeastern Utah is a broad, east-west trending basin that sub-parallels the Precambrian-cored Uinta Mountains to the north. It encompasses more than 26,000 square kilometers

(10,000 mi^2), most of northeastern Utah (figure 4). Structurally, it is a broad east-west asymmetrical syncline with a steep north limb and a gently dipping south limb. The basin is a Laramide orogenic feature, filled primarily with Tertiary alluvial, fluvial, and lacustrine deposits. A number of oil reservoirs occur in the basin as well as other hydrocarbon deposits (gilsonite, oil-shale, and bituminous sandstone). Several significant faults near the south flank of the Uinta Mountains run subparallel to the axis of the basin, and may act as conduits for vertical movement of thermal water.

Ashley Valley

In his detailed report on the thermal waters of Utah, Goode (1978) summarized geothermal occurrences in the Uinta Basin. Thermal water is produced as a byproduct of oil production within the Uinta Basin. At the Ashley Valley field, Goode reported that low-TDS water (1,500 mg/L) at temperatures between 43° and 55°C (109° and 131°F) was produced with oil, separated in settling ponds, and diverted into the local irrigation system. No attempt to use the heat in geothermal applications has been reported.

Wasatch Front Valleys

Regional Setting

Many thermal springs are present along the Wasatch Front, from Utah Valley on the south, to the state line on the north (figures 7 and 8). These systems are just west of the Wasatch Mountains at the eastern edge of the Basin and Range Physiographic Province and within the Intermountain seismic belt. The thermal springs are considered to be the result of deep circulation of meteoric water, heated by the normal geothermal gradient of the Basin and Range province.

The Wasatch Range rises abruptly from the valley floor. This steep mountain front follows the Wasatch Fault zone, where the fault zone has displaced rocks in the upthrown block of the Wasatch Range several tens of thousands of feet from rocks in the downthrown block. Rocks of the downthrown block are buried beneath several thousand feet of lakebed sediment and alluvium.

The Wasatch Front valleys lie immediately west of the Wasatch Range in north-central Utah within what Stokes (1988) refers to as the Wasatch Front Valley section of the Basin and Range physiographic province. Stokes (1988) describes the Wasatch Front as not one continuous open valley, but a number of spurs, or salients divided into distinct geographic segments. Utah Valley lies farthest south and includes Utah Lake. Utah Valley (upper Jordan Valley) is bounded on the north by the Traverse Mountains that separate it from Salt Lake Valley (lower Jordan Valley) to the north. The Salt Lake salient (Beck's spur) forms a partial barrier northeast of the Salt Lake Valley and separates it from the much longer and less well defined tract containing the communities of Bountiful, Centerville, Farmington, Kaysville, Layton, Clearfield, and Ogden. This tract has no distinct name, but here we'll refer to it as the Weber River delta district. North of Ogden another projection, the Pleasant View salient, extends from the Wasatch Range westward into the lowlands, providing a geographic and structural southern boundary to what may be called the lower Bear River Valley. The northernmost valley is referred to as the Malad River Valley, which extends into southern Idaho (Stokes, 1988).

Stokes (1988) subdivides the Wasatch Range into three segments. The northern segment extends from the Bear River narrows on the north to the Weber River on the south. The central segment extends from the Weber River to the American Fork River. The southern segment extends from the American Fork River southward to Salt Creek near Nephi. The northern and southern subdivisions consist mainly of Paleozoic rocks that have been moved eastward along large thrust sheet formed during the Cretaceous Sevier orogeny. Rocks of the central subdivision have remained largely in place, possibly buttressed by the Uinta Mountains massif during the Cretaceous period. The central subdivision also contains several large Tertiary intrusive stocks near Salt Lake City. The Wasatch Range is crosscut by numerous faults and folds, which predate the formation of the Wasatch Fault.

Wasatch Front Valleys - Lower Bear River Valley

The lower Bear River Valley includes the region extending from the Weber-Box Elder County line at the Pleasant View spur northward to the Utah-Idaho border. It includes the area west of the Wasatch and Wellsville Mountains and east of the West Hills, Blue Spring Hills, and Promontory Mountains. Thermal springs in the area were included in early geothermal studies by Mundorff (1970) and Goode (1978). The area was later the focus of State-Federal sponsored geothermal investigations (Murphy and Gwynn, 1979b; Klauk and Budding, 1984). Several of the better-known Utah thermal springs occur in this region including Crystal Hot Springs (Madsen) and Belmont (Udy) Hot Springs.

Utah Hot Springs

Utah Hot Springs issue from several orifices in valley fill at the western edge of the Pleasant View salient about 90 m (300 ft) west of U.S. 89 on the Box Elder-Weber county line. The area is located within a utility and transportation corridor where the discharge, in the past, was channeled to baths, pools, and greenhouses. A small commercial greenhouse presently uses the fluids for heating during winter months. Murphy and Gwynn (1979b) reported that the maximum temperature was 63°C (145°F), although temperatures reported from other studies made from 1843 to 1967 ranged between 57 and 58.5°C (135 and 137°F).

TDS content of Utah Hot Springs water ranges between 18,900 and 25,200 mg/L; 90 percent of the dissolved constituents are sodium and chloride ions. In addition to the high salinity, the water contains 3 to 5 mg/L dissolved iron that oxidizes and precipitates when the water is aerated. Felmlee and Cadigan (1978) reported that the water also contains measurable quantities of radium (66 µµg/L) and uranium (0.04 µg/L).

Crystal (Madsen) Hot Springs

Crystal (Madsens) Hot Springs, located about 2 km (1.3 mi) north of Honeyville in Box Elder

County (figure 7) flow from the base of a small salient extending west from the Wellsville Mountains (northern extension of the Wasatch fault zone). The springs flow from fractured Paleozoic rocks at temperatures between 49.5° and 57°C (121° and 135°F). Although there are a number of warm springs and seeps in the area, the original main spring orifice is no longer visible. A nearby cold spring 11°C (52°F), along with water from the hot springs, is used to help fill a 1.14-million-liter- (300,000-gallon-) pool, while the hot springs alone are used to fill therapeutic hot tubs and mineral pools. Swimming pool temperatures range from 29° to 44°C (85° to 112°F). Roughly 610 m (2,000 ft) south of the main spring, a series of low-flowing warm springs and seeps are present in a small branch of Salt Creek, a tributary of the Bear River (Murphy and Gwynn, 1979a).

Total flow from all springs and seeps at Crystal Hot Springs drains southwest along Salt Creek and has been estimated at about 15,300 L/min (4,000 gpm). Mundorff (1970) estimated discharge of about 6,370 L/min (1,680 gpm) for the main hot spring (Murphy and Gwynn, 1979b).

TDS content of the thermal waters at Crystal (Madsen) Hot Springs is the highest of any spring in Utah with TDS measured values above 46,000 mg/L. Over 90 percent of the ions in solution are sodium and chloride. In addition to high TDS values, the springs reportedly contain elevated levels of radium (220 µµg/L) and uranium (1.5 µg/L) (Felmlee and Cadigan, 1978).

Belmont (Udy) Hot Springs

Belmont Hot Springs (formerly referred to as "Udy Hot Springs") issue to the surface about 1.6 km (1 mi) southwest of Plymouth in northeastern Box Elder County (figure 7) on the floodplain of the Malad River. The springs consist of a number of orifices that form a roughly semicircular pattern on the western flank of the river. The springs flow from fractured Paleozoic limestone at a small escarpment between the flood plain and the higher terraces of the Malad River Valley. Water temperatures range from 34° to 43.5° C (93° to 110° F). A large lake containing several spring orifices is the most conspicuous feature of the springs, but a series of smaller orifices given names such as "Indian Pool," Morning Glory Hole," and "Mud Pots" are present south of the large lake. Water from all orifices drain directly into the Malad River. Development at the Belmont Hot Springs Resort has modified the original springs (Murphy and Gwynn, 1979b).

The Belmont Hot Springs system is situated between the Wasatch Range on the east and the West Hills to the west. The two ranges, different in terms of geology and structure, are separated by Basin and Range structures beneath the Malad River Valley (Murphy and Gwynn, 1979b).

Dissolved constituents, like many other Wasatch Front valley springs, are mainly sodium and chloride ions with TDS values approaching 8,400 mg/L.

In addition to a golf course and camping facilities, Belmont Hot Springs resort includes three therapeutic hot tubs, a swimming pool, SCUBA diving pools, and operates a commercial aquaculture facility to raise lobsters.

Little Mountain Warm Spring

Little Mountain Warm Spring, at the south end of Little Mountain in Box Elder County, has a water temperature of 32°C (90°F). Predominant ions present in the thermal water are bicarbonate, sodium, and chloride (Murphy and Gwynn, 1979b). Klauk and Budding (1984) suggest that Little Mountain Warm Spring and Stinking Hot Springs, located about 1.6 km (1 mi) to the southeast, may be related to the same fault system and, based on water chemistry, the same type of reservoir rocks.

Stinking Hot Springs

Stinking Hot Springs is located about 10 km (6 mi) southwest of Bear River City. The springs issue from faulted Mississippian limestone at the base of the south end of Little Mountain. The springs get their name from the presence of hydrogen sulfide gas in the vapors. Water temperatures are known to range between 39.5° and 51°C (103° and 124°F). Discharge from the spring ranges from 19 to 170 L/min (5 to 45 gpm). TDS content of the sodium chloride-type water ranges from 29,000 to 30,400 mg/L. Mundorff (1970) reported that lithium, bromide, and iodide concentrations are high. The high TDS content likely results from saline minerals within the aquifer (Klauk and Budding, 1984; Mundorff, 1970).

Bothwell (Salt Creek) Warm Springs

Bothwell Warm Springs, 32 km (20 mi) northwest of Brigham City, flows from a small outcrop of fractured Paleozoic limestone with water temperatures ranging from 21° to 23°C (70° to 73°F). Klauk and Budding (1984) reported the TDS content of the water is about 2,000 mg/L, and flow rates of the springs ranged annually from 10,201 to 61,213 L/min (2,244 to13,465 gpm). They also reported that the location recorded by Mundorff (1970) (sec. 2, T.11N., R.4W.) was probably in error, and that Mundorff referred to Bothwell Springs as "Salt Creek Warm Springs." Klauk and

Budding (1984) reported that a salt spring was located and sampled, however, in sec. 6, T.11N., R.3W., about 3.2 km (2 mi) directly east of the location stated for Bothwell. The Utah Division of Wildlife Resources (UDWR) examined these springs in 1999 for possible use as supply water for a warm water fish hatchery (FishPro Inc., 2000). The UDWR eventually dropped this site from further consideration.

Cutler Warm Springs

Cutler Warm Springs were identified in early reports (Mundorff, 1970) as located 16 km (10 mi) northeast of Tremonton, and issuing from Paleozoic limestone within the bed and along the banks of the Bear River, about 1.6 km (1 mi) east of the mapped trace of the Wasatch fault in Box Elder County. Water temperatures reportedly vary between 21° and 27°C (70° and 81°F), and TDS content ranged from 2,000 and 5,000 mg/L. Klauk and Budding (1984), however, reported they could not locate these springs and that they were probably covered as a result of construction of a nearby reservoir.

Chesapeake Duck Club Wells

Goode (1978) reported that in 1925, a 153-m- (502-ft-) deep water well was drilled for the Chesapeake Duck Club in NE¼, NW¼, SW¼, section 27, T.9N., R.3W. The well reportedly produced gas and fluid at a temperature of 74°C (165°F), and was later plugged. Goode (1978) also reported that a second well was drilled to a depth of 152 m (500 ft) and was also plugged due to gas production. No temperature was recorded for the second well. The two wells are located in an area where faulting was noted by Bjorklund and McGreevy (1973, 1974). The faults may be conduits for thermal fluid circulation, which may have been encountered during drilling of these wells (Klauk and Budding, 1984).

Davis No. 1 Geothermal Well

On February 22, 1974, Utah Power & Light Company (now Pacificorp) spudded a geothermal test well in the SW1/4, SW1/4, NW¼, section 16, T.10N., R.2W. in Box Elder County. The well was completed on August 22, 1974 at a depth of 3,354 m (11,005 ft). Temperature logging revealed that the bottom-hole temperature was 105°C (221°F), yielding an overall thermal gradient of 28.3°C/km (1.55°F/100 ft) B much lower than anticipated. Jensen and King (1999) presented three interpretations of the geologic units penetrated by the Davis No. 1 well based on interpretations of cuttings and geophysical logs. They projected the depth to the bottom of valley-fill, Quaternary units between 177 and 207 m (580 and 680 ft). They also projected the depth to the base of Tertiary units (Salt Lake Formation) and the top of pre-Cenozoic rocks (Paleozoic carbonate) at between 1,335 and 1,353 m (4,380 and 4,440 ft). The well penetrated upper Proterozoic rocks (Caddy Canyon Formation) at a fault contact near 2,391 m (7,845 ft). The well penetrated the upper Proterozoic Maple Canyon Formation between 3,179 and 3,228 m (10,430 and 10,590 ft), bottoming in this unit.

Wasatch Front Valleys - Weber River Delta District

The Weber River delta district, in this report, includes that area immediately west of the Wasatch Range, extending southward from the Pleasant View spur at the Weber-Box Elder County line to the Davis-Salt Lake County line near North Salt Lake. The west boundary of Weber River delta district is the eastern shore of the Great Salt Lake. Thermal springs in the area were included in early geothermal studies by Mundorff (1970) and Goode (1978). The area was later the focus of State-Federal sponsored geothermal investigations (Murphy and Gwynn, 1979b; Klauk and Budding, 1984; Klauk and Prawl, 1984; Cole, 1981, 1983).

South Little Mountain Geothermal Area

Murphy and Gwynn (1979b) reported the results of detailed geothermal studies in the "Little Mountain South geothermal area." The reader should refer to their report for more information. The South Little Mountain geothermal area (so termed here to distinguish it from the other "Little Mountain" geothermal area located in Box Elder County to the north) is located about 24 km (15 mi) west of Ogden on the eastern shore of the Great Salt Lake in Weber County. Bear River Bay flows into the Great Salt Lake immediately to the west. Little Mountain is an isolated triangular shaped exposure of Precambrian rock surrounded by valley fill. West of Little Mountain, IMC Kalium Ogden Corp. operates large solar evaporation ponds for extracting potash and salt from Great Salt Lake brine (Bon and Wakefield, 1999). Great Salt Lake Minerals & Chemicals Corp. previously operated the facility and wells were originally recorded with that company name. In addition, Murphy and Gwynn (1979b) reported that other military and commercial facilities are present in the area.

Geothermal manifestations in the area include a few small springs and many, low-temperature flowing wells. The higher temperature wells are located in section 31, T.7N., R.3W. The wells vary in depth from about 122 to 280 m (400 to 920 ft) and penetrate the valley fill, which consists of alternating sand and clay layers. Bolke and Waddell (1972) determined that the wells were completed into four confined aquifers. These aquifers, in general, have higher temperature water and higher TDS with increasing depth. Temperatures in the wells vary from about 25° to 40.5°C (77° to 105°F).

The warm water generally contains less than 1,000 mg/L TDS; the predominant ions are bicarbonate, sodium, and chloride. Bolke and Waddell(1972) suggest that, the low values indicate the water flowing from the wells at South Little Mountain is shallow ground water heated by conduction from an underlying convective hydrothermal system. The underlying system possibly circulates in fractured bedrock. In this model they also postulate that little to no mixing takes place between the two systems (Murphy and Gwynn, 1979b).

Ogden Hot Springs

Mundorff (1970) described the geology, thermal conditions and water chemistry for Ogden Hot Springs. The springs are located at the mouth of Ogden Canyon in SE1/4, SW1/4, SW1/4, section 23, T.6N., R.1W., just east of the City of Ogden in Weber County (figure 7). The springs issue from fractures in Precambrian rocks along the Ogden River. Since people began recording temperatures in the late 1800's, reported temperatures for the springs have ranged from 49° to 66°C (121° to 150°F), but average about 57°C (135°F). Flow rates recorded for the springs have been as high as 379 L/min (100 gpm), although most records indicate that the flow rate is about 132 L/min (35 gpm). TDS content of the sodium chloride-type water from the springs generally varies from 8,650 to 8,820 mg/L. Concentration of manganese is high, and the chemical and thermal characteristics are similar to those for Hooper Hot Springs about 24 km (15 mi) to the southwest.

Hooper Hot Springs and Southwest Hooper Warm Springs

Hooper Hot Springs are located about 16 km (10 mi) southwest of Ogden near the eastern shore of the Great Salt Lake in SE¼, section 27, T.5N., R.3W. in Davis County (figure 7). Mundorff (1970) states that the springs issue from Quaternary deposits, and that they lie about 0.4 km (0.24 mi) west from an inferred fault. In addition to the main hot springs, several small springs and seeps are in the immediate area. Southwest Hooper Warm Springs are located about 0.6 km (0.4 mi) west of the main spring. Mundorff (1970) noted a spring temperature at Hooper Hot Springs of 60°C (140°F) and TDS content of 9,310 mg/L. Temperature of Southwest Hooper Warm Springs was 32°C (90°F) and TDS content was 27,800 mg/L. The water is of sodium chloride-type in both springs. Although calcium concentrations are about the same for both springs, Mundorff (1970) noted that magnesium and potassium concentrations are much higher at Southwest Hooper Warm Springs. Mundorff suggests that the thermal waters at both springs are of the same origin, but water from Southwest Hooper Warm Springs is a mixture of both thermal and shallow ground water.

Wasatch Front Valleys - Salt Lake Valley (Lower Jordan Valley)

Klauk and Darling (1984), assessed of the low-temperature geothermal potential of the lower Jordan Valley (Salt Lake Valley), gathering information mostly on the principal ground-water aquifer of the valley. These workers investigated more that 200 water wells, obtaining temperatures and water analyses throughout the valley. They also gathered thermal gradient data within 30 "holes of opportunity". In addition to presenting existing information on the two known geothermal occurrences (Warm Springs Fault area and the Crystal Hot Springs area, which manifest themselves at the surface) they outlined four areas of thermal ground water that may be indicative of low-temperature thermal anomalies at depth Areas identified as having potential low-temperature geothermal resources are: (1) the north-central valley area, (2) an area immediately north of the Oquirrh Mountains, (3) an east-west oriented portion of the central valley, and (4) a north-south oriented area extending from Draper to Midvale.

Warm Springs Fault Geothermal System

The Warm Springs fault geothermal system extends about 4.9 km (3 mi) in length and 1.2 km (0.75 mi) in width, lying along the base of the Wasatch Range, just north of Salt Lake City (figure 8). The Warm Springs and Hobo faults associated with these springs are local names for segments of the Wasatch fault zone, which forms the boundary between the Salt Lake Valley and the Wasatch Range (Basin and Range and Middle Rocky Mountains Provinces). Beck's Hot Spring, Wasatch Warm Springs, Hobo Warm Springs, and Clark Warm Springs occur along this segment of the fault as well as two, shallow, warm water wells used by local quarry operators. Murphy and Gwynn (1979c) suggested that the thermal springs occur at intersections of the Wasatch fault and older structures that are perpendicular to the fault zone. Discharge temperatures in this system range from 27°C (81° F) at Clark Warm Springs, to 55°C (131°F) at Beck's Hot Spring (Klauk and Darling, 1984).

Crystal (Bluffdale) Hot Springs Geothermal System

The Crystal (Bluffdale) Hot Springs geothermal area is located at the south end of the Salt Lake Valley, near what is called the "Point of the Mountain" (figure 8). Crystal Hot Springs is located in SE¼, NE¼, section 11, T.4S., R.1W., near Utah State Prison. Bluffdale Flower Growers (formerly Utah Roses) operates a geothermal-heated greenhouse complex there (see section on geothermal uses in Utah). Klauk and Darling (1984) reported that surface spring temperatures vary between 55° and 84°C (131° and 183°F). Subsurface temperatures of 88°C+ (190°F+) have been reported in one of two 122-m- (400-ft-) deep production wells. The springs normally issue from valley alluvium into several ponds. When production wells are in operation, the surface springs and ponds reportedly dry up.

Murphy and Gwynn (1979a) studied the geologic aspects of the Crystal Hot Springs geothermal system. The Utah Energy Office (1981) and Morrison-Knudson Company, Inc. (1982) also analyzed technical and economic aspects of the system as part of DOE-sponsored studies in the early 1980s. Klauk and Darling (1984) presented a description of the system in the context of a study of the entire lower Jordan Valley. Crystal Hot Springs is located between two range-front faults with fractured Paleozoic quartzite (at depth) leaking warm water to the surface through unconsolidated material. Temperatures of 55° to 84°C (131° to 183°F) have been measured at the springs, while a production well drilled to supply geothermal water for the Utah State Prison encountered temperatures from 85° to 90°C (185° to 194°F) (Klauk and Darling, 1984).

Utah Roses Geothermal Project

In the early 1980s, Utah Roses, Inc. received funding through a U.S. Department of Energy geothermal program to complete a geothermal production well. The well would be used for space heating a commercial greenhouse in Sandy (a suburb of Salt Lake City). The project originally was to drill and complete a deep (1,220 m [4,000 ft]) well that would produce at least 50°C (122°F) water at a rate of 2,271 L/min (600 gpm). The well was eventually drilled 1,527 m (5,009 ft), producing water at a temperature of 49°C (120°F) at a flow rate of only 757 L/min (200 gpm). As a result of low flows and low temperature, the project was abandoned. However, Utah Roses (now Bluffdale Flower Growers) eventually built a geothermal greenhouse facility at Crystal Hot Springs in southern Salt Lake County (Klauk and Darling, 1984).

Wasatch Front Valleys - Utah and Goshen Valleys

As part of an overall assessment of the geothermal potential of the Wasatch Front, Davis and Cook (1983) performed a detailed gravity survey of Utah County to delineate the structural framework needed to understand geothermal resources within Utah and Goshen Valleys. Utah Valley and Goshen Valley are grabens displaced downward with respect to the Wasatch Range, the West Mountains, and the Oquirrh-Boulter-Tintic fault block to the west. The greatest depth to bedrock is probably in the southern part of Utah Valley, where Davis and Cook (1983) interpreted the depth to Paleozoic rocks to be about 4,175 m (13,700 ft). The depth to bedrock in the complexly faulted Goshen Valley graben was interpreted to be more than 1,890 m (6,200 ft). Modeling of the gravity data indicated the association of (1) Saratoga Hot Springs, Lincoln Point Warm Springs, Crater Hot Springs, and Warm Springs at Bird Island with the Utah Lake fault zone; (2) Goshen Warm Springs with the Long Ridge fault; and (3) other warm springs with other fault zones. Their gravity studies substantiate the idea that most of the springs in Utah Valley are fault controlled (Klauk and Darling, 1984).

Klauk and Davis (1984) performed a temperature survey and chemical analyses of wells and springs in Utah and Goshen Valleys as part II of the project described in the previous paragraph. As a result of their work, they identified five areas in Utah County warranting further investigation for low-temperature geothermal resources. One area in northern Utah Valley coincides with the Utah Lake fault zone and includes Saratoga Hot Springs. Water temperatures within this area range from 21° to 43°C (70° to 109°F). Two other geothermal areas in southern Utah Valley are also spatially related to the Utah Lake fault zone (including Lincoln Point-Bird Island, and an area north of Payson), and based on water chemistry, appear distinguishable from the other waters in the valley. Temperatures for these two areas range from 21° to 32°C (70° to 90°F) (Klauk and Darling, 1984). The fourth area includes Castilla and Thistle Hot Springs (see section on Wasatch and Uinta Mountains) located in Spanish Fork Canyon where spring temperatures approach 50°C (122°F). The fifth area lies in Goshen Valley and includes a group of water wells and Goshen Warm Springs ranging in temperature from 20 to 27°C (68° to 81°F).

Saratoga Hot Springs

Saratoga Hot Springs issue from unconsolidated Quaternary deposits along the northwest shore of Utah Lake in SE1/4, SW1/4, section 25, T.5S., R.1W. in Utah County (figure 8). Other hot springs, known locally as Crater Springs, issue beneath Utah Lake about 0.8 km (0.5 mi) east of Saratoga Springs. Infrequent measurements since the early 1900s show that spring temperatures have ranged from 38° to 44°C (100° to 111°F). The springs are spatially related to the trend of the Utah Lake fault zone (Mundorff, 1970). Klauk and Davis (1984) report that water from Saratoga Hot Springs is calcium-sodium chloride-sulfate-bicarbonate type, slightly acidic to slightly basic, and slightly saline with TDS ranging from 1,428 to 1,790 mg/L.

Lincoln Point Warm Springs

Lincoln Point Warm Springs are located in section 2, T.8S., R.1E. along the southern shore of Utah Lake at the north end of West Mountain (figure 8), a complex north-south trending, steep-sided horst. Here, Paleozoic limestone and quartzite of the Oquirrh Formation are folded and fractured by numerous faults. The Cretaceous-Tertiary North Horn Formation underlies slope-wash clay and gravel, and overlies Paleozoic rocks. Springs discharge warm, saline water from gravels along the shoreline. Abundant travertine and tufa deposits are associated with the springs (Baskin and others, 1994). Temperatures of the springs range from 25° to 32°C (77° to 89°F). The waters are strongly sodium chloride with TDS content at about 6,000 mg/L (Mundorff, 1970).

Bird Island Warm Springs

Bird Island is a small island in Utah Lake located about 3.2 km (2 mi) north-northeast of Lincoln Point. The island consists of travertine and tufa deposits with wave-worked, rounded travertine and tufa gravel along the island beaches. Warm, saline springs (located at SE¼, NW1/4, SW1/4 section 26, T.7S., R.1E.) discharge at temperatures between 30° and 32°C (86° and 90°F) from the edge of the island and beneath the surface of Utah Lake (Baskin and others, 1994). The spring water is strongly sodium-chloride type with TDS ranging from 6,300 to 7,400 mg/L.

Goshen Warm Springs

Goshen Warm Springs are about 3.2 km (2 mi) east of Goshen and about 4.8 km (3 mi) southwest of Santaquin in Utah County. The springs issue from colluvium directly west of the Long Ridge fault zone in SW¼, section 8, T.10S., R.1E. Klauk and Davis (1984) recorded a surface temperature is 21°C (70°F) and TDS content of 1,298 mg/L, and according to Mundorff (1970) the water is strongly sodium chloride. A number of warm wells are also present in the vicinity. The Utah Division of Wildlife Resources has considered developing a warm-water fish hatchery at Goshen Warm Springs to raise warm-water sport fish and other native aquatic species.

Northwestern Utah

Hydrothermal systems revealed by thermal springs and wells are scattered throughout this large, sparsely populated region of northwestern Utah, which includes all of northern and western Box Elder County. The region generally covers the area northwest of the Great Salt Lake, from the Promontory Mountains to the Raft River Range. Mundorff (1970) included information on thermal springs and general geology in northwestern Utah as part of his report on major thermal springs in the state. Goode (1978) also reported on thermal springs in Grouse Creek and Hansel Valley as part of an overall study of thermal waters in Utah.

Grouse Creek - Raft River

The Grouse Creek - Raft River area lies in the northwest part of Box Elder County and includes the Grouse Creek drainage and the southern flank of the Raft River Mountains. Hood and Price (1970) and Goode (1978) describe a hot spring (Warburton Spring) yielding 852 L/min (225 gpm) of low TDS water (248 mg/L) located in NE¼, NW¼, section 11, T.11N., R.19W. Goode (1978) describes the spring as issuing from Paleozoic rocks in a tributary (?) of Grouse Creek (Death Creek). These authors also describe another thermal spring 20°C (68°F) near Kimber Ranch, in NE¼, SE¼, section 30, T.10N., R.18W., also in the Grouse Creek drainage. Hood (1971) reports on a thermal spring in NE¼, NE¼, section 19, T.12N., R.15W. that flows 26.5°C (80°F), low-TDS water (223 mg/L) at a rate of 1,287 L/min (340 gpm). Several other springs in the area issue at temperatures from 20° to 23°C (68° to 73°F).

Curlew and Hansel Valleys

Davis and Kolesar (1984) studied the hydrology of north-central Box Elder County as it relates to thermal springs and wells in and around Curlew and Hansel Valleys. They recorded the highest water temperatures of 31°C (88°F), 30°C (86°F), and 29°C (84°F) in separate geographic regions. TDS contents range from 294 to 11,590 mg/L, but are generally greater than 1,100 mg/L. The warmer thermal waters are sodium-chloride type.

Both the Hansel and Promontory Mountains are bounded by north-northeast trending normal faults. Hansel Valley is a graben lying between the two ranges. Movement along the range-bounding faults is documented. In 1934, Hansel Valley was the site of the largest earthquake (6.6 magnitude) in Utah's recorded history.

Davis and Kolesar (1984) reported that a normal fault occurs along the east side of Curlew Valley. They also suggested that, based upon gravity data from Cook and others (1964), a system of north to northeast-trending normal faults is present throughout the central part of the valley and the Wildcat Hills. Howes (1972) mapped ring structures in the Wildcat Hills consisting of curved perlite dikes. Howes (1972) also found compound basaltic necks with well-developed columnar joints and volcanic vents that once extruded perlite and rhyolite.

Davis and Kolesar (1984) identified five areas with possible potential for commercial geothermal resources. These include (1) the area they refer to as "area A" in the northern Curlew Valley, (2) the area they refer to as "area B" in Hansel Valley just adjacent to the northwest edge of the Promontory Mountains, (3) an area 8 to 16 km (5 to 10 mi) north of the Wildcat Hills, (4) the western edge of the northern Promontory Mountains east of Snowville, and (5) the western edge of the Hansel Mountains in T.13N., R.8W., and T.12N., R.8W.

Blue Creek Springs

Blue Creek Springs are located in Box Elder County north of the Promontory Mountains in Blue Creek Valley in section 29, T.13N., R.5 W. (Bolke and Price, 1972). Springs emerge from the north end of Anderson Hill at temperatures between 27° and 29°C (81° and 84°F) and flow southward into Blue Creek Reservoir. Cole (1983) reported that the springs issue at a flow rate of about 1,800 L/min (480 gpm), and the fluids contain about 2,000 mg/L TDS. Goode (1978) reported a much higher flow of 21,276 L/min (4,680 gpm) from the springs. The UDWR recently completed feasibility studies for developing a warm-water hatchery to raise sport fish and native threatened and endangered fish at Blue Creek Springs (FishPro Inc., 2000). The Division eventually rejected the site from further consideration.

Great Salt Lake Desert and Western Valleys

Hydrothermal systems indicated by thermal springs and wells are scattered throughout this large, sparsely populated region of Utah, which includes western Tooele County. The region extends westward from the Cedar Mountains in central Tooele County across the Bonneville Salt Flats to the Nevada-Utah 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. Goode (1978) also reported on thermal springs in this region as part of an overall study of thermal waters in Utah.

Blue Lake Spring and Bonneville Salt Flats

Low-temperature thermal waters are present in the western part of the Great Salt Lake Desert, as recorded in wells used for brine production and mineral extraction around the Bonneville Salt Flats, and as thermal springs at Blue Lake and Salt Spring. Turk (1973) presents data on 13 "deep brine wells" drilled to depths ranging from 326 m to 631 m (1,070 to 2,070 ft). The highest temperature recorded was 88°C (190°F), measured in the drilling mud of one well designated as "DBW-3" while circulating at a depth of 499 m (1,637 ft). The brine produced from these deep wells contains 120,000 to 130,000 mg/L TDS.

Blue Lake and Salt Spring, located in western Tooele County near the Utah-Nevada border, are small lakes fed by thermal springs. Although the temperatures of the spring vents (located beneath Blue Lake) are not known, the temperature of Blue Lake is fairly constant at about 29°C (84°F). The area, which includes a small parcel of private land, adjacent to a state wildlife preserve, both enclosed by a military reservation, is valuable for the recreational opportunities offered in the form of year-round diving, and as a wildlife habitat.

Skull Valley - Tooele Valley

Thermal springs occur along the east and west flanks of the Stansbury Mountains in Tooele County, just south of the southern shoreline of the Great Salt Lake. Thermal springs issue from fractured bedrock and alluvium at temperatures ranging from 19° to 22.7°C (66° to 73°F) from the northern edge of the range and along its western side. Big Warm Springs, located on the northern edge of the range in SE¼, SE¼, section 8, T.1S., R.7W., issues at high flow rates of over 11,400 L/min (3,000 gpm) at a temperature of 19°C (66°F). The water is strongly sodium chloride with a TDS concentration of about 7,150 mg/L. Several other springs with similar type waters issue along the western flank of the Stansbury Range at temperatures of about 23°C (73°F). The alignment of springs and other evidence suggests the presence of a buried Quaternary fault (Mundorff, 1970).

At Grantsville Warm Spring, located about 5 km (3 mi) northwest of Grantsville in Tooele County (figure 4), springs issue from lake-bed sediments at a combined discharge rate of about 1,510 L/min (400 gpm) at temperatures from 24° to 32°C (75° to 90°F). Water chemistry of the springs approach the salinity of sea-water with TDS concentration of about 26,500 mg/L. Bonneville SeaBase, a commercial SCUBA diving facility developed at Grantsville Warm Springs, is located about 64 km (40 mi) west of Salt Lake City. SeaBase consists of several dive pools, stocked with tropical marine fish, fed by thermal water from Grantsville Warm Springs.

Fish Springs Flat

Hot springs also issue in and along the margins of Snake Valley, Tule Valley, and Fish Springs Flat of western Utah. Wilson Health Springs, the site of an abandoned resort of the same name at the north end of the Fish Springs Range (figure 4), issues from small mounds at temperatures approaching 60°C (140°F), with flow rates varying up to 380 L/min (100 gpm). Thermal fluids at Wilson are moderately saline with TDS content slightly over 21,000 mg/L (Blackett, 1994). Chemical geothermometers suggest equilibration temperatures of less than 100°C (212°F). The Fish Springs National Wildlife Refuge lies along the northeast flank of the Fish Springs Range. These broad wetlands are fed by a number of springs with temperatures ranging between 20° and 29°C (68° and 84°F). Wilson Health Springs is the northernmost, and hottest, of a series of north-trending, warm springs.

Tule Valley

Several thermal springs issue at temperatures between 24° and 31°C (75° and 88°F) near the basin floor in Tule Valley. The springs lie along a north-northeast trend suggesting that their position is related to a buried fault or fault zone (Stephens, 1977).

Snake Valley and Gandy Warm Springs

Four springs and four wells scattered throughout Snake Valley issue low-temperature water from 20° to 27°C (68° to 81°F). The warmest of these - Gandy Warm Springs (SW¼, SE¼, section 31, T.15S., R.19W., Millard County) - issues from near the base of the southern part of the Deep Creek Range near the Utah-Nevada border (figure 4). The Utah Division of Wildlife Resources recently completed feasibility studies for developing a warm-water hatchery to raise sport fish and native aquatic species. As a result of the study, Gandy Warm Springs ranked highest among five candidate sites for establishing a warm-water hatchery using water-quality, water-quantity, and land-suitability criteria (FishPro Inc., 2000).

Sevier Thermal Area

Mabey and Budding (1987) proposed the name "Sevier thermal area" for a region of southwest Utah where all of the state's known moderate- and high-temperature (>90°C [194°F]) hydrothermal systems occur. The Sevier thermal area (figure 5) covers a portion of the eastern Basin and Range Physiographic Province, and part of the Basin and Range-Colorado Plateau transition zone. The area, which includes all of the Sevier, Black Rock, and Escalante Deserts of southwestern Utah, is characterized by (1) abundant late Cenozoic normal faults, (2) Tertiary plutonic and volcanic rocks and Quaternary basalt, (3) high regional heat flow, and (4) a complex structural history. The Intermountain seismic belt, a north-south oriented zone of active seismicity (Smith and Sbar, 1974), traverses the eastern portion of the Sevier thermal area. The east-west-oriented southern Nevada seismic belt intersects the Intermountain seismic belt near Cedar City.

Sevier and Blackrock Deserts

Ross and others (1993) described the geothermal setting of the Black Rock and Sevier Deserts in Millard and Juab Counties and present the results of self-potential studies at the Meadow-Hatton geothermal area and at the Crater Springs KGRA. The Sevier and Black Rock Deserts are contiguous, complexly faulted structural basins that have characteristics similar to other basins in the Basin and Range province (figure 5). The Sevier Desert detachment, a gently (3 to 4 degrees) westward-dipping detachment surface, separates shallow (< 5 km [3 mi]) extensional structures from deeper, pre-Basin and Range structures (Allmendinger and others, 1983; Anderson and others, 1983; Planke and Smith, 1991). Mountain ranges on the east and west bound low-lying valleys that are underlain by thick sedimentary fill that thins toward the basin margins. Listric and planar faults that die-out upward into the basin fill separate the main part of the Sevier and Black Rock Desert basins into a number of buried, smaller basins.

A series of bimodal volcanic rocks, ranging in age from Pliocene (2.7 Ma) through Holocene (< 1 ka) are aligned roughly north-south through the Sevier and Black Rock Deserts. Pliocene volcanic rocks (2.1 Ma to 2.7 Ma) located in the southern part of the Black Rock Desert consist of basalt, rhyolite, and rhyodacite. Quaternary volcanic units are mainly basalt flows ranging in age from about 1.5 Ma at Beaver Ridge to less that 1,000 years B.P. at Ice Springs. A small rhyolite dome at White Mountain, dated by Nash (1986) at 0.4 Ma, is considered the youngest rhyolite flow in Utah. Younger Quaternary basaltic rocks include the Pavant Ridge basalt (0.22-0.16 Ma) and ash erupted from Pavant Butte (15,000 years B.P.); basaltic flows, tuff, and cinders from the Tabernacle Hill vent (14,300 years B.P, figure 9); and the Ice Springs basalt flow (660 years B.P). The basalt of Tabernacle Hill erupted into Lake Bonneville at or near the Provo shoreline and exhibits features typical of basaltic eruptions into water. Quaternary basaltic units in the central and northern Sevier Desert include the Deseret basalt flows (0.4 Ma) and the basalt flows and scoria at Fumarole Butte and Crater Bench (0.9 Ma) in the Crater Springs KGRA (Oviatt, 1989; Oviatt and others, 1991).

Oviatt (1991) mapped numerous, north-northeast-oriented faults cutting Quaternary units in the Black Rock Desert. The Pavant-Tabernacle-Beaver Ridge fault zone is a broad zone of faults primarily cutting the Beaver Ridge and Tabernacle Hill flows. The Ice Springs basalt, the youngest volcanic unit, is not cut by faults within this zone. Faults in the southern extension of the Clear Lake fault zone and faults near Hatton Hot Springs cut post-Lake Bonneville deposits, and therefore have probably been active throughout the Quaternary. Faults in the Cove Creek dome area cut Tertiary basalt flows and lie along the same structural trend as the Pavant-Tabernacle-Beaver Ridge fault zone.

A doubly-plunging anticline in Tertiary basalt and Quaternary lacustrine deposits to the south of Twin Peaks is known as the Cove Creek dome. Crecraft and others (1981) reported about 400 m (1,300 ft) of uplift of lacustrine limestone near Cove Creek. Oviatt (1991) postulated that the distribution of the lacustrine units indicated that the Cove Creek dome was uplifted approximately 300 to 400 m (1,000 to 1,300 ft), and while most of the uplift probably took place during the late Tertiary, other evidence suggests that uplift continued after late Tertiary and may be as young as Holocene.

Abraham (Baker, Crater) Hot Springs

The Crater Springs geothermal area surrounds a Quaternary eruptive center known as Fumarole Butte in the northern Sevier Desert of Juab County (figure 10). Early Pleistocene basalt flows (0.9 Ma) erupted from the vent area and formed a broad volcanic apron now known as Crater Bench. The Drum Mountains fault zone, a north-northeast trending zone of high-angle normal faults, offsets basalt flows along the west-central side of Crater Bench at Fumarole Butte. Warm vapor rises from several fissures in the vicinity of Fumarole Butte. Abraham Hot Springs, also referred to in literature as "Crater Springs" or "Baker Hot Springs," issues 8 km (5 mi) to the east of Fumarole Butte along the east margin of the Crater Bench basalt flows. Mabey and Budding (1987) postulated that the vapor venting from Fumarole Butte and the thermal waters at Abraham Hot Springs are part of the same geothermal system.

Temperatures at Abraham range up to 87°C (189°F). Rush (1983) estimated total flow rates from about 40 spring orifices at between 5,400 and 8,400 L/min (1,400 and 2,200 gpm). The geologic structure controlling the system is unknown, and the reservoir temperature is uncertain. Samples of cold springs issuing from the same site were collected for analyses as part of this study in order to develop more accurate mixing models. Analyses of the cold water, however, revealed that this water is very similar in composition to that of the hot springs, and suggests that the cold springs are merely cooled hot water. According to the classification of Back (1961), the thermal water is sodium calcium-chloride type. Geothermometers suggest equilibration temperatures in the range 87° to 116°C (189° to 241°F).

Meadow and Hatton Hot Springs

The Meadow-Hatton area (figure 11) is located less than 2 km (1.3 mi) west of Interstate Highway 15 in Millard County. Fillmore, the county seat with a population of 2,000 people (1990 census), is located about 10 km (7 mi) to the northeast. The small community of Meadow (population 250, 1990 census) is situated on Interstate Highway 15, less than 2 km (1.3 mi) from the thermal area. The Pavant Valley and the Black Rock Desert comprise mostly irrigated croplands. Land ownership in the Pavant Valley and Black Rock Desert is a combination of private, state, and federal parcels.

The Meadow-Hatton geothermal area (figure 11) consists of a large travertine mound, marshland, and thermal springs located about 16 km (10 mi) southwest of the town of Fillmore on the east side of the Black Rock Desert in Millard County. The Black Rock Desert contains some of the state's youngest volcanic rocks -- some being only a few hundred years old. Hatton Hot Spring issues from the south end of a large, northeast-trending travertine mound at a temperature of 63°C (145°F). Meadow Hot Springs, comprising several thermal springs in a northeast alignment and located in a marshy area about 2 km (1.3 mi) northwest of the Hatton travertine mound, issue at temperatures up to 41°C (106°F). Flow rates from the springs are low and reportedly vary from 0 to 240 L/min (63 gpm). The spring waters are probably coupled to the regional ground-water flow system of the Pavant Valley and Black Rock Desert.

Ross and others (1993) described two fluid samples from the Meadow Hot Springs area (MI-080 and MI-082) in conjunction with the results of self-potential surveys completed in the area. Self-potential surveys revealed a high-amplitude, negative anomaly beneath the southern part of the travertine mound. More recent chemical data show very different values for potassium, silica, and fluoride concentrations compared to earlier data, suggesting temporal variations in spring chemistry. Standard geothermometers range between 205°C (401°F) (Na-K-Ca) and 86°C (187°F) (Na-K-Ca-Mg), with most likely equilibration temperatures around 108°C (226°F) (quartz conductive). Based on the results of the new chemical analyses, the fluids appear to be highly evolved with a very complex thermal history (Ross and others, 1993).

Neels Area

An area near the Neels railroad siding northeast of the Cricket Mountains is a geothermal enigma. Lee (1908) described events during drilling of a 609 m (2,000 ft) water-supply well in 1906 near Neels by the San Pedro, Los Angeles, and Salt Lake Railroad. During drilling, hot water was encountered at several horizons, and steam apparently vented continually from the well-bore. Reportedly, some oil was encountered, and a pocket of gas was penetrated at a depth of 549 m (1,802 ft). The well was eventually abandoned because of drilling difficulties and poor water quality.

An intriguing bit of information was a water analysis on a sample taken from a depth of 426 m (1,398 ft) (Lee, 1908). The sample had a TDS content of 3,345 parts per million and reported "siliceous matter" (presumably SiO_2) content of 370 parts per million. Silica geothermometers applied to the latter value yield an equilibrium temperature of over 200°C (392°F), suggesting the possibility of a high-temperature reservoir somewhere in the subsurface. Two other water samples taken at horizons both above and below the 426-m (1,400-ft) depth yielded more normal values for silica.

Cominco American, Inc. completed a deep test well (2 Beaver River) to a depth of 4,021 m (13,193 ft) near the Neels siding in 1980. The well reportedly penetrated an unconformity at 610 m (2,000 ft) and Precambrian rocks at 756 m (2,480 ft). The well also penetrated a thrust fault at 2,557 m (8,390 ft), continued in lower Paleozoic rocks to total depth, and probably bottomed in Cambrian Tintic Quartzite (Utah Division of Oil, Gas and Mining well files). Geophysical logs indicate that a bottom hole temperature of 153°C (308°F) was measured five hours after circulation of the drilling mud was stopped. This well was later plugged back to 180 m (600 ft) and converted to a water well.

Cove Fort-Sulphurdale

The Cove Fort-Sulphurdale geothermal area lies on the northwest side of the Tushar Mountains, and is roughly 32 km (20 mi) north along Interstate Highway 15 from the town of Beaver (figure 12). The Tushar Mountains consist primarily of mid-Tertiary quartz latite and alkali rhyolite ash-flow tuffs of the Marysvale volcanic field. To the north, the Pavant Range consists of thrusted pre-Tertiary sedimentary rocks and tilted Tertiary sediments. Tertiary volcanics of the Marysvale field overlap the pre-Tertiary sedimentary rocks on the south end of the Pavant Range. A large basaltic andesite flow of Pleistocene age lies a few kilometers to the west of the geothermal area (Hintze, 1980; Mabey and Budding, 1987).

Ross and Moore (1985) described the results of previous geological investigations, presented the findings of detailed geophysical studies, and proposed a conceptual model for the geothermal system at Cove Fort. They characterized the system as resulting from a combination of complex geologic structures that localize the geothermal source. The oldest structures are Sevier-age thrust faults, mapped to the north in the Pavant Range and penetrated by deep drilling at Cove Fort. Moore and others (1979) reported that one deep drill hole (Utah State 31-33, MI-097 on figure 12) at Cove Fort intersected Paleozoic dolomite thrust above Triassic siltstone and limestone.

Basin and Range tectonism produced numerous north-northeast-striking high-angle normal faults, in addition to large penecontemporaneous gravitational slide blocks. The gravity-slide blocks are low-permeability layers that cap portions of the geothermal system. At the surface, the trends of faults are delineated by local alignments of sulfur deposits, acid-altered alluvium, and gas seeps. The surface manifestations occur throughout an area of about 47 square kilometers (18 mi^2) and probably reflect boiling and degassing of chloride-rich brine from a thermal water table 400 m (1,300 ft) below the surface. Dry steam at about 150°C (300°F) is produced from relatively shallow production wells (180-

400 m [600-1,300 ft] deep) completed into fractured reservoir rocks near Sulphurdale.

Mother Earth Industries, Inc. installed the first power-generation facility at Cove Fort in 1985. It originally consisted of four binary-cycle power units with a total capacity of 3 MW (gross). The power system was later supplemented by a turbine generator (2 MW gross), placed upstream from the binary units in order to take better advantage of the temperature and pressure conditions of the producing reservoir. In the fall of 1990, the City of Provo in cooperation with the Utah Municipal Power Authority (UMPA), dedicated the Bud L. Bonnett geothermal power plant at Cove Fort. The Bonnett plant is referred to here as the UMPA Cove Fort Station No. 1 plant. The plant, rated at 8.5 MW (gross), became the third geothermal power facility owned by UMPA and Provo to go on-line at the Sulphurdale field. Because H_2S is produced as a non-condensable component of the dry steam, the facility includes a sulfur abatement plant designed to produce 1.36 metric tons (1.5 tons) per day of sulfur (Geothermal Resources Council, 1990).

A total of six production wells (three 18-cm- [7-in] diameter wells and three 33-cm [13-in] diameter wells) supply steam to the three power units. Although specific information is not available, steam supply wells reportedly produce from the shallow, vapor-dominated part of the geothermal system, at depths between 335 and 366 m (1,100 and 1,200 ft). Reductions of reservoir pressures necessitated that the developers drill and complete new production wells into the deeper, liquid-dominated portion of the system. The estimated net output from all three power units is about 10 MW (Richard Judd, UMPA; and Jay Hauth, consultant, personal communication, 1991).

Escalante Desert

The Escalante Desert (figure 5) is a northeast-southwest elongate basin measuring approximately 120 by 45 km (75 by 28 mi) that includes much of the Sevier thermal area as defined by Mabey and Budding (1987). Mountains and hills composed primarily of Tertiary ash-flow tuff and younger volcanic flows and domes surround it. Ash-flow tuff units range in age from 32 to 19 Ma. Rhyolite and dacite flows and domes range in age from 13 to 8.5 Ma (Rowley and others, 1979). Upper Tertiary and Quaternary unconsolidated and semi-consolidated material, likely more than 1.6 km (1 mi) thick, fill the deeper parts of the valley (Blackett and others, 1990).

The Escalante valley lies between two major, roughly east-west-oriented igneous belts, also known as mineral belts. The Pioche-Marysvale igneous belt (Oligocene) lies to the north, and the Delamar-Iron Springs igneous belt (Miocene) lies to the south. Rowley and others (1979) suggest that the Pioche-Marysvale and the Delamar-Iron Springs igneous belts are structurally controlled, and are associated with two east-west-oriented lineaments that coincide with the igneous belts -- the Blue Ribbon lineament to the north and the Timpahute lineament to the south (figure 5).

Gravity studies by Pe and Cook (1980) suggest the presence of many Basin and Range block-faulted structures buried beneath the Escalante Desert. However, the Antelope Range fault located on the southeast side of the valley is the only large-scale, mapped fault showing displacement during the Quaternary (Anderson and Christenson, 1989).

The principal water-bearing unit of the Escalante Valley consists of unconsolidated and semi-consolidated materials of Quaternary age. Another ground-water source consists of water in Tertiary volcanic rocks along the low-lying margins of the Escalante Valley (Mower, 1982). Ground-water use for irrigation from the principal water-bearing unit of the Escalante Valley has modified the natural subsurface drainage patterns. Subsurface water in the southwest part of the valley discharges to a large water-table depression near the community of Beryl Junction. Subsurface water within the northeast portion of the valley discharges to the northeast, the natural drainage direction, toward the Milford area. Recharge to the ground-water system is from subsurface inflow from bedrock as well as inflow from stream channels. Recharge is also from irrigation and direct precipitation (Klauk and Gourley, 1983).

Roosevelt Hot Spring Geothermal Area

The Roosevelt Hot Springs KGRA, situated on the west side of the Mineral Mountains along the northern edge of the Escalante Desert (figure 13), is the most studied geothermal area in Utah. Geothermal resources at Roosevelt Hot Springs have been of commercial interest since the early 1970s, and have been actively developed for power generation since the late 1970s. Ward and others (1978) and Ross and others (1982) presented geological, geophysical, and geochemical data for the Roosevelt Hot Springs geothermal area. Mabey and Budding (1987) summarized the findings of the previous workers at Roosevelt.

The geologic setting of the Mineral Mountains is unusual with respect to other ranges in the region. The range consists mostly of a Tertiary pluton with six major phases of quartz monzonitic to leucocratic granitic rocks, two diorite stocks, and several types of mafic dikes, thought to be the intrusive equivalents of the Mount Belknap volcanics (21 to 16 Ma) in the Tushar Mountains. Price and Bartley (1990) described a major, low-angle, gently arched, normal fault along the west flank of the Mineral Range. This structural detachment zone places hanging-wall Paleozoic and Mesozoic sedimentary rocks and Tertiary volcanic rocks against footwall Tertiary intrusive rocks. They suggested a structural history involving east-west extension that produced the low-angle detachment zone and high-angle east-west-oriented faults. Continued east-west extension eventually produced north-south-oriented, high-angle normal faults which cross-cut the older detachment and high-angle east-west structures. Quaternary rhyolitic volcanism (0.8 to 0.5 Ma) occurred in the central part of the range (Lipman and others, 1978) and basaltic flows later (70,000 to 10,000 years ago) occurred to the north (Sibbett and Nielson, 1980).

Heat-flow studies by Wilson and Chapman (1980) identified an area of anomalous heat flow extending about 5 km (3 mi) wide and 20 km (12 mi) long over the Roosevelt Hot Springs geothermal area. Heat-flow values in excess of 1,000 mW/m^2 enclose an area roughly 2 km (1.2 mi) wide by 8 km (5 mi) long that is thought to coincide with the near-surface part of the geothermal system. Using gravity data, Becker and Blackwell (1993) infer a deep, cylindrically shaped, anomalous mass approximately 10-15 km (6-9 mi) in diameter situated about 5 km (3 mi) beneath the geothermal field to be a young intrusion.

Production from the Roosevelt geothermal area is primarily from highly fractured Tertiary granite and Tertiary (?) metamorphic rocks. The fracturing within the geothermal reservoir appears to be associated with the intersection of a system of north-south trending Basin and Range normal faults with somewhat older east-west oriented structures (Mabey and Budding, 1987).

Utah Power (a Pacificorp company) operates the single-flash, Blundell geothermal power station at the Roosevelt Hot Springs geothermal area (figure 13 and figure14). Intermountain Geothermal Company, a subsidiary of California Energy Company and the current field developer, produces geothermal brine for the Blundell plant from four wells that tap a production zone in fractured, crystalline rock. The production zone depths range generally between 640 and 1,830 m (2,100 and 6,000 ft). This zone is reportedly tilted to the west, probably reflecting westward down-stepping of crystalline reservoir rocks by Basin and Range faulting. Reservoir temperatures are typically between 270° and 315°C (520° and 600°F) (Blackett and Ross, 1992).

Wellhead separators, which are used to "flash" the geofluid and partition it into liquid and vapor phases, are installed on each of the production wells. The liquid phase, or geothermal brine, is channeled back into the reservoir through three gravity-fed injection wells. The vapor phase, or steam-fraction, is collected from the four wells and directed into the power plant. After exiting the power plant, the spent steam flows through a condensing unit, and the resulting condensate is also discharged to the injection wells (Monte Nolan, Utah Power, personal communication, 1991).

The temperature of the steam upon entering the Blundell plant ranges between 177° and 204°C (350 and 400°F), with steam pressures approaching 7.7 kg/cm^2 (109 psi). The plant produces 26 MW gross output (23 MW net) with all four wells operating. Roughly two percent of the vapor phase is non-condensable gas, which is vented to the atmosphere (Kit Wareham, Utah Power, personal communication, 1991).

Thermo Hot Springs Area

The Thermo Hot Springs geothermal area is located within the northeast part of the Escalante Desert in southern Beaver County (figure 15). Thermal water discharges from two large spring mounds, consisting primarily of cemented windblown quartz sand and silt, situated near the axial drainage of the Escalante Desert valley. The Shauntie Hills, located to the northwest, and the Black Mountains, located to the southeast, consist largely of volcanic mudflow deposits, mudflow breccias, and lava flows of dacitic and rhyodacitic composition. Rocks in the Black Mountains and the Shauntie Hills probably erupted from separate, although possibly time-equivalent (Miocene, 29 to 19 Ma) strato-volcanos. Rowley (1978) mapped an exposure of rhyolite 3.2 km (2 mi) to the east of the hot spring mounds, for which he obtained a date of 10.3 Ma.

Northeast-oriented normal faults that displace Quaternary valley-fill units and form a broad zone of faulting, are mapped along the hot spring mounds and elsewhere in the vicinity. Faults mapped within the volcanic units of the low hills southeast of the thermal area, and within the Black Mountains, exhibit a dominant northwest orientation. The orientation of these two sets of structures and the position of the hot springs led Rowley and Lipman (1975) to suggest that a structural intersection localized the geothermal system. Based upon the regional gravity data of Sawyer and Cook (1977) and Cook and others (1981), Mabey and Budding (1987) postulated that a subsurface fault with several hundred feet of displacement (down to the west) passes through the hot springs area.

Mariner and others (1978) reported a temperature of 89.5°C (193.1°F), and discharge rates between 30 and 120 L/min (8 and 32 gpm) at Thermo Hot Springs. Blackett and Ross (1992) reported a much reduced flow. Klauk and Gourley (1983) reported spring temperatures ranging from 42 to 78°C (108 to 172°F), and the results of water analyses on four spring samples. Klauk and Gourley (1983) indicated that the Thermo water is sodium-calcium chloride-sulfate-bicarbonate in character and enriched in Na, K, and SO_4. They also reported quartz-conductive geothermometer temperatures, ranging from 128 to 131°C (262 to 268°F).

Republic Geothermal, Inc. contributed temperature-gradient, geophysical, and geochemical data in support of geothermal studies in the area. The data package includes primarily information from temperature-gradient boreholes and water analyses, as well as production test and temperature data from a deep (2,221 m [7,288 ft]) exploratory drill hole. The distribution of anomalous temperature gradients indicates warmer shallow temperatures in the vicinity of the hot springs. Although most of the thermal gradient holes are shallow and relatively widely spaced, the temperature data indicate that anomalous temperatures may extend eastward several thousand feet from the spring mounds.

Ross and others (1991a) performed self-potential (SP) surveys near Thermo Hot Springs to determine the SP expression of the geothermal system. The SP surveys, covered an area of approximately 10.4 square kilometers (4.0 mi^2) and showed no outstanding anomalies across the two spring mounds. A broad, complex SP low, however, occurs in the southeast part of the area near the Minersville road, approximately 1.6 km (1 mi) southeast of the southern mound. The anomaly occurs over alluvium, perhaps 15 m (50 ft) above the level of the valley floor. No drill hole or geophysical data are available in the immediate area to give any insight into the probable source of the SP anomaly. The anomaly occurs on the up-thrown side of a mapped, northeast-oriented fault, and its shape somewhat mimics the topography of an overlying alluvial fan, suggesting some contribution from fluids within or beneath this fan. Northwest-oriented drainage patterns and similarly oriented faults mapped in bedrock to the south and southeast suggest the source could occur at a buried fault intersection.

Newcastle Geothermal Area

The Newcastle area (figure 16) is located near the south end of the Escalante Valley in Iron County. The area is underlain by an aquifer containing low- and moderate-temperature geothermal fluid, and construction of new commercial greenhouse facilities is increasing use of the geothermal aquifer. The UGS and the University of Utah (U of U) analyzed 27 thermal-gradient drill holes, and performed geophysical surveys, and geologic mapping and wrote an assessment of the resource (Blackett and Shubat, 1992). UGS and U of U continue to monitor the Newcastle Geothermal System (Blackett and others, 1997).

The unincorporated town of Newcastle -- located near State Highway 56 connecting Cedar City, 48 km (30 mi) to the east, to a number of small communities in the Escalante Valley to the west --

lies just north of the center of the geothermal system. Geothermal water is used to heat an LDS chapel in the town. Cedar City is situated along Interstate Highway 15, and is served by a Union Pacific rail-line and a scheduled-service airport. The Escalante Valley is an agricultural region that produces potatoes, alfalfa, corn, and livestock.

A maximum temperature of 130°C (266°F) was measured in a geothermal exploration well, which penetrated the geothermal aquifer (outflow plume). Production wells at the greenhouses generally produce fluids in the range of 75°C to 95°C (167°F to 203°F). Geothermometers suggest maximum resource temperatures of up to 166°C (331°F), with more common temperatures of 140° to 150°C (284° to 302°F).

Geothermal production wells tap an unconfined, alluvial aquifer, which contains hot water and covers an area of several square miles. Thermal water originates from a buried point-source near a range-front fault, and spills into the aquifer. The fluids cool by conduction and probably mix with shallow groundwater at the system margins.

Beryl Area

The Beryl area is located within the southern Escalante Valley of Iron County, south of the Wah Wah and Indian Peak ranges, near the rail sidings of Beryl and Zane. Goode (1978) reported a temperature of 149°C (300°F) from a depth of 2,134 m (7,000 ft) measured within a 3,748 m- (12,295 ft-) deep well that he termed "De Armand #1." Goode also reported that, upon testing, the well flowed at a rate of 3,785 L/min (1,000 gpm) and that the water contained less than 4,000 mg/L TDS. No flowing temperature was given. According to records obtained from the Utah Division of Water Rights, three companies B "McCulloch Oil Corporation (MCR Geothermal Corp.), Geothermal Kinetics, Inc., and Utah Power & Light Company" B formed a partnership to drill and complete a well referred to as "MCO-GKI-UPL-DeArman #1." The well was located in the SW¼, SE¼, SW¼, section 18, T.34S., R.16W. and drilled during the spring of 1976. Documents filed with the Division of Water Rights during December of 1981 and correspondence dated November 12, 1985, suggest that the well was drilled to a depth of at least 2,361 m (7,745 ft) and that it did not comply with state-regulated abandonment procedures at that time.

Klauk and Gourley (1983) made no mention of the above-referenced ("DeArman") well, but reported a temperature of 60°C (140°F) measured at a depth of 2,461 m (8,072 ft) within an unnamed geothermal test well located in the NE¼, NE¼, NW¼, section 22, T.34S., R.16W. This location corresponds to a well reportedly drilled in 1976 by MCR Geothermal Corp., and referred to as "State #1" (letter from Utah Division of Water Rights to Insurance Company of North America, dated November 12, 1985).

Wood's Ranch is located just south of the Wah Wah Mountains in the northwest part of the Escalante Valley in Iron County (figure 4). One of two wells, a 61-m (200-ft) deep water well drilled for irrigation on the ranch produces 36.5°C (97.7°F) water. No hot springs are present. A self-potential survey performed by workers from the University of Utah and the UGS (Ross and others, 1991b) revealed a broad, negative SP anomaly interpreted as thermal up-flow. Beyond the SP survey and one water analyses, no exploration has been carried out on the property. Chemical geo-thermometers suggest reservoir temperatures in the range of 100° to 115°C (212° to 239°F). The warm water produced from the well may be a mixture of thermal water and non-thermal ground-water from the Escalante Valley aquifer. The area is somewhat remote with no incorporated communities nearby. The Union Pacific rail line crosses the Escalante Valley within 1.6 km (1 mi) of Wood's Ranch. Access roads into the area are both improved county and BLM roads, and jeep trails. Land ownership in the vicinity of the thermal wells is private. Surrounding lands are federal and state owned.

Sanpete and Sevier Valleys

The Sanpete and Sevier Valleys form a long, narrow, northeast-southwest depression in central Utah (figure 17). Although appearing geologically simple, surficial deposits mask a structurally complex area of subsidence caused by faulting, folding, and dissolution of salt from Jurassic formations. Warm springs and wells occur throughout both valleys, although, the hotter springs are located at the southern margin of the Sevier Valley.

Three hot spring areas extend over a distance of about 10 km (6 mi) at the southern end of the Sevier Valley. The springs B Monroe, Red Hill, and Joseph B were originally included in the Monroe-Joseph KGRA. Brook and others (1979) considered Monroe and Red Hill Hot Springs as one system, and considered Joseph Hot Springs a separate, but similar, system. The springs are associated with Quaternary normal faults which offset widespread mid-Tertiary, intermediate volcanic rocks erupted from the Monroe Peak and Mount Belknap calderas, and other sources farther westward (Mabey and Budding, 1994).

Monroe-Joseph Geothermal Area

Monroe Hot Springs and Red Hill Hot Springs are situated less than a 0.8 km (0.5 mi) east of the town of Monroe, a community of about 1,470 people (1990 census) located about 5 km (3 mi) east of Interstate Highway 70 in Sevier County (figure 17). Monroe was the site of a number of geoscience and exploratory drilling studies sponsored by the U.S. Department of Energy in the late 1970's and early 1980's to assess resource potential (Mabey and Budding, 1987). Although feasibility studies based upon fluid temperatures and flow-rates from a DOE-sponsored production well showed that a district-heating system was not economical, the area could be attractive for process or agricultural direct-heat applications.

The Monroe and Red Hill Hot Springs issue at about 77°C (170°F) near the surface trace of the Sevier fault, adjacent to the Sevier Plateau. The Sevier fault is a 482-km (300-mi) long zone of rupture extending from the Grand Canyon northward into central Utah. Chemical geothermometers suggest maximum resource temperatures of about 110°C (230°F). Maximum measured temperature is 77°C (171°F) at Red Hill Hot Springs and 76°C (169°F) at Monroe Hot Springs. Combined flows for the Monroe-Red Hill system have been estimated at about 1,200 L/min (320 gpm).

Joseph Hot Spring discharges from a spring mound near the Dry Wash fault, which parallels the Sevier River along the northwest edge of a group of hills that are part of the Antelope Range. The springs issue at 63°C (145°F) with flow rates approaching 121 L/min (32 gpm).

At Monroe Hot Springs, Mystic Hot Springs Resort uses geothermal water to heat a swimming pool, several therapeutic baths, and for tropical fish ponds. Richfield (population - 5,590 - 1990 census), the county seat of Sevier County is located a few miles to the north along Interstate Highway 70. The Sevier-Sanpete Valley is an agricultural region extending for about 129 km (80 mi) northeastward from the Monroe area. Land ownership in the Sevier Valley is mostly private.

St. George Basin Geothermal Area

The St. George basin geothermal area covers roughly 650 square kilometers (250 mi^2) in extreme southwestern Utah and includes the Santa Clara and Virgin River Valleys in Washington County (figure 18). The area coincides with the St. George basin subprovince of Stokes (1977). The Pine Valley Mountains to the north, the Beaver Dam Mountains to the west, the Hurricane Cliffs to the east, and the Utah-Arizona state line to the south border the basin. The basin lies along the western margin of the Colorado Plateau, just east and south of the Basin and Range - Colorado Plateau

Transition Zone.

Sedimentary strata folded along northeast axes characterize the St. George basin, although many consider the basin as part of the Colorado Plateau. Strata in the region generally dip gently northeastward, and the basin is bordered structurally on the east by the Hurricane fault, and on the west by the Grand Wash-Gunlock fault (Petersen, 1983).

The basin is underlain by a thick sequence of Paleozoic and Mesozoic strata, sandwiched between Precambrian metamorphic rocks, exposed in the Beaver Dam Range, and a series of Tertiary intrusive and volcanic rocks exposed in the Pine Valley and Bull Valley Mountains, respectively. Hamblin (1970) described four stages of Late Cenozoic basalt flows and cinder cones in the St. George basin that form many elongate eroded ridges.

Two major structural trends include northeasterly aligned folds and faults of Laramide age, and post-Laramide north-south oriented extensional faults. The Virgin anticline, a major Laramide feature, extends northeasterly across the center of the basin for about 27 km (17 mi). The Hurricane fault, a post-Laramide feature, is an active normal fault that extends for over 300 mi (482 km) from Cedar City through northwestern Arizona. The Grand Wash-Gunlock fault, which was active during Pleistocene time, can be traced from Gunlock, Utah southward for about 160 km (100 mi) into Arizona. The Washington fault, an active normal fault extending southward from the foothills of the Pine Valley Mountains across the Virgin anticline and into Arizona, nearly bisects the St. George basin (Sommer and Budding, 1994).

Thermal Springs at Pah Tempe Resort

Pah Tempe Hot Springs, also known as La Verkin or Dixie Hot Springs, are located along the Virgin River where the river cuts through Timpoweap Canyon along the Hurricane Cliffs.
The north-trending Hurricane fault lies a short distance west of the springs. The springs issue from multiple vents in fractured Permian Toroweap Limestone. Widespread basalt flows ranging in age from 2 million years B.P. to 1,000 years B.P. lie in the vicinity of the springs, possibly relating to local heat sources for the thermal water.

In the mid-1980s, construction of a water pipeline for the Quail Creek (off-line storage) reservoir reportedly disrupted the discharge of existing hot springs and new springs emerged at lower bank-levels along the Virgin River (Ben Everitt, Utah Division of Water Resources, verbal communication, 1993). Flows to the original springs were partly restored after installation of a clay and cement seal in the construction area. In September 1992, a 5.8 magnitude earthquake evidently contributed to another disruption of spring flows as discharge decreased and again new springs emerged at lower bank- levels along the Virgin River (Ken Anderson, Pah Tempe Resort, verbal communication, 1993). Available analyses for the springs, done prior to the earthquake, are variable and possibly reflect differences in sample collection points. Blackett (1994) obtained a post-earthquake spring sample collected from one of the new spring orifices where the Quail Creek pipeline crosses the Virgin River. The post-earthquake sample results were similar to the previous analyses. The water is a sodium calcium-chloride, sulfate, and bicarbonate type. Geothermometers suggest equilibration temperatures between 75°C and 80°C (167°F and 176°F).

Flow rate, chemistry, and temperature have varied through time. Mundorff (1970), and Sommer and Budding (1994) reported that temperatures recorded at the springs have varied over the last 100 years from 38° to 56°C (100° to 133°F). It is not clear whether the spring temperatures have declined over the past century or if the earlier temperatures recorded were inaccurate. Recent measurements have shown the springs to issue at temperatures near 42°C (108°F). Flow rates measured by several workers suggest that the combined flows for all of the vents range between 17,000 and 19,000 L/min (4,500 and 5,000 gpm). Pah Tempe Springs are relatively high TDS content, ranging between 8,390 and 9,340 mg/L.

Veyo Hot Spring

Veyo Hot Spring is located southeast of the town of Veyo along the Santa Clara River. Here the river has incised 1 and 2 million-year-old basalt flows to form a steep-walled canyon. Mundorff (1970) reported that spring temperatures ranged from 32° to 37°C (90° to 97°F), TDS values ranged from 389 to 402 mg/L, and the flow rate was constant at 456 L/min (120 gpm). Budding and Sommer (1986) reported a temperature measurement of 29.5°C (85°F).

Other St. George Basin Thermal Springs

A warm spring, locally referred to as Washington Hot Pot, located north of Washington City fills a circular depression about 9 m (30 ft) in diameter with a maximum depth of 1.5 m (4.9 ft). The spring is in the Navajo Sandstone and is a little over 1 km (0.6 mi) west of the Washington fault. A temperature of 24.5°C (76°F) was measured in February 1986 and a water sample contained a calculated dissolved solids content of 311 mg/L. Budding and Sommer (1986) recorded a temperature of 23°C (73°F) at Green Spring, located 1.2 km (0.7 mi) west of Washington Hot Pot. Budding and Sommer (1986) also measured a temperature of 20°C (68°F) at West St. George Spring, located near the northwest edge of the city, and an unnamed spring just northwest of Interstate Highway15 between Washington and Middleton. Washington City Spring, about 1 km (0.6 mi) east of the hot pot, issues at 19.5°C (67°F).

Thermal Wells in the St. George Basin

Sommer and Budding (1994) reported the results of temperature measurements and water chemistry for 17 water wells in the St. George Basin. Temperatures in the wells ranged from 19.5 to 40°C (67° to 104°F) with the warmer wells located north of St. George and Washington City. Dissolved solids content in these wells ranged from 120 to 1,360 mg/L and the warmer wells contained higher TDS values.

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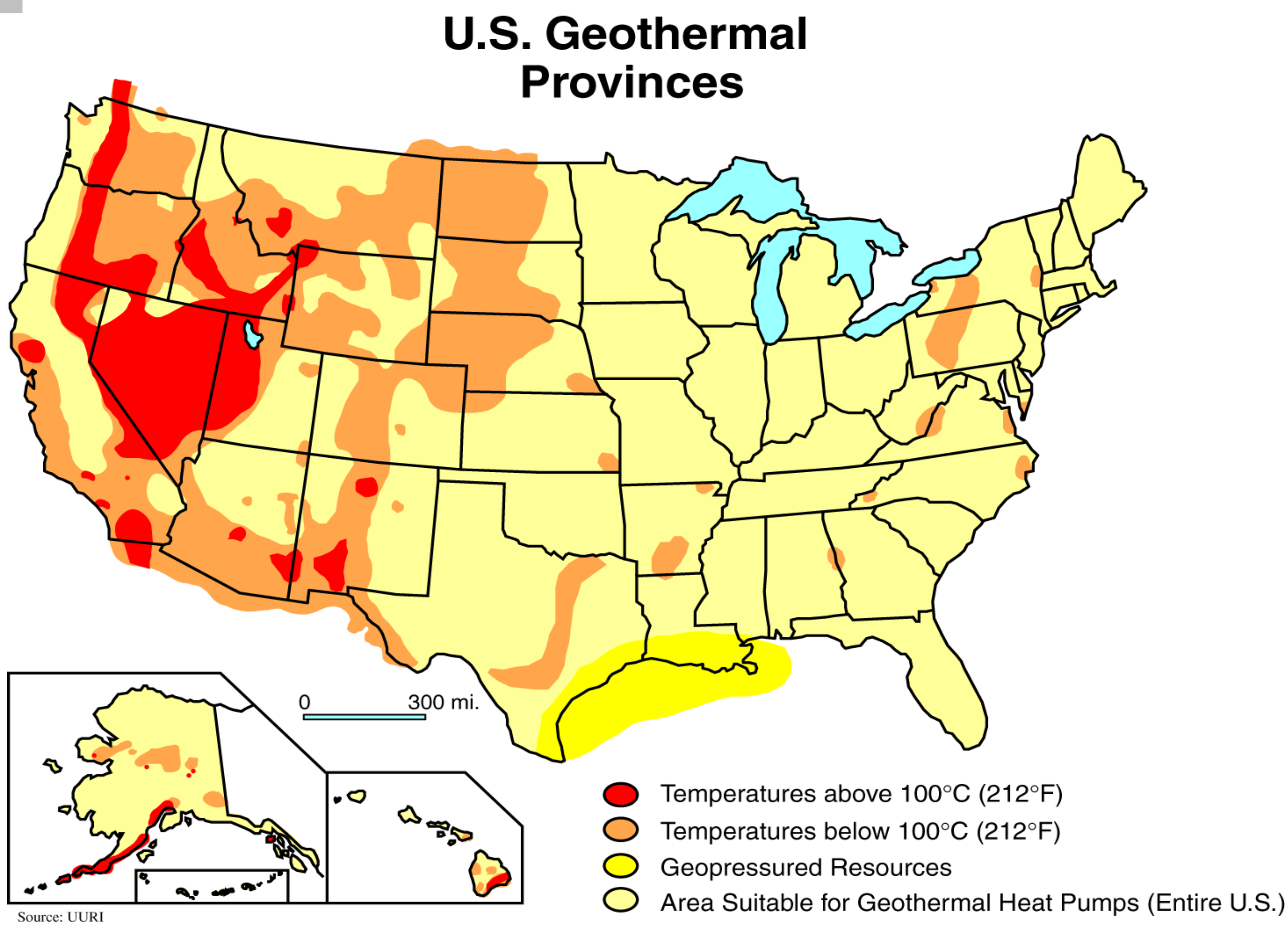

Figure 1. Geothermal resource map of the United States showing general areas of occurrence and resource type (from Energy and Geoscience Institute, University of Utah).

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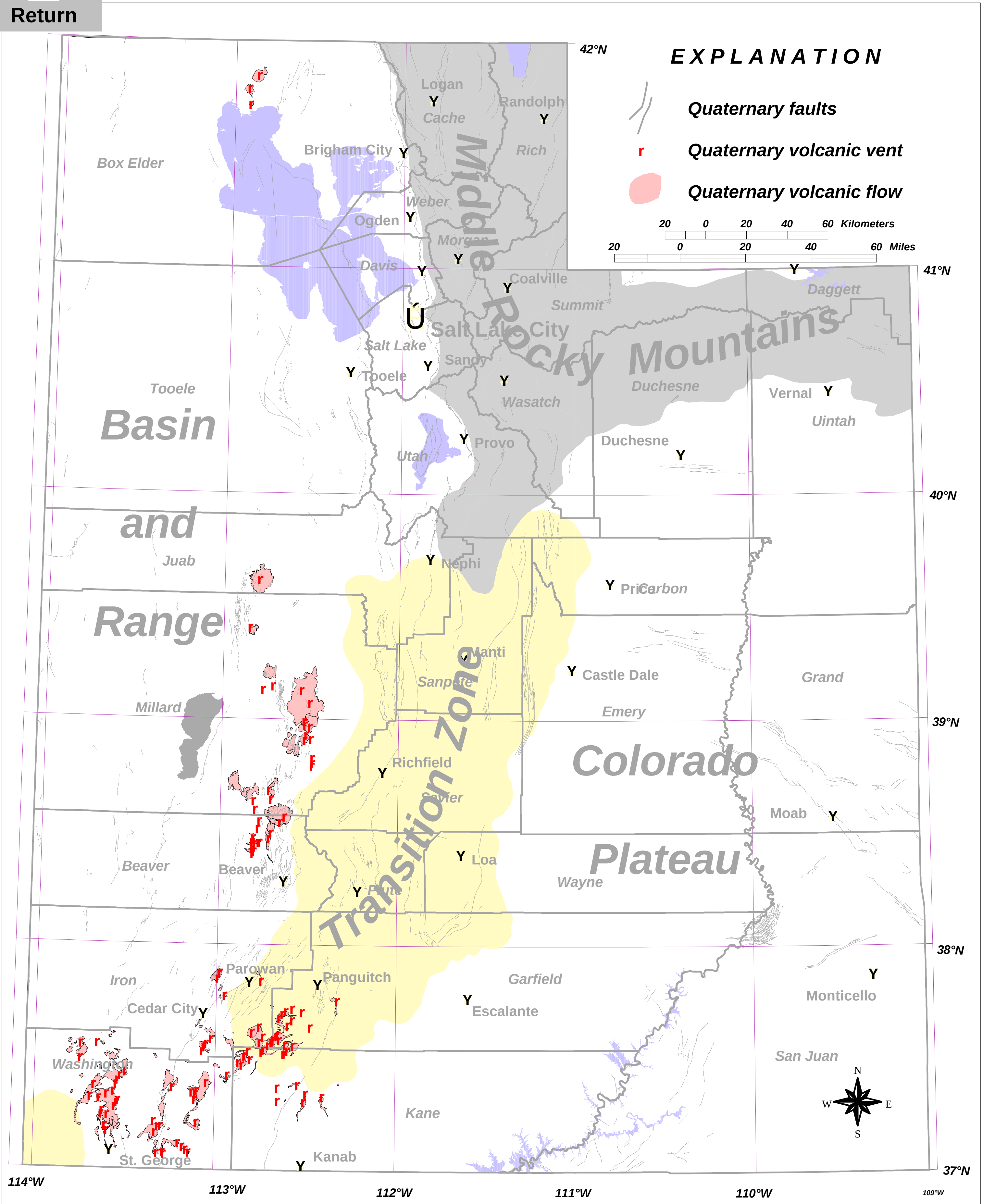

Figure 2. Physiographic provinces, Quaternary faults, Quaternary volcanic rocks, and Quaternary volcanic vents in Utah (after Stokes, 1977; Hecker, 1993; and Black and others, 2000).

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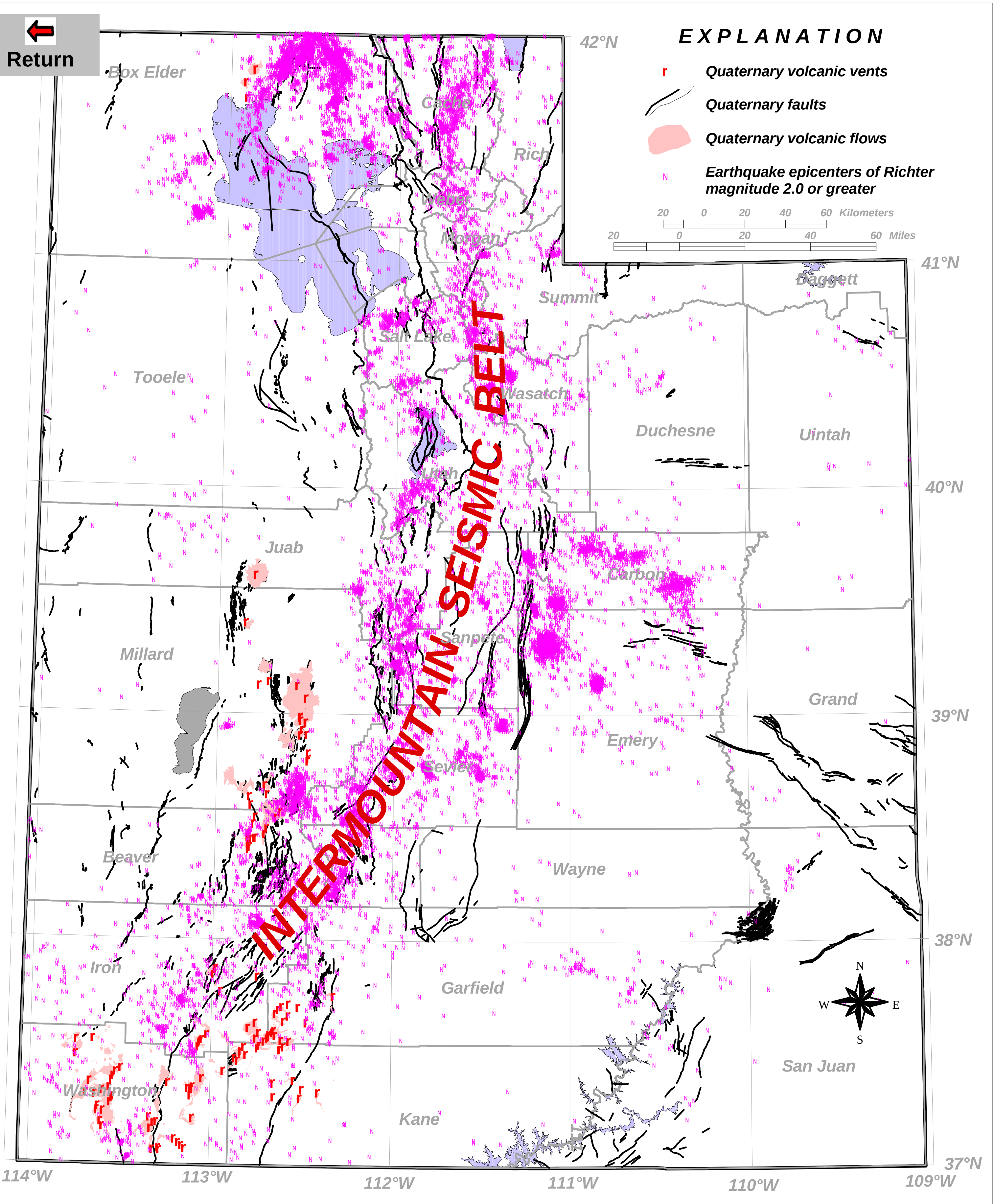

Figure 3. Earthquake epicenters and Quaternary tectonic features in relation to the Intermountain seismic belt (after Smith and Sbar, 1974; Hecker, 1993; and Black and others, 2000).

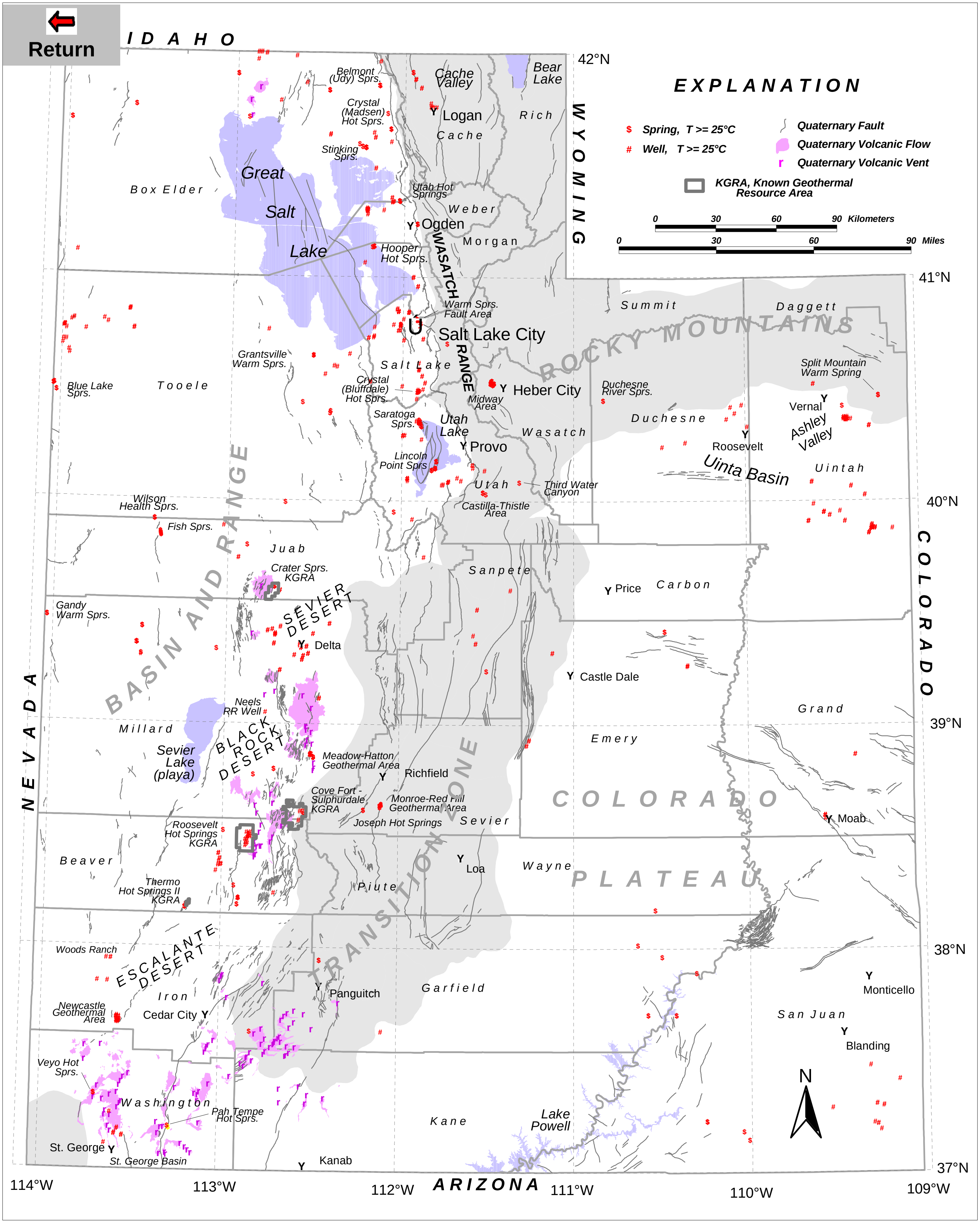

Figure 4. Geothermal resources of Utah showing thermal wells and springs, Quaternary tectonic and volcanic features, and major physiographic regions.

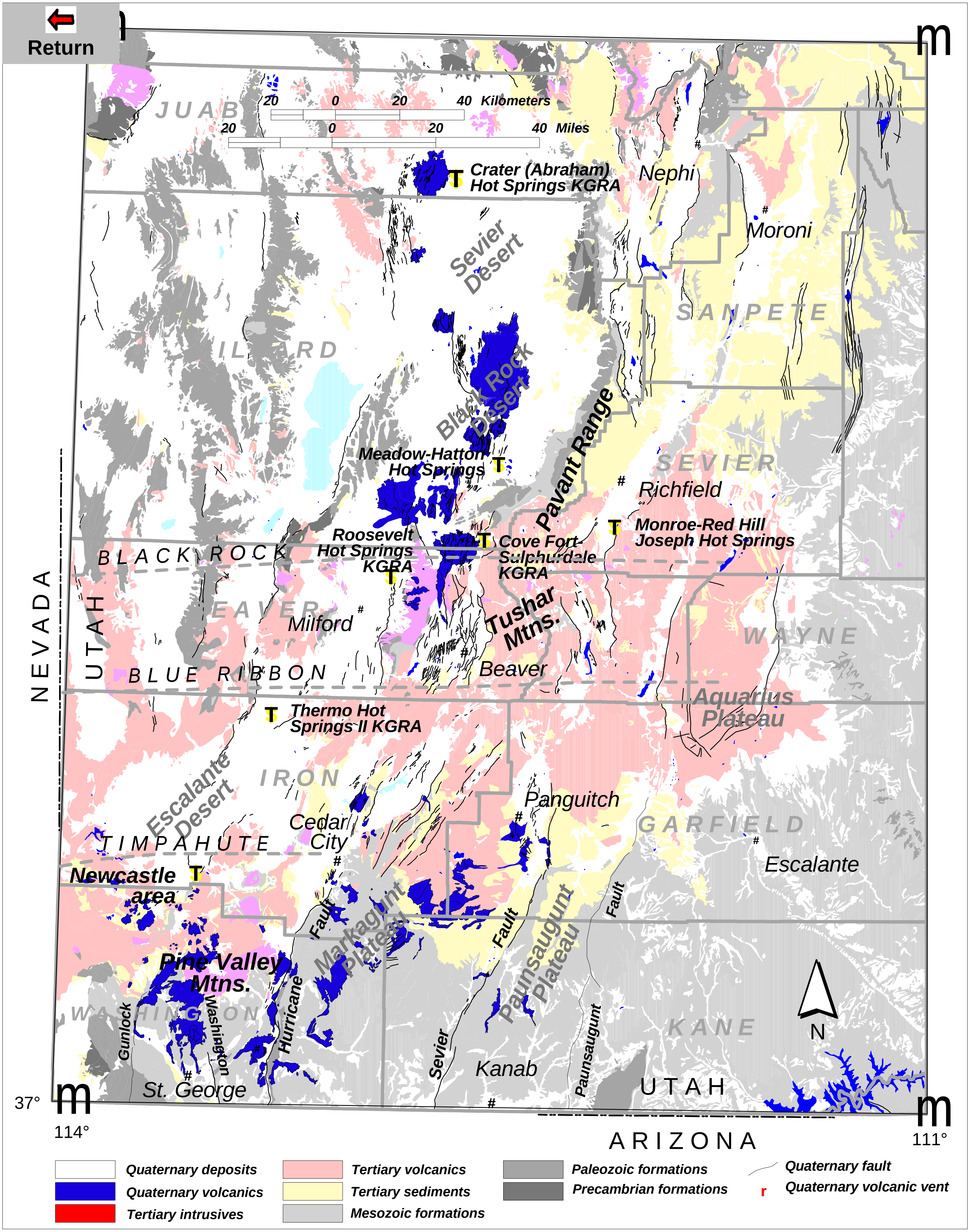

Figure 5. Southwestern Utah's "Sevier thermal area" showing locations of principal geothermal areas, general geology, Quaternary faults, and Quaternary volcanic features. East-west dashed lines approximate the trends of (from north to south) the Black Rock, Blue Ribbon, and Timpahute lineaments (modified from Magey and Budding, 1987; Hecker, 1993; Black and others, 2000; and Hintze and others, 2000).

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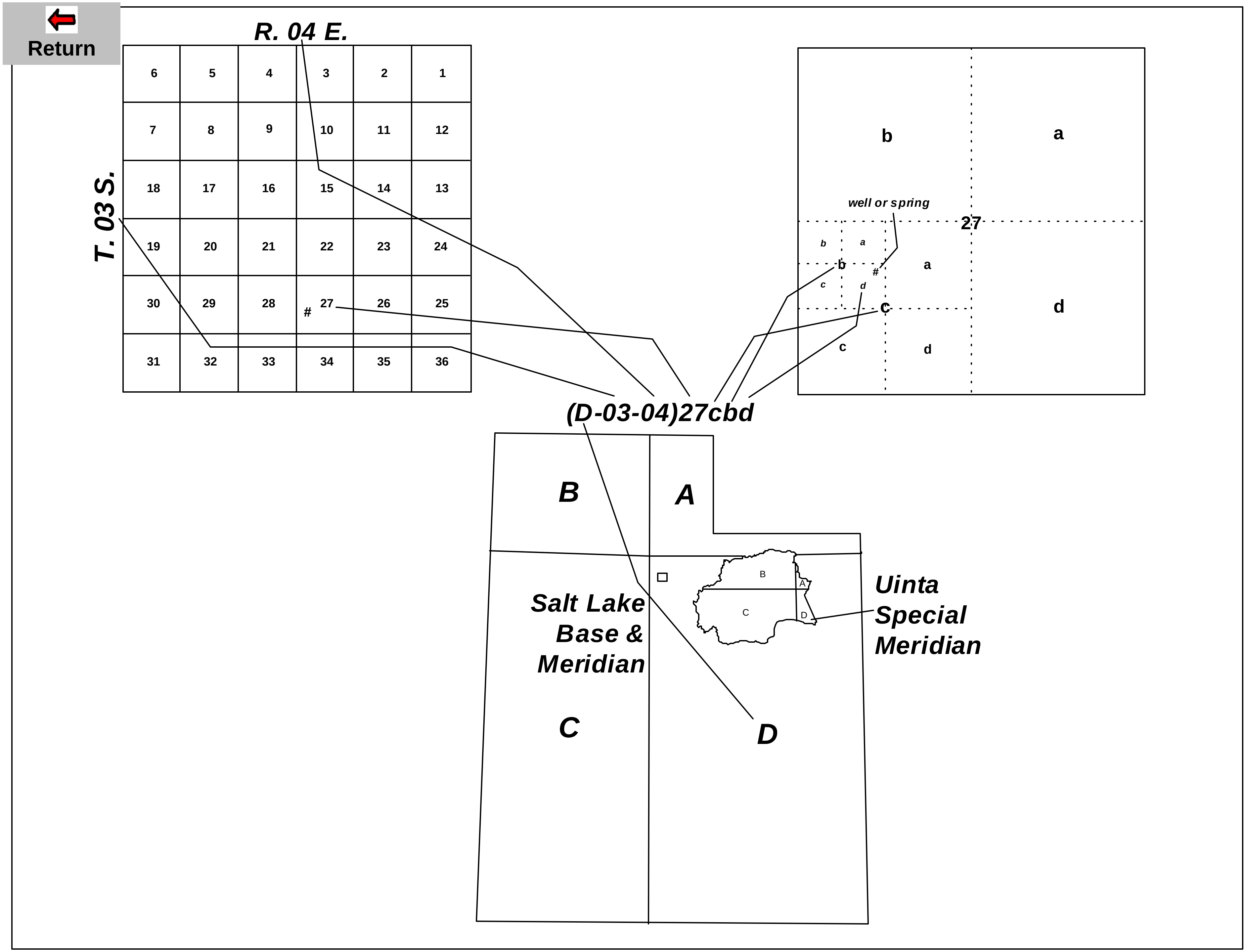

Figure 6. Well and spring numbering system in Utah.

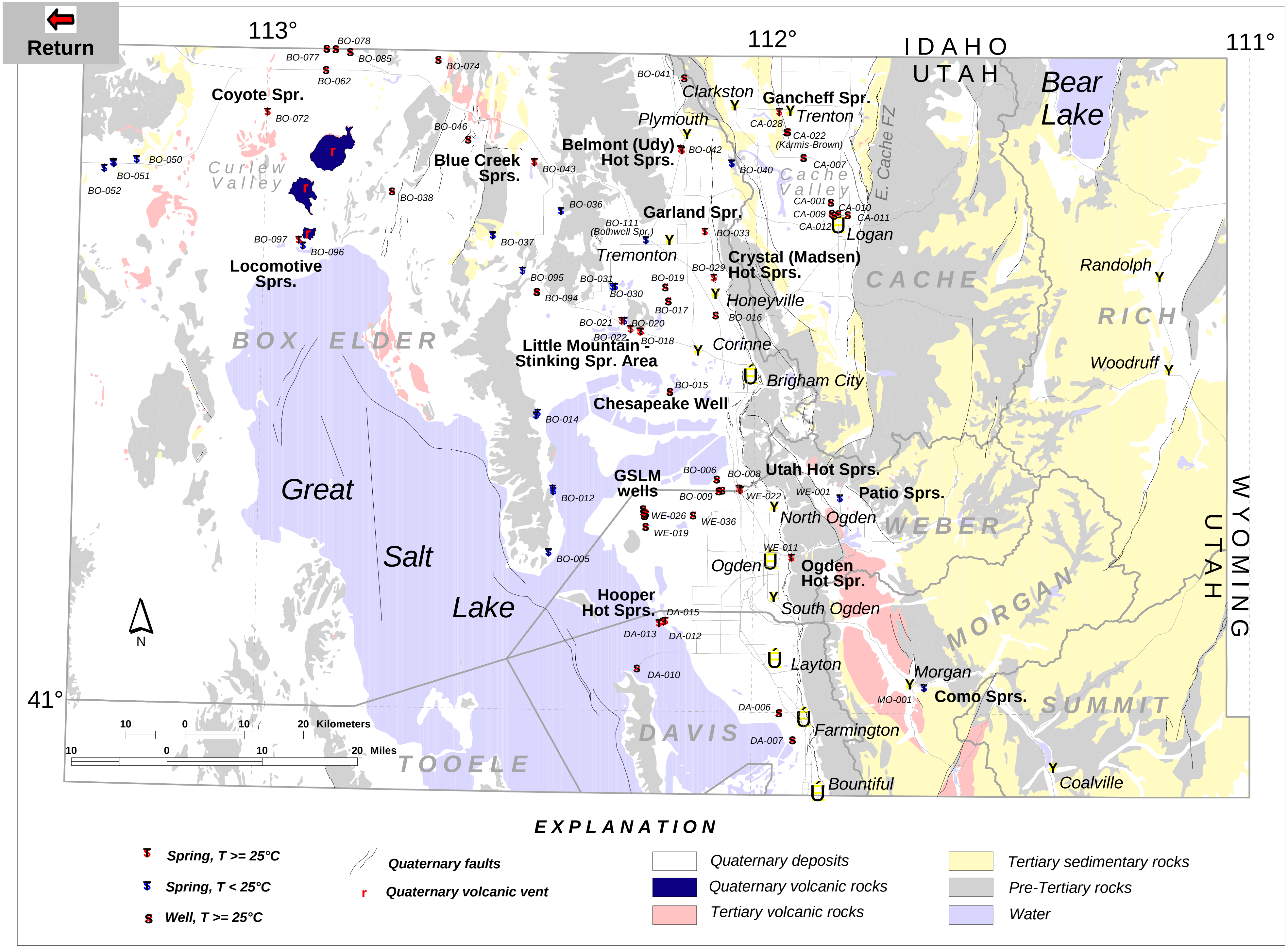

Figure 7. General geology, thermal wells, and springs within the northern Great Salt Lake and northern Wasatch Front region (modified from Hecker, 1993; Black and others, 2000; and Hintze and others, 2000).

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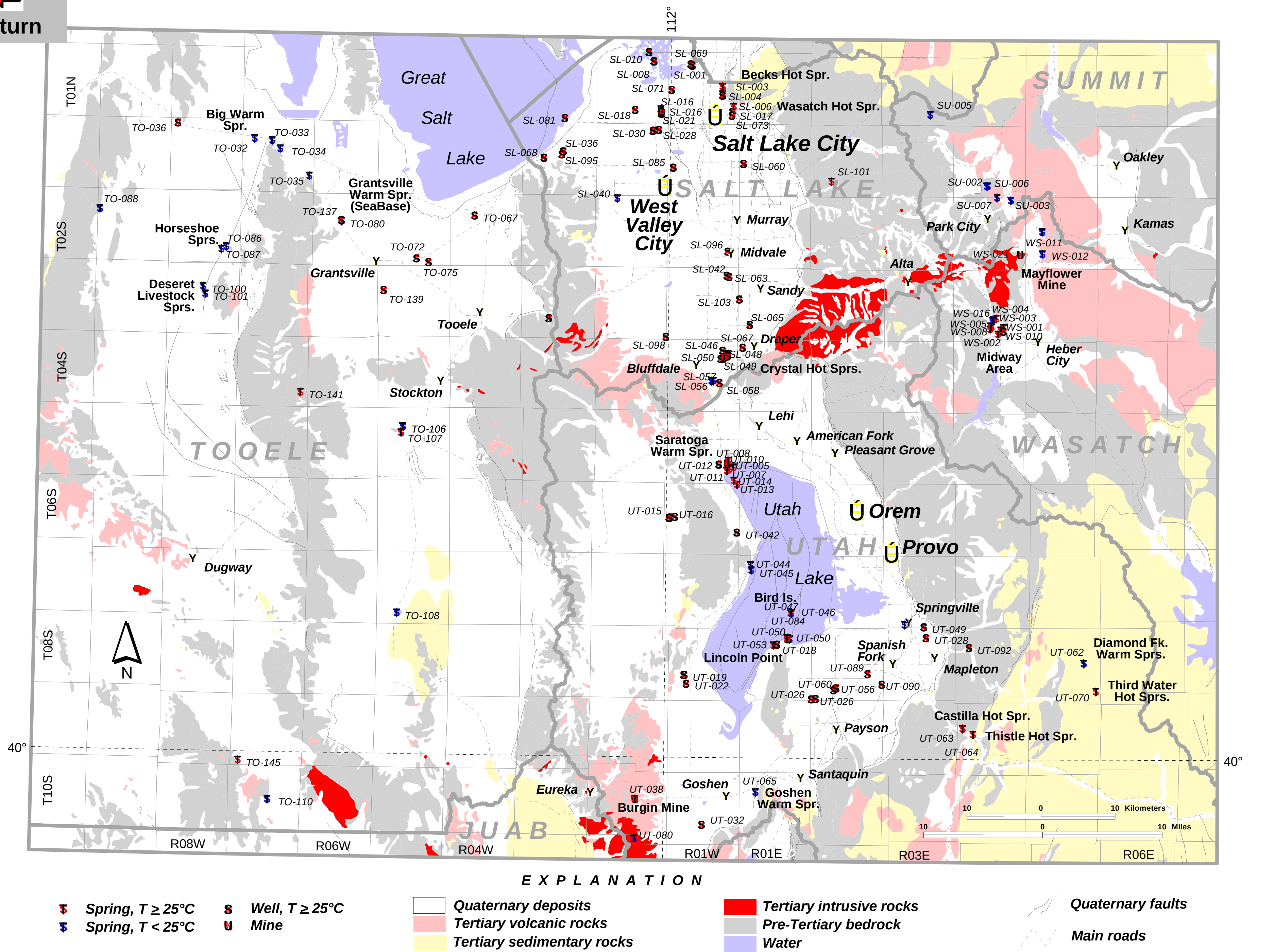

Figure 8. General geology, thermal wells, and thermal springs within the southern Wasatch Front region (modified from Black and others, 2000; and Hintze and others, 2000).

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Figure 9. Photo of a basaltic tuff cone within a 14,300 year-old volcanic crater at Tabernacle hill in the Black Rock Desert of Millard County.

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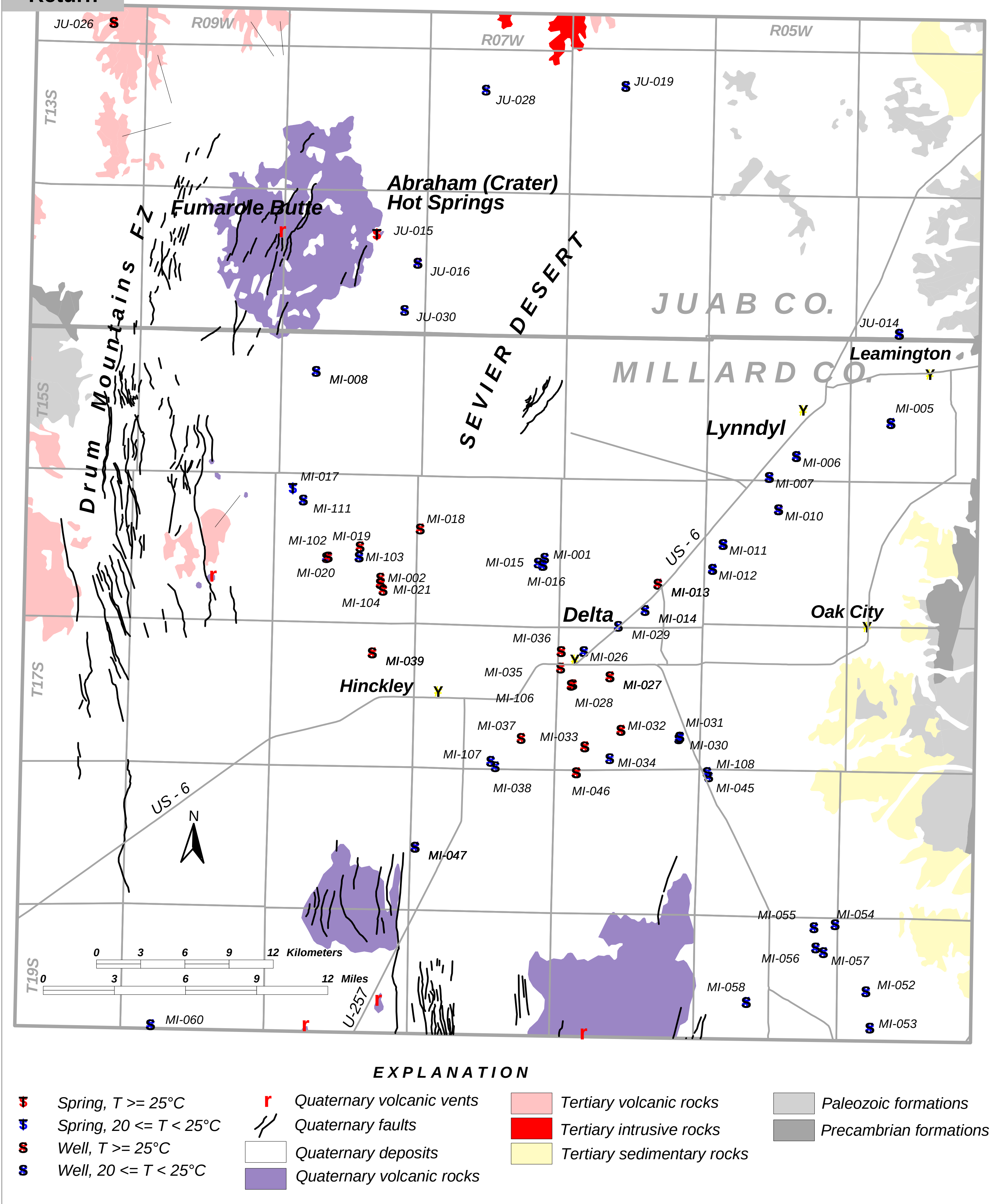

Figure 10. General geology and geothermal sources in the northern Sevier Desert, Millard and Juab Counties, Utah (modified from Hecker and others, 1993; Black and others, 2000; and Hintze and others, 2000).

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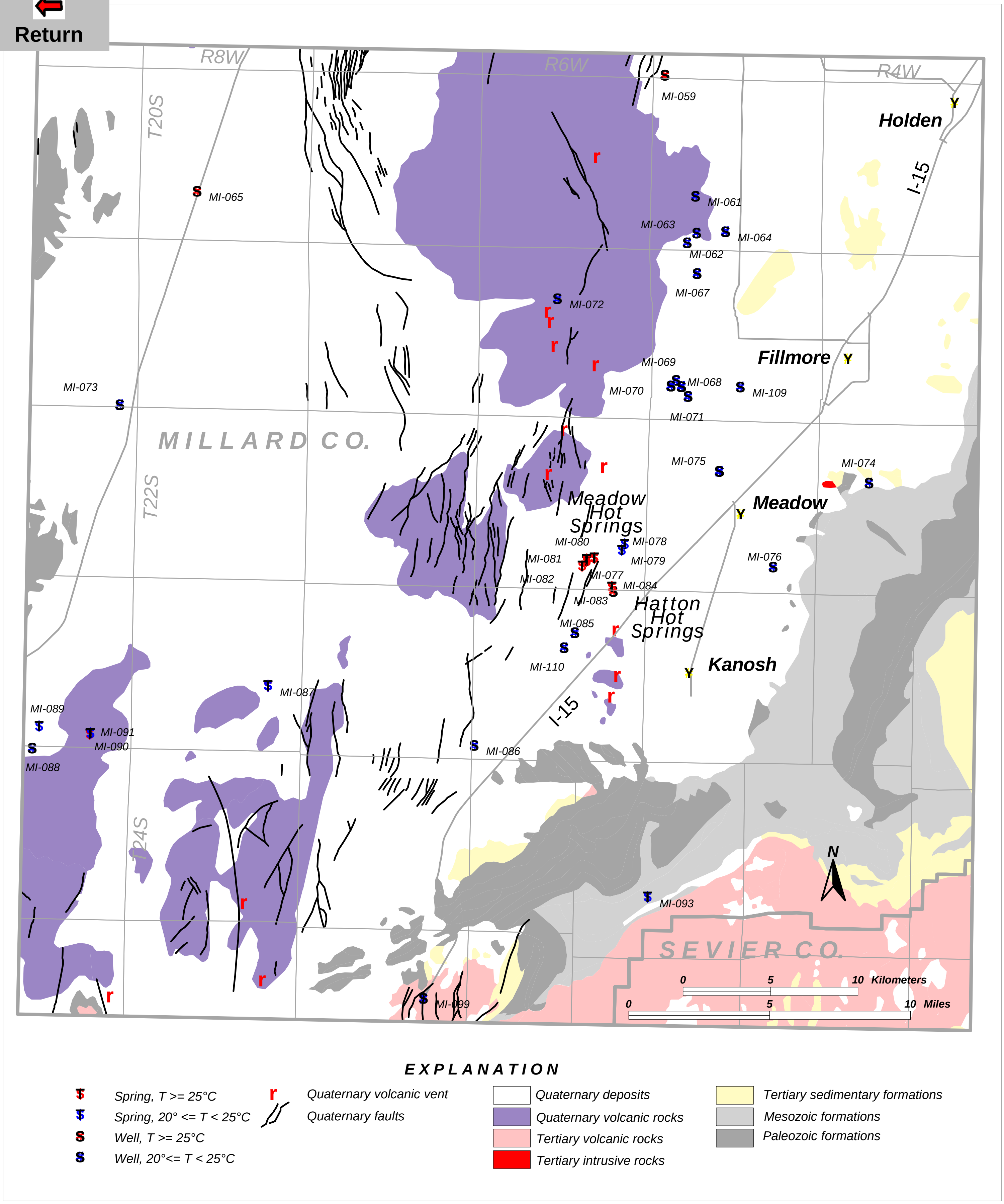

Figure 11. General geology and geothermal sources in the southern Sevier Desert and Black Rock Desert, Millard and Sevier Counties, Utah (modified from Hecker, 1993, Black and others, 2000; and Hintze and others, 2000).

Return

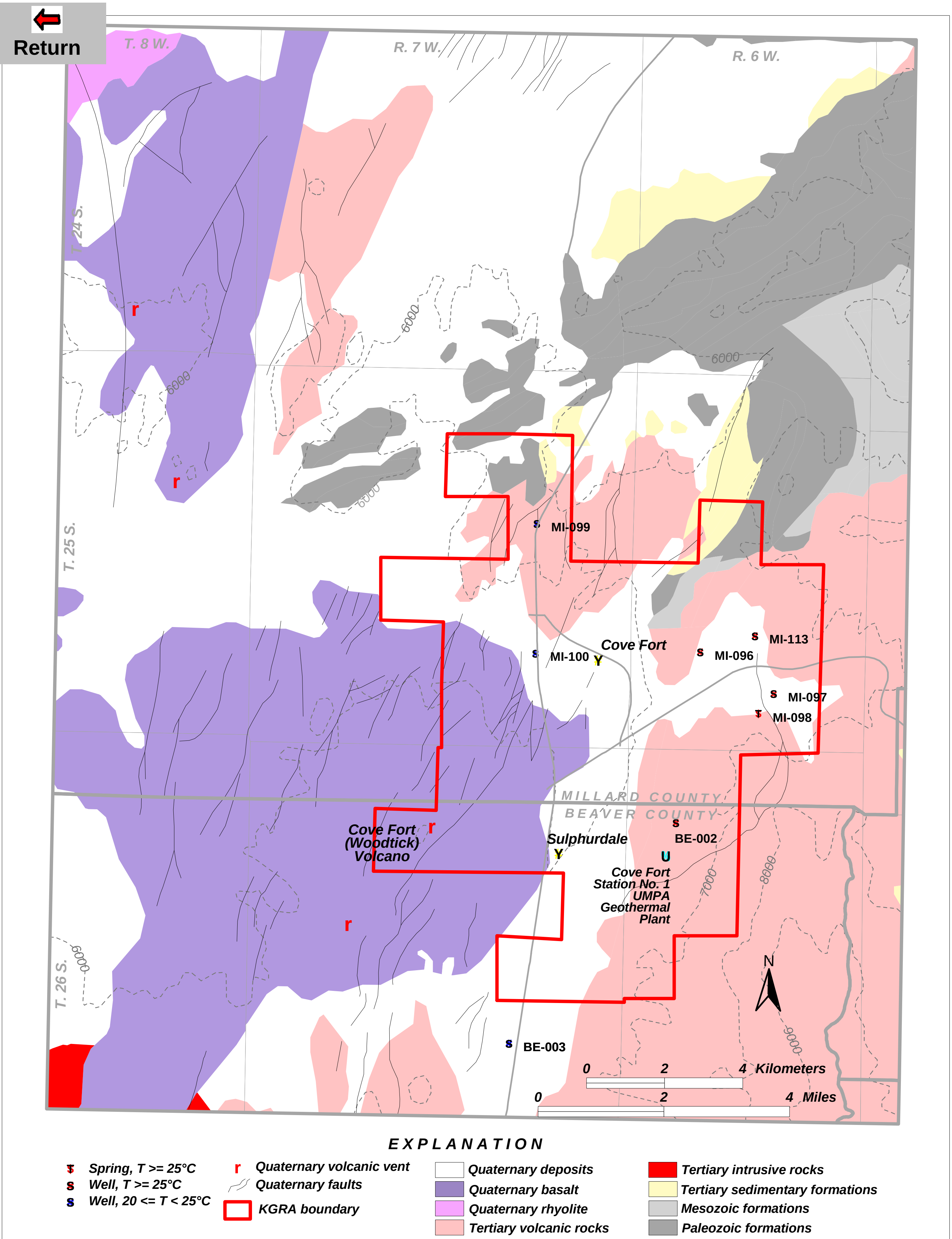

Figure 12. General geology and geothermal sources of the Cove Fort-Sulphurdale KGRA and vicinity, Millard, Beaver, and Sevier Counties, Utah (modified from Hecker, 1993; Black and others, 2000; and Hintze and others, 2000).

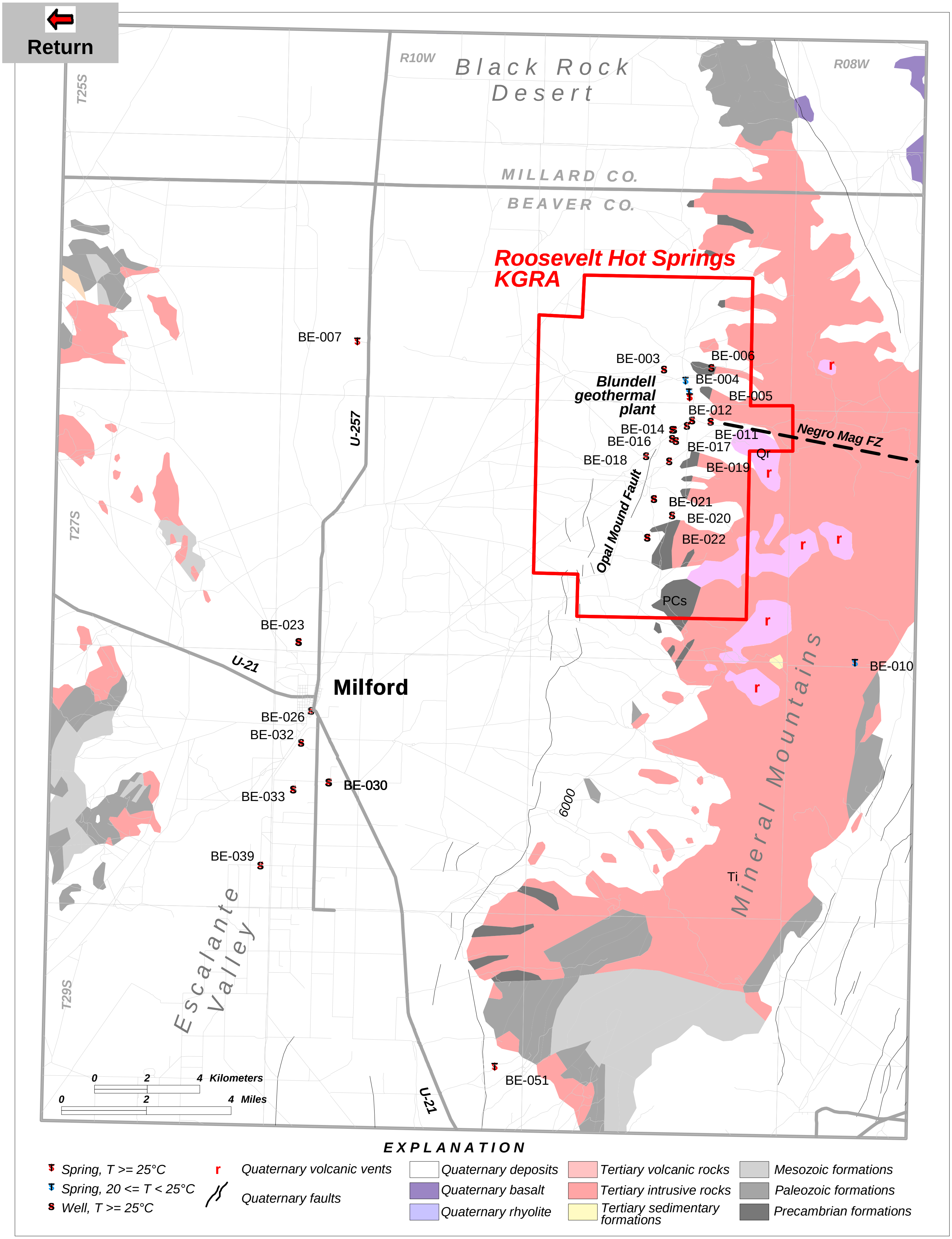

Figure 13. General geology and geothermal sources of the Roosevelt Hot Springs KGRA and vicinity, Beaver and Millard Counties, Utah (modified from Hecker, 1993; Black and others, 2000; and Hintze and others, 2000).

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Figure 14. Photo of Utah Power's Blundell geothermal power plant at Roosevelt Hot Springs geothermal area near Milford.

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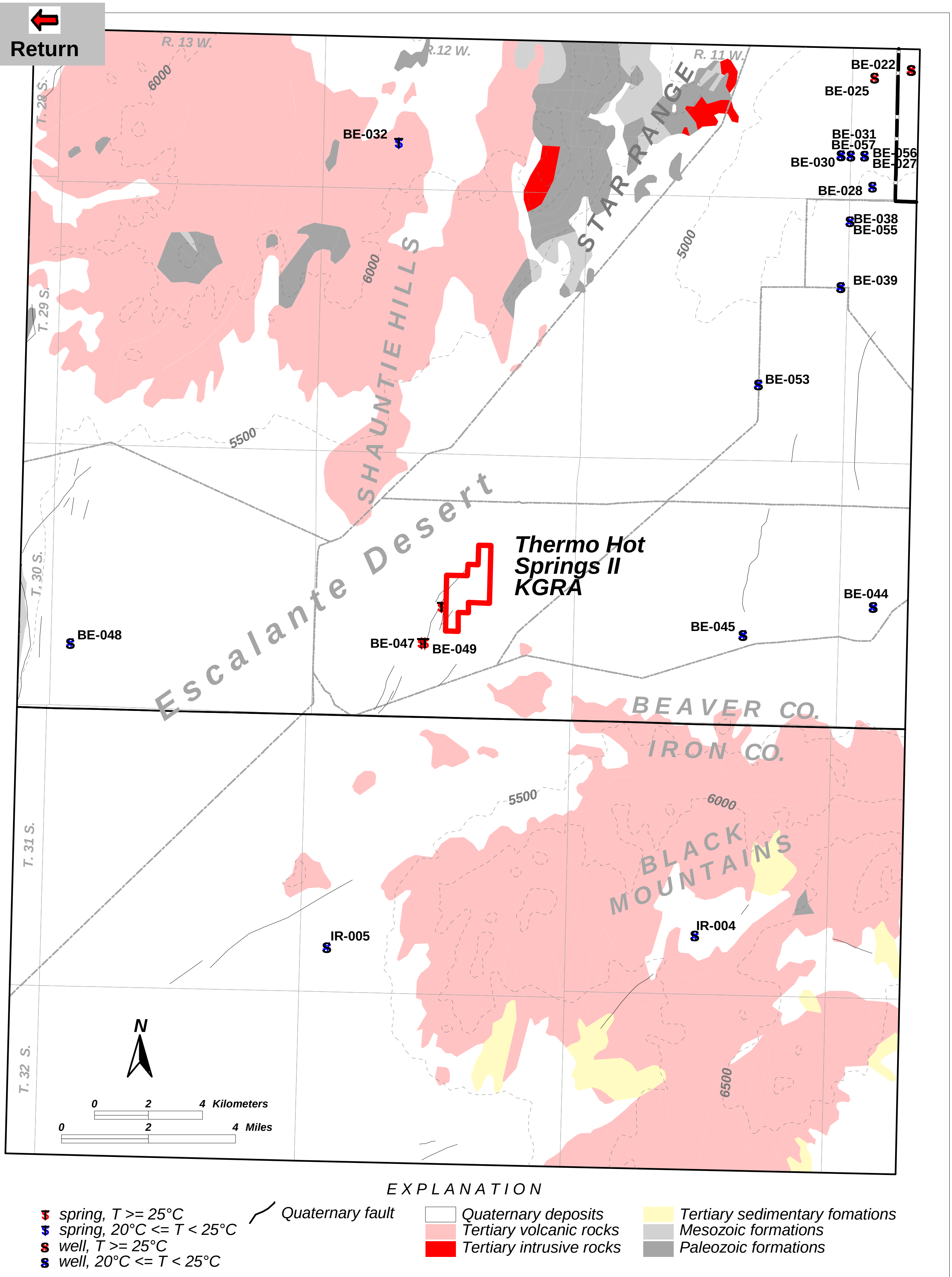

Figure 15. General geology and geothermal sources of the Thermo Hot Springs II KGRA and vicinity, Beaver and Iron Counties, Utah (modified from Black and others, 2000; and Hintze and others, 2000).

Figure 16. General geology and geothermal sources of the Newcastle geothermal area and vicinity, Iron County, Utah (modified from Black and others, 2000; and Hintze and others, 2000).

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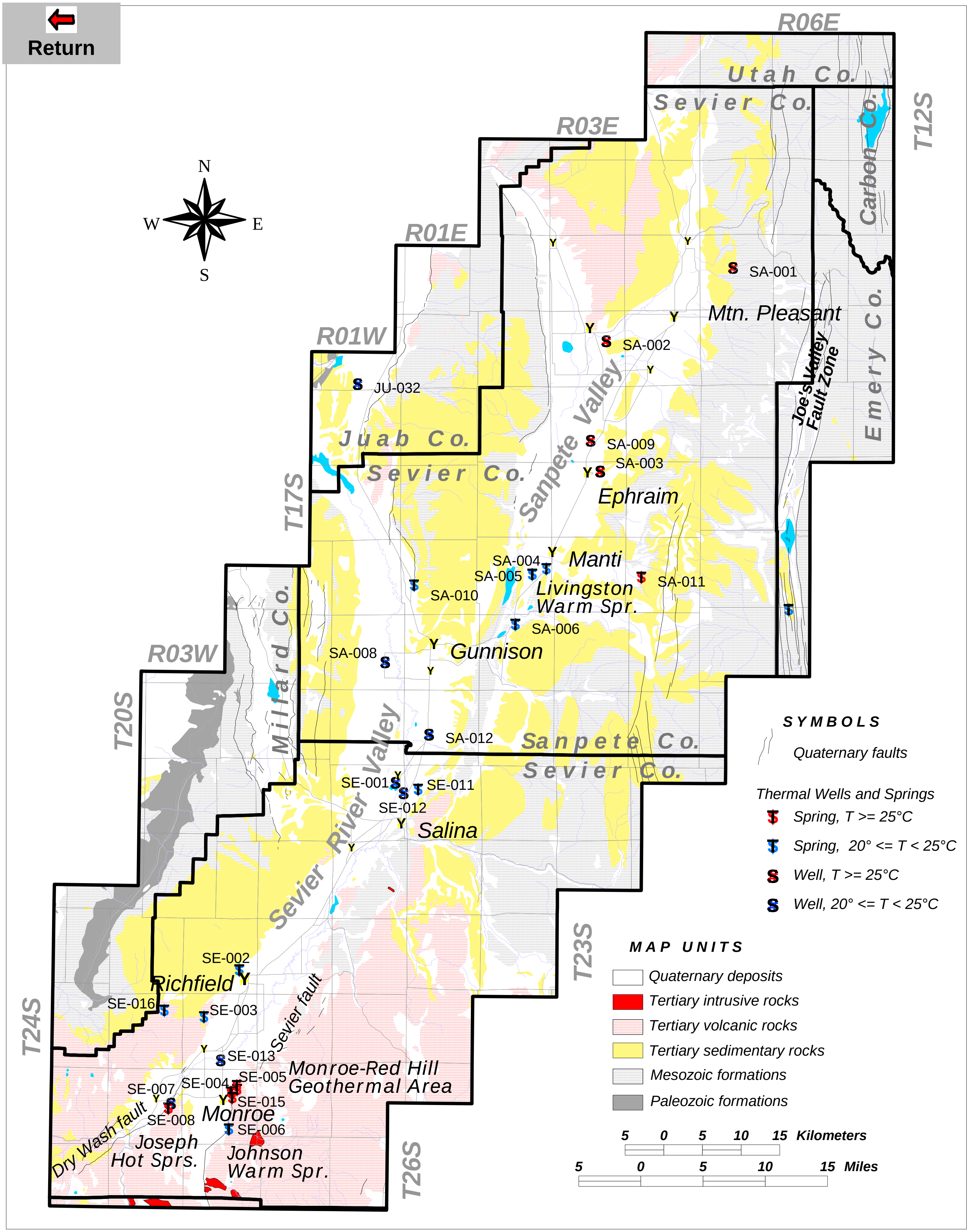

Figure 17. General geology and geothermal sources of the Sanpete and Sevier Valleys and vicinity, Sanpete and Sevier Counties, Utah (modified from Black and others, 2000; and Hintze and others, 2000).

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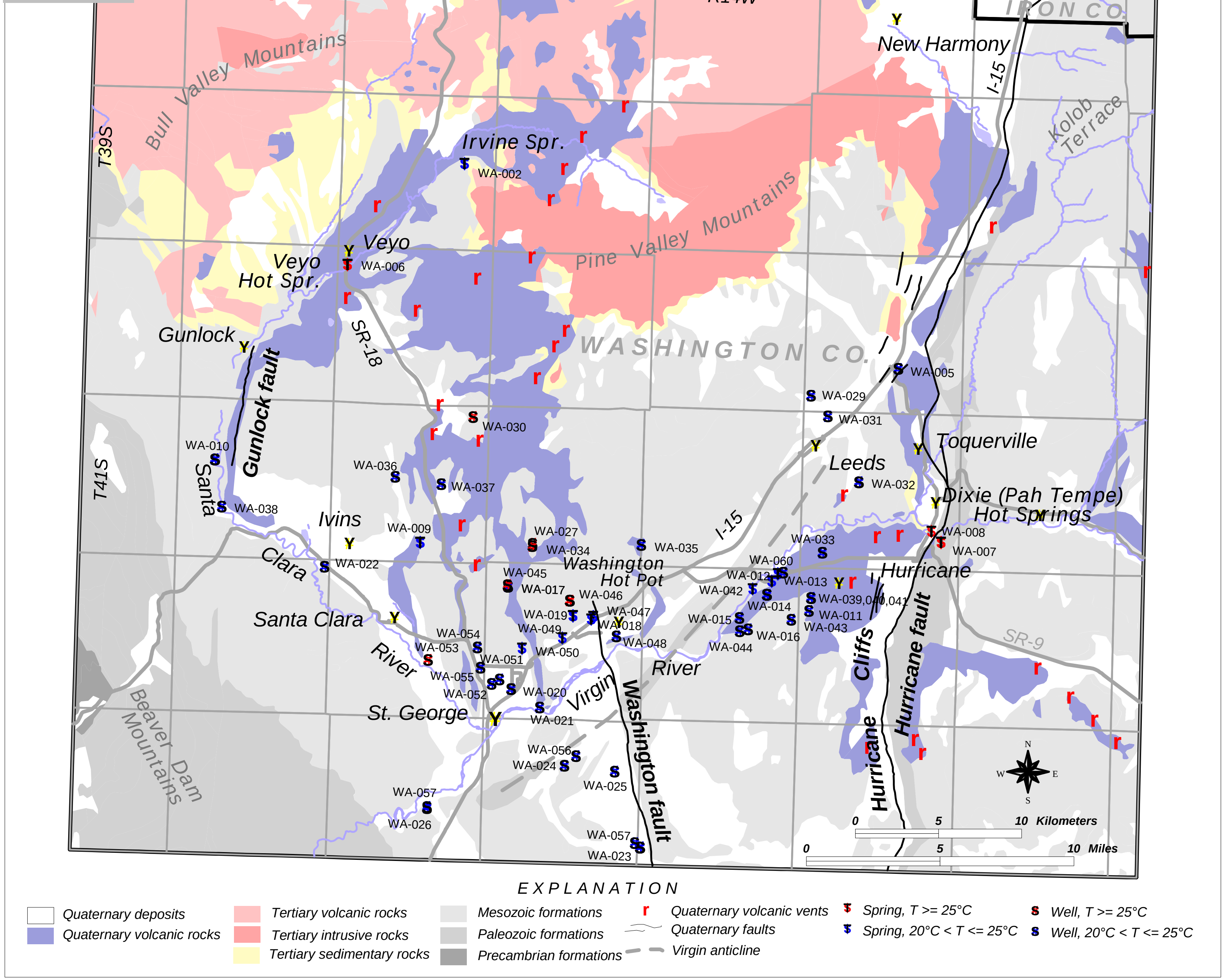

Figure 18. General geology and geothermal sources of the St. George basin geothermal area and vicinity, Washington County, Utah (modified from Hecker, 1993; Hintze and others, 2000; and Black and others, 2000).

Return

Table 1. Geothermal resource classification (modified from White and Williams, 1975)

Resource Type	Temperature Characteristics
Convective Hydrothermal Resources	
vapor dominated	~ 240°C
hot-water dominated	~ 30°C to 350°C
Conductive Hydrothermal Resources	
High Plains deep regional aquifers sedimentary basins	~ 40°C to 150°C
Gulf Coast geopressured basins	~ 90°C to 200°C
Atlantic Coastal Plain buried radiogenic plutons	~ 30°C to 150°C
Hot Rock Resources	
partially molten (magma)	> 600°C
solidified (hot, dry rock)	~ 90°C to 650°C

Return

Table 2. Explanation of data-fields included within the GIS coverage of Quaternary faults and folds in Utah (from Hecker, 1993).

FIELDNAME	FIELD CONTENTS
LOCNUM UGS:	location number
FEATURE:	1 = fault, 2 = anticline, 3 = syncline, 4 = monocline
TYPE:	1 = surface, 2 = inferred/approximate, 3 = buried/concealed, 4 = hypothetical, 5 = plunging
AGE:	Probable age of most recent movement 1 = Holocene (red) 1 - 30,000 ya 2 = Late Pleistocene (orange) 10,000 - 130,000 ya 3 = Mid to Late Pleistocene (green) 10,000 - 750,000 ya 4 = Early to Mid Pleistocene (purple) 130,000 - 1,650,000 ya 5 = Quaternary (black) < 1,650,000 ya
RUPTURE:	Relative likelihood of displacement of ground surface by faulting: 1 = high, 2 = moderate to high, 3 = moderate, 4 = low to moderate, 5 = low, 6 = very low
NUMBER:	Assigned by USGS within Western Hemisphere Database
NAME:	Common name of fault/fold in the geologic literature
USGSAGE:	Time of most recent paleoevent on fault feature 1 = Historic (red) a specific year 2 = Holocene and Post-Glacial (orange) < 15 Ka 3 = Late Quaternary (green) < 130 Ka 4 = Mid to Late Quaternary (blue) < 750 Ka 5 = Quaternary (black) < 1.6 Ma
SLIPRATE:	Average activity on fault feature, amount of movement: A = > 5 mm/yr, B = 1 - 5 mm/yr, C = < 1mm/yr
RELIABILITY:	Continuousness of feature: X = continuous (solid line);Y = discontinuous (dashed line); Z = concealed (dotted line).
MOVEMENT:	Principal sense of movement of faults: N = normal, NS = normal/sinistral, S = sinistral T = thrust, R = reverse, O = oblique, D = dextral
SCALE:	Scale denominator of source map

Return

Table 3. Explanation of data-fields included within the GIS coverages for Quaternary volcanic flows and vents in Utah (from Hecker, 1993).

FIELDNAME	FIELD CONTENTS
LOCNUM UGS:	location number
FEATURE:	7 = volcanic flow; 8 = volcanic vent
TYPE:	not applicable
AGE:	Probable age of most recent activity: 1 = Holocene (red) 1 _ 30,000 ya 2 = Late Pleistocene (orange) 10,000 _ 130,000 ya 3 = Mid to Late Pleistocene (green) 10,000 _ 750,000 ya 4 = Early to Mid Pleistocene (purple) 130,000 _ 1,650,000 ya 5 = Quaternary (black) < 1,650,000 ya

Return

Table 4. Cutoff temperatures applied to geothermal wells and springs in Utah counties.

County	Cutoff Temp (°C)	County	Cutoff Temp (°C)
Beaver	20	Piute	20
Box Elder	20	Salt Lake	20
Cache	18	San Juan	20
Carbon	20	Sevier	20
Davis	20	Sanpete	19
Duchesne	18	Summit	18
Emery	20	Tooele	19
Garfield	19	Uintah	18
Grand	20	Utah	20
Iron	20	Wasatch	18
Juab	20	Washington	20
Kane	20	Wayne	20
Millard	20	Weber	20
Morgan	19		

Return

Table 5. Utah geothermal database (UTAHGEO.dbf), data field summary.

FIELD NAME	FIELD CONTENTS	UNITS
------------------------ *Descriptive Data* --		
ID	unique record ID	number
MAPNO	map number (see table 6)	County code + number
COUNTY	county	NA
SOURCE	well/spring name or designation	NA
LOCATION	well and spring numbering system for Utah	cadastral coords.
IDNAME	USGS naming convention	Lat(dms)/Long(dms)
TYPE	well (W), spring (S), oil-field drain (D) mine (M), collector (C)	NA
TEMP	measured temperature	degrees Celsius
CLASS	classification for 25°C < T, T $\geq$ 25°C	see footnote[1]
DEPTH	depth of well	meters
FLOW	flow rate	liters per minute
LONG	longitude west	decimal degrees
LAT	latitude north	decimal degrees
UTME	UTM east coordinate for zone 12	meters
UTMN	UTM north coordinate for zone 12	meters
LEVEL	depth to water level (negative if above ground)	meters
STATUS	pumped (P), flowing (F)	NA
DATE	date of sample (if available)	mm/dd/yy
REFERENCE	short citation for source of data	NA
------------------------ *Fluid Chemistry Data* --		
PH	pH	pH units
COND	conductivity	microseimens
NA	sodium	mg/L
K	potassium	mg/L
CA	calcium	mg/L
MG	magnesium	mg/L
AL	aluminum	mg/L
FE	iron	mg/L
SIL	silica (SiO_2)	mg/L
B	boron	mg/L
LI	lithium	mg/L
BIC	bicarbonate (HCO_3)	mg/L
SULF	sulfate (SO_4)	mg/L
CL	chloride	mg/L
F	fluoride	mg/L
AS	arsenic	mg/L
TDSM	TDS measured	mg/L
TDSC	TDS calculated	mg/L
CHGBAL	charge balance	(cations/anions)x100

[1] WELHI, SPRHI $\geq$ 25°C; WELLO, SPRLO < 25°C

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Table 6. List of county codes used in "MAPNO" field[1].

Code	County	Code	County
BE	Beaver	PI	Piute
BO	Box Elder	SL	Salt Lake
CA	Cache	SJ	San Juan
CR	Carbon	SE	Sevier
DA	Davis	SA	Sanpete
DU	Duchesne	SU	Summit
EM	Emery	TO	Tooele
GA	Garfield	UI	Uintah
GR	Grand	UT	Utah
IR	Iron	WS	Wasatch
JU	Juab	WA	Washington
KA	Kane	WY	Wayne
MI	Millard	WE	Weber
MO	Morgan		

[1]No thermal springs or wells were recorded in Daggett and Rich Counties.

GEOTHERMAL GRADIENT DATA FOR UTAH

by

Robert E. Blackett

February 2004
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
in cooperation with
U.S. Department of Energy, National Renewable Energy Lab

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CONTENTS

FIGURE

PLATE

ABSTRACT

The Utah Geological Survey compiled information from exploratory temperature-gradient boreholes from a variety of publicly available sources including the Southern Methodist University Geothermal Laboratory, U.S. Geological Survey, recently released industry data, and internal unpublished reports. The data consist of 979 records for 952 boreholes throughout Utah, formatted for use with geographic information systems. Also included are detailed descriptions of the database sources and data-field parameters.

INTRODUCTION

Thermal methods for geothermal exploration involve the measurement of subsurface temperature at specified depths in exploratory boreholes. Using temperature-depth measurements, geothermal explorers or researchers can determine thermal gradients and (when coupled with other down-hole data) heat flow. These down-hole temperature measurements comprise the only geothermal exploration method for direct detection of geothermal resources. Other geophysical techniques are considered as indirect methods, and can only suggest the possibility of a geothermal system at depth. Temperature logs of boreholes are made by lowering a sensitive thermistor probe -- capable of measuring temperature differences of about 0.01°C -- on a conductor cable, recording probe resistance, and converting resistance data to temperatures at specified depths in the borehole. All data in this report were obtained using calibrated thermistor probes having an accuracy of at least 0.1°C. Small temperature logging units for shallow boreholes (< 1,000 meters [3,280 ft]) can be highly portable, mounted to a hand-crank cable reel. More sophisticated, deep-hole units are truck mounted with several thousand meters of conductor cable connected to electronic recording gear and a motor-driven winch (Wright, 1991).

During the 1970s and early 1980s, the energy industry and government agencies actively explored areas within the western United States for geothermal potential. One exploration method involved the drilling of numerous, shallow, thermal-gradient boreholes for heat-flow studies. As interest in geothermal development decreased during the late 1980s and 1990s, several companies no longer viewed these data as proprietary. The companies, in conjunction with the U.S. Geological Survey (USGS), released thermal-gradient and other geophysical data to the general public. The USGS, and also Southern Methodist University (SMU) Geothermal Laboratory, made much of this information available via the Internet. In Utah, the Utah Geological Survey (UGS) and other state agencies, under cost-share agreements with federal agencies, also compiled geothermal information including results of thermal-gradient drilling. These data were commonly recorded in internal reports or merely within agency files, but were not broadly distributed.

Regional heat-flow studies have shown the mean heat flow for the Basin and Range Province to be about 86 $m\text{W/m}^2$ and the mean heat flow for the Colorado Plateau to be about 59 $m\text{W/m}^2$ (Maria Richards, 2003, SMU, written communication based on the work of Blackwell and others, 1991; and Morgan and Gosnold, 1989). Henrikson (2000), using 88 new heat-flow measurements from Utah, showed that corresponding mean heat-flow values for the new sites are about 91 $m\text{W/m}^2$ in the Basin and Range and about 62 $m\text{W/m}^2$ in the Colorado Plateau.

SOURCES OF DATA

Thermal-gradient data associated with this report were derived from various sources including the aforementioned heat-flow database compiled by and maintained through the SMU Geothermal Laboratory. In addition, thermal-gradient data for Utah were extracted from several unpublished state-agency reports, as described previously, and from the work of Henrikson (2000).

In addition to data extracted from published documents, the SMU thermal-gradient data for Utah were derived from a number of sources including Amax Geothermal, Phillips Petroleum Company, and Chevron Geothermal. CalEnergy Inc. reportedly purchased the subsurface temperature data from the Chevron/Phillips projects. The U.S. Department of Energy acquired part of this subsurface temperature data set for the Idaho National Engineering and Environmental Laboratory (INEEL). Working with INEEL, USGS personnel inventoried and digitized the CalEnergy data, and then combined this data set with miscellaneous data from Geothermal Resources International, Aminoil USA, Amax, and data from other companies acquired earlier by INEEL. The USGS later posted all of the data on the Internet (Sass and others, 1999).

The data as received by the USGS and SMU were in a variety of formats and units, and most locations were listed by section, township, and range. They were primarily copies of field data sheets, but some were in interpretive reports, and others were analogue temperature-depth plots at various scales. Gradient values shown in the database were obtained directly from the field data sheets or plots. These were usually based on a visual straight-line fit of the data from the lowermost section of the hole.

SMU also included thermal-gradient data from a number of published documents, which are listed in the "References and Data Sources" section of this report. Similar but previously unpublished information, provided by Republic Geothermal Inc. (1977) and made available through the University of Utah Energy and Geoscience Institute (EGI), were also folded into the data set. Thermal-gradient data compiled by Henrikson (2000), describing new heat-flow determinations in Utah, were also incorporated. Several dozen records were also extracted from UGS files and Reports of Investigation publication series. These are also listed in the "References and Data Sources" section of this report. Overall, the UGS augmented the SMU/USGS-maintained thermal-gradient dataset for Utah, consisting of 617 boreholes, including data from 335 additional boreholes to create the current database containing 979 records for 952 boreholes. Also, the UGS effort included using copies of the raw Amax temperature profiles (acquired through EGI) to check and correct entries where necessary.

DATA CONTENT AND ORGANIZATION

The temperature-gradient data for all 952 boreholes are depicted in two maps, a spreadsheet file, and in Appendix A. Figure 1 is a small-scale general map of Utah showing the locations of temperature-gradient boreholes included in the database, color-coded for relative gradient magnitudes. Plate 1 is a larger-scale (1:750,000), more detailed map showing (1) geology and physiography; (2) borehole locations with relative gradient magnitudes and designations; and (3) locations of thermal wells, springs and geothermal areas from previous studies (Blackett and Wakefield, 2002). The thermal-gradient data set described here is

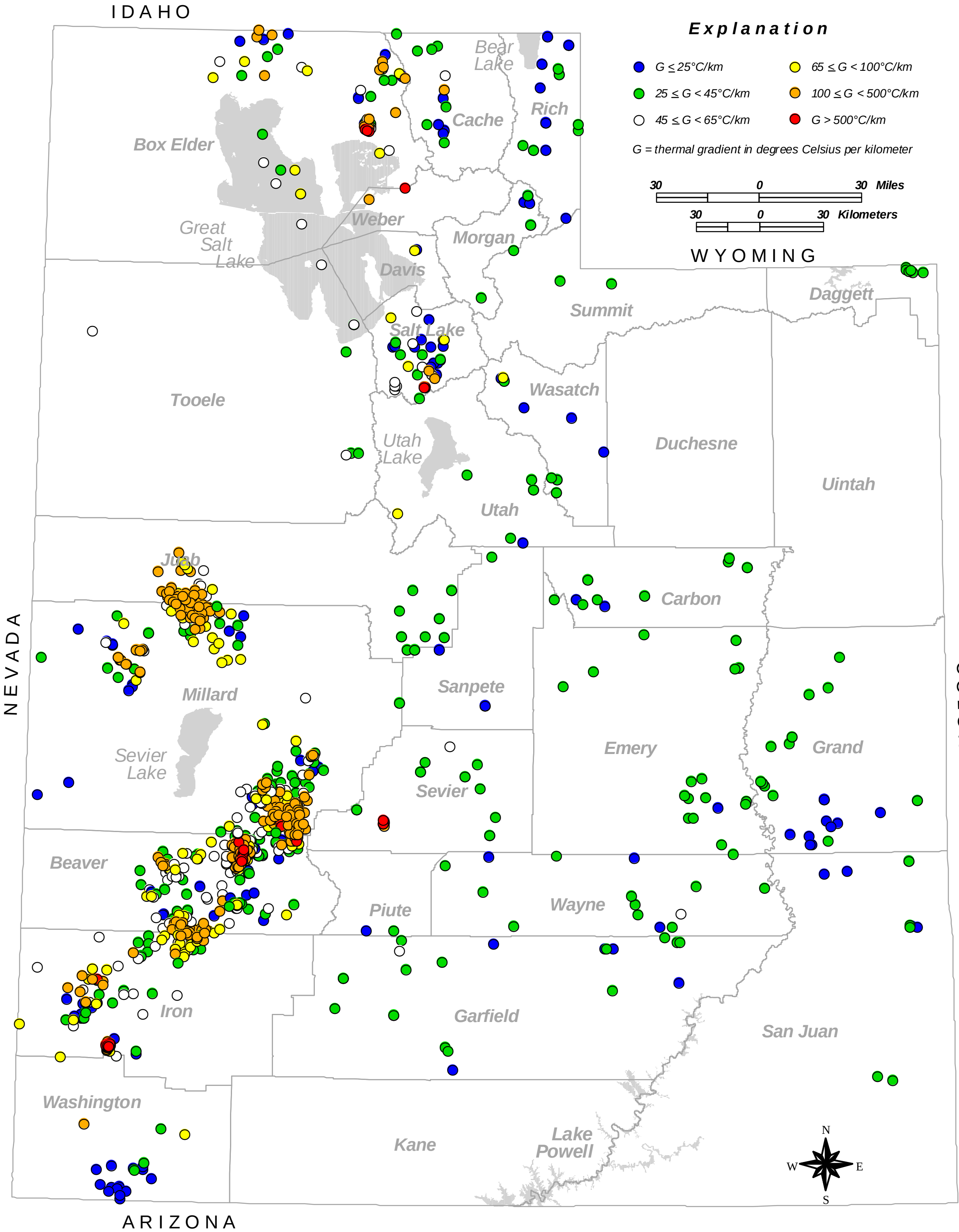

Figure 1. Locations of thermal-gradient boreholes in Utah showing relative gradient magnitudes.

contained within the MS Excel® spreadsheet "ut_tg_data.xls." An abbreviated version of the data set is included as Appendix A.

DATABASE FIELD DESCRIPTIONS

The following list, somewhat modified from the SMU Geothermal Laboratory's Web site (http://www.smu.edu/geothermal/), describes the data fields for the Utah thermal-gradient database contained in attached file ut_tg_data.xls and the condensed version of the data in Appendix A.

REGION_LOC: Refers to geothermal area, physiographic subdivision, or geographic feature where appropriate.

HOLE_NAME: the most common name used in reports. Some boreholes have more than one name and the other name(s) are given in the comments section.

PUB_REF: Publication (or reference) code listed within the "References and Data Sources" section. The code is composed of three parts: (1) Author code is the first four letters of the primary author's last name. If the author's name is less than four characters, then the remaining spaces are blank. (2) Year published code. This code refers to the last two digits of the year published. (3) Number of authors on paper. If there is only one author then the position is blank. If there are nine or more authors then 9 is the value.

> Example: CHAP813 refers to a paper published in 1981 by Chapman and two other authors.
>
> Note: Materials were also coded according to the type of information and this code is used when no specific author is given.

COUNTY: County name.

MAPNO: Data point index numbers used as labels on Plate 1. The MAPNO field's contents consist of a two-digit county code followed by a sequential number within each county.

PROVINCE: Major physiographic province.

LAT_NORTH: North latitude in decimal degrees.

LON_WEST: West longitude (negative) in decimal degrees.

DMS_DMS: Unique identifier string consisting of degrees, minutes, and seconds of latitude then longitude. Identifier is used for geographic sorting of records.

TRS: Township, Range, Section, and subdivision. The system of numbering wells and springs in Utah is based on the cadastral land-survey system of the U.S. Government. The number designates a location and describes its position in the land net. The land-survey system divides the state into four quadrants with respect to the Salt Lake Base Line and Meridian (origin in Salt Lake City), and these quadrants are designated by uppercase letters as follows: A-northeast, B-northwest; C-southwest; and D-southeast. Numbers designating the township and range (in that order) follow the quadrant letter, and all three are enclosed in parentheses. The number after the parentheses indicates the section and is followed by the three (or fewer) letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section -- usually 10 acres (0.04 km^2) in area. The quarters of each subdivision are designated by lowercase letters as follows: a, northeast; b, northwest; c, southwest; and d, southeast. For example, the well/spring number "(C-36-15)20bca" describes a location in T.36S., R.15W., in the northeast quarter of the southwest quarter of the northwest quarter of section 20. The Uinta Special Meridian is a separate land-survey coordinate system for the Uinta Basin in northeastern Utah. A preceding "U," for example U(B-01-08) 30ddb, designates wells and springs located using this system.

UTM_E/UTM_N: Universal Transverse Mercator (UTM) coordinates in meters east and north of the Zone 12 origin. Where UTM coordinates were not available, geographic (Lat/Long) coordinates were converted to UTM coordinates based on the North American Datum of 1927. Coordinates were converted using the software package “Corpswin” version 5.11.08 developed by the U.S. Army Corps of Engineers.

ELEV_M: Elevation of the surface location of the hole given in meters above mean sea level.

MEAS_DATE: Measurement date of the temperature log from which the thermal-gradient results were determined. It is in the form MM/DD/YY.

DRILL_DATE: Date of hole drilling or well completion. It is in the form MM/DD/YY.

DRILL_DEPTH: Total drilled depth in meters.

BHT_C: Bottom-hole temperature in degrees Celsius (ºC).

WAT_TABLE: Depth to static water level in meters.

MAX_TEMP: Maximum measured temperature, in degrees Celsius (ºC), not necessarily bottom-hole temperature. Depth to the interval (in meters) where MAX_TEMP occurred may be indicated.

START_M/END_M: Starting and ending depths for the gradient interval, in meters.

AVGTCU: Average thermal conductivity. Laboratory or estimated thermal conductivity measurement for the depth interval. The unit is Watts/meter/Kelvin (*W/m/K).*

UCGRAD, Sym, <SE>: Uncorrected gradient & standard error. Calculated or estimated uncorrected thermal-gradient measurement is for the depth interval Start_m to End_m. Uncorrected refers to gradient data not corrected for terrain effects. Sym _ Symbols used (for example, <, >, or*) refer to greater than, less than, or estimate of gradient. If a statistical mean method is used, then the standard error (SE) of the mean is included. The unit is degrees Celsius per kilometer (°C/Km).

GRAD_CLASS: General divisions for uncorrected thermal-gradient values (within the UCGRAD data field, in ºC/km) determined in boreholes. Class codes contained in the database include the following: “LOGRAD” < 25; “MLGRAD” = 25, < 45; “MEGRAD” = 45, < 65; “MHGRAD” = 65, < 100; “HIGRAD” = 100, < 500; “UHGRAD” = 500. This field is used for geographic information system visual displays.

ACKNOWLEDGEMENTS

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APPENDIX A

Abbreviated Thermal Gradient Database for Utah

Note that the interval for which gradients were computed does not appear in this abbreviated version of the thermal-gradient database. Simply computing gradients using the DEPTH and bottom hole temperature (BHT) values does not necessarily yield the value shown in the UCGRAD field. The computed gradient interval is included, however, within the expanded T/G database. The reader is encouraged to access the expanded database for more information (file "*ut_tg_data.xls*"). Within the UCGRAD field, the notation "NA" means "not applicable," either resulting from isothermal or erratic temperature profiles. Blank entries within the "DEPTH" or "BHT" fields denote missing data.

REGION_LOC	HOLE_NAME	PUB_REF	COUNTY	MAPNO	TRS	UTM_E (m)	UTM_N (m)	DEPTH (m)	BHT (°C)	UCGRAD (°C/km)
Cove Fort	42-7	GLEN822	Beaver	BE-1	(C-26-06)07ba	363176	4269746	2358	170	NA
Cove Fort	P91-4	HUTT92	Beaver	BE-2	(C-26-06)18	362875	4267442	745	163	1456
Cove Fort	431	AMAX98	Beaver	BE-3	(C-26-06)20c	363786	4266139	70	14	75
Cove Fort	430	AMAX98	Beaver	BE-4	(C-26-06)30d	363418	4263980		12	42
Cove Fort	34-7	HUTT92	Beaver	BE-5	(C-26-06)07	363492	4269330	355	177	470
Cove Fort	161	AMAX98	Beaver	BE-6	(C-26-07)12da	362284	4269062	89	38	172
Cove Fort	399	AMAX98	Beaver	BE-7	(C-26-07)12da	362032	4269221	92	42	346
Cove Fort	269	AMAX98	Beaver	BE-8	(C-26-07)13ac	361677	4267696	64	22	182
Cove Fort	212	AMAX98	Beaver	BE-9	(C-26-07)14db	360029	4267669	35	17	255
Cove Fort	367	AMAX98	Beaver	BE-10	(C-26-07)17a	355718	4267945	28	13	19
Cove Fort	150	AMAX98	Beaver	BE-11	(C-26-07)18c	352931	4267141	35	13	40
Cove Fort	149	AMAX98	Beaver	BE-12	(C-26-07)19b	352914	4266653	40	13	25
Cove Fort	152	AMAX98	Beaver	BE-13	(C-26-07)20d	355668	4265637	58	16	108
Cove Fort	154	AMAX98	Beaver	BE-14	(C-26-07)21d	357385	4265595		14	27
Cove Fort	268	AMAX98	Beaver	BE-15	(C-26-07)23d	360477	4265374	60	17	97
Cove Fort	323	AMAX98	Beaver	BE-16	(C-26-07)27d	358779	4264039	35	12	49
Cove Fort	155	AMAX98	Beaver	BE-17	(C-26-07)28b	356059	4264575		17	44
Cove Fort	147	AMAX98	Beaver	BE-18	(C-26-07)30a	354199	4264942	54	14	48
Cove Fort	148	AMAX98	Beaver	BE-19	(C-26-07)31d	354205	4262844		15	49
Cove Fort	287	AMAX98	Beaver	BE-20	(C-26-07)35c	359251	4262576		14	31
Cove Creek	276	AMAX98	Beaver	BE-21	(C-26-08)05c	344924	4270545	147	20	50
Cove Creek	368	AMAX98	Beaver	BE-22	(C-26-08)17b	345271	4268218	59	15	33
Roosevelt HS	Crater-2	SILL772	Beaver	BE-23	(C-26-08)30cda	343168	4264140	90	9	10
Roosevelt HS	82-33	FAUL94	Beaver	BE-24	(C-26-09)03ac	337698	4264060	1892	265	57
Roosevelt HS	UU76TG6	SILL772	Beaver	BE-25	(C-26-09)07caa	333876	4269934	98	20	28
Roosevelt HS	170	AMAX98	Beaver	BE-26	(C-26-09)08b	335100	4270497	68	19	59
Roosevelt HS	418	AMAX98	Beaver	BE-27	(C-26-09)10ab	338800	4270277	66	17	33
Roosevelt HS	191	AMAX98	Beaver	BE-28	(C-26-09)13c	341240	4268075	50	15	43
Roosevelt HS	UU76TG5	SILL772	Beaver	BE-29	(C-26-09)14daa	340893	4268159	50	15	49
Roosevelt HS	192	AMAX98	Beaver	BE-30	(C-26-09)15b	338541	4268251	59	25	208
Roosevelt HS	UU76TG1	SILL772	Beaver	BE-31	(C-26-09)15cba	338150	4268303	60	26	166
Roosevelt HS	438	AMAX98	Beaver	BE-32	(C-26-09)16a	337568	4268448	88	19	80

REGION_LOC	HOLE_NAME	PUB_REF	COUNTY	MAPNO	TRS	UTM_E (m)	UTM_N (m)	DEPTH (m)	BHT (°C)	UCGRAD (°C/km)
Roosevelt HS	341	AMAX98	Beaver	BE-33	(C-26-09)16b	336856	4268551	75	16	40
Roosevelt HS	UU76TG0	SILL772	Beaver	BE-34	(C-26-09)16bdc	336697	4268488	78	19	62
Roosevelt HS	437	AMAX98	Beaver	BE-35	(C-26-09)16d	337779	4267678	75	16	64
Roosevelt HS	UU76TG3	SILL772	Beaver	BE-36	(C-26-09)19dbc	333997	4266501	100	36	49
Roosevelt HS	383	AMAX98	Beaver	BE-37	(C-26-09)20ac	335577	4266930	43	37	468
Roosevelt HS	UU-7513	SILL772	Beaver	BE-38	(C-26-09)20ac	335645	4266911	43	37	567
Roosevelt HS	190	AMAX98	Beaver	BE-39	(C-26-09)25d	342204	4264348		14	30
Roosevelt HS	UU76	SILL772	Beaver	BE-40	(C-26-09)25dca	341960	4264341	150	15	30
Roosevelt HS	189	AMAX98	Beaver	BE-41	(C-26-09)26a	340494	4265181		20	75
Roosevelt HS	382	AMAX98	Beaver	BE-42	(C-26-09)27bb	338015	4265700	35	31	455
Roosevelt HS	UU-73	SILL772	Beaver	BE-43	(C-26-09)27bbb	337935	4265887	35	31	48
Roosevelt HS	336	AMAX98	Beaver	BE-44	(C-26-09)28d	337682	4265026		61	362
Roosevelt HS	16	AMAX98	Beaver	BE-45	(C-26-09)29a	336447	4266039		69	420
Roosevelt HS	PHIL-4	SILL772	Beaver	BE-46	(C-26-09)30c	333307	4264794	55	35	393
Roosevelt HS	14	AMAX98	Beaver	BE-47	(C-26-09)32a	335862	4263887	138	43	440
Roosevelt HS	RHS-25	SILL772	Beaver	BE-48	(C-26-09)32aa	335512	4263849	144	51	205
Roosevelt HS	335	AMAX98	Beaver	BE-49	(C-26-09)33b	336733	4263824		43	109
Roosevelt HS	188	AMAX98	Beaver	BE-50	(C-26-09)34a	339504	4263646		90	403
Roosevelt HS	426	AMAX98	Beaver	BE-51	(C-26-09)35c	340537	4262971		23	108
Roosevelt HS	12-35	FAUL94	Beaver	BE-52	(C-26-09)35c	339371	4264004	2232	227	NA
Roosevelt HS	427	AMAX98	Beaver	BE-53	(C-26-09)36a	341724	4263413		15	64
Roosevelt HS	425	AMAX98	Beaver	BE-54	(C-26-09)36b	341378	4264031		18	57
Roosevelt HS	24-36	FAUL94	Beaver	BE-55	(C-26-09)36b	340130	4262679	1738	149	79
Roosevelt HS	193	AMAX98	Beaver	BE-56	(C-26-10)19d	334318	4266438	98	37	300
Roosevelt HS	198	AMAX98	Beaver	BE-57	(C-26-10)25a	332340	4265258		33	105
Roosevelt HS	PHIL-3	SILL772	Beaver	BE-58	(C-26-10)25a	332305	4265648	85	31	120
Roosevelt HS	1-26	SHAN835	Beaver	BE-59	(C-26-10)26ca	328699	4265502	3855	230	60
Milford Valley	23	AMAX98	Beaver	BE-60	(C-26-11)24ac	322712	4267274	124	21	86
Mineral Mtns.	146	AMAX98	Beaver	BE-62	(C-27-08)04d	346909	4261348	85	12	35
Mineral Mtns.	Ryans	SILL772	Beaver	BE-63	(C-27-08)04dcd	346857	4260883	100	11	20
Mineral Mtns.	169	AMAX98	Beaver	BE-64	(C-27-08)05c	344346	4260998	152	11	16
Mineral Mtns.	101	AMAX98	Beaver	BE-65	(C-27-08)06a	343974	4262037	48	11	48

REGION_LOC	HOLE_NAME	PUB_REF	COUNTY	MAPNO	TRS	UTM_E (m)	UTM_N (m)	DEPTH (m)	BHT (°C)	UCGRAD (°C/km)
Mineral Mtns.	Crater-3	SILL772	Beaver	BE-66	(C-27-08)06aa	344328	4261853	59	11	18
Mineral Mtns.	Bearskin	SILL772	Beaver	BE-67	(C-27-08)08baa	344799	4260511	156	11	36
Roosevelt HS	Negro-21	SILL772	Beaver	BE-68	(C-27-09)01	340399	4261752	32	18	150
Roosevelt HS	103	AMAX98	Beaver	BE-69	(C-27-09)01b	341091	4261894		36	217
Roosevelt HS	102	AMAX98	Beaver	BE-70	(C-27-09)01bc	341166	4261913	22	19	375
Roosevelt HS	122	AMAX98	Beaver	BE-71	(C-27-09)02b	339992	4261883	30	20	257
Roosevelt HS	14-2	WARD7810	Beaver	BE-72	(C-27-09)02b	339339	4261951	1862	268	NA
Roosevelt HS	429	AMAX98	Beaver	BE-73	(C-27-09)02c	339922	4261418	102	25	127
Roosevelt HS	6	AMAX98	Beaver	BE-74	(C-27-09)02c	339552	4261270	54	18	143
Roosevelt HS	RHS-20	SILL772	Beaver	BE-75	(C-27-09)02caa	339895	4261818	105	25	133
Roosevelt HS	428	AMAX98	Beaver	BE-76	(C-27-09)02d	340746	4261179	55	21	120
Roosevelt HS	54-3	FAUL94	Beaver	BE-77	(C-27-09)03a	338660	4262042	878	261	10
Roosevelt HS	374	AMAX98	Beaver	BE-78	(C-27-09)03bb	337947	4262495	69	76	768
Roosevelt HS	28-3	FAUL94	Beaver	BE-79	(C-27-09)03c	337871	4260970	1097	261	NA
Roosevelt HS	3-1	FAUL94	Beaver	BE-80	(C-27-09)03c	338584	4261744	831	254	NA
Roosevelt HS	35-3	FAUL94	Beaver	BE-81	(C-27-09)03c	338286	4261661	762	260	NA
Roosevelt HS	UU-751A	SILL772	Beaver	BE-82	(C-27-09)03cbb	337674	4261596	69	76	745
Roosevelt HS	DH-11	BLAC741	Beaver	BE-83	(C-27-09)04ad	337441	4262068	58	45	455
Roosevelt HS	11	AMAX98	Beaver	BE-84	(C-27-09)04b	336680	4262094	60	45	475
Roosevelt HS	381	AMAX98	Beaver	BE-85	(C-27-09)04dd	337475	4261260	65	49	523
Roosevelt HS	UU-751B	SILL772	Beaver	BE-86	(C-27-09)04dda	337551	4261143	65	49	569
Roosevelt HS	12	AMAX98	Beaver	BE-87	(C-27-09)05b	334605	4262569	150	42	169
Roosevelt HS	DH-12	BLAC741	Beaver	BE-88	(C-27-09)05b	335014	4262226	147		155
Roosevelt HS	10	AMAX98	Beaver	BE-89	(C-27-09)07c	333008	4259616	192	41	160
Roosevelt HS	DH-10	BLAC741	Beaver	BE-90	(C-27-09)07cc	332835	4260130	189		91
Roosevelt HS	RHS-14	SILL772	Beaver	BE-91	(C-27-09)07cc	332938	4259703	195	41	75
Roosevelt HS	4	AMAX98	Beaver	BE-92	(C-27-09)07d	333982	4259462	168	41	145
Roosevelt HS	DH-4	BLAC741	Beaver	BE-93	(C-27-09)07d	334168	4259991	168		96
Roosevelt HS	RHS-15	SILL772	Beaver	BE-94	(C-27-09)07dd	334272	4259556	175	42	90
Roosevelt HS	9-1	LEAR852	Beaver	BE-95	(C-27-09)09ba	336947	4260612	2099	225	56
Roosevelt HS	13-10	FAUL94	Beaver	BE-96	(C-27-09)10b	337734	4260263	1631	248	28
Roosevelt HS	Big Cedar	SILL772	Beaver	BE-97	(C-27-09)14bdc	339487	4258440	100	20	66

REGION_LOC	HOLE_NAME	PUB_REF	COUNTY	MAPNO	TRS	UTM_E (m)	UTM_N (m)	DEPTH (m)	BHT (°C)	UCGRAD (°C/km)
Roosevelt HS	15	AMAX98	Beaver	BE-98	(C-27-09)15a	338922	4259017		53	402
Roosevelt HS	25-15	FAUL94	Beaver	BE-99	(C-27-09)15bc	338076	4258191	2287	235	73
Roosevelt HS	DH-6	BLAC741	Beaver	BE-100	(C-27-09)16	339895	4261829	95		91
Roosevelt HS	DH-5	BLAC741	Beaver	BE-101	(C-27-09)16a	336210	4259572	140		411
Roosevelt HS	72-16	WARD7810	Beaver	BE-102	(C-27-09)16a	337360	4259038	382	243	612
Roosevelt HS	RHS-7	SILL772	Beaver	BE-103	(C-27-09)16ad	337610	4258433	90	95	700
Roosevelt HS	199	AMAX98	Beaver	BE-104	(C-27-09)16bb	336295	4259240	140	74	441
Roosevelt HS	105	AMAX98	Beaver	BE-105	(C-27-09)16d	337155	4257943	18	33	1210
Roosevelt HS	7	AMAX98	Beaver	BE-106	(C-27-09)16d	337469	4258370	85	95	553
Roosevelt HS	DH-7	BLAC741	Beaver	BE-107	(C-27-09)16d	337534	4258990	85		501
Roosevelt HS	DH-8	BLAC741	Beaver	BE-108	(C-27-09)16d	337296	4258440	15		1092
Roosevelt HS	379	AMAX98	Beaver	BE-109	(C-27-09)17a	335681	4260568	185	62	250
Roosevelt HS	5	AMAX98	Beaver	BE-110	(C-27-09)17a	335908	4259312		59	333
Roosevelt HS	PHIL-5	SILL772	Beaver	BE-111	(C-27-09)17a	335819	4258803	185	62	140
Roosevelt HS	GPC-15	HELT78	Beaver	BE-112	(C-27-09)18	334241	4258047	576	69	63
Roosevelt HS	52-21	GETT78	Beaver	BE-113	(C-27-09)21ab	336771	4257118	2316	206	60
Roosevelt HS	9	AMAX98	Beaver	BE-114	(C-27-09)21c	336461	4256447	77	26	150
Roosevelt HS	DH-9	BLAC741	Beaver	BE-115	(C-27-09)21dd	337051	4257135	73		140
Roosevelt HS	121	AMAX98	Beaver	BE-116	(C-27-09)29a	335691	4255497	30	18	217
Roosevelt HS	196	AMAX98	Beaver	BE-117	(C-27-09)29ac	335333	4255553	109	32	187
Milford Valley	339	AMAX98	Beaver	BE-118	(C-27-09)30a	333649	4255606	88	32	217
Milford Valley	125	AMAX98	Beaver	BE-119	(C-27-09)32a	335534	4254246	35	21	93
Roosevelt HS	DH-2	BLAC741	Beaver	BE-120	(C-27-09)32a	335456	4255968	34		89
Milford Valley	436	AMAX98	Beaver	BE-121	(C-27-09)32b	334455	4254468	88	17	117
Milford Valley	435	AMAX98	Beaver	BE-122	(C-27-09)32c	334535	4253256	60	13	52
Roosevelt HS	UU76-1A	SILL772	Beaver	BE-123	(C-27-09)34cab	338052	4263465	64	108	1313
Roosevelt HS	EV4113	SILL772	Beaver	BE-124	(C-27-09)35	340534	4252269	36	10	44
Mineral Mtns.	195	AMAX98	Beaver	BE-125	(C-27-09)35d	339937	4253446	35	10	21
Roosevelt HS	EV4115	SILL772	Beaver	BE-126	(C-27-09)35db	340189	4252487	70	12	37
Milford Valley	22	AMAX98	Beaver	BE-127	(C-27-10)07c	323780	4260324	89	20	48
Milford Valley	3	AMAX98	Beaver	BE-128	(C-27-10)10d	329663	4259530	191	36	270
Roosevelt HS	DH-3	BLAC741	Beaver	BE-129	(C-27-10)10ddd	329607	4260198	203	36	60

REGION_LOC	HOLE_NAME	PUB_REF	COUNTY	MAPNO	TRS	UTM_E (m)	UTM_N (m)	DEPTH (m)	BHT (°C)	UCGRAD (°C/km)
Roosevelt HS	PHIL-2	SILL772	Beaver	BE-130	(C-27-10)12d	332785	4259409	115	34	120
Roosevelt HS	384	AMAX98	Beaver	BE-131	(C-27-10)12dd	332518	4259770	115	34	195
Milford Valley	13	AMAX98	Beaver	BE-132	(C-27-10)23c	329844	4256540	144	32	218
Roosevelt HS	RHS-5	SILL772	Beaver	BE-133	(C-27-10)23ca	329644	4257377	151	32	58
The Big Wash	332	AMAX98	Beaver	BE-134	(C-27-11)03d	317870	4261444	64	19	82
The Big Wash	329	AMAX98	Beaver	BE-135	(C-27-11)07d	314849	4260280	60	16	40
The Big Wash	327	AMAX98	Beaver	BE-136	(C-27-11)08a	316172	4261260	109	18	36
The Big Wash	330	AMAX98	Beaver	BE-137	(C-27-11)17ad	316420	4259112	37	16	63
The Big Wash	331	AMAX98	Beaver	BE-138	(C-27-11)17d	316060	4259031	40	17	92
The Big Wash	333	AMAX98	Beaver	BE-139	(C-27-12)10b	309038	4261493	60	19	83
The Big Wash	334	AMAX98	Beaver	BE-140	(C-27-12)11b	310766	4261475	104	22	47
The Big Wash	409	AMAX98	Beaver	BE-141	(C-27-12)19d	305358	4256974	96	18	62
San Francisco Mt	326	AMAX98	Beaver	BE-142	(C-27-12)22b	299065	4258183	70	29	130
The Big Wash	315	AMAX98	Beaver	BE-143	(C-27-12)32cc	305618	4253980	110	23	96
The Big Wash	407	AMAX98	Beaver	BE-144	(C-27-12)34a	309670	4254941	95	18	49
San Francisco Mt	337	AMAX98	Beaver	BE-145	(C-27-13)03c	299696	4262443	152	17	26
San Francisco Mt	432	AMAX98	Beaver	BE-146	(C-27-13)14d	301918	4258790	64	12	31
San Francisco Mt	433	AMAX98	Beaver	BE-147	(C-27-13)16b	297638	4260118	58	22	140
San Francisco Mt	325	AMAX98	Beaver	BE-148	(C-27-13)22b	299116	4257771	94	35	220
San Francisco Mt	388	AMAX98	Beaver	BE-149	(C-27-13)26acb	301014	4256644	200	42	142
San Francisco Mt	403	AMAX98	Beaver	BE-150	(C-27-13)26d	301310	4256062	65	24	161
San Francisco Mt	434	AMAX98	Beaver	BE-151	(C-27-13)27d	299833	4255677	45	22	222
San Francisco Mt	318	AMAX98	Beaver	BE-152	(C-27-13)36d	303109	4254297	68	18	92
San Francisco Mt	319	AMAX98	Beaver	BE-153	(C-27-13)36d	303083	4254641	53	17	93
Milford Valley	338	AMAX98	Beaver	BE-154	(C-28-09)04b	336106	4252746	88	17	56
Mineral Mtns.	194	AMAX98	Beaver	BE-155	(C-28-09)16b	336279	4249213	25	12	35
Milford Valley	341	AMAX98	Beaver	BE-156	(C-28-10)01b	331672	4252905		22	52
Milford Valley	133	AMAX98	Beaver	BE-157	(C-28-10)21d	327543	4246542	30	15	60
Star Range	131	AMAX98	Beaver	BE-158	(C-28-11)28a	317270	4246179		17	12
The Big Wash	408	AMAX98	Beaver	BE-159	(C-28-12)05d	306235	4252011	143	18	48
The Big Wash	405	AMAX98	Beaver	BE-160	(C-28-12)07c	304402	4251023	65	16	59
The Big Wash	317	AMAX98	Beaver	BE-161	(C-28-12)08c	305854	4250343	88	18	64

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The Big Wash	316	AMAX98	Beaver	BE-162	(C-28-12)09c	307288	4250731	78	16	46
The Big Wash	404	AMAX98	Beaver	BE-163	(C-28-12)15c	309177	4249331	95	15	36
San Francisco Mt	312	AMAX98	Beaver	BE-164	(C-28-13)02cd	301282	4252820	103	18	53
The Big Wash	406	AMAX98	Beaver	BE-165	(C-28-13)13c	302108	4249080	95	16	56
White Mountain	311	AMAX98	Beaver	BE-166	(C-28-13)35c	300841	4244514	42	14	40
Wah Wah Valley	310	AMAX98	Beaver	BE-167	(C-28-14)03bd	289092	4253514	220	26	42
Wah Wah Valley	308	AMAX98	Beaver	BE-168	(C-28-14)27	289555	4246917	230	20	35
Wah Wah Valley	402	AMAX98	Beaver	BE-169	(C-28-14)36d	293381	4244579	65	17	58
Beaver Basin	413	AMAX98	Beaver	BE-170	(C-29-06)19b	361751	4237436	95	16	44
Mineral Mtns.	213	AMAX98	Beaver	BE-171	(C-29-08)06ab	342815	4242910	98	13	14
Beaver Basin	417	AMAX98	Beaver	BE-172	(C-29-08)26a	349277	4235794	95	16	49
Mineral Mtns.	214	AMAX98	Beaver	BE-173	(C-29-09)02cc	339034	4241875	148	12	11
Mineral Mtns.	216	AMAX98	Beaver	BE-174	(C-29-09)16cd	336027	4238516	90	13	44
Mineral Mtns.	410	AMAX98	Beaver	BE-175	(C-29-09)19a	333430	4238203	60	14	26
Mineral Mtns.	106	AMAX98	Beaver	BE-176	(C-29-09)20a	334874	4237340		21	77
Mineral Mtns.	163	AMAX98	Beaver	BE-177	(C-29-09)20a	335367	4237941	62	13	1
Mineral Mtns.	0	AMAX98	Beaver	BE-178	(C-29-09)20c	334567	4235615	93	16	49
Mineral Mtns.	324	AMAX98	Beaver	BE-179	(C-29-09)20c	333913	4237016	58	15	18
Mineral Mtns.	411	AMAX98	Beaver	BE-180	(C-29-09)20c	334211	4237032	55	17	28
Mineral Mtns.	103	AMAX98	Beaver	BE-181	(C-29-09)20cd	334760	4236887	24	14	70
Mineral Mtns.	412	AMAX98	Beaver	BE-182	(C-29-09)21a	336827	4237867	58	11	35
Beaver Basin	220	AMAX98	Beaver	BE-183	(C-29-09)26dc	339976	4235095	64	16	41
Mineral Mtns.	134	AMAX98	Beaver	BE-184	(C-29-09)29b	334335	4235819	52	14	44
Milford Valley	301	AMAX98	Beaver	BE-185	(C-29-10)03b	327911	4242481	50	14	64
Mineral Mtns.	217	AMAX98	Beaver	BE-186	(C-29-10)12ca	331475	4240541	97	14	15
Milford Valley	302	AMAX98	Beaver	BE-187	(C-29-10)15b	328185	4239289	60	16	107
Minersville	218	AMAX98	Beaver	BE-188	(C-29-10)24cd	331247	4236782	97	17	36
Minersville	303	AMAX98	Beaver	BE-189	(C-29-10)33a	326630	4234515	45	14	135
Thermo HS	E-1	REPU77	Beaver	BE-190	(C-29-11)11dbb	321036	4240304	146	22	55
Thermo HS	E-21	REPU77	Beaver	BE-191	(C-29-11)11dbb	320232	4241075	450	39	57
Star Range	172	AMAX98	Beaver	BE-192	(C-29-12)02d	310814	4242320	50	16	34
Thermo HS	EV-1322	REPU77	Beaver	BE-193	(C-29-12)33dcc	306395	4234302	152	21	39

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Thermo HS	128	AMAX98	Beaver	BE-194	(C-29-12)36b	311223	4234738	30	14	37
Thermo HS	EV-1512	REPU77	Beaver	BE-195	(C-29-12)36ccc	311251	4234090	152	19	34
White Mountain	286	AMAX98	Beaver	BE-196	(C-29-13)06b	294525	4243129	75	14	18
White Mountain	285	AMAX98	Beaver	BE-197	(C-29-13)07a	294639	4241760	66	18	82
White Mountain	283	AMAX98	Beaver	BE-198	(C-29-13)08a	296830	4242271	67	14	26
White Mountain	284	AMAX98	Beaver	BE-199	(C-29-13)18a	295296	4241121	65	16	46
Wah Wah Valley	304	AMAX98	Beaver	BE-200	(C-29-14)12c	292164	4241512	157	24	70
Beaver Basin	414	AMAX98	Beaver	BE-201	(C-30-07)02a	358070	4232616	70	18	84
Beaver Basin	416	AMAX98	Beaver	BE-202	(C-30-08)03b	348340	4233003	95	15	28
Beaver Basin	415	AMAX98	Beaver	BE-203	(C-30-08)10c	347145	4229950	95	13	16
Minersville	300	AMAX98	Beaver	BE-204	(C-30-10)06d	323987	4232163	41	14	17
Minersville	421	AMAX98	Beaver	BE-205	(C-30-10)13c	331321	4228543	85	19	55
Black Mtns.	420	AMAX98	Beaver	BE-206	(C-30-10)28d	326559	4225868	80	21	92
Black Mtns.	419	AMAX98	Beaver	BE-207	(C-30-10)32c	324150	4223955	90	22	90
Thermo HS	EV-2222	REPU77	Beaver	BE-208	(C-30-11)18bdd	313311	4229442	152	20	56
Black Mtns.	345	AMAX98	Beaver	BE-209	(C-30-11)22a	318952	4228732	29	21	297
Black Mtns.	186	AMAX98	Beaver	BE-210	(C-30-11)26d	319869	4225792	35	19	157
Black Mtns.	108	AMAX98	Beaver	BE-211	(C-30-11)27b	317992	4226922	91	20	65
Black Mtns.	118	AMAX98	Beaver	BE-212	(C-30-11)30d	313460	4226159	28	17	84
Black Mtns.	274	AMAX98	Beaver	BE-213	(C-30-11)32a	315044	4225245	64	24	122
Black Mtns.	347	AMAX98	Beaver	BE-214	(C-30-11)34b	317970	4225557	37	18	133
Black Mtns.	289	AMAX98	Beaver	BE-215	(C-30-11)34cb	317744	4224463	63	19	72
Black Mtns.	224	AMAX98	Beaver	BE-216	(C-30-11)36a	321432	4225113	67	20	82
Thermo HS	129	AMAX98	Beaver	BE-217	(C-30-12)01b	311223	4233972	38	15	32
Thermo HS	348	AMAX98	Beaver	BE-218	(C-30-12)04d	307187	4232579	40	17	94
Thermo HS	E-5a	REPU77	Beaver	BE-219	(C-30-12)08cbb	304578	4230915	46	15	33
Thermo HS	EV-1410	REPU77	Beaver	BE-220	(C-30-12)09daa	307811	4231673	152	24	51
Thermo HS	116	AMAX98	Beaver	BE-221	(C-30-12)11b	309475	4232269	40	17	82
Thermo HS	EV-1033	REPU77	Beaver	BE-222	(C-30-12)12bcb	311107	4231866	152	21	61
Thermo HS	E-20	REPU77	Beaver	BE-223	(C-30-12)17dcc	306147	4229279	116	27	133
Thermo HS	EV-1622	REPU77	Beaver	BE-224	(C-30-12)20caa	305274	4228359	152	22	100
Thermo HS	349	AMAX98	Beaver	BE-225	(C-30-12)20d	305956	4227645	29	12	63

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Thermo HS	E-22	REPU77	Beaver	BE-226	(C-30-12)21cbc	306103	4227647	552	51	70
Thermo HS	350	AMAX98	Beaver	BE-227	(C-30-12)22c	308274	4228156	29	22	494
Thermo HS	119	AMAX98	Beaver	BE-228	(C-30-12)23b	309400	4229084	265	14	222
Black Mtns.	346	AMAX98	Beaver	BE-229	(C-30-12)25d	312473	4226292	30	18	187
Thermo HS	352	AMAX98	Beaver	BE-230	(C-30-12)27a	309218	4226923	30	15	94
Thermo HS	351	AMAX98	Beaver	BE-231	(C-30-12)27c	307878	4226622	32	26	331
Thermo HS	E-10	REPU77	Beaver	BE-232	(C-30-12)29ccc	304449	4226077	143	31	136
Thermo HS	E-23	REPU77	Beaver	BE-233	(C-30-12)29ccc	304460	4226085	750	32	120
Thermo HS	353	AMAX98	Beaver	BE-234	(C-30-12)29d	305347	4226349	29	14	110
Thermo HS	57-29	REPU77	Beaver	BE-235	(C-30-12)29dcb	305495	4226452	2221	160	49
Thermo HS	EV-232	REPU77	Beaver	BE-236	(C-30-12)29ddd	305976	4226141	152	30	124
Thermo HS	250	AMAX98	Beaver	BE-237	(C-30-12)32d	305515	4224968	68	20	111
Thermo HS	251	AMAX98	Beaver	BE-238	(C-30-12)34a	308561	4225840	67	24	121
Black Mtns.	249	AMAX98	Beaver	BE-239	(C-30-12)36a	312456	4225194	67	19	66
Black Mtns.	113	AMAX98	Beaver	BE-240	(C-30-12)36dd	312295	4224276	63	26	131
Escalante Des.	BM-4	CHAP813	Beaver	BE-241	(C-30-12)36ddc	312234	4224333	65	26	163
Thermo HS	320	AMAX98	Beaver	BE-242	(C-30-13)02c	300290	4233152	123	18	22
Thermo HS	E-6	REPU77	Beaver	BE-243	(C-30-13)02cbc	299780	4232623	128	17	24
Thermo HS	E-7	REPU77	Beaver	BE-244	(C-30-13)17abb	296530	4231090	143	23	51
Thermo HS	EV-540	REPU77	Beaver	BE-245	(C-30-13)24add	302892	4228566	152	24	60
Thermo HS	E-12	REPU77	Beaver	BE-246	(C-30-13)34abb	299628	4226185	137	18	57
Thermo HS	EV-411	REPU77	Beaver	BE-247	(C-30-13)36aaa	302827	4226082	152	23	41
Wasatch Front	UT/GH-B	MURP792	Box Elder	BO-1	(B-07-02)14ddd	413842	4576460	27	59	633
Wasatch Front	Christensen 1-9	HENR00	Box Elder	BO-2	(B-09-03)24da	406199	4594483	1829	107	58
Great Salt Lake	Chesapeak Energy Co. #1A	HENR00	Box Elder	BO-3	(B-09-03)27cc	402021	4592995	1408	97	69
Little Mountain	RDH-21	AMAX98	Box Elder	BO-4	(B-10-01)01acc	397002	4609256	19	16	240
Little Mountain	RDH-13	AMAX98	Box Elder	BO-5	(B-10-03)18baa	397734	4606824	147	17	34
Little Mountain	RDH-14	AMAX98	Box Elder	BO-6	(B-10-03)18bcb	397566	4606183	152	17	32
Little Mountain	RDH-27	AMAX98	Box Elder	BO-7	(B-10-03)18dcb	397841	4605601	152	19	36
Little Mountain	RDH-9	AMAX98	Box Elder	BO-8	(B-10-03)19bda	397727	4604604	106	21	64
Little Mountain	RDH-8	AMAX98	Box Elder	BO-9	(B-10-03)19cbb	397016	4604425	112	38	200
Little Mountain	RDH-22	AMAX98	Box Elder	BO-10	(B-10-04)01cad	396189	4608956	37	14	53

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Little Mountain	RDH-17	AMAX98	Box Elder	BO-11	(B-10-04)11dcd	394900	4606843	66	19	NA
Little Mountain	RDH-18	AMAX98	Box Elder	BO-12	(B-10-04)12abd	396501	4608064	17	12	20
Little Mountain	RDH-23a	AMAX98	Box Elder	BO-13	(B-10-04)12bba	395671	4608275	23	14	32
Little Mountain	RDH-23b	AMAX98	Box Elder	BO-14	(B-10-04)12cab	395960	4607538	24	15	13
Little Mountain	RDH-15	AMAX98	Box Elder	BO-15	(B-10-04)13dad	396926	4605703	141	24	66
Little Mountain	RDH-16	AMAX98	Box Elder	BO-16	(B-10-04)14cdc	394886	4605333	27	20	100
Little Mountain	RDH-6	AMAX98	Box Elder	BO-17	(B-10-04)23dda	395236	4604140	30	22	500
Little Mountain	RDH-7	AMAX98	Box Elder	BO-18	(B-10-04)24aca	396577	4604642	142	28	96
Little Mountain	RDH-26	AMAX98	Box Elder	BO-19	(B-10-04)24bcd	395824	4604486	152	27	78
Little Mountain	RDH-1	AMAX98	Box Elder	BO-20	(B-10-04)24dcd	395864	4603742	12	47	2000
Little Mountain	RDH-2	AMAX98	Box Elder	BO-21	(B-10-04)25aad	396809	4603395	42	38	546
Wasatch Front	C(M)/GH-A	MURP792	Box Elder	BO-22	(B-11-02)29dad	409573	4612296	67	61	263
Wasatch Front	BEP-05	KLAU842	Box Elder	BO-23	(B-11-03)05	397832	4619760	43	14	34
Wasatch Front	BEP-06	KLAU842	Box Elder	BO-24	(B-11-04)03	392186	4619287	86	14	18
Wasatch Front	BEP-07	KLAU842	Box Elder	BO-25	(B-11-04)04	392019	4618981	90	15	21
Curlew Valley	TG-14	DAVI842	Box Elder	BO-26	(B-11-12)04cbc	407567	4627432	65	15	44
Curlew Valley	TG-15	DAVI842	Box Elder	BO-27	(B-11-12)05dbb	323556	4629013	56	14	75
Wasatch Front	BEP-10	KLAU842	Box Elder	BO-28	(B-12-02)03	412530	4629281	88	20	11
Wasatch Front	BEP-02	KLAU842	Box Elder	BO-29	(B-12-03)11	404294	4627477	35	15	27
Wasatch Front	BEP-01	KLAU842	Box Elder	BO-30	(B-12-04)22	392818	4622979	37	13	64
Wasatch Front	BEP-12	KLAU842	Box Elder	BO-31	(B-13-02)28	411414	4630498	184	22	65
Wasatch Front	UDY/GH-B	MURP792	Box Elder	BO-32	(B-13-03)23bdb	403762	4633880	82	45	325
Wasatch Front	BEP-13	KLAU842	Box Elder	BO-33	(B-13-03)28	401654	4632168	30	15	185
Hansel Valley	TG-01	DAVI842	Box Elder	BO-34	(B-13-06)30bbc	367963	4631848	93	17	86
Curlew Valley	TG-09	DAVI842	Box Elder	BO-35	(B-13-07)23bcd	365110	4633506	65	14	46
Curlew Valley	TG-10	DAVI842	Box Elder	BO-36	(B-13-09)01bcd	349088	4638486	101	8	39
Curlew Valley	TG-06	DAVI842	Box Elder	BO-37	(B-13-10)11dcd	338430	4636283	39	13	65
Curlew Valley	TG-07	DAVI842	Box Elder	BO-38	(B--13-10)34dd	336945	4629806	22	15	44
Curlew Valley	TG-13	DAVI842	Box Elder	BO-39	(B-13-11)10cdc	326466	4636626	82	17	59
Wasatch Front	BEP-04	KLAU842	Box Elder	BO-40	(B-14-02)11	403303	4636403	66	19	140
Wasatch Front	BEP-11	KLAU842	Box Elder	BO-41	(B-14-03)35	404409	4639749	130	14	10
Curlew Valley	TG-12	DAVI842	Box Elder	BO-42	(B-14-08)06abb	351382	4648930	43	16	135

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Curlew Valley	TG-11	DAVI842	Box Elder	BO-43	(B-14-08)28bbb	353757	4642400	51	11	44
Curlew Valley	TG-03	DAVI842	Box Elder	BO-44	(B-14-09)02dbb	347839	4629658	100	24	267
Curlew Valley	TG-08	DAVI842	Box Elder	BO-45	(B-14-09)04cbb	344111	4648129	76	20	119
Curlew Valley	TG-16	DAVI842	Box Elder	BO-46	(B-14-09)10ada	347215	4646797	27	12	11
Curlew Valley	TG-05	DAVI842	Box Elder	BO-47	(B-14-10)15bbb	336114	4645871	105	14	NA
Curlew Valley	TG-02	DAVI842	Box Elder	BO-48	(B-15-08)36cba	358945	4649546	29	10	18
Curlew Valley	TG-04	DAVI842	Box Elder	BO-49	(B-15-09)28dbd	345213	4651129	134	42	182
Great Salt Lake	Indian Cove - State of Utah #1	HENR00	Box Elder	BO-50	(B-GSL)	364637	4573531	2399	148	62
Great Salt Lake	Indian Cove - State of Utah #1	HENR00	Box Elder	BO-50	(B-GSL)	364637	4573531	1076	76	71
Great Salt Lake	State of Utah "J" #1	HENR00	Box Elder	BO-51	(B-GSL)	361828	4584823	2073	138	67
Great Salt Lake	State of Utah "L" #1	HENR00	Box Elder	BO-52	(B-GSL)	365275	4559593	3490	167	48
Great Salt Lake	State of Utah "Q" #1	HENR00	Box Elder	BO-53	(B-GSL)	346667	4601767	1488	65	44
Great Salt Lake	State of Utah K#1	HENR00	Box Elder	BO-54	(B-GSL)	347046	4588530	1279	58	45
Great Salt Lake	State of Utah P #1	HENR00	Box Elder	BO-55	(B-GSL)	353203	4578451	2391	108	45
Great Salt Lake	W ROZEL STATE UNIT #1	HENR00	Box Elder	BO-56	(B-GSL)	355092	4585022	2591	105	41
Wasatch Front	BEP-03	KLAU842	Box Elder	BO-57	(C-12-02)02	414043	4628308	82	20	135
Wasatch Front	BEP-09	KLAU842	Box Elder	BO-58	(C-13-03)22	403070	4632797	72	24	129
Cache Valley	CVG-06	DEVR82	Cache	CA-1	(A-09-01)10add	432194	4598067	41	12	32
Cache Valley	CVG-03	DEVR82	Cache	CA-2	(A-10-01)16bbd	429450	4606610	85	13	15
Cache Valley	CVG-04	DEVR82	Cache	CA-3	(A-10-01)23baa	433144	4614946	199	16	40
Cache Valley	CVG-01	DEVR82	Cache	CA-4	(A-10-01)26bbb	432295	4603518	53	11	NA
Cache Valley	CVG-02	DEVR82	Cache	CA-5	(A-10-01)27dad	432078	4602565	49	11	NA
Cache Valley	CVG-07	DEVR82	Cache	CA-6	(A-11-01)03acd	431952	4619166	112	11	NA
Cache Valley	CVG-09	DEVR82	Cache	CA-7	(A-12-01)27aaa	432386	4622848	38	33	297
Cache Valley	CVG-10	DEVR82	Cache	CA-8	(A-13-01)03adb	429057	4643366	125	14	36
Cache Valley	CVG-08	DEVR82	Cache	CA-9	(A-13-01)35cdc	432840	4629605	127	16	52
Cache Valley	Steven Szot 1	HENR00	Cache	CA-10	(A-14-01)30ba	426485	4642404	2721	122	45
Cache Valley	CVG-05	DEVR82	Cache	CA-11	(B-10-01)13bca	424447	4606350	34	11	29
Cache Valley	CVG-12	DEVR82	Cache	CA-12	(B-14-01)28cdb	419929	4641142	54	16	36
Cache Valley	CVG-11	DEVR82	Cache	CA-13	(B-15-02)32dda	409740	4649271	179	13	31
Book Cliffs	Stone Cabin #4-A-19	HENR00	Carbon	CR-1	(D-12-15)19aa	566375	4399588	2193	64	29
Book Cliffs	Stobin Federal 21-22	HENR00	Carbon	CR-2	(D-12-15)22ba	566410	4401509	2135	65	31

REGION_LOC	HOLE_NAME	PUB_REF	COUNTY	MAPNO	TRS	UTM_E (m)	UTM_N (m)	DEPTH (m)	BHT (°C)	UCGRAD (°C/km)
Wasatch Plateau	Wildcat Canyon Fed #1	HENR00	Carbon	CR-3	(D-13-08)23cc	499880	4391188	1445	47	32
Wasatch Plateau	Wildcat Canyon Fed #1	HENR00	Carbon	CR-3	(D-13-08)23cc	499880	4391188	969	36	37
Book Cliffs	Jack Canyon 101	HENR00	Carbon	CR-4	(D-13-16)04ab	575003	4397037	4124	114	28
Book Cliffs	Jack Canyon 101	HENR00	Carbon	CR-4	(D-13-16)04ab	575003	4397037	5460	155	28
Book Cliffs	Jack Canyon 101	HENR00	Carbon	CR-4	(D-13-16)04ab	575003	4397037	968	36	38
Wasatch Plateau	Gordon Creek #1	HENR00	Carbon	CR-5	(D-14-08)19dc	494358	4381835	3106	74	24
Wasatch Plateau	Gordon Creek #1	HENR00	Carbon	CR-5	(D-14-08)19dc	494358	4381835	3555	87	25
Wasatch Plateau	State of Utah "S" #1	HENR00	Carbon	CR-6	(D-14-08)33ad	497792	4379325	1246	53	43
Mancos Lowland	Pinnacle Peak Unit #2	HENR00	Carbon	CR-7	(D-14-09)19dd	504182	4381812	960	40	41
Mancos Lowland	Gov't W.A. Drew #1	HENR00	Carbon	CR-8	(D-14-09)34cc	508041	4378596	4241	54	13
Mancos Lowland	State #1-16	HENR00	Carbon	CR-9	(D-14-11)16dc	526753	4383400	3701	96	26
Mancos Lowland	State #1-16	HENR00	Carbon	CR-9	(D-14-11)16dc	526753	4383400	1919	60	31
Uinta Mtns.	Clay Basin Unit Well 59-S	HENR00	Daggett	DG-1	(A-03-24)16cc	649777	4538740	1833	46	25
Uinta Mtns.	Clay Basin Unit #24-S	HENR00	Daggett	DG-2	(A-03-24)21cb	649895	4537909	1765	50	28
Uinta Mtns.	Clay Basin Unit #62	HENR00	Daggett	DG-3	(A-03-24)21cc	651055	4537167	1707	54	32
Uinta Mtns.	Clay Basin Unit #28-S	HENR00	Daggett	DG-4	(A-03-24)22db	652232	4537657	1800	62	34
Uinta Mtns.	Clay Basin Unit Well 46-S	HENR00	Daggett	DG-5	(A-03-24)26bc	653010	4536696	1859	49	27
Uinta Mtns.	12-29 Clay Basin Fed	HENR00	Daggett	DG-6	(A-03-25)29bc	657902	4536666	2222	68	31
Hill AFB	HAFB-1	GLEN807	Davis	DA-1	(A-04-01)16cdd	419351	4547315	390	13	NA
Hill AFB	HAFB-2	GLEN807	Davis	DA-2	(A-04-01)20adb	418505	4546769	994	40	80
Wasatch Plateau	Clear Creek Unit 1	HENR00	Emery	EM-1	(D-14-07)19cd	484182	4381782	2852	81	28
Mancos Lowland	Skyline Spjut #16-1	HENR00	Emery	EM-2	(D-16-11)16ba	526239	4365119	2880	82	28
Book Cliffs	Wilcox #1-24	HENR00	Emery	EM-3	(D-16-15)24dd	569871	4362559	2615	74	28
Book Cliffs	Wilcox #1-24	HENR00	Emery	EM-3	(D-16-15)24dd	569871	4362559	3867	117	30
Book Cliffs	Range Creek Fed Unit #2	HENR00	Emery	EM-4	(D-17-16)27bd	569356	4348837	2027	59	29
Wasatch Plateau	Fed 41-33	HENR00	Emery	EM-5	(D-18-07)33aa	488354	4340558	3746	99	27
Mancos Lowland	Lawrence 15-1	HENR00	Emery	EM-6	(D-18-08)01dc	502562	4347530	2965	98	33
Book Cliffs	Range Creek Fed #1	HENR00	Emery	EM-7	(D-18-16)06ab	571007	4349406	4307	112	26
Book Cliffs	Range Creek Fed #1	HENR00	Emery	EM-7	(D-18-16)06ab	571007	4349406	2269	63	28
Green River Des.	Texaco Gov't Weber #1	HENR00	Emery	EM-8	(D-23-13)13db	548684	4295534	1890	57	30
Green River Des.	Jessies Twist Fed #1-9	HENR00	Emery	EM-9	(D-23-14)09dd	553737	4296843	1663	59	36
Green River Des.	IRON WASH FEDERAL #1	HENR00	Emery	EM-10	(D-24-13)03db	545386	4289090	1159	41	35

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Green River Des.	Fed #11-24-13	HENR00	Emery	EM-11	(D-24-13)11ac	547332	4287814	1287	42	33
Green River Des.	Fed Armstrong #1	HENR00	Emery	EM-12	(D-24-14)10aa	555464	4288255	2220	82	37
Green River Des.	Fed #1-29MW	HENR00	Emery	EM-13	(D-24-15)29ba	561351	4283315	2572	60	24
Green River Des.	Ruby#1	HENR00	Emery	EM-14	(D-24-16)15ca	574761	4286204	1405	42	30
Green River Des.	Gruver Fed #1-22	HENR00	Emery	EM-15	(D-24-16)22ba	574424	4285025	1402	53	38
Green River Des.	Temple Wash Govt. 998-A-#1	HENR00	Emery	EM-16	(D-25-13)11bb	547466	4278349	1577	48	30
Green River Des.	Paradox #1-12	HENR00	Emery	EM-17	(D-25-13)12ba	549520	4278306	1506	46	31
Green River Des.	N Spring Cr. Fed #1	HENR00	Emery	EM-18	(D-26-15)21ab	562907	4265672	1879	66	35
High Plateaus	Allen Fee #1	HENR00	Garfield	GA-1	(C-31-02)03cc	412120	4220663	1768	76	43
High Plateaus	Forest Cr. Divide Unit #1	HENR00	Garfield	GA-2	(C-31-02)28ba	411188	4215569	1122	52	47
High Plateaus	Boulder Mtn. Fed #1	HENR00	Garfield	GA-3	(C-31-04)18ba	455538	4218579	2654	64	24
High Plateaus	Black Canyon #1	HENR00	Garfield	GA-4	(C-32-02)23db	414583	4206477	3367	108	32
High Plateaus	Dixie Unit #2	HENR00	Garfield	GA-5	(C-33-04)02cc	384942	4202446	3138	86	27
High Plateaus	Dixie Unit #2	HENR00	Garfield	GA-5	(C-33-04)02cc	384942	4202446	4653	150	32
High Plateaus	Dixie Unit #2	HENR00	Garfield	GA-5	(C-33-04)02cc	384942	4202446	2360	76	32
High Plateaus	Clay Creek Fed 13-29	HENR00	Garfield	GA-6	(C-34-02)29cc	408763	4185257	3828	98	26
High Plateaus	Clay Creek Fed 13-29	HENR00	Garfield	GA-6	(C-34-02)29cc	408763	4185257	2941	77	26
High Plateaus	Dixie #1-19	HENR00	Garfield	GA-7	(C-34-04)19ca	381026	4188109	2829	73	26
Henry Mtns.	Fed Apple #22-7	HENR00	Garfield	GA-8	(D-31-09)22ac	508681	4216387	1905	54	28
Henry Mtns.	Fed Apple Bush Flats #22-4	HENR00	Garfield	GA-9	(D-31-09)22bb	507830	4216653	2074	49	24
Henry Mtns.	Ellen Unit #1	HENR00	Garfield	GA-10	(D-31-09)24cd	511969	4216247	2454	54	22
Henry Mtns.	Poison Sprs Unit #2 USA	HENR00	Garfield	GA-11	(D-31-12)04aa	536136	4221966	1329	45	34
Henry Mtns.	Dirty Devil Fed #1	HENR00	Garfield	GA-12	(D-31-13)07ac	542213	4219488	1448	42	29
Henry Mtns.	Garfield Fed #1	HENR00	Garfield	GA-13	(D-31-13)08bc	543221	4219571	1297	43	33
High Plateaus	Fed Harvey #1-10R	HENR00	Garfield	GA-14	(D-32-01)10bb	431386	4210347	1525	55	36
Henry Mtns.	Fed Cave Flat #24-7	HENR00	Garfield	GA-15	(D-33-09)24ac	511751	4196897	1903	52	27
Henry Mtns.	Hog Canyon #1	HENR00	Garfield	GA-16	(D-33-13)08bb	543084	4200564	2021	49	24
Kaiparowits Plat	Upper Valley #22	HENR00	Garfield	GA-17	(D-36-01)14bd	432875	4170091	2465	63	26
Kaiparowits Plat	Upper Valley Unit #39	HENR00	Garfield	GA-18	(D-36-01)24cb	434252	4168005	2176	62	28
Kaiparowits Plat	Trap Canyon #1	HENR00	Garfield	GA-19	(D-37-02)19ab	436514	4159344	2326	52	22
Book Cliffs	One Eye State 17-3	HENR00	Grand	GR-1	(D-17-21)17bd	618726	4354338	2988	100	33
Book Cliffs	Bogart Canyon 14-4	HENR00	Grand	GR-2	(D-18-20)35bc	613228	4339915	2460	73	30

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Book Cliffs	Rattlesnake Canyon 2-12	HENR00	Grand	GR-3	(D-19-19)02cb	604027	4336868	1460	45	31
Book Cliffs	Rattlesnake Canyon 2-12	HENR00	Grand	GR-3	(D-19-19)02cb	604027	4336868	2483	77	31
Mancos Lowland	Federal 1-26	HENR00	Grand	GR-4	(D-21-17)26ad	586102	4312255	2521	68	27
Book Cliffs	Blaze A No.1	HENR00	Grand	GR-5	(D-21-18)12ca	596378	4316614	2291	75	33
Book Cliffs	Blaze A No.1	HENR00	Grand	GR-5	(D-21-18)12ca	596378	4316614	1765	62	35
Book Cliffs	#1 Salt Valley N.W. Unit	HENR00	Grand	GR-6	(D-21-18)23bc	594801	4313842	2375	71	30
Mancos Lowland	Govt Smoot #3	HENR00	Grand	GR-7	(D-23-17)17da	581540	4295715	2648	72	27
Mancos Lowland	Gorman Fed #1	HENR00	Grand	GR-8	(D-23-17)21ba	582323	4294747	2742	74	27
Mancos Lowland	Fed Skyline #1A S.W.	HENR00	Grand	GR-9	(D-23-17)21dd	583134	4293567	2704	73	27
Mancos Lowland	Shell Quintana Fed #1-1	HENR00	Grand	GR-10	(D-24-17)01ca	587093	4289037	2786	79	28
Salt Anticline	Salt Valley #1	HENR00	Grand	GR-11	(D-24-20)16ba	611319	4287064	2666	60	23
Salt Anticline	Salt Valley #1	HENR00	Grand	GR-11	(D-24-20)16ba	611319	4287064	3449	78	23
Salt Anticline	Salt Valley #1	HENR00	Grand	GR-11	(D-24-20)16ba	611319	4287064	3206	75	23
Salt Anticline	Conoco Federal #31-1	HENR00	Grand	GR-12	(D-24-23)31db	637969	4281143	3442	67	20
Salt Anticline	Onion Creek Fed No.1	HENR00	Grand	GR-13	(D-24-25)18bc	655484	4286750	5752	141	24
Salt Anticline	Onion Creek Fed No.1	HENR00	Grand	GR-13	(D-24-25)18bc	655484	4286750	3843	97	25
Green River Des.	Quintana 1-35	HENR00	Grand	GR-14	(D-25-18)35cd	595395	4270732	2478	54	22
Salt Anticline	Moab Fed 16-9	HENR00	Grand	GR-15	(D-25-20)09dd	612268	4277055	3037	59	19
Salt Anticline	Gold Bar Unit No.2	HENR00	Grand	GR-16	(D-25-20)23cd	614513	4274112	2951	71	24
Salt Anticline	Arches Fed. 1	HENR00	Grand	GR-17	(D-25-21)18cb	617650	4275790	2439	55	22
Green River Des.	Mineral Canyon Federal 1-3	HENR00	Grand	GR-18	(D-26-19)03ad	604156	4269587	2492	52	21
Green River Des.	USA Sunburst #1	HENR00	Grand	GR-19	(D-26-19)14cc	604767	4265544	2470	55	22
Green River Des.	Mineral Canyon #1-14	HENR00	Grand	GR-20	(D-26-19)14dc	605576	4265654	2487	52	21
Canyonlands	Coors USA No.1-10-LC	HENR00	Grand	GR-21	(D-26-20)10cd	613207	4267357	2597	66	25
Black Mtns.	252	AMAX98	Iron	IR-1	(C-31-11)02ba	319415	4223915	60	30	268
Black Mtns.	59	AMAX98	Iron	IR-2	(C-31-11)03db	318004	4223180	704	59	28
Black Mtns.	279	AMAX98	Iron	IR-3	(C-31-11)07d	313324	4221010	65	16	52
Black Mtns.	290	AMAX98	Iron	IR-4	(C-31-11)09b	315859	4222140	20	16	198
Black Mtns.	291	AMAX98	Iron	IR-5	(C-31-11)09b	315799	4221820	63	25	178
Black Mtns.	BM-3	CHAP813	Iron	IR-6	(C-31-11)09bcd	315878	4221429	65	25	178
Black Mtns.	51-A	AMAX98	Iron	IR-7	(C-31-11)10a	318352	4222251	710	42	NA
Black Mtns.	62-A	AMAX98	Iron	IR-8	(C-31-11)10cb	317320	4221996	485	56	81

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Black Mtns.	288	AMAX98	Iron	IR-9	(C-31-11)14b	319265	4220332	83	21	110
Black Mtns.	222	AMAX98	Iron	IR-10	(C-31-11)16b	315857	4220108	67	18	90
Black Mtns.	342	AMAX98	Iron	IR-11	(C-31-11)18a	313521	4220006		18	43
Black Mtns.	BM-1	CHAP813	Iron	IR-12	(C-31-11)18adb	313700	4220169	75	17	49
Black Mtns.	160	AMAX98	Iron	IR-13	(C-31-11)19a	313060	4218684	42	15	72
Black Mtns.	BM-2	CHAP813	Iron	IR-14	(C-31-11)19c	312613	4217562	45	15	78
Black Mtns.	171	AMAX98	Iron	IR-15	(C-31-11)27b	317601	4216516	45	13	39
Black Mtns.	223	AMAX98	Iron	IR-16	(C-31-11)29c	314134	4216128	67	15	44
Black Mtns.	343	AMAX98	Iron	IR-17	(C-31-12)01a	312108	4223403		31	145
Thermo HS	354	AMAX98	Iron	IR-18	(C-31-12)01b	310951	4224185		25	119
Thermo HS	126	AMAX98	Iron	IR-19	(C-31-12)03d	308436	4222789	28	19	204
Thermo HS	355	AMAX98	Iron	IR-20	(C-31-12)04a	306951	4223391	38	15	72
Black Mtns.	183	AMAX98	Iron	IR-21	(C-31-12)15c	307784	4219318	30	15	65
Black Mtns.	221	AMAX98	Iron	IR-22	(C-31-12)16a	306944	4219771	92	19	64
Black Mtns.	280	AMAX98	Iron	IR-23	(C-31-12)25d	311895	4216113	60	15	58
Black Mtns.	115	AMAX98	Iron	IR-24	(C-31-12)29ad	305727	4216558	63	18	90
Black Mtns.	BM-7	CHAP813	Iron	IR-25	(C-31-12)29da	305744	4216557	68	18	84
Black Mtns.	322	AMAX98	Iron	IR-26	(C-31-12)32d	305592	4214229	53		119
Black Mtns.	278	AMAX98	Iron	IR-27	(C-31-12)33d	306886	4214606	63	17	58
Black Mtns.	114	AMAX98	Iron	IR-28	(C-31-12)35d	310103	4214156	45	16	75
Escalante Des.	EV-122	REPU77	Iron	IR-29	(C-31-13)02ddb	300628	4222700	152	21	68
Escalante Des.	E-14	REPU77	Iron	IR-30	(C-31-13)06caa	293009	4222570	146	19	31
Escalante Des.	E-13	REPU77	Iron	IR-31	(C-31-13)10daa	299302	4220796	140	18	71
Escalante Des.	E-15	REPU77	Iron	IR-32	(C-31-13)20dac	296005	4217659	143	23	62
Escalante Des.	E-16	REPU77	Iron	IR-33	(C-31-14)13cdc	292910	4219298	107	17	32
Escalante Des.	E-18	REPU77	Iron	IR-34	(C-31-14)16dda	288077	4219430	152	18	40
Escalante Des.	LUND-1	CHAP813	Iron	IR-35	(C-31-14)32dd	285966	4214854	32	19	132
Escalante Des.	EV-3122	REPU77	Iron	IR-36	(C-31-14)36daa	292743	4215224	95	14	39
Escalante Des.	ED-7	CHAP813	Iron	IR-37	(C-31-16)10db	269619	4222153	100	17	51
Black Mtns.	281	AMAX98	Iron	IR-38	(C-32-12)02c	309431	4212828	89	22	89
Escalante Des.	321	AMAX98	Iron	IR-39	(C-32-12)16d	306813	4209803		16	28
Escalante Des.	LUND-2	CLEM812	Iron	IR-40	(C-32-14)03dd	289321	4213179	93	15	40

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Escalante Des.	EV-3312	REPU77	Iron	IR-41	(C-32-14)03ddd	289459	4212994	96	14	41
Escalante Des.	EVG-02	KLAU823	Iron	IR-42	(C-32-14)10cbd	288262	4211963	30	15	46
Escalante Des.	ED-8	CHAP813	Iron	IR-43	(C-32-15)22cd	278701	4208574	100	20	57
Escalante Des.	EVG-06	KLAU823	Iron	IR-44	(C-32-15)31bbb	273351	4206656	30	15	83
Escalante Des.	ED-6	CHAP813	Iron	IR-45	(C-32-16)28ccc	266779	4207239	100	20	56
Escalante Des.	EVG-03	KLAU823	Iron	IR-46	(C-32-16)28ccc	266774	4207242	165	26	70
Escalante Des.	HV-1	CHAP813	Iron	IR-47	(C-32-19)26ccc	240822	4208022	60	13	49
Escalante Des.	ED-9	CHAP813	Iron	IR-48	(C-33-14)32dd	285704	4195461	100	19	46
Escalante Des.	Table Butte Unit #1	HENR00	Iron	IR-49	(C-33-15)36bb	281246	4196611	5643	208	37
Escalante Des.	Table Butte Unit #1	HENR00	Iron	IR-49	(C-33-15)36bb	281246	4196611	2258	87	39
Escalante Des.	EVG-05	KLAU823	Iron	IR-50	(C-33-16)02bbb	266655	4202186	57	23	138
Beryl	381	AMAX98	Iron	IR-51	(C-33-16)08c	264764	4201966	60	21	77
Beryl	382	AMAX98	Iron	IR-52	(C-33-16)10	267402	4201924	65	34	172
Beryl	415	AMAX98	Iron	IR-53	(C-33-16)11	269023	4202022	33	29	766
Beryl	417	AMAX98	Iron	IR-54	(C-33-16)13	271645	4201393	45	17	101
Beryl	416	AMAX98	Iron	IR-55	(C-33-16)14	268709	4201476	28	17	38
Escalante Des.	EVG-07	KLAU823	Iron	IR-56	(C-33-16)24cca	271729	4199266	50	14	114
Escalante Des.	EVG-04	KLAU823	Iron	IR-57	(C-33-17)02ddc	261817	4203868	60	23	138
Beryl	335	AMAX98	Iron	IR-58	(C-33-17)19ddd	254973	4198176	55	19	102
Beryl	379	AMAX98	Iron	IR-59	(C-33-17)25	262281	4197039	32	16	53
Beryl	380	AMAX98	Iron	IR-60	(C-33-17)26ddd	260935	4196145	24	17	150
Escalante Des.	ED-11	CHAP813	Iron	IR-61	(C-34-12)04aa	306623	4194663	100	19	50
Escalante Des.	EDE-1	CHAP813	Iron	IR-62	(C-34-13)08abd	294903	4195503	76	14	30
Escalante Des.	ED-10	CHAP813	Iron	IR-63	(C-34-14)36cc	290555	4185497	92	18	46
Escalante Des.	EVG-08	KLAU823	Iron	IR-64	(C-34-15)01bac	281540	4195081	65	16	60
Escalante Des.	EDC-1	CHAP813	Iron	IR-65	(C-34-15)16ccc	276070	4190776	30	13	41
Escalante Des.	EDC-2	CHAP813	Iron	IR-66	(C-34-16)0cbb	269747	4194916	59	15	31
Escalante Des.	EVG-09	KLAU823	Iron	IR-67	(C-34-16)17cda	265517	4191419	68	16	63
Escalante Des.	EVG-01	KLAU823	Iron	IR-68	(C-34-16)18cdb	263526	4191507	100	20	78
Escalante Des.	EVG-10	KLAU823	Iron	IR-69	(C-34-16)18cdb	263434	4191326	58	18	114
Escalante Des.	EDC-3	CHAP813	Iron	IR-70	(C-34-16)18cdc	263528	4191128	64	16	68
Escalante Des.	EVG-11	KLAU823	Iron	IR-71	(C-34-16)22abb	268729	4190835	44	11	NA

REGION_LOC	HOLE_NAME	PUB_REF	COUNTY	MAPNO	TRS	UTM_E (m)	UTM_N (m)	DEPTH (m)	BHT (°C)	UCGRAD (°C/km)
Escalante Des.	EDC-4	CHAP813	Iron	IR-72	(C-34-16)22bad	268438	4190621	67	15	66
Escalante Des.	EVG-13	KLAU823	Iron	IR-73	(C-34-16)28bcc	266390	4188588	66	12	NA
Escalante Des.	EVG-14	KLAU823	Iron	IR-74	(C-34-16)31ccd	263312	4186269	60	13	38
Beryl	334	AMAX98	Iron	IR-75	(C-34-17)07	254799	4192628	65	12	NA
Escalante Des.	EVG-12	KLAU823	Iron	IR-76	(C-34-17)24bdb	262094	4190685	85	13	NA
Escalante Des.	EVG-15	KLAU823	Iron	IR-77	(C-35-16)06bbc	263016	4186154	60	12	NA
Escalante Des.	EVG-16	KLAU823	Iron	IR-78	(C-35-17)01bcc	261288	4185680	58	11	10
Escalante Des.	EVG-18	KLAU823	Iron	IR-79	(C-35-17)01ddc	262559	4183884	58	14	33
Escalante Des.	EVG-17	KLAU823	Iron	IR-80	(C-35-17)03ccc	258104	4184817	58	15	20
Escalante Des.	EVG-20	KLAU823	Iron	IR-81	(C-35-17)12acc	262190	4183865	43	11	NA
Escalante Des.	EVG-19	KLAU823	Iron	IR-82	(C-35-17)12bcc	261310	4183920	45	11	NA
Escalante Des.	EVG-22	KLAU823	Iron	IR-83	(C-35-17)16aca	257601	4182702	55	14	73
Escalante Des.	EVG-21	KLAU823	Iron	IR-84	(C-35-17)18abd	254227	4182925	55	15	35
Escalante Des.	ED-2	CHAP813	Iron	IR-85	(C-35-17)21dd	257780	4180188	70	16	51
Escalante Des.	ED-3	CHAP813	Iron	IR-86	(C-35-20)24cc	232228	4180978	102	19	82
Escalante Des.	IRON-1	CHAP813	Iron	IR-87	(C-36-14)27cdb	287171	4168039	80	14	28
Escalante Des.	IRON-2	CHAP813	Iron	IR-88	(C-36-14)34caa	287465	4166766	55	13	24
Newcastle	NC-12	CHAP813	Iron	IR-89	(C-36-15)10ba	277153	4174133	118	18	21
Newcastle	NC-09	BLAC973	Iron	IR-90	(C-36-15)16cb	275264	4171792	91	53	445
Newcastle	NC-27	BLAC906	Iron	IR-91	(C-36-15)17bb	273724	4172441	18	20	100
Newcastle	NC-17	BLAC906	Iron	IR-92	(C-36-15)17cad	274400	4171893	18	31	847
Newcastle	NC-13	BLAC973	Iron	IR-93	(C-36-15)17dac	274880	4171575	121	73	920
Newcastle	NC-16	BLAC906	Iron	IR-94	(C-36-15)17dca	274507	4171552	18	32	931
Newcastle	NC-08	CHAP813	Iron	IR-95	(C-36-15)17dd	275058	4171414	78	88	846
Newcastle	NC-25	BLAC906	Iron	IR-96	(C-36-15)19a	273260	4171168	18	35	800
Newcastle	NC-26	BLAC906	Iron	IR-97	(C-36-15)19a	272724	4171174	18	22	100
Newcastle	NC-11	BLAC973	Iron	IR-98	(C-36-15)19a	273106	4170789	152	90	1173
Newcastle	NC-23	BLAC906	Iron	IR-99	(C-36-15)19d	273278	4169750	15	25	200
Newcastle	NC-21	BLAC906	Iron	IR-100	(C-36-15)20a	274432	4170550	18	50	800
Newcastle	NC-07	BLAC973	Iron	IR-101	(C-36-15)20aa	275166	4170941	91	43	282
Newcastle	NC-15	BLAC973	Iron	IR-102	(C-36-15)20aa	274851	4171148	100	90	925
Newcastle	NC-22	BLAC906	Iron	IR-103	(C-36-15)20b	274147	4170904	18	39	500

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Newcastle	NC-10	CHAP813	Iron	IR-104	(C-36-15)20bb	273726	4170793	152	104	1833
Newcastle	MN-07	UTAH03	Iron	IR-105	(C-36-15)20bca	273877	4170613	152	112	1267
Newcastle	CHR-1	BLAC906	Iron	IR-106	(C-36-15)20bcb	273745	4170643	152	121	NA
Newcastle	MN-06	UTAH03	Iron	IR-107	(C-36-15)20bcb	273745	4170643	152	109	1517
Newcastle	NC-20	BLAC906	Iron	IR-108	(C-36-15)20c	274779	4170525	23	45	800
Newcastle	NC-24	BLAC906	Iron	IR-109	(C-36-15)20c	273739	4170015	18	50	800
Newcastle	NC-05	CHAP813	Iron	IR-110	(C-36-15)20ca	274201	4170104	36	86	1869
Newcastle	NC-19	BLAC906	Iron	IR-111	(C-36-15)20cac	274194	4169990	15	80	4258
Newcastle	NC-18	BLAC906	Iron	IR-112	(C-36-15)20cad	274357	4169980	13	80	4960
Newcastle	NC-06	CHAP813	Iron	IR-113	(C-36-15)20cc	273821	4169750	127	93	381
Newcastle	NC-14	BLAC906	Iron	IR-114	(C-36-15)20dbb	274467	4170284	65	96	6697
Newcastle	NC-04	CHAP813	Iron	IR-115	(C-36-15)29bb	273587	4168839	91	33	199
Newcastle	NC-02	CHAP813	Iron	IR-116	(C-36-15)29dc	274545	4168151	89	23	89
Newcastle	NC-03	CHAP813	Iron	IR-117	(C-36-15)30da	273378	4168541	89	26	116
Escalante Des.	ED-1	CHAP813	Iron	IR-118	(C-37-18)36ccd	251547	4165655	101	19	74
Spor Mt.	SM-5	CHAP786	Juab	JU-1	(C-12-12)19cca	307275	4404075		27	177
Drum Mtns.	T-109	SASS996	Juab	JU-2	(C-13-11)17bd	318928	4395459	152	20	49
Spor Mt.	SM-4	CHAP786	Juab	JU-3	(C-13-12)05dca	309990	4398454	72	20	95
Spor Mt.	SM-1	CHAP786	Juab	JU-4	(C-13-12)06aaa	308873	4399404	88	19	65
Spor Mt.	SM-2	CHAP786	Juab	JU-5	(C-13-12)06aaa	308873	4399437	83	17	63
Spor Mt.	SM-3	CHAP786	Juab	JU-6	(C-13-12)09dbc	311376	4396565	81	21	91
Drum Mtns.	T-104	SASS996	Juab	JU-7	(C-13-12)15cd	312626	4395054	153	34	126
Drum Mtns.	T-103	SASS996	Juab	JU-8	(C-13-12)18ac	308209	4395719	64	28	193
Spor Mt.	Spor-Mt	COST732	Juab	JU-9	(C-13-12)05db	309990	4398454			56
Drum Mtns.	T-096	SASS996	Juab	JU-10	(C-13-13)18cc	297613	4395249	96	26	106
Drum Mtns.	T-097	SASS996	Juab	JU-11	(C-13-14)17ca	299511	4385758	96	31	164
Gunnison Plat.	WXC Howard #2	HENR00	Juab	JU-12	(C-14-01)05ad	435681	4386252	2847	72	25
Gunnison Plat.	WXC Howard #2	HENR00	Juab	JU-12	(C-14-01)05ad	435681	4386252	3275	110	34
Juab Valley	WXC-Howard 1-A	HENR00	Juab	JU-13	(C-14-01)05ba	417485	4386358	3699	119	32
Drum Mtns.	T-108	SASS996	Juab	JU-14	(C-14-11)06dd	317904	4388448	96	17	46
Drum Mtns.	T-111	SASS996	Juab	JU-15	(C-14-11)10dd	322869	4386483	96	21	89
Drum Mtns.	T-094	SASS996	Juab	JU-16	(C-14-11)19ad	317947	4384191	154	50	179

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Drum Mtns.	T-113	SASS996	Juab	JU-17	(C-14-11)21cd	320511	4383575	96	17	53
Drum Mtns.	T-079	SASS996	Juab	JU-18	(C-14-11)31bb	316593	4381446	96	29	175
Drum Mtns.	T-107	SASS996	Juab	JU-19	(C-14-12)01aa	316639	4389405	96	18	46
Drum Mtns.	T-106	SASS996	Juab	JU-20	(C-14-12)14aa	314986	4386112	154	41	153
Drum Mtns.	T-072	SASS996	Juab	JU-21	(C-14-12)19cc	307021	4383679	96	37	128
Drum Mtns.	T-119	SASS996	Juab	JU-22	(C-14-12)21bb	310375	4384928	154	47	171
Drum Mtns.	T-071	SASS996	Juab	JU-23	(C-14-12)23dd	314756	4383711	96	33	246
Drum Mtns.	T-117	SASS996	Juab	JU-24	(C-14-12)26bb	313626	4383183	152	55	195
Drum Mtns.	T-102	SASS996	Juab	JU-25	(C-14-12)27dd	313022	4381902	149	50	226
Drum Mtns.	T-118	SASS996	Juab	JU-26	(C-14-12)29dd	309873	4381979	145	38	140
Drum Mtns.	T-100	SASS996	Juab	JU-27	(C-14-13)11cb	303995	4387495	96	39	108
Drum Mtns.	T-099	SASS996	Juab	JU-28	(C-14-13)15db	303124	4385887	96	29	202
Drum Mtns.	T-098	SASS996	Juab	JU-29	(C-14-13)21ac	301458	4384597	153	43	188
Drum Mtns.	T-085	SASS996	Juab	JU-30	(C-14-13)24aa	306791	4384795	96	17	84
Drum Mtns.	T-086	SASS996	Juab	JU-31	(C-14-13)25cc	305605	4382048	154	45	197
Drum Mtns.	T-073	SASS996	Juab	JU-32	(C-14-13)28ad	301844	4382921	96	30	168
Gunnison Plat.	WXC State#1	HENR00	Juab	JU-33	(C-15-01)36ba	414676	4358085	2726	80	29
Gunnison Plat.	WXC State#1	HENR00	Juab	JU-33	(C-15-01)36ba	414676	4358085	3350	116	35
Juab Valley	WXC-State #2	HENR00	Juab	JU-34	(C-15-02)01cc	411429	4376247	2314	72	31
Gunnison Plat.	Sevier Bridge Unit #1	HENR00	Juab	JU-35	(C-16-01)11dc	423584	4364197	2744	97	35
Gunnison Plat.	WXC Barton #1	HENR00	Juab	JU-36	(C-16-01)32db	418450	4358089	4242	142	33
Gunnison Plat.	WXC Barton #1	HENR00	Juab	JU-36	(C-16-01)32db	418450	4358089	3616	122	34
Gunnison Plat.	WXC Barton #1	HENR00	Juab	JU-36	(C-16-01)32db	418450	4358089	2946	105	36
Juab Valley	Monroe 13-7	HENR00	Juab	JU-37	(C-16-02)13ac	412057	4364130	4789	138	29
Juab Valley	Monroe 13-7	HENR00	Juab	JU-37	(C-16-02)13ac	412057	4364130	3400	103	30
Gunnison Plat.	Chicken Creek Federal #16-34	HENR00	Juab	JU-39	(D-15-01)16cd	430228	4372669	2079	47	23
Gunnison Plat.	Chicken Creek Federal #16-34	HENR00	Juab	JU-39	(D-15-01)16cd	430228	4372669	2454	66	27
Gunnison Plat.	Gunnison State #1	HENR00	Juab	JU-40	(D-16-01)15aa	432197	4363751	3389	76	22
Gunnison Plat.	Gunnison State #1	HENR00	Juab	JU-40	(D-16-01)15aa	432197	4363751	4607	116	25
Drum Mtns.	T-076	SASS996	Juab	JU-41	(C-13-14)34ab	303013	4381559	96	23	104
Drum Mtns.	T-078	SASS996	Juab	JU-42	(C-14-12)33ba	310751	4381587	96	48	211
Drum Mtns.	T-057	SASS996	Juab	JU-43	(C-14-12)34dc	312700	4380429	96	28	150

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Drum Mtns.	T-077	SASS996	Juab	JU-44	(C-14-13)20cd	309079	4383516	153	50	246
Drum Mtns.	T-056	SASS996	Juab	JU-45	(C-14-13)35dc	304537	4380631	95	35	159
Drum Mtns.	T-053	SASS996	Millard	MI-1	(C-15-09)20bc	337669	4374090	96	16	24
Drum Mtns.	T-044	SASS996	Millard	MI-2	(C-15-10)13da	325914	4375493	96	18	46
Drum Mtns.	T-043	SASS996	Millard	MI-3	(C-15-10)18bd	326782	4375844	96	36	252
Drum Mtns.	T-052	SASS996	Millard	MI-4	(C-15-10)22aa	332092	4374764	96	24	71
Drum Mtns.	T-046	SASS996	Millard	MI-5	(C-15-10)31ca	326523	4370667	96	16	26
Little Drum-Keg	UT-18C	TEPL823	Millard	MI-6	(C-15-11)01dd	325272	4378658	80	15	26
Drum Mtns.	T-080	SASS996	Millard	MI-7	(C-15-11)05bd	318697	4379509	96	24	128
Drum Mtns.	T-058	SASS996	Millard	MI-8	(C-15-11)06cc	316699	4378667	96	30	197
Drum Mtns.	T-082	SASS996	Millard	MI-9	(C-15-11)07cc	316746	4377000	96	45	166
Drum Mtns.	T-115	SASS996	Millard	MI-10	(C-15-11)09ba	320382	4378026	153	32	137
Drum Mtns.	T-081	SASS996	Millard	MI-11	(C-15-11)10bb	321385	4378002	154	34	128
Drum Mtns.	T-114	SASS996	Millard	MI-12	(C-15-11)15ab	322349	4376314	96	30	181
Drum Mtns.	T-116	SASS996	Millard	MI-13	(C-15-11)17cc	318024	4375304	153	43	182
Drum Mtns.	T-093	SASS996	Millard	MI-14	(C-15-11)29ac	318976	4373061	153	39	142
Little Drum-Keg	UT-18B	TEPL823	Millard	MI-15	(C-15-11)30bb	317225	4371803	150	70	310
Drum Mtns.	T-062	SASS996	Millard	MI-16	(C-15-11)30bd	317078	4372883	96	34	204
Drum Mtns.	T-059	SASS996	Millard	MI-17	(C-15-12)07db	307900	4377548	96	24	164
Drum Mtns.	T-095	SASS996	Millard	MI-18	(C-15-12)09ad	311352	4378019	96	27	140
Drum Mtns.	T-083	SASS996	Millard	MI-19	(C-15-12)11bb	313506	4378188	154	39	122
Drum Mtns.	T-MX-60A	SASS996	Millard	MI-20	(C-15-12)19ad	308089	4374767	372	30	98
Little Drum-Keg	UT-18A	TEPL823	Millard	MI-21	(C-15-12)19da	308182	4374570	150	26	104
Drum Mtns.	T-084	SASS996	Millard	MI-22	(C-15-12)23bd	313847	4374515	96	31	164
Drum Mtns.	T-092	SASS996	Millard	MI-23	(C-15-12)25bc	314847	4373159	96	38	224
Drum Mtns.	T-061	SASS996	Millard	MI-24	(C-15-12)27ac	312692	4372988	154	28	133
Drum Mtns.	T-060	SASS996	Millard	MI-25	(C-15-12)29ca	309077	4372965	96	19	84
Drum Mtns.	T-101	SASS996	Millard	MI-26	(C-15-13)01ac	306089	4379667	96	37	197
Drum Mtns.	T-074	SASS996	Millard	MI-27	(C-15-13)04dd	301745	4379036	96	18	60
Drum Mtns.	T-075	SASS996	Millard	MI-28	(C-15-13)14cb	303737	4376209	96	17	69
Tule Valley	TV-04	SASS996	Millard	MI-29	(C-15-15)30b	278409	4374116	55	15	29
Tule Valley	TV-05	SASS996	Millard	MI-30	(C-15-15)33cac	281290	4370479	30	13	95

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Drum Mtns.	T-049	SASS996	Millard	MI-31	(C-16-09)19ad	336427	4364159	96	17	16
Drum Mtns.	T-048	SASS996	Millard	MI-32	(C-16-09)31cc	335340	4360296	96	18	38
Drum Mtns.	T-051	SASS996	Millard	MI-33	(C-16-10)01ad	334959	4369373	96	17	26
Drum Mtns.	T-050	SASS996	Millard	MI-34	(C-16-10)10cb	331322	4367045	154	17	22
Drum Mtns.	T-047	SASS996	Millard	MI-35	(C-16-10)31ca	326017	4360870	155	29	97
Drum Mtns.	T-045	SASS996	Millard	MI-36	(C-16-11)04cb	319741	4368971	96	22	86
Drum Mtns.	T-089	SASS996	Millard	MI-37	(C-16-11)07aa	317142	4368292	95	24	102
Drum Mtns.	T-066	SASS996	Millard	MI-38	(C-16-11)23da	323241	4363856	96	20	80
Drum Mtns.	T-087	SASS996	Millard	MI-39	(C-16-12)04ab	310299	4370159	96	17	58
Drum Mtns.	T-063	SASS996	Millard	MI-40	(C-16-12)09cc	309532	4366957	96	16	44
Drum Mtns.	T-088	SASS996	Millard	MI-41	(C-16-12)11cc	312641	4367326	96	16	44
Drum Mtns.	T-064	SASS996	Millard	MI-42	(C-16-12)12ac	314806	4367829	96	26	137
Drum Mtns.	T-091	SASS996	Millard	MI-43	(C-16-12)23ba	312898	4364876	96	16	38
Drum Mtns.	T-065	SASS996	Millard	MI-44	(C-16-12)25cc	314238	4362068	96	18	77
Tule Valley	367/TV-14	AMAX98	Millard	MI-45	(C-16-14)	292966	4365937			31
Tule Valley	TV-14	SASS996	Millard	MI-46	(C-16-14)	293110	4365933	61	16	26
Tule Valley	377/TV-06	AMAX98	Millard	MI-47	(C-16-16)34b	273176	4361858	60	14	5
Tule Valley	TV-06	SASS996	Millard	MI-48	(C-16-16)34b	272737	4361689	61	14	57
Tule Valley	418/TV-07	AMAX98	Millard	MI-49	(C-16-16)36c	276154	4360483	35	14	22
Tule Valley	TV-07	SASS996	Millard	MI-50	(C-16-16)36c	275853	4360117	47	14	22
Confusion Basin	BISHOP SPRINGS UNIT #1	HENR00	Millard	MI-51	(C-16-17)08cb	259930	4367978	4120	100	24
Drum Mtns.	T-MX-67C	SASS996	Millard	MI-52	(C-17-09)19dd	336461	4353462	42	14	75
Drum Mtns.	T-MX-67B	SASS996	Millard	MI-53	(C-17-10)27bc	330150	4352820	58	19	66
Drum Mtns.	T-MX-67A	SASS996	Millard	MI-54	(C-17-10)29dc	327723	4352318	59	18	93
Drum Mtns.	T-067	SASS996	Millard	MI-55	(C-17-11)01cd	323976	4358287	96	22	69
Tule Valley	369/TV-01	AMAX98	Millard	MI-56	(C-17-14)07c	287432	4357945	44	14	117
Tule Valley	TV-01	SASS996	Millard	MI-57	(C-17-14)07c	287722	4357934	46	14	104
Tule Valley	368/TV-02	AMAX98	Millard	MI-58	(C-17-14)08d	289733	4357882	60	20	161
Tule Valley	TV-02	SASS996	Millard	MI-59	(C-17-14)08d	288866	4357717	61	20	164
Tule Valley	TV-03	SASS996	Millard	MI-60	(C-17-14)09b	290461	4358229	49	17	58
Tule Valley	366	AMAX98	Millard	MI-61	(C-17-14)09d	291021	4357659	60	18	55
Tule Valley	370/TV-15	AMAX98	Millard	MI-62	(C-17-15)19d	278705	4354389	60	27	147

REGION_LOC	HOLE_NAME	PUB_REF	COUNTY	MAPNO	TRS	UTM_E (m)	UTM_N (m)	DEPTH (m)	BHT (°C)	UCGRAD (°C/km)
Tule Valley	TV-15	SASS996	Millard	MI-63	(C-17-15)19d	278855	4354477	55	26	228
Tule Valley	371/TV-08	AMAX98	Millard	MI-64	(C-17-15)29a	279680	4353161	60	16	62
Tule Valley	TV-08	SASS996	Millard	MI-65	(C-17-15)29a	280250	4352957	61	16	108
Tule Valley	372/TV-09	AMAX98	Millard	MI-66	(C-17-15)34b	282221	4351424	60	29	270
Tule Valley	TV-09	SASS996	Millard	MI-67	(C-17-15)34b	282652	4351408	61	28	208
Confusion Basin	FEDERAL 1-28	HENR00	Millard	MI-68	(C-17-19)28aa	242568	4354521	2372	93	39
Tule Valley	373/TV-10	AMAX98	Millard	MI-69	(C-18-14)08d	289159	4347157	60	35	319
Tule Valley	TV-11	SASS996	Millard	MI-70	(C18-14)30bad	287189	4343656	58	20	88
Tule Valley	TV-10	SASS996	Millard	MI-71	(C-18-14)8d	288883	4347720	58	34	332
Tule Valley	375	AMAX98	Millard	MI-72	(C-18-15)01d	286327	4349089	45	13	27
Tule Valley	TV-16	SASS996	Millard	MI-73	(C-18-15)20cbb	278583	4344894	46	13	27
Confusion Basin	State AB #1	HENR00	Millard	MI-74	(C-18-16)02cc	273999	4349225	3515	96	27
Gunnison Plat.	WXC USA #1-2	HENR00	Millard	MI-75	(C-19-02)24cb	411282	4333028	5398	138	26
Gunnison Plat.	WXC USA #1-2	HENR00	Millard	MI-75	(C-19-02)24cb	411282	4333028	1563	47	30
Sevier-Blackrock	SB-ST-2	SASS996	Millard	MI-76	(C-19-06)21bbb	367078	4334896	522	48	64
Tule Valley	374/TV-17	AMAX98	Millard	MI-77	(C-19-15)01a	285524	4340591	55	13	12
Tule Valley	TV-12	SASS996	Millard	MI-78	(C-19-15)11bda	283856	4338749	47	11	16
Sevier-Blackrock	Fed #2	HENR00	Millard	MI-79	(C-20-08)28bc	347514	4323095	4018	141	35
Sevier-Blackrock	SB-ST-1	SASS996	Millard	MI-80	(C-20-08)29ddb	346958	4322681	474	56	98
Black Rock Des	112	AMAX98	Millard	MI-81	(C-21-07)24a	362552	4315169	68	13	68
Meadow-Hatton	264	AMAX98	Millard	MI-82	(C-22-05)30c	373277	4302524	90	12	10
Meadow-Hatton	263	AMAX98	Millard	MI-83	(C-22-05)32d	375268	4301138	100	13	25
Meadow-Hatton	259	AMAX98	Millard	MI-84	(C-22-06)01c	371445	4308925	93	15	35
Black Rock Des	255	AMAX98	Millard	MI-85	(C-22-06)05b	362499	4310086	35	13	32
Meadow-Hatton	109B	AMAX98	Millard	MI-86	(C-22-06)11b	370331	4308144		12	211
Meadow-Hatton	265	AMAX98	Millard	MI-87	(C-22-06)11c	369803	4307698	18	14	113
Meadow-Hatton	422	AMAX98	Millard	MI-88	(C-22-06)11c	369833	4307386	96	21	86
Meadow-Hatton	109A	AMAX98	Millard	MI-89	(C-22-06)11d	371097	4307776		18	54
Meadow-Hatton	120	AMAX98	Millard	MI-90	(C-22-06)20b	364713	4305707	42	15	19
Meadow-Hatton	254	AMAX98	Millard	MI-91	(C-22-06)22b	368113	4305661	25	15	50
Meadow-Hatton	424	AMAX98	Millard	MI-92	(C-22-06)23d	370844	4304495	92	18	44
Meadow-Hatton	344	AMAX98	Millard	MI-93	(C-22-06)35d	370712	4300645	25	67	11

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Sevier-Blackrock	Hole in Rock #1	HENR00	Millard	MI-94	(C-22-07)30cd	353907	4302680	3160	99	31
Meadow-Hatton	164	AMAX98	Millard	MI-95	(C-23-06)03cd	368596	4299203		30	29
Meadow-Hatton	258	AMAX98	Millard	MI-96	(C-23-06)08a	365441	4299034	97	17	50
Meadow-Hatton	227	AMAX98	Millard	MI-97	(C-23-06)10ba	368592	4298959	34	27	374
Black Rock Des	282	AMAX98	Millard	MI-98	(C-23-06)21a	367016	4295089	97	14	30
Black Rock Des	260	AMAX98	Millard	MI-99	(C-23-06)27cd	368560	4292832	55	16	35
Black Rock Des	256	AMAX98	Millard	MI-100	(C-23-07)06b	353452	4300612	92	16	42
Black Rock Des	247	AMAX98	Millard	MI-101	(C-23-07)11a	360560	4298453	67	16	42
Black Rock Des	245	AMAX98	Millard	MI-102	(C-23-07)21ab	355346	4295427	65	16	38
Black Rock Des	248	AMAX98	Millard	MI-103	(C-23-07)24b	361875	4295177	67	19	43
Black Rock Des	372	AMAX98	Millard	MI-104	(C-23-07)30b	352927	4294272			28
Black Rock Des	243	AMAX98	Millard	MI-105	(C-23-07)33d	353448	4289056	61	17	50
Twin Peaks	266	AMAX98	Millard	MI-106	(C-23-08)15d	349032	4296910	97	16	26
Twin Peaks	201	AMAX98	Millard	MI-107	(C-23-08)22cd	348715	4295317	76	32	290
Twin Peaks	277	AMAX98	Millard	MI-108	(C-23-08)26b	350789	4293812	69	16	39
Twin Peaks	185	AMAX98	Millard	MI-109	(C-23-08)28b	346596	4294470	32	19	151
Black Rock Des	244	AMAX98	Millard	MI-110	(C-23-08)32b	357371	4291627	62	18	60
Twin Peaks	159	AMAX98	Millard	MI-111	(C-23-08)33dc	346761	4291769	90	22	108
Twin Peaks	297	AMAX98	Millard	MI-112	(C-23-08)34bb	348053	4292965	97	30	150
Twin Peaks	295	AMAX98	Millard	MI-113	(C-23-08)35b	350160	4292259	95	17	45
Twin Peaks	202	AMAX98	Millard	MI-114	(C-23-08)36bb	351366	4293058	95	17	31
Twin Peaks	TP7	CARR812	Millard	MI-115	(C-23-09)	339005	4292066	90	19	50
Confusion Basin	Antelope Valley State 36-22	HENR00	Millard	MI-116	(C-23-18)36bd	255474	4295120	2928	51	17
Black Rock Des	238	AMAX98	Millard	MI-117	(C-24-06)05a	365881	4290147	98	19	55
Black Rock Des	359	AMAX98	Millard	MI-118	(C-24-06)09b	366562	4288725	89	30	150
Black Rock Des	357	AMAX98	Millard	MI-119	(C-24-06)15b	367706	4286952	84	22	125
Black Rock Des	237	AMAX98	Millard	MI-120	(C-24-06)17c	364973	4286299	78	19	62
Black Rock Des	253	AMAX98	Millard	MI-121	(C-24-06)19cb	362829	4285004	75	39	294
Black Rock Des	360	AMAX98	Millard	MI-122	(C-24-06)30b	363266	4284108	93	38	250
Black Rock Des	386	AMAX98	Millard	MI-123	(C-24-06)31caa	363329	4282146	58	34	412
Black Rock Des	257	AMAX98	Millard	MI-124	(C-24-06)31cc	362626	4281799	65	34	277
Black Rock Des	107	AMAX98	Millard	MI-125	(C-24-06)31d	363861	4281256	110	51	488

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Black Rock Des	235	AMAX98	Millard	MI-126	(C-24-07)01ab	362275	4290219			41
Black Rock Des	127	AMAX98	Millard	MI-127	(C-24-07)05b	355000	4290737		25	139
Black Rock Des	242	AMAX98	Millard	MI-128	(C-24-07)07b	354888	4292227	67	18	62
Black Rock Des	239	AMAX98	Millard	MI-129	(C-24-07)10b	358429	4289010	65	18	83
Black Rock Des	292	AMAX98	Millard	MI-130	(C-24-07)21bb	356489	4286070	95	20	73
Black Rock Des	234	AMAX98	Millard	MI-131	(C-24-07)22b	358665	4285687	60	17	74
Black Rock Des	236	AMAX98	Millard	MI-132	(C-24-07)24bd	361846	4285509	92	53	407
Black Rock Des	204	AMAX98	Millard	MI-133	(C-24-07)29ca	355079	4283642	99	29	174
Cove Creek	296	AMAX98	Millard	MI-134	(C-24-07)31cc	353243	4281733	65	26	218
Black Rock Des	275	AMAX98	Millard	MI-135	(C-24-07)34ab	358739	4282977	75	35	243
Black Rock Des	361	AMAX98	Millard	MI-136	(C-24-07)35b	359833	4282347	100	33	302
Black Rock Des	262	AMAX98	Millard	MI-137	(C-24-07)36ab	362140	4282928	49	29	300
Black Rock Des	110	AMAX98	Millard	MI-138	(C-24-07)36c	361658	4281727		40	290
Twin Peaks	TP3	CARR812	Millard	MI-139	(C-24-08)	343102	4289131	152	21	45
Twin Peaks	TP4	CARR812	Millard	MI-140	(C-24-08)	343714	4287532	58	19	87
Twin Peaks	TP6	CARR812	Millard	MI-141	(C-24-08)	347538	4289234	151	19	43
Twin Peaks	TP8	CARR812	Millard	MI-142	(C-24-08)	346121	4285653	130	21	56
Twin Peaks	184	AMAX98	Millard	MI-143	(C-24-08)02ad	350739	4290661	114	20	56
Twin Peaks	298	AMAX98	Millard	MI-144	(C-24-08)03c	348273	4290374	65	17	50
Twin Peaks	439	AMAX98	Millard	MI-145	(C-24-08)05b	344777	4291208	62	16	32
Twin Peaks	203	AMAX98	Millard	MI-146	(C-24-08)08cd	345706	4288436	98	19	46
Twin Peaks	182	AMAX98	Millard	MI-147	(C-24-08)09ab	347789	4289162	149	20	39
Black Rock Des	178	AMAX98	Millard	MI-148	(C-24-08)13d	352654	4286573	53	19	102
Twin Peaks	241	AMAX98	Millard	MI-149	(C-24-08)15c	348779	4287278	65	16	68
Twin Peaks	180	AMAX98	Millard	MI-150	(C-24-08)20dd	346335	4285460	130	21	50
Black Rock Des	293	AMAX98	Millard	MI-151	(C-24-08)25d	352950	4283770	60	18	105
Black Rock Des	294	AMAX98	Millard	MI-152	(C-24-08)26d	351176	4284769	63	17	77
Black Rock Des	166	AMAX98	Millard	MI-153	(C-24-08)27d	349120	4284152		20	155
Twin Peaks	TP1	CARR812	Millard	MI-154	(C-24-09)	336344	4290755	49	18	53
Twin Peaks	181	AMAX98	Millard	MI-155	(C-24-09)12cc	341902	4288700	150	21	23
Cove Creek	179	AMAX98	Millard	MI-156	(C-24-09)24cd	342361	4285105	50	13	12
Cove Creek	124	AMAX98	Millard	MI-157	(C-24-09)26d	340769	4283782	75	18	62

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Confusion Basin	Ensign Oil and Gas #1-16	HENR00	Millard	MI-158	(C-24-19)16cb	240626	4289546	3700	82	22
Black Rock Des	387	AMAX98	Millard	MI-159	(C-25-06)04ba	366376	4281010	435	91	187
Cove Fort	261	AMAX98	Millard	MI-160	(C-25-06)06da	364164	4280185	63	36	290
Cove Fort	272	AMAX98	Millard	MI-161	(C-25-06)07d	363977	4278368	65	23	180
Cove Fort	207	AMAX98	Millard	MI-162	(C-25-06)18da	363991	4277147	80	34	250
Cove Fort	208	AMAX98	Millard	MI-163	(C-25-06)19bc	362700	4276037	98	41	290
Cove Fort	270	AMAX98	Millard	MI-164	(C-25-06)19dd	363911	4275006	64	32	320
Cove Fort	111	AMAX98	Millard	MI-165	(C-25-06)21bc	365872	4275605	26	25	445
Cove Fort	66-28	HUTT92	Millard	MI-166	(C-25-06)28	366838	4273480		157	293
Cove Fort	FORMINCO	GLEN822	Millard	MI-167	(C-25-06)29aa	365541	4274612	320		NA
Cove Fort	14-29	GLEN822	Millard	MI-168	(C-25-06)29bc	364148	4274114	799	85	NA
Cove Fort	267	AMAX98	Millard	MI-169	(C-25-06)29da	365360	4273682	55	29	192
Cove Fort	34-30	HUTT92	Millard	MI-170	(C-25-06)30	363549	4273713	758	102	122
Cove Fort	273	AMAX98	Millard	MI-171	(C-25-06)30cc	362921	4273657	65	32	270
Cove Fort	210	AMAX98	Millard	MI-172	(C-25-06)32bb	363889	4273219	98	41	297
Cove Fort	31-33	GLEN822	Millard	MI-173	(C-25-06)33ba	366039	4273105	1591	140	NA
Cove Fort	156	AMAX98	Millard	MI-174	(C-25-07)02cc	359694	4279863	550	91	188
Cove Creek	364	AMAX98	Millard	MI-175	(C-25-07)07a	354464	4279946	47	30	334
Cove Fort	370	AMAX98	Millard	MI-176	(C-25-07)10b	357992	4279160	115	51	300
Cove Fort	358	AMAX98	Millard	MI-177	(C-25-07)12b	361005	4279685	94	24	140
Cove Fort	206	AMAX98	Millard	MI-178	(C-25-07)12bc	361521	4278832	98	41	185
Cove Fort	423	AMAX98	Millard	MI-179	(C-25-07)13b	361036	4277475	65	18	90
Cove Creek	328	AMAX98	Millard	MI-180	(C-25-07)16b	356422	4278001	250	88	176
Cove Creek	371	AMAX98	Millard	MI-181	(C-25-07)17b	355011	4277949	122	40	200
Cove Creek	356	AMAX98	Millard	MI-182	(C-25-07)19b	353082	4276308	92	18	82
Cove Creek	143	AMAX98	Millard	MI-183	(C-25-07)20b	355118	4276692	122	45	271
Cove Fort	187	AMAX98	Millard	MI-184	(C-25-07)22dc	358889	4275215	144	28	257
Cove Fort	209	AMAX98	Millard	MI-185	(C-25-07)24cc	361122	4274920	98	23	200
Cove Fort	158	AMAX98	Millard	MI-186	(C-25-07)26a	360703	4274339	120	20	55
Cove Creek	362	AMAX98	Millard	MI-187	(C-25-07)29a	355655	4274562	90	78	1818
Cove Creek	230	AMAX98	Millard	MI-188	(C-25-07)29bd	355286	4274402	60	24	220
Cove Fort	176	AMAX98	Millard	MI-189	(C-25-07)35c	359444	4272086	38	16	95

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Cove Creek	167	AMAX98	Millard	MI-190	(C-25-08)01cc	351521	4280399	124	43	230
Cove Creek	175	AMAX98	Millard	MI-191	(C-25-08)07c	343050	4278541	62	18	44
Cove Creek	168	AMAX98	Millard	MI-192	(C-25-08)12dd	352567	4279070	134	49	277
Cove Creek	233	AMAX98	Millard	MI-193	(C-25-08)13b	351930	4278027	60	23	150
Cove Creek	369	AMAX98	Millard	MI-194	(C-25-08)14c	350358	4277324	104	29	215
Milford Valley	18	AMAX98	Millard	MI-195	(C-25-08)18a	334678	4278754	120	19	57
Cove Creek	142	AMAX98	Millard	MI-196	(C-25-08)21a	347345	4276881	65	20	100
Cove Creek	363	AMAX98	Millard	MI-197	(C-25-08)22c	347953	4275427	98	20	54
Cove Creek	365	AMAX98	Millard	MI-198	(C-25-08)23c	350176	4275518	100	21	72
Cove Creek	231	AMAX98	Millard	MI-199	(C-25-08)24cd	351991	4275662	65	20	116
Cove Creek	232	AMAX98	Millard	MI-200	(C-25-08)27da	349538	4274009	60	23	84
Cove Creek	366	AMAX98	Millard	MI-201	(C-25-08)35c	350123	4272655	80	16	36
Milford Valley	19	AMAX98	Millard	MI-202	(C-25-10)26c	330955	4274813	150	22	75
Cove Fort	47-6	HUTT92	Millard	MI-203	(C-26-06)06	363522	4270572		158	388
Cove Fort	271	AMAX98	Millard	MI-204	(C-26-07)01ad	362210	4270806	95	39	275
Cove Fort	22-2	AMAX98	Millard	MI-205	(C-26-07)02bb	359874	4271279	1220	96	152
Cove Fort	157	AMAX98	Millard	MI-206	(C-26-07)06b	352971	4271692	42	13	34
Cove Creek	151	AMAX98	Millard	MI-207	(C-26-08)04b	346461	4272103	80	17	63
Milford Valley	123	AMAX98	Millard	MI-208	(C-26-09)05b	334806	4272335	148	22	35
Roosevelt HS	197	AMAX98	Millard	MI-209	(C-26-09)05c	335295	4271514	67	19	60
Roosevelt HS	UU76TG2	SILL772	Millard	MI-210	(C-26-09)05cdb	335074	4270964	68	19	54
Milford Valley	21	AMAX98	Millard	MI-211	(C-26-10)04b	327198	4271918	97	16	37
Tule Valley	TV-17	SASS996	Millard	MI-212	(C-19-15)01a	285685	4341328	61	13	4
Wasatch Back	Gulf - Amoco No.1 East Canyon	HENR00	Morgan	MO-1	(A-02-03)27db	449945	4524340	2758	71	26
Wasatch Back	Amoco - Marathon W 1 Unit #1	HENR00	Morgan	MO-2	(A-05-06)07bb	472961	4559165	2637	54	21
Wasatch Back	Amoco - Marathon W 1 Unit #1	HENR00	Morgan	MO-2	(A-05-06)07bb	472961	4559165	3410	96	28
Wasatch Back	Champlin 432 Amoco C #1	HENR00	Morgan	MO-3	(A-06-05)01dd	472698	4569435	4228	91	22
Wasatch Back	Champlin 432 Amoco C #1	HENR00	Morgan	MO-3	(A-06-05)01dd	472698	4569435	2817	67	24
Wasatch Back	Deseret Working Interest Unit #1	HENR00	Morgan	MO-4	(A-06-05)02cb	469843	4569835	4215	93	22
Wasatch Back	Deseret Working Interest Unit #1	HENR00	Morgan	MO-4	(A-06-05)02cb	469843	4569835	5318	124	23
Wasatch Back	Champlin 473 Amoco B#1	HENR00	Morgan	MO-5	(A-07-05)25ca	471832	4572880	4285	105	25
Wasatch Back	Champlin 473 Amoco B#1	HENR00	Morgan	MO-5	(A-07-05)25ca	471832	4572880	4546	113	25

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Wasatch Back	Champlin 473 Amoco B#1	HENR00	Morgan	MO-5	(A-07-05)25ca	471832	4572880	2966	75	25
High Plateaus	Antimony Canyon #1	HENR00	Piute	PI-1	(C-30-02)30ad	408537	4224764	2416	88	37
High Plateaus	Rocky Ford Unit #1	HENR00	Piute	PI-2	(C-30-03)27cd	395756	4224963	2848	67	23
Bear River	Champlin 388 B #1	HENR00	Rich	RI-1	(A-06-07)35bd	489663	4561953	2611	53	20
Bear River	1-10 Thousand Dollar	HENR00	Rich	RI-2	(A-09-05)10cc	469613	4596713	1410	52	37
Bear River	Chournos #19-1	HENR00	Rich	RI-3	(A-09-06)19aa	474594	4594318	2810	66	24
Bear River	Chournos #19-1	HENR00	Rich	RI-3	(A-09-06)19aa	474594	4594318	1616	47	29
Bear River	Putnam #23-1	HENR00	Rich	RI-4	(A-09-06)23bd	480219	4594245	3795	88	23
Bear River	Putnam #23-1	HENR00	Rich	RI-4	(A-09-06)23bd	480219	4594245	4323	101	23
Bear River	Sugarloaf 11-6	HENR00	Rich	RI-5	(A-10-06)11ac	480355	4607123	4275	86	20
Bear River	Sugarloaf 11-6	HENR00	Rich	RI-5	(A-10-06)11ac	480355	4607123	4634	100	22
Bear River	Sugarloaf 11-6	HENR00	Rich	RI-5	(A-10-06)11ac	480355	4607123	2662	63	24
Crawford Mtns.	Mud Springs 1-8	HENR00	Rich	RI-6	(A-10-08)08dd	495559	4606620	2735	71	26
Crawford Mtns.	Bridger Cr. Unit Fed. 2-20	HENR00	Rich	RI-7	(A-10-08)20da	495649	4603778	2377	60	25
Bear River	Otter Creek 1-21	HENR00	Rich	RI-8	(A-12-06)21ab	477632	4623718	3140	58	19
Bear Lake	South Eden Canyon #1-15	HENR00	Rich	RI-9	(A-13-06)15bd	478423	4634984	3659	71	19
Bear Lake	South Eden Canyon #1-15	HENR00	Rich	RI-9	(A-13-06)15bd	478423	4634984	3250	66	20
Bear Lake	South Eden Canyon #1-15	HENR00	Rich	RI-9	(A-13-06)15bd	478423	4634984	4800	111	23
Bear River	Hogback Ridge #20-1	HENR00	Rich	RI-10	(A-13-07)20da	485971	4632878	2985	82	28
Bear River	Sohio Red Knoll 33-B	HENR00	Rich	RI-11	(A-13-07)33bd	486688	4630168	3741	88	24
Bear River	Sohio Red Knoll 33-B	HENR00	Rich	RI-11	(A-13-07)33bd	486688	4630168	2322	58	25
Bear Lake	Eden State 2-41	HENR00	Rich	RI-12	(A-14-06)02aa	481279	4648077	4759	115	24
Bear Lake	Eden State 2-41	HENR00	Rich	RI-12	(A-14-06)02aa	481279	4648077	4950	120	24
Bear River	S. Rabbit Cr. Nebeker No.14-44	HENR00	Rich	RI-13	(A-14-07)14dd	490849	4643917	2995	64	21
Bear River	S. Rabbit Cr. Nebeker No.14-44	HENR00	Rich	RI-13	(A-14-07)14dd	490849	4643917	2440	57	23
Bear River	S. Rabbit Cr. Nebeker No.14-44	HENR00	Rich	RI-13	(A-14-07)14dd	490849	4643917	3707	92	25
Wasatch Front	JVG-27	KLAU842	Salt Lake	SL-1	(A-01-01)31cca	425175	4514291	89	14	-38
Wasatch Front	Gillmore Fee #1	HENR00	Salt Lake	SL-2	(B-01-01)16dc	419428	4518226	1173	63	54
Wasatch Front	Saltair #1	HENR00	Salt Lake	SL-3	(B-01-02)29cb	407301	4515049	995	67	67
Crystal Hot Spr	SF-1	BLAI812	Salt Lake	SL-4	(B-04-01)12bbc	423064	4482307	154	60	NA
Crystal Hot Spr	USP/TH-1	BLAI812	Salt Lake	SL-5	(B-04-01)12bbd	423132	4482307	306	60	NA
Wasatch Front	JVG-15	KLAU842	Salt Lake	SL-6	(C-01-01)34dda	421565	4504892	57	13	24

REGION_LOC	HOLE_NAME	PUB_REF	COUNTY	MAPNO	TRS	UTM_E (m)	UTM_N (m)	DEPTH (m)	BHT (°C)	UCGRAD (°C/km)
Wasatch Front	JVG-24	KLAU842	Salt Lake	SL-7	(C-02-01)05ccd	417757	4502891	219	24	56
Wasatch Front	JVG-12	KLAU842	Salt Lake	SL-8	(C-02-01)05dac	409385	4503299	91	18	34
Wasatch Front	JVG-14	KLAU842	Salt Lake	SL-9	(C-02-01)09ccc	418332	4501408	139	17	16
Wasatch Front	JVG-23	KLAU842	Salt Lake	SL-10	(C-02-01)23cab	421928	4497639	65	15	25
Wasatch Front	JVG-10	KLAU842	Salt Lake	SL-11	(C-02-02)08acd	408133	4501127	79	13	18
Wasatch Front	JVG-13	KLAU842	Salt Lake	SL-12	(C-02-02)09bca	408821	4501452	49	13	18
Wasatch Front	JVG-20	KLAU842	Salt Lake	SL-13	(C-02-02)22ddd	411666	4497509	179	17	40
Wasatch Front	JVG-22	KLAU842	Salt Lake	SL-14	(C-03-01)06cdd	415411	4492059	231	20	65
Wasatch Front	JVG-06	KLAU842	Salt Lake	SL-15	(C-03-01)11cad	422153	4491653	45	15	47
Wasatch Front	JVG-21	KLAU842	Salt Lake	SL-16	(C-03-01)21daa	419647	4488274	68	13	27
Wasatch Front	JVG-09	KLAU842	Salt Lake	SL-17	(C-03-02)33cad	409041	4484796	128	18	64
Crystal Hot Spr	CGH-C	MURP79	Salt Lake	SL-18	(C-04-01)11add	422843	4482293	85	77	325
Crystal Hot Spr	CGH-B	MURP79	Salt Lake	SL-19	(C-04-01)12bac	423345	4482450	73	36	98
Crystal Hot Spr	CGH-A	MURP79	Salt Lake	SL-20	(C-04-01)12bbd	423162	4482318	67	68	254
Crystal Hot Spr	CGH-E	MURP79	Salt Lake	SL-21	(C-04-01)12bcc	422987	4482139	61	86	4300
Crystal Hot Spr	CGH-D	MURP79	Salt Lake	SL-22	(C-04-01)12bcd	423153	4481917	72	55	1705
Wasatch Front	JVG-07	KLAU842	Salt Lake	SL-23	(C-04-01)27abb	420584	4476960	95	15	33
Wasatch Front	JVG-25	KLAU842	Salt Lake	SL-24	(C-04-02)03cbc	410051	4482841	160	20	52
Wasatch Front	JVG-11	KLAU842	Salt Lake	SL-25	(C-04-02)09bad	409115	4481132	159	20	46
Wasatch Front	JVG-08	KLAU842	Salt Lake	SL-26	(C-04-02)09caa	409202	4482674	57	16	58
Wasatch Front	JVG-29	KLAU842	Salt Lake	SL-27	(D-01-01)26ddc	432407	4504930	99	18	80
Wasatch Front	JVG-28	KLAU842	Salt Lake	SL-28	(D-01-01)35dcc	432078	4504966	159	17	50
Wasatch Front	JVG-30	KLAU842	Salt Lake	SL-29	(D-02-01)02bbb	431906	4501859	95	11	NA
Wasatch Front	JVG-01	KLAU842	Salt Lake	SL-30	(D-02-01)07dab	426057	4501171	83	13	13
Wasatch Front	JVG-16	KLAU842	Salt Lake	SL-31	(D-02-01)32dbd	427370	4493632	145	11	NA
Wasatch Front	JVG-18	KLAU842	Salt Lake	SL-32	(D-02-01)33dca	428970	4493650	217	11	NA
Wasatch Front	JVG-02	KLAU842	Salt Lake	SL-33	(D-02-01)34	430443	4495512	277	12	26
Wasatch Front	JVG-26	KLAU842	Salt Lake	SL-34	(D-02-01)34acb	430302	4494913	169	10	NA
Wasatch Front	JVG-03	KLAU842	Salt Lake	SL-35	(D-03-01)07caa	426125	4491801	65	14	23
Wasatch Front	JVG-19	KLAU842	Salt Lake	SL-36	(D-03-01)18cba	425312	4490111	99	22	102
Wasatch Front	JVG-17	KLAU842	Salt Lake	SL-37	(D-03-01)20bcd	426513	4488190	159	19	47
Wasatch Front	JVG-04	KLAU842	Salt Lake	SL-38	(D-03-01)21caa	428510	4488037	218	13	4

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Wasatch Front	JVG-05	KLAU842	Salt Lake	SL-39	(D-03-01)29bdb	427646	4486291	43	20	103
Canyonlands	HATCH POINT 27-1A	HENR00	San Juan	SJ-1	(D-27-21)27ca	622259	4253294	2448	59	24
Canyonlands	LION MESA #2-34	HENR00	San Juan	SJ-2	(D-27-21)34ca	611192	4251679	2568	59	23
La Sal Mtns.	Dixie Unit #2	HENR00	San Juan	SJ-3	(D-27-24)15bb	651340	4257918	4682	84	18
La Sal Mtns.	Dixie Unit #2	HENR00	San Juan	SJ-3	(D-27-24)15bb	651340	4257918	1041	37	36
Lisbon Prong	Lisbon C-910	HENR00	San Juan	SJ-4	(D-30-24)10dc	651481	4227538	2710	70	26
Lisbon Prong	Lisbon No. B-614A	HENR00	San Juan	SJ-5	(D-30-24)14ba	652661	4227260	2772	63	23
Lisbon Prong	Lisbon D-715	HENR00	San Juan	SJ-6	(D-30-24)15ad	651814	4226623	2560	70	27
Lisbon Prong	Calvert USA #1 (Lisbon E-718)	HENR00	San Juan	SJ-7	(D-30-25)18bc	655323	4226878	2825	68	24
Blanding Basin	NIELSON "A" #1	HENR00	San Juan	SJ-8	(D-37-22)25bb	636517	4156107	2438	71	29
Blanding Basin	FEDERAL 34-32	HENR00	San Juan	SJ-9	(D-37-23)34ad	643567	4154228	2644	90	34
Wasatch Back	Mount Baldy Unit 1	HENR00	Sanpete	SA-1	(D-12-03)24aa	454543	4401611	4636	130	28
Gunnison Plat.	Chris's Canyon Unit #1	HENR00	Sanpete	SA-2	(D-16-01)33ca	429968	4358121	3352	60	18
Gunnison Plat.	Chris's Canyon Unit #1	HENR00	Sanpete	SA-2	(D-16-01)33ca	429968	4358121	5094	120	24
Wasatch Plateau	United State "E" No.1	HENR00	Sanpete	SA-3	(D-19-03)27ab	451580	4331388	3731	76	20
Wasatch Plateau	United State "E" No.1	HENR00	Sanpete	SA-3	(D-19-03)27ab	451580	4331388	5678	126	22
Wasatch Plateau	United State "E" No.1	HENR00	Sanpete	SA-3	(D-19-03)27ab	451580	4331388	5103	120	24
High Plateaus	Sigurd Unit #1	HENR00	Sevier	SE-1	(C-22-01)14cb	423289	4304778	2765	97	35
High Plateaus	Salina Unit #1	HENR00	Sevier	SE-1	(C-22-01)33aa	421187	4300138	5300	162	31
High Plateaus	Salina Unit #1	HENR00	Sevier	SE-1	(C-22-01)33aa	421187	4300138	2829	96	34
Tushar Mtns.	Paxton #1	HENR00	Sevier	SE-2	(C-24-04)28bc	390980	4282216	3079	79	26
Tushar Mtns.	Paxton #1	HENR00	Sevier	SE-2	(C-24-04)28bc	390980	4282216	4394	113	26
Tushar Mtns.	Paxton #1	HENR00	Sevier	SE-2	(C-24-04)28bc	390980	4282216	3995	111	28
Monroe-Red Hill	RH1	MASE783	Sevier	SE-10	(C-25-03)	404257	4276551		52	591
Monroe-Red Hill	RH2	MASE783	Sevier	SE-11	(C-25-03)	404114	4277008	65	72	NA
Monroe-Red Hill	RH3	MASE783	Sevier	SE-12	(C-25-03)	403829	4277200	48	57	778
Monroe-Red Hill	RH4	MASE783	Sevier	SE-13	(C-25-03)	404110	4276642	90	72	100
Monroe-Red Hill	RH5	MASE783	Sevier	SE-14	(C-25-03)	403968	4276455	46	49	628
Monroe-Red Hill	M2	MASE783	Sevier	SE-3	(C-25-03)	403809	4275536	61	37	336
Monroe-Red Hill	M3	MASE783	Sevier	SE-4	(C-25-03)	403740	4275537	72	62	725
Monroe-Red Hill	M4	MASE783	Sevier	SE-5	(C-25-03)	403661	4275537	40	52	615
Monroe-Red Hill	M5	MASE783	Sevier	SE-6	(C-25-03)	403664	4275726	38	57	739

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Monroe-Red Hill	M6	MASE783	Sevier	SE-7	(C-25-03)	403946	4274613	75	32	238
Monroe-Red Hill	MC1	MASE783	Sevier	SE-8	(C-25-03)	404249	4275897	110	72	130
Monroe-Red Hill	MC2	MASE783	Sevier	SE-9	(C-25-03)	404249	4275897	275	74	30
Wasatch Plateau	Wasatch Plateau #1-25	HENR00	Sevier	SE-15	(D-21-01)25ba	435093	4312075	1116	62	55
Wasatch Plateau	United States D #1	HENR00	Sevier	SE-16	(D-22-03)20bd	447940	4303634	2992	83	28
High Plateaus	Maple Springs #1	HENR00	Sevier	SE-17	(D-23-02)03dd	442279	4298114	2904	84	29
High Plateaus	Maple Springs #1	HENR00	Sevier	SE-17	(D-23-02)03dd	442279	4298114	1215	37	31
Wasatch Plateau	#1 Johnson Livestock etal	HENR00	Sevier	SE-18	(D-23-03)28cb	449159	4292163	3370	94	28
High Plateaus	Paradise Lake 5-1A	HENR00	Sevier	SE-19	(D-25-04)05cd	456521	4278737	1229	48	39
High Plateaus	South Mountain Terrill 1A-1	HENR00	Sevier	SE-20	(D-26-03)01bd	453600	4270054	3348	75	22
High Plateaus	South Mountain Terrill 1A-1	HENR00	Sevier	SE-20	(D-26-03)01bd	453600	4270054	1786	47	26
High Plateaus	South Mountain Terrill 1A-1	HENR00	Sevier	SE-20	(D-26-03)01bd	453600	4270054	2480	67	27
Bear River	Champlin 435 Amoco A-1	HENR00	Summit	SU-1	(A-02-09)01da	511062	4531338	1703	53	31
Wasatch Plateau	UPRR 33-1	HENR00	Summit	SU-2	(A-03-07)33dd	487104	4532340	2210	61	28
Wasatch Plateau	Champlin 475 Amoco "A" #1	HENR00	Summit	SU-3	(A-04-05)17cc	465144	4546787	1286	39	30
Great Salt Lake	State of Utah H #1	HENR00	Tooele	TO-1	(B-GSL)	374777	4540168	1519	71	47
Great Salt Lake	Federal #1	HENR00	Tooele	TO-2	(C-01-17)34ba	266509	4509006	1301	73	56
Uinta Extension	Six Mile Ranch #1	HENR00	Tooele	TO-3	(C-02-0419ba	386162	4498744	1570	49	31
Uinta Extension	Sabie Creek Unit 14-12	HENR00	Tooele	TO-4	(C-07-04)14cb	392170	4451114	1233	45	37
Uinta Extension	Rush Valley Unit 17-10	HENR00	Tooele	TO-5	(C-07-04)17db	388297	4451148	1392	49	35
Uinta Extension	Faust Unit 19-3	HENR00	Tooele	TO-6	(C-07-04)19ba	386157	4450381	986	46	46
Great Salt Lake	State of Utah N #1	HENR00	Tooele	TO-7	(C-GSL)	389852	4511990	1509	58	38
Great Salt Lake	State of Utah N #1	HENR00	Tooele	TO-7	(C-GSL)	389852	4511990	1830	72	39
Great Salt Lake	State of Utah N #1	HENR00	Tooele	TO-7	(C-GSL)	389852	4511990	2000	111	56
Eureka	ET-5	ROY 684	Utah	UT-1	(C-10-02)15dcd	410304	4422526			84
Wasatch Front	Banks #1	HENR00	Utah	UT-2	(D-08-02)13cb	443034	4440958	3961	122	31
Fifthwater	DH101	POWE902	Utah	UT-3	(D-08-06)19	473362	4438449	586		40
Fifthwater	DH103	POWE902	Utah	UT-4	(D-08-06)19	473635	4438470	619		43
Wasatch Back	Cottonwood Canyon #1	HENR00	Utah	UT-5	(D-09-06)07bc	474428	4433462	3959	102	26
Wasatch Back	Cottonwood Canyon #1	HENR00	Utah	UT-5	(D-09-06)07bc	474428	4433462	4568	128	28
Wasatch Back	Cottonwood Canyon #1	HENR00	Utah	UT-5	(D-09-06)07bc	474428	4433462	2708	90	33
Wasatch Back	Fed #1-G24	HENR00	Utah	UT-6	(D-11-04)24ac	463778	4410841	2243	58	26

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Wasatch Plateau	Indianola Unit #1	HENR00	Utah	UT-7	(D-11-05)27dc	469433	4408574	3950	88	22
Wasatch Plateau	Indianola Unit #1	HENR00	Utah	UT-7	(D-11-05)27dc	469433	4408574	5190	126	24
Midway	GW-2	KOHL792	Wasatch	WS-1	(D-03-04)26bbc	460126	4486846	80	38	70
Midway	GW-1	KOHL792	Wasatch	WS-2	(D-03-04)27bdd	459218	4486518	65	24	NA
Midway	GW-3	KOHL792	Wasatch	WS-3	(D-03-04)35bba	460458	4485513	77	43	NA
Midway	GW-4	KOHL792	Wasatch	WS-4	(D-04-04)	460624	4485001	52	12	26
Wasatch Back	West Daniels Land #1	HENR00	Wasatch	WS-5	(D-05-05)11bb	469808	4472393	5264	109	21
Wasatch Back	Current Creek Federal 1-26	HENR00	Wasatch	WS-6	U(C-01-11)26db	492307	4467608	2190	53	24
Uinta Basin	M.A. Smith Oil Investment	HENR00	Wasatch	WS-7	U(C-03-09)16cb	507488	4451547	3081	71	23
Wasatch Back	Exxon Strawberry #1	HENR00	Wasatch	WS-8	U(C-04-11)30ca	485484	4438482	5542	133	24
Wasatch Back	Exxon Strawberry #1	HENR00	Wasatch	WS-8	U(C-04-11)30ca	485484	4438482	3608	100	28
Wasatch Back	Strawberry River #2	HENR00	Wasatch	WS-9	U(C-04-12)26aa	482852	4439309	1513	58	39
Wasatch Back	Buffalo Canyon Unit	HENR00	Wasatch	WS-10	U(C-05-12)13da	484960	4432113	4136	112	27
Wasatch Back	Buffalo Canyon Unit	HENR00	Wasatch	WS-10	U(C-05-12)13da	484960	4432113	3024	85	28
Escalante Des.	ED-4	CHAP813	Washington	WA-1	(C-37-15)03aca	277724	4165844	100	18	51
Grand Staircase	Imperial Fed #19-1	HENR00	Washington	WA-2	(C-40-11)19cc	310095	4128936	737	51	69
St. George Basi	Fed #1-13	HENR00	Washington	WA-3	(C-40-13)13bc	298882	4131507	900	36	40
St. George Basi	TG-06	BUDD862	Washington	WA-4	(C-40-16)08bbc	262774	4133807		70	150
St. George Basi	TG-10	BUDD862	Washington	WA-5	(C-42-13)06bdb	290734	4115219		23	27
St. George Basi	TG-09	BUDD862	Washington	WA-6	(C-42-13)07bdb	290180	4113678		20	6
St. George Basi	TG-13	BUDD862	Washington	WA-7	(C-42-13)18bbc	290308	4112365		20	1
St. George Basi	TG-08	BUDD862	Washington	WA-8	(C-42-13)33aad	294582	4107563		20	19
St. George Basi	TG-11	BUDD862	Washington	WA-9	(C-42-14)15aba	285903	4112564		20	7
St. George Basi	TG-12	BUDD862	Washington	WA-10	(C-42-14)15dbd	286292	4111766		18	34
St. George Basi	TG-16	BUDD862	Washington	WA-11	(C-42-15)10bcd	275698	4113940		27	NA
St. George Basi	TG-18	BUDD862	Washington	WA-12	(C-42-16)14daa	268581	4112123		19	NA
St. George Basi	TG-07	BUDD862	Washington	WA-13	(C-43-14)17cdd	282434	4101794		22	19
St. George Basi	TG-02	BUDD862	Washington	WA-14	(C-43-15)07bbb	270180	4104872		18	NA
St. George Basi	TG-14	BUDD862	Washington	WA-15	(C-43-15)10cca	275453	4103698		20	21
St. George Basi	TG-03	BUDD862	Washington	WA-16	(C-43-15)11ddd	278373	4103421		21	22
St. George Basi	TG-15	BUDD862	Washington	WA-17	(C-43-15)12bdd	279105	4104157		20	8
St. George Basi	TG-01	BUDD862	Washington	WA-18	(C-43-15)16dcc	274201	4101821		20	24

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St. George Basi	TG-05	BUDD862	Washington	WA-19	(C-43-15)24dcc	279443	4100073		21	22
St. George Basi	TG-04	BUDD862	Washington	WA-20	(C-43-15)25ddd	279856	4098474		17	NA
Green River Des	USA Fed #1	HENR00	Wayne	WY-1	(D-26-16)31cc	568558	4261313	1521	50	33
High Plateaus	Deadman Hollow Unit #1	HENR00	Wayne	WY-2	(D-27-01)23ba	432696	4255887	2415	73	30
High Plateaus	Fish Lake 1-1	HENR00	Wayne	WY-3	(D-27-03)01ca	453444	4259690	3470	82	24
San Rafael Swel	Fed #11-4	HENR00	Wayne	WY-4	(D-27-07)04bb	484974	4260546	1482	60	41
Green River Des	Hanksville Unit #1	HENR00	Wayne	WY-5	(D-27-11)06da	521813	4259618	2194	49	22
High Plateaus	Tanner 1-27	HENR00	Wayne	WY-6	(D-28-03)27dd	450822	4243195	2165	80	37
Henry Mtns.	Federal NO. 22-6	HENR00	Wayne	WY-7	(D-28-10)36dd	520314	4241661	1012	36	36
Green River Des	Biddlecome Ranch Fed #11-20	HENR00	Wayne	WY-8	(D-28-14)20bb	551116	4246203	1542	42	27
Canyonlands	DU-1 - USA #1	HENR00	Wayne	WY-9	(D-28-17)27bb	583283	4244906	1547	51	33
Henry Mtns.	Henry Basin Fed #17-6	HENR00	Wayne	WY-10	(D-29-11)17bd	522494	4237495	1130	40	35
High Plateaus	Lion Mt #1	HENR00	Wayne	WY-11	(D-30-05)19ab	464946	4227054	1292	35	27
Henry Mtns.	USA Pexco #1	HENR00	Wayne	WY-12	(D-30-12)19bb	523793	4232705	1794	51	28
Henry Mtns.	Burr Desert #2	HENR00	Wayne	WY-13	(D-30-12)21bc	534039	4226906	1776	41	23
Green River Des	Burr Desert #1	HENR00	Wayne	WY-14	(D-30-12)24ad	539610	4226587	881	38	43
Green River Des	Dirty Devil Unit #4	HENR00	Wayne	WY-15	(D-30-14)15dd	543664	4233188	773	36	47
Wasatch Front	GSLM/GH-A	MURP792	Weber	WE-1	(B-06-03)06cab	396932	4570923	73	22	144

UTAH'S HIGH TEMPERATURE GEOTHERMAL RESOURCE POTENTIAL – ANALYSIS OF SELECTED SITES

by

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EXECUTIVE SUMMARY

Geothermal sites in Utah, either suitable or potentially suitable for electric power generation, are limited in number given current economics and technology. For this study, we reviewed several hundred geothermal wells and springs in Utah, choosing nine geothermal areas or sites for more detailed review. Two of the areas – Roosevelt hot springs and Cove Fort-Sulphurdale - have been developed for geothermal power since the 1980s, and both will undergo expansion and power plant modification in the near future. Three other sites – Thermo hot springs, Newcastle, and Drum Mountains – experienced significant geothermal exploration in the past, but much more data are needed to fully evaluate them. The remaining four sites in northern Utah are virtually unexplored and were selected on the basis of geothermometry applied to geothermal water issuing at the sites. An overall comparative matrix of the study areas is presented in appendix D.

The original intent of this effort was to rank the sites based upon an economic analysis of their electric power development potential. After entering this process, however, we realized that the required elements for such a ranking (reservoir temperature, depth, flow rates, and volume, among other factors), except in one case, are not known. As a result, for this analysis we classify these nine sites into three tiers based on levels of past exploration and industry interest noted above. Following are discussions of the sites themselves with respect to the classification scheme.

<u>First Tier</u> – Resource undergoing active development, well defined.

Roosevelt hot springs KGRA
Cove Fort-Sulphurdale KGRA

<u>Second Tier</u> – Resource explored, not defined.

Newcastle
Thermo hot springs
Drum Mountains-Whirlwind Valley

Third Tier – Resource essentially not explored, indication of potential resource exists.

Utah hot springs
Ogden hot springs
Hooper hot springs
Crystal-Madsen hot springs

First Tier Sites

Roosevelt Hot Springs – Pacificorp (Utah Power) operates the single-flash Blundell plant (26 MW gross) with current plans to upgrade the plant by adding 13 MW reportedly from a "bottoming cycle" using binary power technology. Pacificorp's recent Integrated Resource Plan identified portfolios containing significant upgrades to the Blundell plant, or building a nearby new plant; no new plant portfolio was selected, however. The geothermal field is controlled by a separate supplier entity – Intermountain Geothermal, a subsidiary of California Energy Company – maintaining the fluid supply to the Blundell plant through several production and injection wells. We are aware of no problems related to existing infrastructure and access that would encumber development. No environmental conflicts would appear to restrict future development, although the area is within mapped habitat for the Greater Sage Grouse, and may include several other listed species. Citizen groups propose part of the Mineral Range to the southeast as "wilderness" under some scenarios.

Cove Fort-Sulphurdale – The Cove Fort-Sulphurdale geothermal field, controlled by Provo City, along with Utah Municipal Power Agency's Bonnett geothermal plant (10 MW gross) was recently sold to private developers (Recurrent Resources). The new owners reportedly plan to decommission the old facility, consisting of a combination of flash and binary power plants, drill new production and injection wells, and construct a new 30 MW (gross) facility using binary technology. Surface land ownership is mixed, primarily USFS and private. No environmental conflicts would appear to restrict future development, although the area is within mapped habitat for the Greater Sage Grouse, a listed species. No wilderness areas are near here and none are recommended for future designation.

Second Tier Sites

Newcastle – The Newcastle area is undergoing active geothermal development for large-scale space heating of commercial greenhouses covering more than 10 ha (25 ac). This area was the recent focus of a U.S. Department of Energy-sponsored project to develop geothermal distributed power systems in the west. However, exploratory drilling in the outflow plume yielded temperatures less than required for commercial power generation. The suspected source-location of the geothermal fluids remains untested to date. Land ownership is mostly private within the current geothermal production area, although the suspected source location lies primarily on land administered by the BLM. No imminent environmental concerns have been identified. Present studies suggest a maximum resource temperature in a range around 130ºC (266ºF).

Thermo Hot Springs II KGRA – The region surrounding Thermo hot springs has been of interest to prospective geothermal developers, although no developable resource is identified. Republic Geothermal and others drilled a number of exploratory boreholes and performed geophysical surveys in the area, measuring a maximum temperature of about 174ºC (345ºF) at a depth of about 2,000 m (6,600 ft). No environmental concerns are present that would outwardly restrict development, although the area is remote and contains several listed species including the Greater Sage Grouse.

Drum Mountains Geothermal Prospect – Amax Geothermal and Phillips Petroleum Company explored the Drum Mountains-Whirlwind Valley area during the late 1970s and early 1980s. They identified no developable geothermal resource from this exploration, although they measured temperatures as high as 70ºC (158ºF) in shallow (generally 150 meters or less) boreholes. As a result, we include the area in our second tier classification even though a resource has yet to be discovered. The area is remote, and locally may contain only one listed species. A BLM wilderness study area (WSA) covers much of the Swasey Mountains directly southwest of Whirlwind Valley.

Third Tier Sites

Utah Hot Springs – The Utah hot springs site is one of three sites situated in the urbanized region along the Wasatch Front of northern Utah. We have identified this and the other two sites mainly on the basis of geothermometry, which suggests that the temperature of resource fluids at depth may exceed 190ºC (374ºF). Utah hot springs is within an urban-industrial setting adjacent to a utility corridor, highway, and Interstate 15. The springs were used for a time at a now-defunct resort, and are currently used to heat a small commercial greenhouse. Minor geothermal exploration was conducted in the early 1980s, but the resource is poorly defined. Although the area is industrial, large-scale development could be problematic due to the number of listed species (10) possibly in the area. Zoning restrictions may also impede development.

Ogden Hot Springs -- This site is also within the urbanized Wasatch Front region. It was identified mainly on the basis of geothermometry, which suggests that the temperature of resource fluids at depth may exceed 190ºC (374ºF). Ogden hot springs is situated near the mouth of Ogden Canyon, near residential neighborhoods, utility lines, water sources, and roads. The springs have no history of extended use other than local recreation and bathing. Moreover, no geothermal exploration beyond surface spring sampling has been reported. Similar to Utah hot springs, large-scale development could be problematic due to the number of listed species (10) possibly in the area. Zoning restrictions may also complicate development.

Hooper Hot Springs -- Hooper hot springs and Southwest Hooper warm springs are located about 16 km (10 mi) southwest of Ogden near the eastern shore of Great Salt Lake in an urbanizing portion of Davis County. Geothermometry suggests resource temperatures at depth near 135ºC (275ºF), although no exploration has been performed to date. The area is within a Utah Wildlife Refuge, which could be problematic for industrial development. This area also contains the largest number of listed species of all geothermal areas considered in this study. Land ownership is a mixture of Utah Sovereign Lands, Utah Wildlife Resources, and private.

Crystal-Madsen Hot Springs – The Crystal-Madsen site is the northernmost of the geothermal areas studied. The area has been extensively developed as a resort, operating commercially at least for the past 75 years. The area is logistically attractive as there is ready access to roads and transmission lines. The resource is virtually unexplored, as only fluids have been sampled and the results reported One thermal-gradient borehole penetrated 67 m (220 ft) at the site and yielded a bottom-hole temperature of 61ºC (148ºF). Land ownership is entirely private, although the USFS designated a wilderness area about 3.2 km (2 mi) east from the site. Utah Wildlife Resources indicates that four listed species are found in the region.

CONTENTS

FIGURES

TABLES

APPENDICES

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 1 hectare (ha) = 2.471 acres (ac) 1 ac = 43,560 ft^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 L/s = 15.85 gal/min
Temperature:	degrees Celsius (ºC) = 5/9 (degrees Fahrenheit [ºF]-32) kelvins (K) = ºC + 273.15
Temperature Gradient:	1ºC/km = 0.05486ºF/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) 1 MW_t for 30 yr = 9.461×10^{14} J
Power or work:	1 watt (W) = 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•ºC

INTRODUCTION

Background

In 2002, the Utah Geological Survey (UGS) and Utah Energy Office (UEO) completed compiling various datasets of geothermal resource information for Utah on compact disk (Blackett and Wakefield, 2002). The "Geothermal Resources of Utah" CD replaced an out-of-date and unavailable geothermal map of Utah, published in 1980 (Utah Geological and Mineral Survey, 1980), and contained data, documents, images, and various GIS layers. This report describes the results of a U.S. Department of Energy (DOE)-sponsored study prepared, in part, using information included in the aforementioned project, and results in a new, enhanced version of the CD. The DOE-sponsored study, described in this document, focuses on evaluating and ranking geothermal resource areas in Utah for electric power development potential.

Presently in Utah, utilities generate electricity from two geothermal resource areas, while businesses extract heat from 13 other geothermal sites for a variety of purposes ranging from greenhouse space heating and aquaculture to spas and SCUBA diving schools. Statewide geothermal resource assessments revealed more than 1,100 wells and springs that produce water at temperatures greater than 20EC (68EF). More than 200 of these sources produce water at or above 30EC (86EF), and 74 of these produce water with temperatures at or above 50EC (122EF). Potentially, some of the unused geothermal sources may be commercially viable as geothermal direct-use projects. A few of these sites may also be developable for electrical generation.

Purpose and Scope

The purpose of this project is to increase awareness of Utah geothermal development potential by using available geothermal resource, socioeconomic, and infrastructure data to profile selected moderate to high temperature (>120ºC [248ºF]) geothermal areas in Utah. We use the profiles and other criteria to qualitatively evaluate areas for geothermal electric power development potential. The effort includes reviews of existing published information plus unpublished, available thermal-gradient data for Utah's high and moderate temperature geothermal areas in the Sevier, Black Rock, and Escalante Deserts of southwestern Utah, and several areas within the Wasatch Front region of northern Utah. Several areas of possible development potential are also described, but not analyzed (figure 1).

Our original objective was to characterize the sites with respect to capital and operating costs for various types of geothermal power plants, and rank them based upon the quality of the resource, availability of land and water, proximity to existing infrastructure (power grid), and economic likelihood of their future development. Since the original conception of the project, however, it became evident that many of the potential areas lacked adequate resource definition to model critical economic parameters. Critical attributes lacking at most potential sites include measured resource temperature, reservoir depth, and volume/flow rates that might be expected from wells. In our initial screening process we made assumptions for these parameters based upon the known geologic setting and geothermometry applied to local thermal waters in order to identify those geothermal areas of prospective value for electric power development. From the original 1,100 geothermal sources in Utah, we identified nine areas where geothermal reservoirs are either known or could potentially be developed. In this document we review each of these nine sites, describing various resource and institutional attributes. The nine sites selected are noted on figure 1 and summarized in table 1.

Information sources include spatial data sets available from the Utah Geological Survey (Black and others, 2003), Utah Automated Geographic Reference Center, U.S. Bureau of Land Management (BLM), the U.S. Geological Survey Water Resources Division, the Utah Division of Water Rights (Water Rights), the University of Utah Department of Geology and Geophysics, and Southern Methodist University's Geothermal Laboratory. These spatial data sets are supplemented by economic and demographic data sets from the U.S. Bureau of Economic Analysis (BEA).

Since the first version of the digital geothermal atlas of Utah (Blackett and Wakefield, 2002) was developed, our effort has focused on incorporating more detailed geothermal resource, institutional, and economic information as part of a U.S. Department of Energy (DOE) sponsored project to enhance the atlas. As part of the enhanced version of the digital geothermal atlas of Utah, this document includes: (1) a summary of legal and institutional issues governing water and geothermal development; (2) county-level economic and demographic data such as income, employment, and population estimates; and (3) thermal-gradient data obtained from published and unpublished sources.

Geothermal Energy For Electric Power

Geothermal-hydrothermal systems are of two main types. Vapor-dominated systems, like those at The Geysers in northern California and Lardarello, Italy, are rare and most valuable. These systems yield nearly pure, high-temperature (> 235°C, or 455°F) steam through production wells from 1 to 4 km (3,300 to 13,000 ft) deep. The steam is processed to remove particulates and non-essential fluid, and then is piped to turbines that spin generators to create electricity. More common are high-temperature systems containing hot water (liquid-dominated) at temperatures from 150°C to 300°C (300°F to 570°F). For these, flash-steam power plants are required. Again, the geothermal fluids are brought to the surface from production wells as much as 4 km (13,000 ft) deep. At these depths, the fluids are highly pressurized, but as pressure is reduced in transit to the power plant, 10 to 40 percent of the water flashes (boils and steam forms from some of the water). The steam is separated from the remaining hot water and fed to a turbine/generator unit to produce electricity. The residual water is usually returned to the reservoir through injection wells to help maintain pressure and prolong productivity.

For intermediate-temperature geothermal reservoirs (those between approximately 120°C and 150°C [248ºF and 300ºF), binary-cycle power plants are the preferred installations. In a binary plant, geothermal water passes through a heat exchanger to heat a secondary, organic, working fluid (for example, isopentane) that vaporizes at temperatures lower than the boiling point of water. In a closed-loop cycle, the working-fluid vapor spins the turbine generator then condenses to liquid before vaporizing again at the heat exchanger. As in a flash-steam cycle, the spent (heat-depleted) geothermal fluid is injected back into the geothermal reservoir.

Flash and binary cycles can be combined in sequence for the most efficient conversion of thermal to electrical energy. In these hybrid power plants, hot water from production wells first flashes to steam, turning a primary turbine generator unit. Steam condensate from the flash cycle then mixes with the residual water and is routed to a binary unit for further generation of electricity.

Geothermal electric-power plants are typically available for generation 95 percent of the time. They are modular and can be installed incrementally on an as-needed basis. Moreover, construction of these plants is a relatively rapid procedure – taking as little as six months to install 0.5 to 10 megawatt units, and 1 to 2 years for clusters of plants with capacities of 250 megawatts or more.

A 2003 draft report by the California Energy Commission (CEC) estimates levelized costs for several, competing "central-station electricity generation technologies" (table 2). CEC found that geothermal flash power plants, at $0.0471/kWh, were nearly competitive on a direct, levelized cost basis with combined-cycle, natural-gas plants, at $0.0458/kWh, for a baseload operative mode. Geothermal flash plants compete favorably with wind and hydropower plants, which had direct, levelized costs of $0.0544/kWh and $0.0720/kWh, respectively (California Energy Commission, 2003). While these estimates are encouraging for geothermal electricity, CEC cautions against comparing competing technologies and fuels on a levelized cost basis alone for several reasons. For example, different technologies and fuels provide different services to end users. Some technologies may have favorable operative mode characteristics or may offer environmental benefits over competing technologies. In addition, depending upon how power generated is sold, lower costs associated with a particular technology may not always be passed along to consumers. On a related note, depending upon how economic risks are shared between ratepayers and investors, changes in fuel costs may or may not be passed along to consumers. Surprisingly, rising fuel costs may even affect prices for renewable electricity sources such as geothermal power as a result of how contracts are structured. Still, CEC notes that "… adoption of a renewable energy project may be viewed as part of a greater fuel diversification strategy, and the State may deem higher cost renewable projects to be an acceptable investment to pay for… price risk mitigation."

PacifiCorp undertakes a similar comparison of electric power generating technology costs in its 2003 Integrated Resource Plan (IRP). In addition to considering capital (unit and transmission) and operating & maintenance (O&M) costs, the company also includes such factors as reserve margin contributions, outage rates, annual heat rates, environmental adders, and fuel costs in its analysis of real levelized costs among competing technologies. The results (table 3) show that the cost of generation from an additional flash generator and bottoming cycle at the company's Blundell geothermal plant is competitive with the costs of other alternatives, including natural-gas, combined-cycle, combustion turbines and pulverized-coal systems. This outcome is reflected in the IRP action plan, which calls for "1,400 MW of primarily wind resources, but also potential geothermal resources" (PacifiCorp, 2003, p. 11). As in the CEC analysis described earlier, however, these estimates should only be considered approximations of the relative costs of competing generation technologies. Real generating costs can be heavily influenced by changes in fuel prices, environmental regulations, and technology.

CHARACTERISTICS OF UTAH GEOTHERMAL SYSTEMS

Resource Economic Factors

The original intent of this study was to rank the various geothermal areas in Utah that are either known to contain high temperature geothermal resources, or are suspected to hold high temperature resources for potential electric power development. Primary factors controlling the economics of geothermal development for electrical power include: (1) availability of land and water, (2) distance from transmission lines and load centers (as well as transmission line capacity), (3) the characteristics of the resource, and (4) the cost of competing electric power sources. However, because critical resource parameters are not known for several of the prospect areas, a ranking based on economic considerations was not possible. Instead, we attempt to characterize the areas in more general terms, discussing both positive and negative attributes of the resource and location with respect to political boundaries, land ownership, infrastructure, environmental concerns, and regional demographics.

Land availability is always the primary consideration in development of a geothermal system. Resources may exist, but if access is restricted or prohibited such as the case with geothermal systems within "withdrawn" land units (national parks, monuments, and wilderness areas), then the system is effectively removed from the available geothermal resource base.

Water availability in the form of water rights is necessary to legally develop a geothermal resource. Because geothermal resources are in many cases considered a special type of ground-water resource, having a right to make "beneficial use" of the water through the state system of water appropriation is of paramount importance. Some water basins are "over appropriated" and thereby closed to additional development. In these cases geothermal developers would need to acquire water rights from private parties, or to establish that geothermal rights are at depth or of such quality that their use for geothermal development would not impact appropriated ground water.

Transmission lines and load center location with respect to geothermal resources may also be important in estimating the viability of a geothermal power system. Producing electricity from geothermal resources involves a mature technology. The time from which a site is confirmed as having development potential (with sufficient water at temperatures high enough to drive turbine blades using a binary or flash system) to the time a facility can produce electricity is short, less than three years. However, due to the often remote locations of geothermal resources, the cost of transmission may make the venture more expensive than a facility that does not need miles of new transmission lines. Constructing transmission lines requires extensive environmental permits, the acquisition of which may stretch out for years before a permit is granted. Available transmission line capacity could also dictate whether or not new lines are needed in order to develop a particular resource.

Resource characteristics include mainly (1) depth of the resource, (2) production capacity (flow rate and volume) of the geothermal reservoir, and (3) temperature of the resource. Production capacity is dependent on a number of physical properties of the reservoir mostly related to porosity, permeability, and reservoir pressure. The chemistry of the fluid may also affect the production capabilities of a reservoir. Regardless of institutional and physical barriers to geothermal development, evaluation of resource characteristics is of primary importance when assessing the development potential of a geothermal prospect. The "footprint" of a typical geothermal-hydrothermal system is small (point source) and usually expressed at the surface as hot springs, fumaroles, and alteration minerals. Geothermal developers rely mostly on geologic mapping, near-surface temperature surveys, and geochemical evidence collected from springs and shallow water wells to first delineate a geothermal prospect. Following this, detailed surface geophysical surveys may be used to establish targets for temperature-gradient drilling, which in turn are used for drilling deeper exploratory wells.

Unfortunately, many geothermal areas in Utah remain unexplored or underexplored with respect to determining resource characteristics. In these cases, it is problematic to estimate those important parameters, like depth and temperature, for input into an economic model. Regardless, nine geothermal source areas are considered in this analysis – some with identified high-temperature resources, others with suspected moderate- to high-temperature resources.

Resource Depth

Typically, hot springs and alteration are merely surface expressions of a deeper geothermal resource. Developers conduct exploration using geological, geochemical, and geophysical methods in order to develop target models. This is followed by exploratory and production drilling. Resource depth is an important factor when considering the economic viability of a geothermal source for electric power generation, as depth determines the cost of production wells, well casing, pump design/selection, and other capital costs.

Estimating resource depth for unexplored geothermal systems is difficult. We approach this problem by proposing an estimated average within a range of depths for unexplored resources based upon known factors including local geology and thermal gradients. Geologic information is available to varying degrees for all of the resource areas in question. Some of these areas have exploratory (thermal gradient) drill holes nearby that permit more accurate estimations of resource depth. Information on statewide thermal-gradient drill holes and individual geothermal areas was obtained from the website of Southern Methodist University's Geothermal Lab (Blackwell and others, 1999), data supplied by Henrikson and Chapman (2002), and data compiled as part of this project.

Resource Flow Rates (Permeability)

Because of the broad variability of physical factors controlling geothermal reservoirs, geothermal reservoir capacity and resource flow rates cannot be estimated without flow data from test wells. These reservoir parameters include reservoir temperature, pressure, permeability (hydraulic conductivity), resource volume, and others. The following discussion of reservoir permeability and porosity is paraphrased from Wright and Culver (1991).

Production from most geothermal reservoirs results from fracture permeability. *Permeability* is a measure of a material's capacity to transmit fluid as a result of pressure differences. Where *permeability* is a property of the medium, *hydraulic conductivity* involves the properties of the medium plus the fluid. In rocks, fluids flow through voids (pores) between mineral grains and along open fractures, often caused by faulting or regional stress. *Porosity* refers to the fraction of void space in a volume of rock. *Effective porosity* refers to the amount of void spaces that are interconnected, allowing fluid to flow through the material. Permeability and porosity can be primary (forming as fractures or voids between grains), or secondary (forming by dissolution of the rock matrix). Primary porosity in sedimentary rocks (sandstone, limestone, or shale) is intergranular, usually decreasing with depth because of compaction and pores filling with cementing minerals. In volcanic rocks, primary intergranular porosity and permeability exists in open spaces and at contacts between individual flows. Features that form secondary porosity and permeability include open fault zones, fractures and fracture intersections, intrusive dikes, and breccia zones.

Permeability in rocks ranges over 12 orders of magnitude. Permeability in pristine, unfractured crystalline rock is commonly low. Local fractured and faulted sites, however, can have permeability enhanced by 4 to 6 orders of magnitude. Most attractive geothermal sources are fracture controlled. Fracture permeability may increase where fracturing and faulting occur in response to both local and regional stresses. Deep, local stresses can occur in response to emplacement of an intrusive body or in response to collapse due to volcanism or dissolution. Regional stresses occur as a result of broad tectonic influences. Thus, an understanding of the geologic structure and tectonic history in a prospect area leads to inferences about higher permeability at depth, thereby helping identify an exploration target. The problem, therefore, is more in locating permeable zones rather than in locating anomalous temperatures. Fractures sufficient to make a geothermal well a good producer need be only a few millimeters in width, but they must be connected into a general fracture network in the rock in order to sustain production of large fluid volumes.

Flow rates reported in the Utah geothermal well and spring database (Blackett and Wakefield, 2002) mainly represent flows occurring at the time of a particular hydrologic survey; they are generally not representative of sustained production flows. As a result, for this study we did not include flow rate in the resource criteria used to determine economic viability. Rather, we assumed a minimum flow necessary to permit a development based on the range of resource temperature and depth indicated from measured temperatures, geothermometry, thermal gradients, and geologic factors.

Flow and volume of a geothermal reservoir are economically important factors when considering a geothermal, power-generation project. The production capacity (flow and volume) will most affect plant capacity, which will indirectly affect the unit cost of electricity. Larger plant capacity often means lower unit cost of electricity.

Resource Temperatures

In general, resource temperatures are inversely correlated with capital costs per kilowatt-hour (Entingh and others, 1994; DiPippo, 1999) and appear to have little effect on O&M costs. According to DiPippo (1999), the former relationship stems from the fact that resource temperature influences the number of wells that must be drilled for a given plant capacity. Entingh and others (1994) note that, “reservoir temperature is the physical factor to which overall project costs are most sensitive.”

The actual reservoir or resource temperature of a geothermal system is difficult to estimate when no deep, temperature measurements are available. Geothermometers can provide some temperature estimates where measured temperatures are not available. Geothermometers, or geoindicators, are computations applied to natural waters from springs or wells based on empirically derived formulae using dissolved chemical species. Geothermometers are used in geothermal exploration to estimate the temperature and composition of the original reservoir fluid at depth prior to cooling by conduction and mixing with shallow ground water at the sample collection point (well or spring). Geothermometers indicate a hotter fluid reservoir somewhere in the system, usually at greater depth, that might reasonably be tapped for delivery to the surface. Geothermometers described in appendix A were applied to the statewide geothermal well and spring database. The results shown in appendix B are sorted with respect to the statewide map number (MAPNO field, based on county code), and represent where the K-Mg geothermometer or measured temperature is 100ºC (212ºF) or greater.

As expected, wells and springs within the two developed, high-temperature geothermal areas – Roosevelt hot springs and Cove Fort-Sulphurdale – ranked as some of the highest-temperature sources on the list, yielding temperatures from 207ºC to 298ºC (405ºF to 568ºF). Somewhat surprising, though, was the high rating predicted by several less-well-known areas. In northern Utah, chemical data from Ogden hot springs and Utah hot springs yielded equilibration K-Mg temperatures of nearly 190ºC (374ºF). The K-Mg geothermometer should be the most reliable for these spring waters (Rick Allis, UGS written communication, March 25, 2000). Although the method may not apply to water samples from deep wells, wells in the Sanpete Valley (J. Paulsen) of central Utah and the Uinta Basin (Ashley Valley) of eastern Utah yielded

K-Mg equilibrium temperatures of 207ºC and 182ºC (405ºF and 360ºF), respectively. Other areas yielding anomalously high equilibrium temperatures include the Hooper hot springs and Southwest Hooper warm springs (120ºC to 135ºC [248ºF to 275ºF]), and Crystal-Madsen hot springs (153ºC [307ºF]).

In some cases, geothermometry for areas originally thought to have high potential resource temperatures yielded equilibrium temperatures only slightly higher than the spring or well temperature. These areas included the Abraham hot springs (90ºC [194ºF]) and the Meadow-Hatton hot springs area (110ºC [230ºF]). This is not to say that higher temperature resources do not exist at depth near these systems. For example, a deep exploratory well "Escalante 57-29," drilled near Thermo hot springs to a depth of 7,287 ft (2,221 m), yielded a measured bottom-hole temperature of 160ºC (320ºF) corroborating a K-Mg equilibrium temperature of 166ºC (331ºF) (quartz temperatures range from 217ºC to 241ºC (423ºF to 466ºF). Thermo hot springs water yielded K-Mg temperatures of only 110ºC to 115ºC (230ºF to 239ºF).

Highly saline well water from the Great Salt Lake desert of Box Elder and Tooele Counties yielded anomalously high temperatures using the K-Mg geothermometer while other indicators did not. As a result, we conclude that the K-Mg indicator yields erroneous results when applied to solutions of very high ionic strength, containing high levels of potassium. We therefore eliminated sources with high K-Mg indicated temperatures from consideration if potassium concentrations were greater than 1,000 mg/L.

FIRST TIER GEOTHERMAL RESOURCE AREAS

This study focused on analysis of infrastructure and resource characteristics of selected geothermal areas in Utah that have either known or potential moderate- to high-temperature (> 120°C [248°F]) geothermal resources. The following sections describe the nine geothermal areas selected for analyses, and seven areas considered but not analyzed. Table 1 lists the various general parameters for each area studied. The study area locations are shown on figure 1. Because most of the geothermal areas lacked sufficient resource information to analyze within the context of a quantitative economic model, we present qualitative information in a three-tiered format. Tier-one areas include the developed Known Geothermal Resource Areas at Roosevelt

Hot Springs and Cove Fort-Sulphurdale. Tier-two areas incorporate geothermal sites where exploration has been performed, but where resources are still largely undefined. These include Thermo hot springs, the Newcastle area, and the Drum Mountains-Whirlwind Valley region. Tier-three sites involve thermal sources where virtually no exploration has taken place, but where geochemical indicators suggest a high temperature resource may be present. Tier-three sites include Utah, Ogden, Hooper, and Crystal-Madsen hot springs.

Roosevelt Hot Springs

Location and Resource Parameters

Long: 112.8503 W; Lat: 38.5019 N; NW¼, SW¼, SE¼, section 34,T.26S., R.09W., SLBM; Beaver County; Measured Temp: 268°C (514ºF); Resource Temp: 270°C (518ºF); Depth: 1,000 to 2,000 m (2,381 to 6,562 ft); Resource Type: high-temp liquid; TDS: 7,000-7,800 mg/L

Area Description and Development Outlook

The Roosevelt hot springs geothermal area is situated on the west flank of the Mineral Range in Beaver County, roughly 16 km (10 mi) northwest of the town of Milford (figure 2). It is the most studied geothermal system in Utah. Ward and others (1978) and Ross and others (1982) presented geological, geophysical, and geochemical data for the Roosevelt hot springs geothermal area. Mabey and Budding (1987) summarized the findings of previous workers. The Mineral Range is primarily a complex of Tertiary-age intrusions and Precambrian metamorphic rocks crosscut by a low-angle, west-dipping detachment zone and Basin-and-Range faults. The active geothermal system is associated with relatively young igneous activity, expressed as Quaternary rhyolite domes (0.5-0.8 Ma) within the Mineral Range, recent Basin and Range-style north-south faulting on the west side of the range, an older east-west fault system, and a still older system of near-vertical faults associated with the low-angle detachment zone. The Opal Mound fault, an important conduit for geothermal fluids, defines the western boundary of a small graben that contains much of the geothermal resource. Production from the Roosevelt geothermal area is primarily from highly fractured Tertiary granite and Precambrian metamorphic rocks. Geothermal resources at Roosevelt hot springs have been of commercial interest since the early 1970s, and have been actively developed for power generation since the late 1970s (Moore and Nielson, 1994).

Heat-flow studies identified an area of anomalous heat flow extending about 5 km (3 mi) wide and 20 km (12 mi) long over the Roosevelt hot springs geothermal area (Wilson and Chapman, 1980). Heat-flow values in excess of 1,000 mW/m^2 enclose an area roughly 2 km (1.2 mi) wide by 8 km (5 mi) long that is thought to coincide with the near-surface part of the geothermal system. Geophysicists infer that a deep, cylindrical body approximately 10-15 km (6-9 mi) in diameter situated about 5 km (3 mi) beneath the geothermal field, is a young igneous intrusion.

Utah Power operates the single-flash (26 MW gross) Blundell geothermal power station at Roosevelt. Intermountain Geothermal Company, the field developer, produces geothermal brine for the plant from four wells that tap a production zone in fractured, crystalline rock. The hot brine is flashed to steam in surface separators. The steam is sent to the power plant and the spent geothermal brine is channeled back into the reservoir through three, gravity-fed, injection wells. The production zone depths range generally between 382 and 2,232 m (1,253 and 7,321 ft). Reservoir temperatures are typically between 240°C and 268°C (464°F and 514°F).

The Blundell geothermal power station generated an average of 166,737 MWh per year from 1992 through 2002 (table 4). Blundell generation has rebounded somewhat over the past two years after a period of decline that began after 1996. The plant generated 184,447 MWh in 2002 (U.S. Department of Energy, 2003. The current plant is scheduled for retirement in 2021, based upon the length of the steam-purchase contract period of 30 years, which began in 1991 (Pacificorp, 2003).

Three alternative portfolios in PacifiCorp's (2003) Integrated Resource Plan (IRP) include a 2007 upgrade at Blundell that would provide an additional 50 MW of capacity for a total of 76 MW. This additional block of electricity would result from adding bottoming cycle to the current Blundell Plant, and adding an additional flash and bottoming cycle system. The assumed total capital cost of the proposed Blundell upgrade is $1,880 $/kW or $94,000,000. Although none of the three portfolios including the Blundell upgrade was eventually selected, the 2003 IRP notes that the upgrade, "… is a very realistic option currently under review by PacifiCorp." PacifiCorp also notes that there is at least one additional site with some development work completed and a known potential plant capacity of 50 MW near the current Blundell plant (Pacificorp, 2003, page 71). During a more recent meeting of geothermal advocates, Pacificorp representatives reported that they plan to add the bottom-cycle (binary) power unit to their existing facility at the Blundell plant. This will expand capacity by about 13 MW (Harold Cunningham, Pacificorp, verbal communication, September 2003).

Pacificorp plans to upgrade the single-flash Blundell plant (26 MW gross) by adding 13 MW reportedly from a "bottoming cycle" using binary power technology. Pacificorp's recent IRP identified portfolios containing significant upgrades to the Blundell plant, or building a nearby new plant; no new plant portfolio was selected, however. The geothermal field is controlled by a separate supplier entity – Intermountain Geothermal Co., a subsidiary of California Energy Company – maintaining the fluid supply to the Blundell plant through several production and injection wells. We are aware of no problems related to existing infrastructure and access that would encumber development. No environmental conflicts would appear to restrict future development, although the area is within mapped habitat for the Greater Sage Grouse, and may include several other listed species. Citizen groups propose part of the Mineral Range to the southeast as "wilderness" under some scenarios.

Cove Fort-Sulphurdale

Location and Resource Parameters

Long: 112.5668 W; Lat: 38.5685 N; T.26S., R06W., sec.07,SE/NE/NW SLB&M; Beaver County; Measured Temp: 150°C; Resource Temp: 150°C; Depth: 180 to 400 m (shallow reservoir); 600-900 m (deep reservoir); Resource Type: dry steam in shallow reservoir, high-temp liquid in deeper reservoir; TDS (mg/L): 9,400 (deep reservoir)

Area Description and Development Outlook

The Cove Fort-Sulphurdale geothermal area lies on the northwest side of the Tushar Mountains, and is roughly 32 km (20 mi) north along Interstate Highway 15 from the town of Beaver (figure 3). The geothermal system results from a combination of complex geologic structures that localize the geothermal source. The oldest structures are Cretaceous-age (Sevier orogeny) thrust faults. Younger Basin and Range structures consist of numerous north-northeast-striking high-angle normal faults. More recent gravity-slide blocks, shed from the northwest flank of the Tushar Mountains, act as low permeability layers that cap portions of the geothermal system. At the surface, the trends of faults are delineated by local alignments of sulfur deposits, acid-altered alluvium, and gas seeps. Surface manifestations occur throughout an area of about 47 km^2 (18 mi^2), and probably reflect boiling and degassing of chloride-rich brine from a thermal water table 400 m (1,300 ft) below the surface. Dry steam at about 150°C (300°F) is produced from relatively shallow production wells (180 to 400 m [600 to 1,300 ft] deep) completed into fractured Paleozoic sandstone (Moore and others, 1979; Ross and Moore, 1985).

The Utah Municipal Power Agency (UMPA) operates four, binary-cycle, power units with a combined capacity of 3 MW (gross), a turbine generator (2 MW gross) placed upstream from the binary units, and a condensing turbine rated at 8.5 MW (gross). UMPA operates the facility known as Cove Fort Station No. 1 for the City of Provo. Because H_2S is produced as a non-condensable gas, the facility includes a sulfur abatement plant designed to produce 1.36 metric tons (1.5 tons) per day of sulfur.

Six production wells (three 18-cm- [7-in] diameter wells and three 33-cm [13-in] diameter wells) supply steam to the three power units. Steam supply wells reportedly produce from the shallow, vapor-dominated part of the geothermal system, at depths between 335 and 366 m (1,100 and 1,200 ft). Reductions of reservoir pressures necessitated completion of new production wells into the deeper, liquid-dominated portion of the system. One deep well was completed into the deeper system and now produces geothermal fluid for the condensing turbine. Spent fluid is channeled back into the deep reservoir through one of the early exploratory wells, which was converted to an injector well. The estimated net output from the three power units is about 10 MW. UMPA is operating the plant somewhat below capacity (4 to 6 MW).

Although the Cove Fort geothermal plant has generated an average of 34,591 MWh per year from 1992 through 2002, annual generation has fluctuated greatly from as high as 47,024 MWh in 1992 to as low as 28,422 MWh in 1995 (table 5). The plant generated 29,681 MWh in 2002.

At the time of this writing, Provo City had reportedly sold their interests at the Cove Fort-Sulphurdale area. The new owners (Recurrent Resources) had not announced future plans for the development of the geothermal field, but reportedly the new operators intend to decommission the existing plant, reconstruct the well field, and build a new power station (30 MW gross) incorporating binary technology (Ray Connors, Sunrise Engineering, verbal communication, September 2003). Surface land ownership is mixed, primarily USFS and private. No environmental conflicts would appear to restrict future development, although the area is within mapped habitat for the Greater Sage Grouse, a listed species. No wilderness areas are near here and none are recommended for future designation.

SECOND TIER GEOTHERMAL RESOURCE AREAS

Newcastle

Location and Resource Parameters

Long: 113.5651 W; Lat: 37.6591 N; T.36S., R.15W., sec. 20, SW/NW/NW SLB&M; Iron County; Measured Temp: 118°C; Resource Temp: 130°C; Depth: 150 to 274 m (from Milgro drilling results); Resource Type: moderate-temp liquid; TDS (mg/L): 1,000 to 1,100

Area Description and Development Outlook

Newcastle is a small, unincorporated rural community located near the south end of the Escalante Valley adjacent to the northwest side of the Antelope Range in Iron County (figure 4). Newcastle is located along State Highway 56. Cedar City and connection to Interstate 15 lie about 48 km (30 mi) to the east along SR-56. A number of small communities in the Escalante Valley to the west from Newcastle are also connected by SR-56. Commercial greenhouse operators use geothermal production wells to tap an unconfined, alluvial aquifer, which covers an area of several square miles. Geothermal water also heats a Church of Jesus Christ of Latter-Day Saints' chapel in the town of Newcastle.

A maximum temperature of 130°C (266°F) was measured in a 1981 geothermal exploration well, which penetrated the outflow plume of the geothermal aquifer (Blackett and others, 1990; Blackett and Shubat, 1992). However, more recent thermal-gradient exploratory holes drilled nearby, record a maximum temperature of about 118°C (244°F) within the outflow plume. Production wells at the greenhouses generally produce fluids in the range of 75°C to 95°C (167°F to 203°F).

Based on shallow borehole data, and detailed self-potential (SP) and resistivity surveys (Ross and others, 1990), thermal water is thought to originate from a buried point source (upflow zone) near a Quaternary range-front fault southeast of Newcastle. The geothermal fluid then spills into the unconfined aquifer, creating a concealed outflow plume. The fluids move northwest within the aquifer cooling by conduction and probably mixing with cooler ground-water at the system margins. Shallow production wells (~ 150 m [500 ft]) tap this aquifer, supplying hot water for greenhouse space heating. Gawlik and Kutcher (2000) reviewed resource and economic parameters associated with a proposed small-scale geothermal power development at Newcastle and suggested that the resource was not large enough to support additional development beyond the existing greenhouse space heating. However, the probable source of the geothermal fluid, near the Antelope Range fault, remains unexplored. Only a few shallow (< 20 m) thermal-gradient boreholes have been drilled near the "throat" of the system. Deeper exploratory drilling into the source (150 to 300 m?) would be necessary to better evaluate the development potential for electric power generation.

The main part of the outflow plume extends northwestward from the Antelope Range fault beneath the privately owned valley floor. The suspected geothermal source area lies along the irregular boundary between private and BLM-administered lands along the foothills southeast of Newcastle. The main part of the suspected source area resides within BLM-administered lands.

The Newcastle area is undergoing active geothermal development for large-scale space heating of commercial greenhouses covering more than 10 ha (25 ac). This area was the recent focus of a U.S. Department of Energy-sponsored project to develop geothermal distributed power systems in the west. However, exploratory drilling in the outflow plume yielded temperatures less than required for commercial power generation. The suspected source-location of the geothermal fluids remains untested to date. Land ownership is mostly private within the current geothermal production area, although the suspected source location lies primarily on land administered by the BLM. Questions about the production temperature and capacity of the resource, however, remain as paramount obstacles to the extent of future development. No imminent environmental concerns have been identified. Present studies suggest a maximum resource temperature in a range around 130ºC (266ºF).

Thermo Hot Springs

Location and Resource Parameters

Long: 113.2036; Lat: 38.1731; T.30S., R12W., sec 28, SE/SE/NE; Beaver County
Measured Temp (°C): 174; Resource Temp: 160 to 217°C; Depth: 2,050 m; Resource Type: high-temp liquid; TDS (mg/L): 1,300 to 3,300 (data from Republic well Escalante 57-29)

Area Description and Development Outlook

The Thermo hot springs geothermal area is located within the northeast part of the Escalante Desert in southern Beaver County (figure 5). Thermal water discharges from two large spring mounds, situated near the axial drainage of the Escalante Desert valley. The Shauntie Hills, northwest of the hot springs, and the Black Mountains to the southeast consist of mainly Tertiary lava flows and volcaniclastic deposits (Rowley, 1978).

Northeast-oriented normal faults displace Quaternary valley-fill units and form a broad zone of faulting in and around the hot spring mounds. Faults mapped within the volcanic units of the low hills southeast of the thermal area, and within the Black Mountains, exhibit a dominant northwest orientation. The orientation of these two sets of structures and the position of the hot springs suggest that a structural intersection localizes the geothermal system. Regional gravity data suggest that a subsurface fault with several hundred feet of displacement (down to the west) passes through the hot springs area (Mabey and Budding, 1987). Blackett and Ross (1992) reported an interesting negative self-potential (SP) anomaly about 1 kilometer (0.6 mi) southeast of the spring mounds, which suggests the possibility of nearby upward-flowing geothermal fluid.

Republic Geothermal, Inc. (1977) contributed temperature-gradient, geophysical, and geochemical data resulting from geothermal studies in the area. The data package includes temperature-gradient borehole data (27 boreholes), water analyses, and production-test and temperature data from a deep (2,221 m [7,288 ft]) exploratory drill hole (Escalante 57-29). Mabey and Budding (1987) reported written communication from Republic indicating that this drill hole penetrated alluvium to about 350 m (1,148 ft), volcanic rock to 960 m (3,150 ft), and sedimentary-metamorphic rocks to 1,500 m (4,921) ft) where granite was encountered. The granite extended to total depth. Republic measured static temperatures on January 6, 1978 revealing a maximum temperature of 173.7ºC (344.7ºF) at a depth of 2,043 m (6,700 ft) – the maximum depth of recorded temperatures.

Although indicators suggest that a moderate- to high-temperature resource exists at Thermo, no developable resource has been defined to date – due mainly to lack of permeability. Maximum measured water temperature in the springs is 89.5ºC (193.1ºF) and estimates of the discharge range from about 30 to 120 l/min (8 to 32 gpm). Rush (1983) estimated the reservoir temperature between 140ºC and 200ºC (284ºF - 392ºF). Geothermometers applied to three water analyses of the hot springs yielded equilibrium temperatures ranging from 110º to 148ºC, while fluid samples from Escalante 57-29 yielded temperatures ranging from 166º to 241ºC (appendix B).

The region surrounding Thermo hot springs has been of interest to prospective geothermal developers, although no developable resource is identified. Republic Geothermal and others drilled a number of exploratory boreholes and performed geophysical surveys in the area, measuring a maximum temperature of about 174ºC (345ºF) at a depth of about 2,000 m (6,600 ft). No environmental concerns are present that would outwardly restrict development, although the area is remote and contains several listed species including the Greater Sage Grouse.

Drum Mountains Geothermal Prospect

Location and Resource Parameters

Long: 113.1533 W; Lat: 39.4900 N; T.14-15S., R.12-13W. SLB&M; Juab & Millard Counties; Measured Temp: ?; Resource Temp: ?; Depth: ?; TDS: ?.

Area Description and Development Outlook

The Drum Mountains geothermal prospect is located roughly 64 km (40 mi) WNW of the town of Delta, Utah (figure 6). Near the head of the Whirlwind Valley, the prospect extends across a broad area astride the Juab-Millard County line. Geothermal companies (primarily Phillips and Chevron) focused exploration on this area during the 1970s and 1980s, drilling nearly 80 thermal-gradient boreholes, and performing geophysical and geochemical surveys. The Little Drum Mountains, flanking the east side of the valley, consist mainly of Eocene-Oligocene intermediate volcanic rocks associated with a deeply eroded volcano complex. To the west lie the Swasey Mountains and the House Range consisting of Cambrian Tintic or Prospect Mountain Quartzite and series of overlying Cambrian clastic and carbonate rock units.

Rowley (1998) describes broad transverse zones and related Cenozoic igneous belts in the Great Basin. These east-west aligned zones include numerous geologic structures, igneous centers, mineralized districts, and hot springs that appear related in space and time. Rowley deduces that hot springs and hydrothermally altered rock may be concentrated along transverse zones because of long-lived faults, providing pathways for ground water and magma bodies. The Drum Mountains geothermal prospect lies within one of Rowley's igneous belts (Ely-Tintic igneous belt) and near two (Payson and Sand Pass) transverse zones. Later overprinting of Basin and Range faulting produced a number of north-south oriented faults (Drum Mountains fault zone).

The nearby Crater Springs geothermal area surrounds a Quaternary eruptive center known as Fumarole Butte (figure 6). See the section on "Crater Springs" in this report for more information.

Sass and others (1999) present summaries of exploratory drill-hole data for the Drum Mountain area acquired by the U.S. Geological Survey from several companies (primarily Phillips Petroleum and Chevron) that explored the region during the 1970s and early 1980s. These data were further summarized, combined with other data sets and made available through the Internet by the Geothermal Laboratory at Southern Methodist University (Blackwell and others, 1999). The Internet address is: http://www.smu.edu/geothermal/.

Figure 6 shows the distribution of these drill holes and the relative magnitudes of measured temperature gradients in the Drum Mountains area. Borehole data indicate mostly moderate to high thermal gradients relative to average Basin and Range values. Boreholes in this area vary in depth generally from 96 to 153 m (315 to 502 ft). One borehole was completed to a depth of 372 m (1,220 ft). The highest bottom-hole temperature was 70°C (158°F) at a depth of 150 m (492 ft) measured in a borehole drilled in section 30, T.15S., R.11W., near the east edge of the Whirlwind Valley and west side of the Little Drum Mountains. Beyond these data, no identified moderate-high temperature geothermal system has been publicly reported. The presence of young volcanic activity, young faults and geothermal springs, however, suggests that the area may contain significant geothermal resources.

Amax Geothermal and Phillips Petroleum Company explored the Drum Mountains-Whirlwind Valley area during the late 1970s and early 1980s. They identified no developable geothermal resource from this exploration, although they measured temperatures as high as 70ºC (158ºF) in shallow (generally 150 meters or less) boreholes. As a result, we include the area in our second tier classification even though a resource has yet to be discovered. The area is remote, and locally may contain only one listed species. A BLM WSA covers much of the Swasey Mountains directly southwest of Whirlwind Valley.

THIRD TIER GEOTHERMAL RESOURCE AREAS

Utah Hot Springs

Location and Resource Parameters

Long: 112.0278 W; Lat: 41.3375 N; T.07N., R.02W., sec 14, SW/SE/SE SLB&M; Weber County; Measured Temp: 59°C; Resource Temp: 192°C (from K/Mg geothermometer); Depth 1,800 m(?); Resource Type: high-temp liquid (?); TDS: 22,000 mg/L.

Area Description and Development Outlook

Utah hot springs issue from several orifices in Pleistocene valley fill sediments at the western edge of the Pleasant View spur, or salient, about 90 m (300 ft) west of U.S. 89 on the Box Elder-Weber County line (figure 7). The area is located within a utility and transportation corridor where the discharge, in the past, was channeled to baths, pools, and greenhouses. A small commercial greenhouse presently uses the fluids for heating during winter months. The maximum temperature reported is 63°C (145°F), although temperatures reported in most studies ranged between 57°C and 58.5°C (135°F and 137°F) (Murphy and Gwynn, 1979).

Total dissolved solids content of Utah hot springs water ranges between 18,900 and 25,200 mg/L, consisting mainly of sodium chloride. In addition to the high salinity, the water contains 3 to 5 mg/L dissolved iron that oxidizes and precipitates when the water is aerated. The iron compounds have reportedly led to scale buildup in piping and heat exchangers within the greenhouses. Felmlee and Cadigan (1978) have reported that the water also contains measurable quantities of radium (66 μμg/L) and uranium (0.04 μg/L). Cole (1983) included Utah hot springs as part of a geothermal-geochemical research project, and suggested that the hot spring discharge fluids appear to have circulated to depths in excess of 5 km (3 mi), thermally equilibrating with reservoir rock at temperatures above 200ºC (392ºF).

A shallow temperature survey (1 to 1.5 m depth) reported by Murphy and Gwynn (1979), indicated the temperature anomaly is centered on the main spring. Shallow temperatures decrease rapidly with distance northward from the main spring as the 25ºC isotherm is encountered about 75 m (250 ft) north. Southward from the main spring, temperatures decrease less with distance as another spring orifice (measured temperature 40ºC) occurs about 150 m (500 ft) to the southeast. The 25°C isotherm extends westward about 200 m (650 ft) to the Allen Plant Co. greenhouses.

The Wasatch Range to the east is a complex of Cretaceous-age (Sevier orogeny) thrust sheets involving Precambrian and early Paleozoic rocks. The Pleasant View spur (Gilbert, 1928) or salient, a prominent bedrock block projecting westward from the Wasatch Range north of Ogden, is part of the mountain mass displaced by normal faulting down and west from the main massif. The bedrock block within the salient remains high relative to the Basin-and-Range grabens to the west. Cluff and others (1970) note that the bounding structures of the Pleasant View spur are mostly concealed and not fully understood. A normal fault separates the eastern edge of the spur from the main Wasatch Range. A fault scarp, which marks the southwestern edge of the spur, is mapped near Utah hot springs (figure 7). Cluff and others (1970) identified two sets of lineaments, roughly perpendicular to one another, within the Pleasant View salient. One set of lineaments strikes northwestward, parallel to the Wasatch Range, while the other strikes to the northeast. Near the western edge of the salient at least two of the northeast striking lineaments appear to intersect the fault scarp at the salient's western edge. The northernmost intersection is close to Utah hot springs. Based on limited information, Murphy and Gwynn (1979) postulate that displacement on most of the internal structures of the salient does not appear large.

Utah hot springs are situated nearly due west of the boundary between the Weber and Brigham City segments of the Wasatch fault, where Personius (1990) describes surficial deposits and structural geology along these two fault segments. His work shows that at least three Holocene faults on the west flank of the Pleasant View spur postdate Bonneville lake cycle (between 30 and 10 ka) deposits and trend roughly at right angles to the Brigham City segment of the Wasatch Fault. The three faults are marked by 3-5 m high scarps formed in Bonneville-lake-cycle lacustrine gravels. The northernmost scarp also appears to cut Holocene fluvial and lacustrine deposits near the hot springs. He also notes that the springs appear localized at the intersection of this young fault and an older buried fault, described by Davis (1985), that flanks the west side of the spur.

Murphy and Gwynn (1979) also reported the results of temperature-gradient drill hole UT/GH-B. As part of a small DOE-funded project, the borehole was drilled to 30.5 m (100 ft).

They reported the hole would not stay open unless casing was installed as drilling proceeded. At a depth of 22 m (72 ft) a small volume of artesian flow was noted. In the 27 to 30 m (90 to 100 ft) interval, artesian flow increased to 227 L/min (60 gpm) and drilling ended. Grouting controlled flow from the hole. Borehole UT/GH-B encountered a series of sandy clay layers interbedded with sand and gravel layers. The overlying sandy clay confines the water in the sand and gravel layers, creating artesian conditions. An undetermined volume of thermal water is transported away from the springs in the sand and gravel aquifer. Temperature of water flowing from UT/GH-B (prior to grouting?) was 59ºC (138°F). Murphy and Gwynn (1979) measured conductivity at 4.05×10^4 μmohs/cm at 25°C (77°F). At 21 m (69 ft) pieces of saturated wood were blown from the borehole; samples sent to the U.S. Geological Survey's radiocarbon lab in Reston, Virginia yielded an age of 27,100 ± 600 years BP. Temperature profile for UT/GH-B is a simple curve showing temperature increasing with depth to a maximum of 59°C (138°F) at total depth (30.5 m, 100 ft).

The Utah hot springs site is one of three sites situated in the urbanized region along the Wasatch Front of northern Utah. We have identified this and the other two sites mainly on the basis of geothermometry. Geothermometry suggests that the temperature of resource fluids at depth may exceed 190ºC (374ºF). Utah hot springs is within an urban-industrial setting adjacent to a utility corridor, highway, and Interstate 15. The springs were used for a time at a now-defunct resort, and are currently used to heat a small commercial greenhouse operation. Minor geothermal exploration was conducted in the early 1980s, but the resource is poorly defined. Although the area is industrial, large-scale development could be problematic due to the number of listed species (10) possibly in the area. Small-scale geothermal power development, however, would likely blend well with other uses. Zoning restrictions in this "urban-fringe" area could impede some types of future development.

Ogden Hot Springs

Location and Resource Parameters

Long: 111.9233 W; Lat: 41.2356 N;T.06N, R.01W., sec. 23, SE/SW/SW SLB&M; Weber County; Measured Temp: 57°C; Resource Temp: 190°C (from K/Mg geothermometer); Depth: 1,800 m; Resource Type: high-temp liquid (?); TDS (mg/L): 8,800

Area Description and Development Outlook

Ogden hot springs, located at the mouth of Ogden Canyon on the east side of Ogden in Weber County, issue from fractures in Proterozoic (?) rocks along the Ogden River (figure 8). Nelson and Personius (1993) show the surface trace of the Wasatch fault a few hundred feet west of the springs. Undoubtedly, some (or even most) of the bedrock fractures near the springs are associated with the Wasatch fault. Since the late 1800s, workers have reported temperatures for the springs ranging from 49°C to 66°C (121°F to 150°F), but averaging about 57°C (135°F) (Mundorff, 1970). Flow rates recorded for the springs have been as high as 379 L/min (100 gpm), although most records indicate that the flow rate is about 132 L/min (35 gpm). TDS content of the sodium-chloride-type water from the springs generally varies from 8,650 to 8,820 mg/L. Concentration of manganese is high, and the chemical and thermal characteristics are similar to those for Hooper hot spring about 24 km (15 mi) to the southwest. Cole (1982, 1983) included Ogden hot springs as part of a geothermal-geochemical research project, and suggested that the hot spring discharge fluids appear to have circulated to depths in excess of 5 km (3 mi), equilibrating at temperatures above 200ºC (392ºF).

This site also occurs within the urbanized Wasatch Front region. It was identified mainly on the basis of geothermometry, which suggests that the temperature of resource fluids at depth may exceed 190ºC (374ºF). Ogden hot springs is situated near the mouth of Ogden Canyon, near residential neighborhoods, utility lines, water sources, and roads. The springs have no history of extended use other than local recreation and bathing. Moreover, no geothermal exploration beyond surface spring sampling has been reported. Similar to Utah hot springs, large-scale development could be problematic due to the number of listed species (10) possibly in the area. Zoning restrictions in this "urban-fringe" area may also complicate certain types of development.

Hooper Hot Springs

Location and Resource Parameters

Long: 112.1753 W; Lat: 41.1370 N; T.05N., R.03W., sec 27 SE/NW/SW SLB&M; Davis County; Measured Temp: 57°C; Resource Temp: 135°C; Depth: 1,500 m (from temp grad 91.6°C/km); Resource Type: low- to mod-temp liquid; TDS (mg/L): 8,600

Area Description and Development Outlook

Hooper hot springs and Southwest Hooper warm springs are located about 16 km (10 mi) southwest of Ogden near the eastern shore of the Great Salt Lake in Davis County (figure 9). The springs issue from Quaternary sedimentary deposits, and lie about 0.4 km (0.24 mi) west from an inferred fault. In addition to the main hot springs, several small springs and seeps are in the immediate area. Southwest Hooper warm springs are located about 0.6 km (0.4 mi) west of the main spring. Temperature at Hooper hot springs is about 57°C (135°F) with TDS content of about 8,600 mg/L. Temperature of Southwest Hooper warm springs is 32°C (90°F) with a TDS content of about 27,800 mg/L. The water is of sodium chloride-type in both springs. Although calcium concentrations are about the same for both springs, Mundorff (1970) noted that magnesium and potassium concentrations are much higher at Southwest Hooper warm springs. They suggest that the thermal waters at both springs are of the same origin, but water from Southwest Hooper warm springs is a mixture of both thermal and shallow ground water (Great Salt Lake brine). Geothermometers indicate equilibrium temperatures of about 135ºC (275ºF).

Geothermometry suggests resource temperatures at depth near 135ºC (275ºF), although no exploration has been performed to date. The area is within a Utah Wildlife Refuge, which could be problematic for industrial development. This area also contains the largest number of listed species of all geothermal areas considered in this study. Surface ownership and administration include mainly State Sovereign Lands and Division of Wildlife Resources lands along the eastern Great Salt Lake shoreline (figure 9). Both of these land divisions appear established as wildlife preserves. The geothermal resource area coincides with a Utah Division of Wildlife Resources designated wildlife refuge. Private lands extend eastward from these Sovereign and Division of Wildlife Resources lands.

Crystal-Madsen Hot Springs

Location and Resource Parameters

Long: 112.0864 W; Lat: 41.6600 N; T.11N., R.02W., sec. 29 SE/NE/SE SLB&M; Box Elder County; Measured Temp: 54°C; Resource Temp: 153°C; Depth 3,580 m (from temp grad ~ 40°C/km); Resource Type: mod- to high-temp liquid; TDS: 43,600 mg/L.

Area Description and Development Outlook

Crystal (Madsen) hot springs, located about 2 km (1.3 mi) north of Honeyville in Box Elder County, flow from the base of a small salient extending west from the Wellsville Mountains (northern extension of the Wasatch fault zone) (figure 10). Springs flow from fractured Paleozoic rocks at temperatures between 49.5°C and 57°C (121°F and 135°F). Although there are a number of warm springs and seeps in the area, the original main spring orifice is no longer visible, since it was enclosed in a box about 75 years ago. A nearby cold spring 11°C (52°F), along with water from the hot springs, is used to fill a 1.14-million-liter- (300,000-gallon-) pool, while the hot springs alone are used to fill therapeutic hot tubs and mineral pools (Blackett and Wakefield, 2002). Swimming pool temperatures range from 29° to 44°C (85° to 112°F). Roughly 610 m (2,000 ft) south of the main spring, a series of low-flowing warm springs and seeps are present in a small branch of Salt Creek, a tributary of the Bear River (Murphy and Gwynn, 1979).

The flow from all springs and seeps drains southwest along Salt Creek and has been estimated at about 15,300 L/min (4,000 gpm). The main hot spring discharges at a rate of about 6,370 L/min (1,680 gpm).

Dissolved constituents of the thermal water are the highest of any spring in Utah with TDS values above 46,000 mg/L. Over 90 percent of the ions in solution are sodium and chloride. Milligan and others (1966) estimated that the Crystal-Madsen system produces 450 tons (408 mt) of salt per day. In addition to high TDS values, the springs reportedly contain elevated levels of radium (220 µµg/L) and uranium (1.5 µg/L) (Felmlee and Cadigan, 1978). Geothermometry suggest equilibration temperatures near 150ºC (300ºF), although these values might be questionable given the high TDS of the spring waters.

The Wellsville Mountains (north extension of the Wasatch Range) consist mostly of faulted Paleozoic sedimentary rocks dipping northeastward from 20 to 60 degrees. These carbonate rocks contain some quartzite and shale. Displacement across the northeast-trending fractures within the range is generally small, but fractures dissect the range into a number of small fault blocks. The range is bound on the east and west by basin-and-range normal faults.

Murphy and Gwynn (1979) describe the bedrock and alluvium mantle of the Madsen salient. The only known bedrock exposures are found at the western edge of the salient, east and southeast of the springs. Exposed rocks are primarily bluish gray, Paleozoic limestone striking N 40° W and dipping 60 to 85 degrees eastward. Remnants of a more extensive Tertiary (?) conglomerate are scattered across the western edge of the salient, unconformable atop Paleozoic bedrock. Quaternary and recent alluvium covers much of the salient and varies in thickness up to several tens of meters. Alluvium is thickest where the salient and Wellsville Mountains meet, and along the north and west edges. Murphy and Gwynn (1979) identify a large landslide mass northeast of the springs exposing a "scarp of alluvium" (?) about 30 m (100 ft) thick. Black and others (2003), using mapping by Oviatt (1986), show several northeast-southwest Quaternary faults intersecting the Collinston segment of the Wasatch fault near the hot springs.

The Salt Creek drainage exposes a 20 cm (7 in) thick layer of hot-spring tufa. This thermal spring deposit is brown with a fibrous, vuggy texture. The tufa appears laterally extensive and may have been penetrated by borehole C(M)/GH-A at 6.7 m (22 ft).

Crystal-Madsen hot springs issue along faults at the western edge of the Madsen salient or spur. The salient is small relative to the Pleasant View or Salt Lake salients, but, in similar fashion, is a fault block intermediate in elevation between the Wellsville Mountains to the east and the graben to the west.

The Crystal-Madsen site is the northernmost of the geothermal areas studied. The area has been extensively developed as a resort, operating commercially at least for the past 75 years. The area is logistically attractive for development as there is ready access to roads and transmission lines. The resource is virtually unexplored, as only fluids have been sampled and their analytical results reported. One thermal-gradient borehole penetrated 67 m (220 ft) at the site yielding bottom-hole temperature of 61ºC (148ºF). Land ownership is entirely private, although the USFS designated a wilderness area about 3 km (2 mi) east of the site. Utah Wildlife Resources indicates that four listed species are found in the region.

GEOTHERMAL AREAS CONSIDERED BUT NOT ANALYZED

Several areas described below were considered for inclusion in this study, but were not analyzed because resource temperatures appear too low and reservoirs are undefined. In most cases, geothermometry (geo-indicators described in appendix A) suggested resource temperatures below the threshold (120ºC [248ºF]) established for this study. In nearly all cases, though, reservoir parameters, such as depth, volume, and flow capacity of the resource, were also undetermined. These resource areas, however, should be considered in future studies of potential sites for geothermal direct use.

Beryl Area

Location and Resource Parameters

Long: 113.6870 W; Lat: 37.8390 N; T.34S., R.16W., sec. 18, SW/SE/SW SLB&M; Iron County; Measured Temp: 149ºC; Resource Temp: 149ºC (?); Depth: 2,134 m (?); TDS: ~ 4,000 mg/L.

Area Description

The Beryl area is located within the southern Escalante Valley of Iron County, south of the Wah Wah and Indian Peak Ranges, near the rail sidings of Beryl and Zane (figure 1). Goode (1978) reported a temperature of 149°C (300°F) from a depth of 2,134 m (7,000 ft) measured within a 3,748 m- (12,295 ft-) deep well that he termed "De Armand #1." Goode also reported that, upon testing, the well flowed at a rate of 3,785 L/min (1,000 gpm) and that the water contained less than 4,000 mg/L dissolved solids. No flowing temperature was given.

According to records obtained from Water Rights, three companies -- McCulloch Oil Corporation (MCR Geothermal Corp.), Geothermal Kinetics, Inc., and Utah Power & Light Company -- formed a partnership to drill and complete a well referred to as "MCO-GKI-UPL-DeArman #1." The well was located in the SW¼SE¼SW¼ section 18, T. 34 S., R. 16 W., and was drilled during the spring of 1976. Documents filed with Water Rights during December 1981 and correspondence dated November 12, 1985, suggest that the well was drilled to a depth of at least 2,361 m (7,745 ft) and that it did not comply with state-regulated abandonment procedures at that time.

Klauk and Gourley (1983) made no mention of the above-referenced ("DeArman") well, but reported a temperature of 60°C (140°F) measured at a depth of 2,461 m (8,072 ft) within an unnamed geothermal test well located in the NE¼NE¼NW¼ section 22, T. 34 S., R. 16 W. This location corresponds to a well reportedly drilled in 1976 by MCR Geothermal Corp., and referred to as "State #1" (letter from Water Rights to Insurance Company of North America, dated November 12, 1985).

Wood's Ranch is located just south of the Wah Wah Mountains in the northwest part of the Escalante Valley in Iron County, roughly 16 km (10 mi) NNW of the DeArman #1 well. One of two wells, a 61-m- (200-ft-) deep water well drilled for irrigation on the ranch produces 36.5°C (97.7°F) water. No hot springs are present. A self-potential survey performed at Wood's Ranch by workers from the University of Utah and the UGS (Ross and others, 1991) revealed a broad, negative SP anomaly interpreted as thermal up-flow. Beyond the SP survey and one water analysis, the property remains unexplored. Chemical geothermometers suggest reservoir temperatures in the range of 100°C to 115°C (212°F to 239°F). The warm water produced from the well may be a mixture of thermal water and non-thermal ground water from the Escalante Valley aquifer. The area is somewhat remote with no incorporated communities nearby. The Union Pacific rail line crosses the Escalante Valley within 1.6 km (1 mi) of Wood's Ranch. Access roads into the area are both improved county and BLM roads, and jeep trails. Land ownership in the vicinity of the thermal wells is privately owned. Surrounding lands are federal and state owned.

The Beryl area has been included in projections of possible geothermal resource areas in Utah for the production of geothermal electric power. We did not include the area as part of this effort, however, due to the depth (2.36 km) versus the temperature (149ºC) of the resource. This yields an uncorrected geothermal gradient of about 59ºC/km – a relatively normal gradient for the region. This area may still be valuable as a target for future exploration.

Uinta Basin – Ashley Valley

Location and Resource Parameters

Long: 109.4160 W; Lat: 40.3650 N; T.05S., R.22E., sec. 23 SLB&M; Uintah County; Measured Temp: 40ºC to 56ºC; Resource Temp: ?; Depth: 1,300 m; TDS: 2,000 mg/L.

Area Description

The Uinta Basin in northeastern Utah is a broad, east-west trending basin that sub-parallels the Proterozoic-rock-cored Uinta Mountains to the north. It encompasses more than 26,000 km^2 (10,000 mi^2), most of northeastern Utah (figure 1). Structurally, it is a broad east-west asymmetrical syncline with a steep north limb and a gently dipping south limb. The basin is a Laramide orogenic feature, filled primarily with Tertiary alluvial, fluvial, and lacustrine deposits. A number of oil reservoirs occur in the basin as well as other hydrocarbon deposits (gilsonite, oil shale, and bituminous sandstone). Several significant faults near the south flank of the Uinta Mountains run subparallel to the axis of the basin, and may act as conduits for vertical movement of thermal water.

In his detailed report on the thermal waters of Utah, Goode (1978) summarized geothermal occurrences in the Uinta Basin. Thermal water is produced as a by-product of oil production within the Uinta Basin. At the Ashley Valley field, Goode reported that low-TDS water (1,500 mg/L) at temperatures between 43° and 55°C (109° and 131°F) was produced with oil, separated in settling ponds, and diverted into the local irrigation system. Wells are about 1,300 m (4,265 ft) deep. No attempt to use the heat in geothermal applications has been reported.

Crater Springs

Location and Resource Parameters

Long: 112.7281 W; Lat: 39.6125 N; T.14S., R.08W., sec. 10, NE/SW/SE SLB&M; Juab County; Measured Temp: 75º - 85ºC; Resource Temp: 87º to 116ºC; Depth: ?; TDS: 3,600 to 4,000 mg/L.

Area Description

The Crater Springs geothermal area surrounds a Quaternary eruptive center known as Fumarole Butte in the northern Sevier Desert of Juab County (figures 1 and 6). Early Pleistocene basalt flows (0.9 Ma) erupted from the vent area and formed a broad volcanic apron now known as Crater Bench. The Drum Mountains fault zone, a north-northeast trending zone of high-angle normal faults, offsets basalt flows along the west-central side of Crater Bench at Fumarole Butte. Warm vapor rises from several fissures in the vicinity of Fumarole Butte. Abraham hot springs, also referred to in literature as "Crater Springs" or "Baker hot springs," issues 8 km (5 mi) to the east of Fumarole Butte along the east margin of the Crater Bench basalt flows. Mabey and Budding (1987) postulated that the vapor venting from Fumarole Butte and the thermal waters at Abraham hot springs are part of the same geothermal system.

Temperatures at Abraham hot springs range up to 87°C (189°F). Rush (1983) estimated total flow rates from about 40 spring orifices at between 5,400 and 8,400 L/min (1,400 and 2,200 gpm). The thermal water is sodium and calcium-chloride type. The geologic structure controlling the system is unknown, and the reservoir temperature is uncertain. Samples of cold springs issuing from the same site were collected for analyses as part of this study in order to develop more accurate mixing models. Analyses of the cold water, however, revealed that this water is very similar in composition to that of the hot springs, and suggests that the cold springs are merely cooled hot water. Geothermometers suggest equilibration temperatures in the range 87°C to 116°C (189°F to 241°F).

Meadow and Hatton Hot Springs

Location and Resource Parameters

Long: 112.4900 W; Lat: 38.8500 N; T.22S., R.06W., sec. 35, NW/SE/SE SLB&M; Millard County; Measured Temp: 29º to 66ºC; Resource Temp: ~ 110ºC; Depth: ?; TDS: 4,450 mg/L.

Area Description

The Meadow-Hatton area (figure 1) is located less than 2 km (1.3 mi) west of Interstate 15 in Millard County. Fillmore, the county seat with a population of 2,000 people, is located about 10 km (7 mi) to the northeast. The small community of Meadow (population 250) is situated on Interstate15, less than 2 km (1.3 mi) from the thermal area. The Pavant Valley and the Black Rock Desert comprise mostly irrigated croplands. Land ownership in the Pavant Valley and Black Rock Desert is a combination of private, state, and federal parcels administered by the BLM.

The Meadow-Hatton geothermal area consists of a large travertine mound, marshland, and thermal springs located about 16 km (10 mi) southwest of the town of Fillmore on the east side of the Black Rock Desert in Millard County. The Black Rock Desert contains some of the state's youngest volcanic rocks -- some being only a few hundred years old. Hatton hot spring issues from the south end of a large, northeast-trending travertine mound at a temperature of 63°C (145°F). Meadow hot springs, comprising several thermal springs in a northeast alignment and located in a marshy area about 2 km (1.3 mi) northwest of the Hatton travertine mound, issue at temperatures up to 41°C (106°F). Flow rates from the springs are low and reportedly vary from 0 to 240 L/min (63 gpm). The spring waters are probably coupled to the regional ground-water flow system of the Pavant Valley and Black Rock Desert.

Ross and others (1993) described two fluid samples from the Meadow hot springs area in conjunction with the results of self-potential surveys completed in the area. Self-potential surveys revealed a high-amplitude, negative anomaly beneath the southern part of the travertine mound. More recent chemical data show very different values for potassium, silica, and fluoride concentrations compared to earlier data, suggesting temporal variations in spring chemistry.

Standard geothermometers range between 205°C (401°F) (Na-K-Ca) and 86°C (187°F) (Na-K-Ca-Mg), with most likely equilibration temperatures around 108°C (226°F) (quartz conductive). Based on the results of the new chemical analyses, the fluids appear to be highly evolved with a very complex thermal history (Ross and others, 1993).

Monroe-Joseph Area

Location and Resource Parameters

Long: 112.1070 W; Lat: 38.6330 N; T.25S., R.03W., sec. 10, NE/SE/SE SLB&M; Sevier County; Measured Temp: 70ºC to 76ºC; Resource Temp: 94ºC to 110ºC; Depth: ?; TDS: 2,650.

Area Description

Monroe hot springs and Red Hill hot springs are situated less than a 0.8 km (0.5 mi) east of the town of Monroe, a community of about 1,470 people located about 5 km (3 mi) east of Interstate 70 in Sevier County (figure 1). Richfield (population - 5,590), the county seat of Sevier County, is located a few miles to the north along Interstate 70. The Sevier-Sanpete Valley is an agricultural region extending for about 129 km (80 mi) northeastward from the Monroe area. Land ownership in the Sevier Valley is mostly private.

Monroe was the site of a number of geoscience and exploratory drilling studies sponsored by the DOE in the late 1970s and early 1980s to assess resource potential. Mabey and Budding (1987) summarized the results of various workers. Although feasibility studies based upon fluid temperatures and flow rates from a DOE-sponsored production well showed that a district-heating system was not economical, the area could be attractive for process or agricultural direct-heat applications. At Monroe hot springs, Mystic Hot Springs Resort uses geothermal water to heat a swimming pool, several therapeutic baths, and for tropical fish ponds.

The Monroe and Red Hill hot springs issue at about 77°C (170°F) near the surface trace of the Sevier fault, adjacent to the Sevier Plateau. The Sevier fault is a 482-km- (300-mi-) long zone of rupture extending from the Grand Canyon northward into central Utah. Chemical geothermometers suggest maximum resource temperatures of about 110°C (230°F). Maximum measured temperature is 77°C (171°F) at Red Hill hot springs and 76°C (169°F) at Monroe hot springs. Combined flows for the Monroe-Red Hill system have been estimated at about 1,200 L/min (320 gpm).

Joseph hot spring discharges from a spring mound near the Dry Wash fault, which parallels the Sevier River along the northwest edge of a group of hills that are part of the Antelope Range. The springs issue at 63°C (145°F) with flow rates approaching 121 L/min (32 gpm).

North Sanpete Valley Wells

Location and Resource Parameters

Long: 111.5653 W; Lat: 39.3628 N; T.07S., R.03W., sec. 03, SE/NW/SE SLB&M; Sanpete County; Measured Temp: 38°C, Resource Temp: ?; Depth: (?); Resource Type: (?); TDS: 8,260 mg/L.

Area Description

The Sanpete and Sevier Valleys form a long, narrow, northeast-southwest depression in central Utah (North Sanpete Valley on figure 1). The area may appear geologically simple, but surface deposits mask a structurally complex area of subsidence caused by faulting, folding, and dissolution of salt from Jurassic formations. Warm springs and wells are present throughout both valleys, although the hotter springs are located at the southern margin of the Sevier Valley. In the Sanpete Valley, several warm wells suggest the possibility of a hidden (blind) geothermal system somewhere below the valley floor. Geothermometers applied to chemical analyses of the J. Paulsen well suggest the possibility of a high temperature geothermal system at depth, although measured temperatures are relatively low. High TDS values within ground water from in Jurassic evaporite deposits in this region may yield anomalously high geothermometer temperatures, however.

GEOTHERMAL RESOURCE REGULATION AND OWNERSHIP IN UTAH

General Description

Ownership or control of geothermal resources in Utah has historically followed both ownership of land and water rights. Beginning in the mid-1970s, rapid escalation of energy prices resulted in increased interest in exploiting geothermal resources throughout the United States. The Geothermal Steam Act of 1970 governs leasing and development of geothermal resources on Federal land. In Utah, statutes were not enacted until 1981, addressing the regulation of geothermal resource development at the state level, particularly with regard to water rights issues. Geothermal resource regulation in Utah is detailed in the following section. Similar regulations for several of the surrounding western states and the Federal Government are summarized in appendix C.

When the Roosevelt hot springs area was explored and developed in the mid-1970s, high-temperature, geothermal-water-rights issues involved a long process partly because there was no statute at the time addressing this unique resource. The state had no procedures to administer the exploration, construction, testing, and allocation of deep and/or high pressure geothermal waters. The enactment of the Utah Geothermal Resource Conservation Act of 1981 defined such geothermal resources as heat contained in water for those resources with temperatures greater than 120ºC (248°F) and designated the Utah Division of Water Rights as the administering agency.

The statute also assigned Water Rights the ability to declare unit agreements to assure the sharing of the geothermal resource. This could be done at the request of an interest owner or by the Division's initiative. The unit for Roosevelt hot springs was, however, guided by BLM rules modeled on federal oil and gas units. (BLM has rules for units for oil and gas, and the Utah Division of Oil, Gas and Mining Board can review those decisions to assure that the resource is conserved and all owners fairly represented.) The Roosevelt hot springs unit is the only geothermal production unit established in Utah thus far. Issues of ownership of water rights, which are connected to geothermal resources, are resolved through a hearing process before Water Rights, rather than the Division of Oil, Gas and Mining.

All water projects regardless of temperature require an application to appropriate water. Such applications currently involve a four to six month process if there are no problems or challenges. Water users in closed basins are the most concerned when water rights for geothermal projects are advertised, even if the use is non-consumptive due to re-injection of geothermal fluids. Existing users are commonly concerned that geothermal development will have an adverse affect on water availability and quality. In these cases, such as the sites along the urban areas of the Wasatch Front, Water Rights requires evidence of adequate separation of the deep strata bearing geothermal resources from the surface and shallow ground water resources to prevent any impact to existing rights, to return the water to protect the geothermal resource, and to prevent interference between water rights. Geothermal waters are often at depth, from "ancient" waters and of poor quality, but the burden is on the geothermal resource developer to prove there will be no impact.

Obtaining water rights and geothermal rights might be even more difficult in the future in closed basins. There are several Utah water basins with full allocation and some with over-allocation of water as a result of early rights being used to their full extent and more consumptive crops and operations are being employed. Some basins are experiencing falling water tables, partly caused by the recent extended drought (1998 to present). In spite of this, non-consumptive projects such as space heating and aquaculture operations have been approved. High-temperature projects, even existing ones, have been limited due to economics in the power industry, rather than difficulty in obtaining the necessary water right. Low-temperature geothermal (below 120ºC [248ºF]) resources can be treated as a "special" water resource at the Utah State Engineer's discretion, which allows the consideration of other factors besides priority date of water right.

Utah Geothermal Resource Conservation Act

The Utah State Legislature enacted the Utah Geothermal Resource Conservation Act (Utah Code Title 73, Chapter 22) in 1981 (amended in 1987 and 1988) to:

- Promote the discovery, development, production, utilization, and disposal of geothermal resources in the State of Utah in such manner as will prevent waste, protect correlative rights, and safeguard the natural environment and the public welfare;

- Authorize, encourage, and provide for the development and operation of geothermal resource properties so that the maximum ultimate economic recovery of geothermal resources may be obtained through, among other things, agreements for cooperative development, production, injection, and pressure maintenance operations.

Definitions in the Utah Act

Correlative rights mean the rights of each geothermal owner in a geothermal area to produce without waste his just and equitable share of the geothermal resource underlying the geothermal area.

Division means the Division of Water Rights, Utah Department of Natural Resources – the agency given the responsibility of regulating geothermal development in Utah.

Geothermal fluid means water and steam at temperatures greater than 120ºC (248ºF) naturally present in a geothermal system.

Geothermal system means any strata, pool, reservoir, or other geologic formation containing geothermal resources.

Geothermal resource means (a) the natural heat of the earth at temperatures greater than 120ºC (248ºF); and (b) the energy, in whatever form, including pressure, present in, resulting from, created by, or which may be extracted from that natural heat, directly or through a material medium. Geothermal resource does not include geothermal fluids.

Material medium means geothermal fluids, or water and other substances artificially introduced into a geothermal system to serve as a heat transfer medium.

Waste means any inefficient, excessive, or improper production, use, or dissipation of geothermal resources. Wasteful practices include, but are not limited to: (a) transporting or storage methods that cause or tend to cause unnecessary surface loss of geothermal resources; or

(b) locating, spacing, constructing, equipping, operating, producing, or venting of any well in a manner that results or tends to result in unnecessary surface loss or in reducing the ultimate economic recovery of geothermal resources.

Well means any hole drilled, converted, or reactivated for the discovery, testing, production, or subsurface injection of geothermal resources.

Features of the Utah Act

Ownership of a geothermal resource derives from an interest in land and not from an appropriative right to geothermal fluids. However, the mass transfer of heat is normally dependant on the withdrawal of water (or steam) from the geothermal system, which implies that a developer should obtain a water right though the appropriative process. The exception may be whereby a “material medium” (or working fluid) is used to extract the heat energy, such as the case with a hot dry rock project. This definition of geothermal resource ownership applies to all lands in the State of Utah, including federal and Indian lands to the extent allowed by law. When these lands are committed to a unit agreement involving lands subject to federal or Indian jurisdiction, Water Rights may, with respect to the unit agreement, deem this chapter complied with if the unit operations are regulated by the United States and Water Rights finds that conservation of geothermal resources and prevention of waste are accomplished under the unit agreement.

Geothermal fluids are deemed to be a special kind of underground water resource, related to and potentially affecting other water resources of the state. The utilization or distribution for their thermal content and subsurface injection or disposal constitutes a beneficial use of the water resources of the state. Therefore, geothermal owners are required to file an application with Water Rights in order to appropriate geothermal fluids that will be extracted from geothermal wells.

Cooperative or unit operation of geothermal areas may be formed following an adjudicative proceeding to consider the need for “unitizing” a geothermal area. Any affected person or organization may request Water Rights to initiate this process. Water Rights shall order the operating unit if it finds that a geothermal resource exists, and unitizing a field is necessary to prevent waste, to protect correlative rights, or to prevent the drilling of unnecessary wells, and it will not reduce the ultimate economic recovery of geothermal resources. As of January 2004, no persons or organizations have approached Water Rights to unitize geothermal fields in Utah.

Rights to geothermal resources and to geothermal fluids to be extracted in the course of production of geothermal resources are based on the principle of correlative rights. Correlative rights refer to the right of each landowner in a geothermal area to produce "without waste" their just and equitable share of the geothermal resource underlying a geothermal area.

Jurisdiction of the Division of Water Rights includes the authority over all persons and property, public and private, necessary to enforce the provisions of [the act]. Water Rights has issued rules (R655) governing geothermal resource development.

Geothermal Steam Act of 1970

Overview – The Geothermal Steam Act of 1970 (Act) governs development of geothermal steam and related resources on public land in the United States.

Selected Definitions – Geothermal lease, a lease issued under the authority of this Act; Geothermal steam and associated geothermal resources, (1) all products of geothermal processes, embracing indigenous steam, hot water, and hot brines; (2) steam and other gases, hot water and hot brines resulting from water, gas, or other fluids artificially introduced into geothermal formations; (3) heat or other associated energy found in geothermal formations; and (4) any byproduct derived from them. Secretary, Secretary of the Interior.

Lands Subject to Leasing - The Act authorizes the Secretary to issue leases for development and utilization of geothermal steam and associated geothermal resources in lands administered by the Secretary including: public, withdrawn and acquired lands; national forests or other lands administered by the USFS, including public, withdrawn and acquired lands; and lands conveyed by the U.S. subject to a reservation to the U.S. of geothermal steam and associated geothermal resources. Geothermal leases for lands withdrawn or acquired to aid functions of the Departments of Interior and Agriculture may be issued only under terms and conditions that ensure the lands are used for their intended purposes. The Act prohibits issuance of geothermal leases on, (1) lands in the National Park System; (2) lands in a fish hatchery administered by the Secretary, wildlife refuge, wildlife range, game range, wildlife management area, waterfowl production area or lands acquired or reserved for the protection and conservation of fish and wildlife threatened with extinction; and (4) tribally or individually owned Indian trust or restricted lands. The Secretary also is prohibited from issuing leases on lands not subject to leasing under § 226-3 of the Mineral Leasing Act of 1920 (wilderness study areas).

Geothermal Leases - The Act sets forth detailed provisions governing the issuance and administration of geothermal steam leases, including: (1) competitive bidding for leases; rents and royalties; (2) lease duration, acreage and termination; and (3) disposition of moneys from sales, bonuses, royalties, and rentals. A lessee may use as much of the surface of the land covered by the lease as the Secretary finds necessary for the production, utilization, and conservation of geothermal resources. The Act must be administered under the principles of multiple-use of lands and resources.

Significant Thermal Features - The Act directs the Secretary to maintain a list of significant thermal features within National Park System units, including 16 specified units. The Secretary must maintain a monitoring program for these features and establish a research program on geothermal resources within units with these features. If the Secretary determines that exploration, development, or utilization of lands subject to a lease application is reasonably likely to have a significant adverse effect on a significant thermal feature within a National Park System unit, the Secretary is prohibited from issuing the lease. If these activities are reasonably likely to have an adverse effect, the Secretary must include specified stipulations in leases or drilling permits to protect the significant thermal features.

Regulations - The Secretary must prescribe regulations to carry out the Act. The regulations may include provisions for, (1) prevention of waste; (2) development and conservation of geothermal and other natural resources; (3) protection of the public interest; (4) protection of water quality and other environmental qualities.

The BLM released the final rule, published in the Federal Register on September 30, 1998 (Bureau of Land Management, 1998) governing geothermal resources leasing and operations on public lands. The final rule amends the regulations, which implement the Geothermal Steam Act of 1970. The rulemaking addresses leasing, permitting and operational requirements for geothermal exploration, drilling, and utilization operations. The final rule (1) rewrites all the geothermal resource development regulations in a plain language style, (2) reduces and streamlines permitting and information requirements, (3) provides the BLM with the maximum possible flexibility regarding permit issuance allowing BLM to accommodate the full range of potential geothermal operations and development scenarios, and (4) reorganizes the regulations to provide specific permit application informational requirements allowing BLM and their customers to interpret regulatory requirements more consistently.

ACCESS TO GEOTHERMAL RESOURCES

Table 6 presents the general land ownership for the selected geothermal sites analyzed in this study. More detailed land ownership information is also shown on the figures associated with the individual areas. Most of the areas encompass a variety of federal, state, and private ownership. Federal land management agencies include the BLM, the U.S. Forest Service (USFS), and the U.S. Bureau of Indian Affairs (Tribal). State management agencies include the Utah School and Institutional Trust Lands Administration (SITLA), Utah Division of Forestry, Fire, and State Lands (FFSL), and Utah Division of Wildlife Resources (DWLR).

The accessibility to resources for the various land management units in Utah is described in the following paragraphs.

Federal Lands

The BLM leases federal land, including USFS land, for geothermal exploration and development. The BLM also monitors and supervises development operations of the leases.

Much of the geothermal activity on public lands takes place in California, which has more than 23 producing leases, followed by Nevada, Utah, and New Mexico. The BLM geothermal program has more than 58 producing leases, produces 24.2 megawatt-hours of energy per year, and accounts for more than $12 million in revenues per year (Farhar and Heimiller, 2003).

During the late 1970s and early 1980s, when interest in geothermal development was very high, the BLM issued more than 130 competitive leases and 280 non-competitive leases involving almost 800,000 acres (323,750 ha) in Utah. These leases were grouped mainly around Roosevelt hot springs, the Cove Fort-Sulphurdale area, Thermo hot springs, Drum Mountains-Sevier Desert, and Newcastle.

All leases except those at Roosevelt, Thermo, Cove Fort, and Newcastle expired by the end of their 10-year primary term -- the period given for lessees to discover, develop and begin production of the resource. During 2002, leases within the Roosevelt Unit, but outside the Participating Area, also expired in accordance with terms of the unit agreement.

In Utah, the BLM established Known Geothermal Resource Area (KGRA) status, based upon competitive interests or geological criteria, in four areas enclosing roughly 60,000 acres (24,300 ha). Table 7 shows the approximate surface-area ownership within the Utah KGRAs (source: James Fouts, BLM, written communication, 2001).

In Utah, the BLM established Known Geothermal Resource Area (KGRA) status, based upon competitive interests or geological criteria, in four areas enclosing roughly 60,000 acres (24,300 ha). Table 7 shows the approximate surface-area ownership within the Utah KGRAs (source: James Fouts, BLM, written communication, 2001).

Although competitive geothermal leases apply only to BLM and USFS lands within the KGRAs, in all cases except Thermo hot springs, the Utah KGRAs enclose a mixture of federal, state, private, and Indian lands. BLM administers all lands within the Thermo KGRA. In addition to BLM-administered and private lands, the Cove Fort-Sulphurdale KGRA also encloses lands controlled by the USFS and the Paiute Tribe.

Table 8 is a summary of federal geothermal leases in Utah according to the BLM's lands and records system (accessed June 2003). Federal geothermal leases in the Roosevelt hot springs and Cove Fort-Sulphurdale geothermal areas involve significant acreage -- 2,323 acres (940 ha) at Roosevelt involving 5 leases, and one lease enclosing 2,594 acres (1,050 ha) of USFS and BLM lands at Cove Fort. Because these lands were within KGRAs, the leases were acquired by competitive bidding. While the competitive bid process generates significant dollars for public lands agencies, potential lessees complain that the sealed bid process inflates the up-front costs of acquiring federal lands and has the potential of allowing an adversarial party to acquire small portions of high potential areas so that they must be included in any geothermal resource development as working interests. From the BLM's perspective, the competitive bidding process assures fair payment for the resource and also discourages speculative holding of leases during the 10-year primary term.

The Utah State Office of the BLM held a geothermal lease sale on December 9, 2003 within all Utah KGRAs. They reportedly leased nearly 2,670 ha (6,600 ac.) within the Roosevelt Hot Springs and the Cove Fort-Sulphurdale KGRAs.

More recently issued two non-competitive federal leases in two of the sites featured as potential electrical generating sites—at Newcastle and at Thermo hot springs (August 1999 and October 2002, respectively). These leases were issued to the interested lessees for a standard rental fee with a primary term of 10-years.

In the case of low- and moderate-temperature (< 120°C, 248°F) geothermal resources for direct use of geothermal fluid, the BLM would reportedly issue a lease on Federal land, requiring royalty payments based upon "equivalent Btu" heat content (enthalpy) of the fluids (Robert Henricks, BLM, verbal communication, June 2003).

State Lands

Water Rights is the lead agency for regulating development of geothermal resources in Utah. A water right, for all practical purposes, is necessary for exploiting geothermal energy even though by statute, geothermal resources are defined as the heat contained in water or steam in excess of 120ºC (248ºF), rather than the water itself. In order to acquire ownership or rights to develop geothermal resources, parties must have water rights containing geothermal resources and control (by fee title or lease) of the surface land overlying geothermal resources.

SITLA manages mineral leasing on state trust lands. FFSL acts as the leasing agency for sovereign lands, lands controlled by the Division of Wildlife Resources, the Utah Division of Parks and Recreation, and the Utah Department of Transportation. These agencies do not define geothermal resources in their administrative rules; rather, geothermal resources are defined in individual leases.

The ownership pattern of state trust lands (the vast majority of Utah state lands) is scattered throughout the state commonly with four sections (normally 2, 16, 32 and 36) per township. These lands are managed for the benefit of public schools and other institutions. The exceptions to this pattern are where private ownership existed before statehood, usually along the major rivers where the most arable land existed. More recently, the federal government and SITLA have negotiated land trades consolidating state ownership into larger blocks. Within the nine geothermal areas considered here, state ownership consists of either small, isolated tracts or is absent.

SITLA uses a separate lease category covering geothermal resources under a special lease form designed for "geothermal products." Obtaining a geothermal lease involves an "over-the-counter" application process. In addition to geothermal steam, the lease defines geothermal products as hot water, steam by-products, steam condensates, minerals, and chemicals. Geothermal products also include electrical and other energy derived, generated, or manufactured from water, and other by-products derived or obtained from the leasehold estate. If lessees develop water resources on trust lands, lessees must make application for appropriation in the name of SITLA. Presently, SITLA administers nine active geothermal leases covering 3,322 acres (1,344 ha) within and around the Roosevelt hot springs KGRA (2,482 ac., 1,004 ha), Cove Fort-Sulphurdale KGRA (400 ac., 162 ha), and Thermo Hot Springs II KGRA (440 ac., 178 ha).

Private Lands

Acquisition of geothermal resources on private lands is much more difficult to track than on federal or state lands. Water Rights records show that water rights acquired for hot springs are used for a variety of direct applications such as space heating of buildings and greenhouses, spas and recreational sites. In most cases, though, geothermal resources at these sites are generally not well explored, are underutilized, and have undergone sporadic development. The reasons for this are unclear and may stem from the relatively small size of individual private parcels, the multitude of owners, and/or the lack of guidance and structure of a regulatory agency. Transfer of water rights is governed by sale of the property containing the source (spring or well), subject to approval by Water Rights.

In some instances, in other states, existing geothermal users have stalled larger geothermal direct-use projects proposed by municipal governments, arguing that wider use of geothermal heat might impinge upon their use. This has led to inflation of project costs, underutilization of the system (low load factor) as potential customers balk at connecting to the system, and a resulting poor public perception of geothermal energy.

PLANNING AND ZONING IN WASATCH FRONT URBAN AREAS

In urban areas, planning guidelines and zoning regulations have an additional impact on development of lands within a given municipal or county jurisdiction. Zoning regulation is an overlay, which seeks to implement planning goals, and applies irrespective of whether land is in private or public ownership. Planning and zoning entities provide regulation and guidance on what developments can take place within their jurisdictional boundaries. Zoning requirements designate areas of industrial or commercial development, seek to preserve neighborhoods and designate open space or other community amenities. While basically restrictive in nature, the purpose of such planning is to create a framework, which balances neighborhood, and commercial or industrial needs. Planning commission decisions often involve compromises, which promote the best interests of the city or county as a whole without infringing on the quality of life of neighborhoods.

Three of the nine sites examined in this study occur along the heavily urbanized Wasatch Front—Hooper hot springs in Davis County, and Utah and Ogden hot springs in Weber County. Zoning regulations in the vicinity of Ogden hot springs are particularly complex. The springs are within Ogden Canyon. Facilities sited to develop this resource could fall within either Ogden City or Weber County jurisdiction. Both county and city certainly have vested interests, which are different but not necessarily opposed to each other. Both entities are committed to open space, building restrictions on steep slopes, and preservation or upgrading of the watershed in Ogden Canyon. Both entities also have an interest in clean sources of electrical power as they face growth over the next few decades.

Ogden City Zoning

Ogden City's Planning Division identifies its environmental resources as follows: "Ogden enjoys the benefits of many natural resources and natural features. The urbanized area contains parks, trails, native vegetation, and some wildlife while the surrounding mountains and river basins offer stunning views, fresh water, refuge for large game animals, and opportunities for hiking, skiing and solitude. At the same time, this natural environment challenges the community to address natural hazards, encroachment on wildlife habitat, air and water pollution and other ways of living and doing business that affect these natural resources and features." The document provides guidelines for siting (and availability of) electrical utilities.

Ogden hot springs are at the heart of these highly valued environmental resources. Ogden City has designated the area adjacent of Ogden hot springs as dedicated to very large single-family lots (minimum of 743 m^2 [8,000 ft^2]), open space and sensitive areas because of steep mountain slopes and watershed issues for Ogden Canyon.

The Ogden Planning Division oversees land use regulations within Ogden City. The Planning Division serves as the advisory staff to the Planning Commission, the Mayor's Administrative Review Meeting, the Ogden Trails Network Committee, the Board of Zoning Adjustment, and the Ogden City Landmarks Commission. Among the functions of the Planning Division which could affect utility siting are:

1. Review development plans to insure they meet the regulations of the City and that the design and layout of the development will be a good neighbor and not detract from the safety and welfare of Ogden residents. Some of those general reviews include site plan review, historic preservation reviews, and approved sign permits.

2. Provide general information to questions about zoning regulations, procedures for getting a development plan approved, possible development options to guide projects through the development process, and how to obtain a permit or a letter of conformance when refinancing.

3. Meet the changing needs of Ogden City, develop zoning ordinance revisions, and review requests for zoning map revisions.

Zoning is a classification system, which divides property into various land uses. An alphanumeric numbering scheme is used to distinguish between intensity of uses within each land use category. The broad categories include residential, commercial, manufacturing, professional, mixed uses, and uses within the Ogden Industrial Park and Ogden Business Depot.

In addition to the zoning categories, which are scattered throughout the community, there are specific zone classifications for particular areas including the Central Business District, Downtown Buffer Overlay, the area surrounding the Central Business District, the area surrounding Rainbow Gardens, and a Sensitive Area Overlay Zone for mountain areas where there may be severe slope, rockfall, or other geological hazards.

Uses are identified in the Zoning Ordinance as "Permitted", "Conditional", or "Not Permitted". Division staff may approve permitted uses, while Conditional Uses require Planning Commission approval. Options for pursuing a use classified as "not permitted" would be to either petition the City for an ordinance amendment, or petition to rezone the property to a zone designation, which would allow the use.

Weber County Zoning

Weber County's uniform zoning ordinance was adopted to regulate the location, height and bulk of buildings and other structures; the percentage of lot which may be occupied; the size of lots, courts and other open spaces; the density and distribution of population; the location and use of buildings and structures for trade, industry, residence, recreation, public activities, or other purposes; and the uses of land for trade, industry, recreation, or other purposes. The ordinance divides the county into 34 zone classes generally categorized as residential, gravel, agricultural, forestry, shoreline, commercial resorts, commercial, manufacturing, open space, and floodplain.

Sections of the ordinance specifically address electrical generating facilities. The following excerpts from Weber County code apply to public buildings and public utility substations and structures. Numbers refer to specific paragraphs.

26-1. Location: The location and arrangement of Public Buildings and Public Utility Substations and structures will comply with requirements set forth in this Chapter and will be in accordance with construction plans submitted to and approved by the Planning Commission.

26-2. Minimum Lot Area - Public Utility Substations.

26-3. Minimum Yards: Each Public Utility Substation shall maintain the minimum yards required for a dwelling in the same zone except that the rear yard may be reduced to the following: 1.5 m (5 ft) in a residential zone; 3 m (10 ft) in an agricultural zone; 6 m (20 ft) in a forest zone.

26-4. Street Access: Each Public Utility Substation shall be located on a lot with adequate access from a street, alley, right-of-way, or easement.

ENVIRONMENTAL CONFLICTS

NEPA and Special Land Management Designations

The National Environmental Policy Act of 1969 (NEPA) is the basic national charter for protection of the environment. It establishes policy, sets goals, and provides means for carrying out the policy. NEPA is a law of disclosure ensuring that environmental information is available to public officials and citizens before decisions are made and actions are taken with respect to projects on federal lands or using federal money. Prior to any project involving federal resources NEPA requires reviews of specific proposed actions, involvement of the public in the decision process, and consideration of reasonable alternatives. The emphasis is to inform affected parties, be consistent with existing management planning, and minimize impacts to the environment.

Special management prescriptions for federal and state lands may have implications for industrial development including geothermal resources. These prescriptions include designations for wilderness character or wilderness study areas (WSAs) and areas of critical environmental concerns (ACECs) associated with BLM lands. No USFS wilderness lands conflict with these geothermal areas. None of the geothermal areas studied here appear to conflict with BLM WSAs. The Drum Mountains prospect, however, lies directly west of the Swasey Mountain WSA. Current BLM management plans were not reviewed for this effort to determine if ACECs could complicated geothermal development. Newcastle, Thermo, Roosevelt, Cove Fort-Sulphurdale, and the Drum Mountains geothermal study areas all contain some BLM-administered land.

The Endangered Species Act and Sensitive Species

The Endangered Species Act (ESA) of 1973 governs conservation of the ecosystems upon which threatened and endangered (T&E) species depend. All federal agencies are mandated to protect the habitats of T&E species. Moreover, federal agencies must apply their authority to ensure their actions do not jeopardize the continued existence of listed species. The Fish and Wildlife Service within the Department of Interior works with other federal agencies to plan or modify projects so that they will have minimal impact on listed species. The ESA also encourages partnerships with states to develop and maintain conservation programs for resident T&E species.

Among the environmental conflicts that could complicate the development of geothermal power resources in Utah are potential impacts to sensitive plant and animal species found at or near the resource. A review of Federal and State listings identified 25 sensitive animal species and one sensitive plant species within the 7½-minute quadrangles containing the nine geothermal resource sites considered in this study (table 9). Among these were two species that are listed as Threatened, one species that is listed as Endangered, and one species that is a candidate for Federal listing (DWLR, written communication, September 2003). There are also two conservation species that are governed by special, multi-agency conservation agreements. These sensitive species designations can significantly complicate the development of industrial facilities and infrastructure such as power plants and transmission lines through additional planning efforts and mitigation measures, thereby increasing up-front development costs.

ACKNOWLEDGEMENTS

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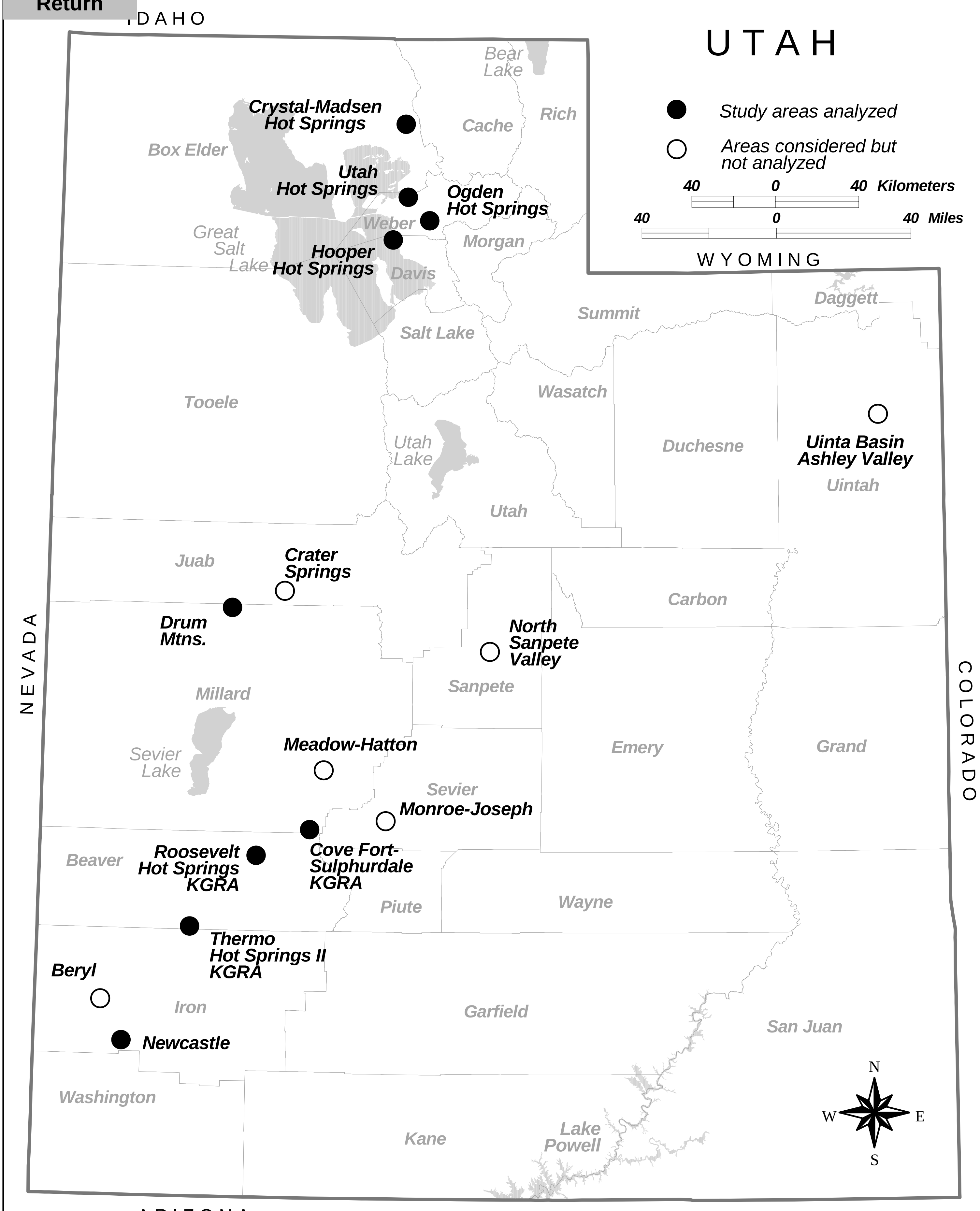

Figure 1. Location of geothermal study areas

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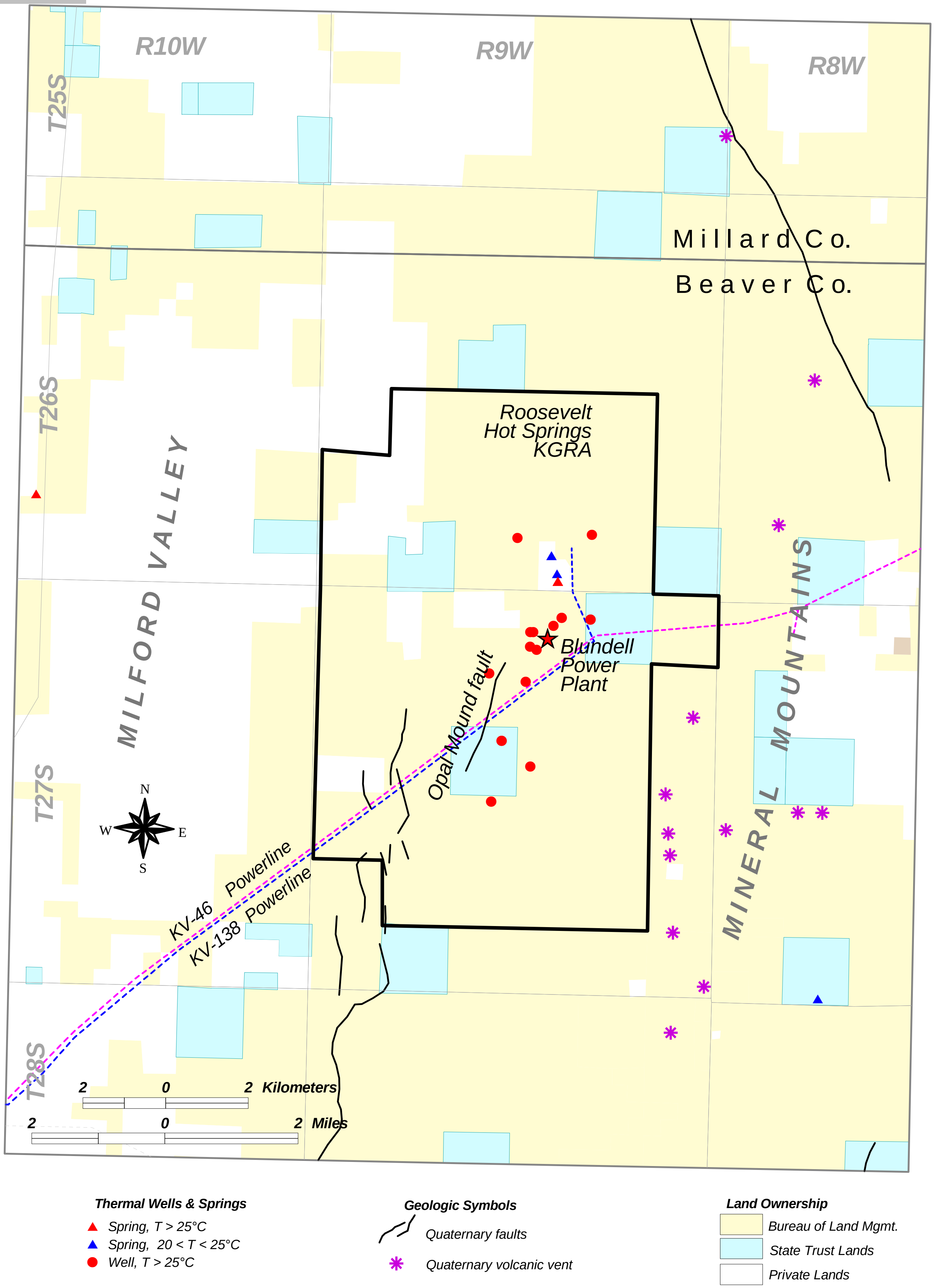

Figure 2. Roosevelt Hot Springs geothermal area showing land ownership patterns, roads, powerlines, general geologic features, and thermal wells and springs. The outline of the Roosevelt KGRA and location of the Blundell power plant are noted.

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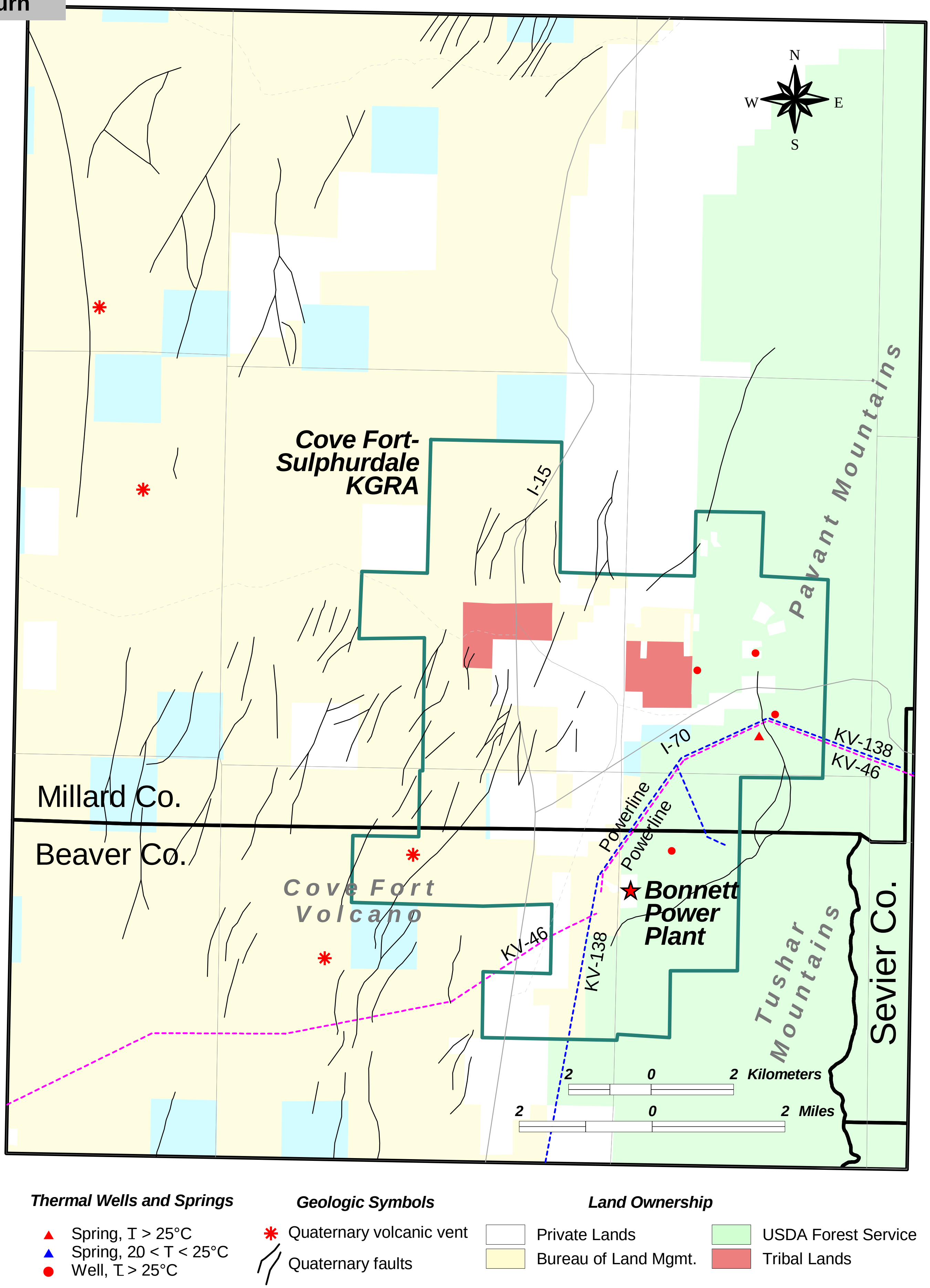

Figure 3. Cove Fort-Sulfurdale Known Geothermal Resource Area (KGRA) and vicinity showing Quaternary features, land ownership, thermal wells, power lines, and roads.

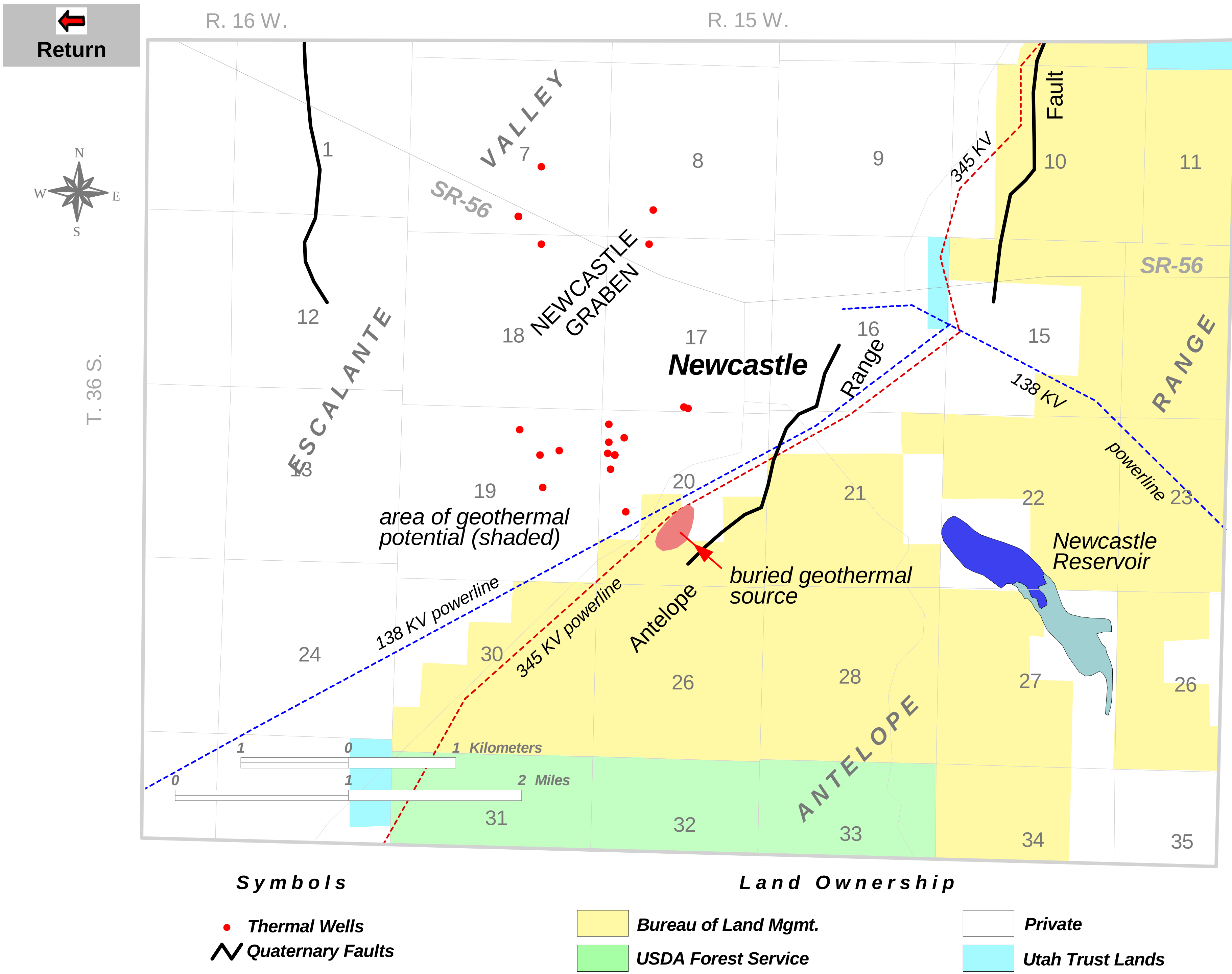

Figure 4. The Newcastle geothermal area showing thermal wells, Quaternary faults, and land ownership.

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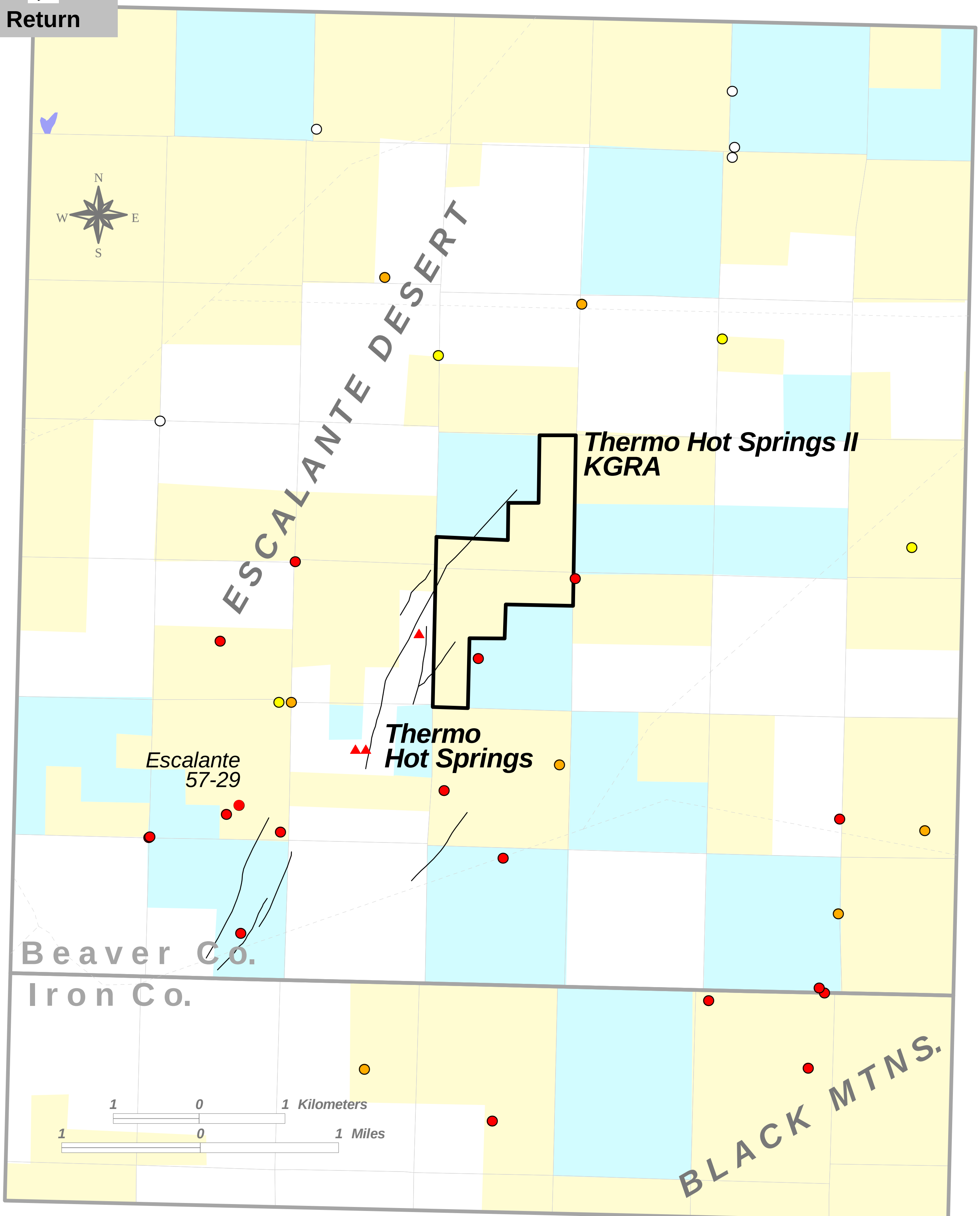

Thermal-Gradient Boreholes
(gradients "G" expressed in °C/km)

- G ≥ 500°C
- 100 ≤ G < 500°C
- 65° ≤ G < 100°C
- 45°C ≤ G < 65°C
- 25°C ≤ G < 45°C
- G < 25°C

Thermal Wells and Springs

- Spring, T > 25°C
- Well, T > 25°C

Quaternary faults

Land Ownership

- Private
- Bureau of Land Mgmt.
- State Trust Lands

Figure 5. Thermo Hot Springs and surrounding area showing thermal-gradient boreholes, thermal wells and springs, and Quaternary faults.

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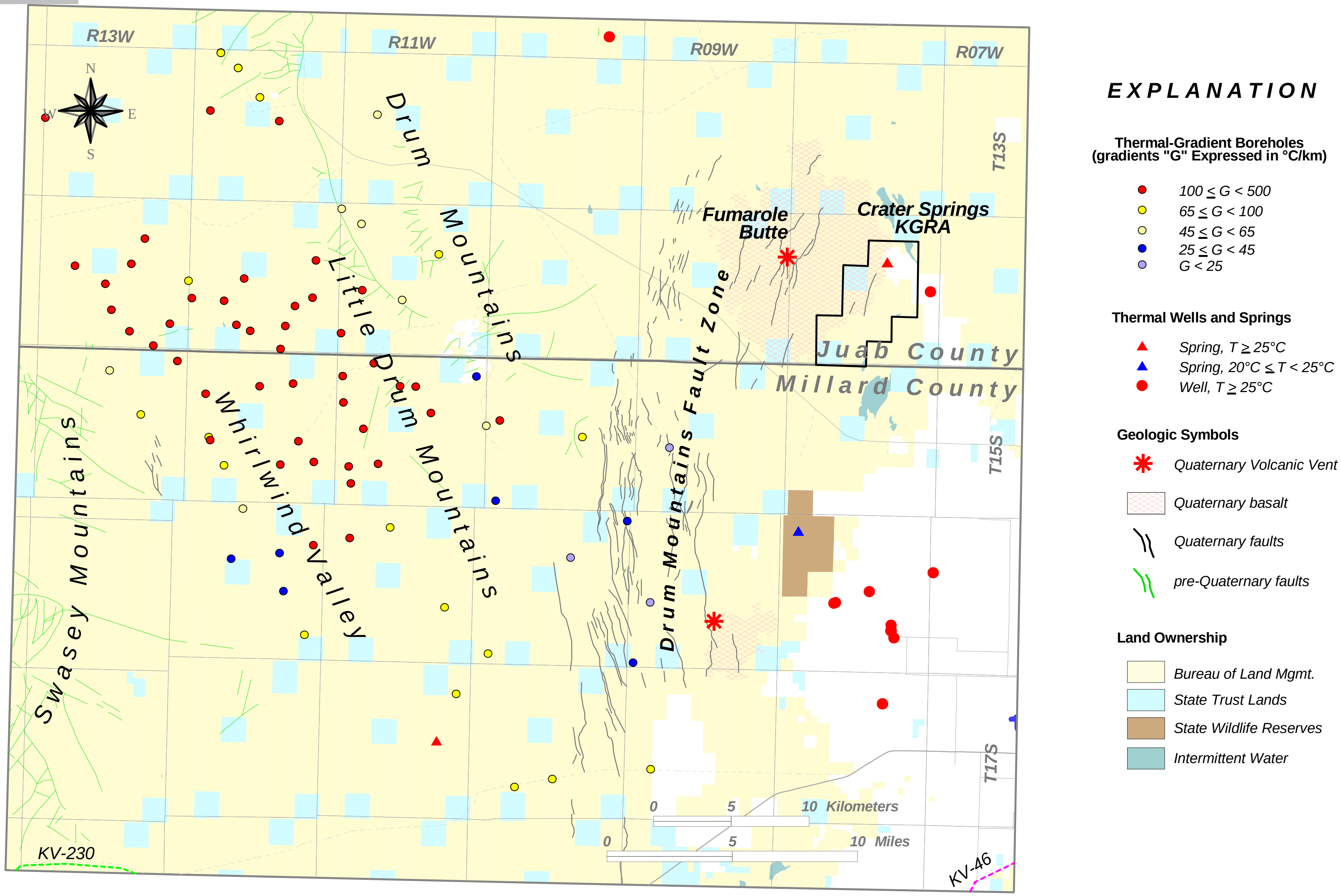

Figure 6. General geology of the Drum Mountains geothermal prospect showing locations of thermal-gradient boreholes, and thermal wells and springs. The Crater Springs and Fumarole Butte geothermal area are shown for reference. The outline along the west side of Crater Bench shows the area included in the Crater Springs Known Geothermal Resource Area (KGRA).

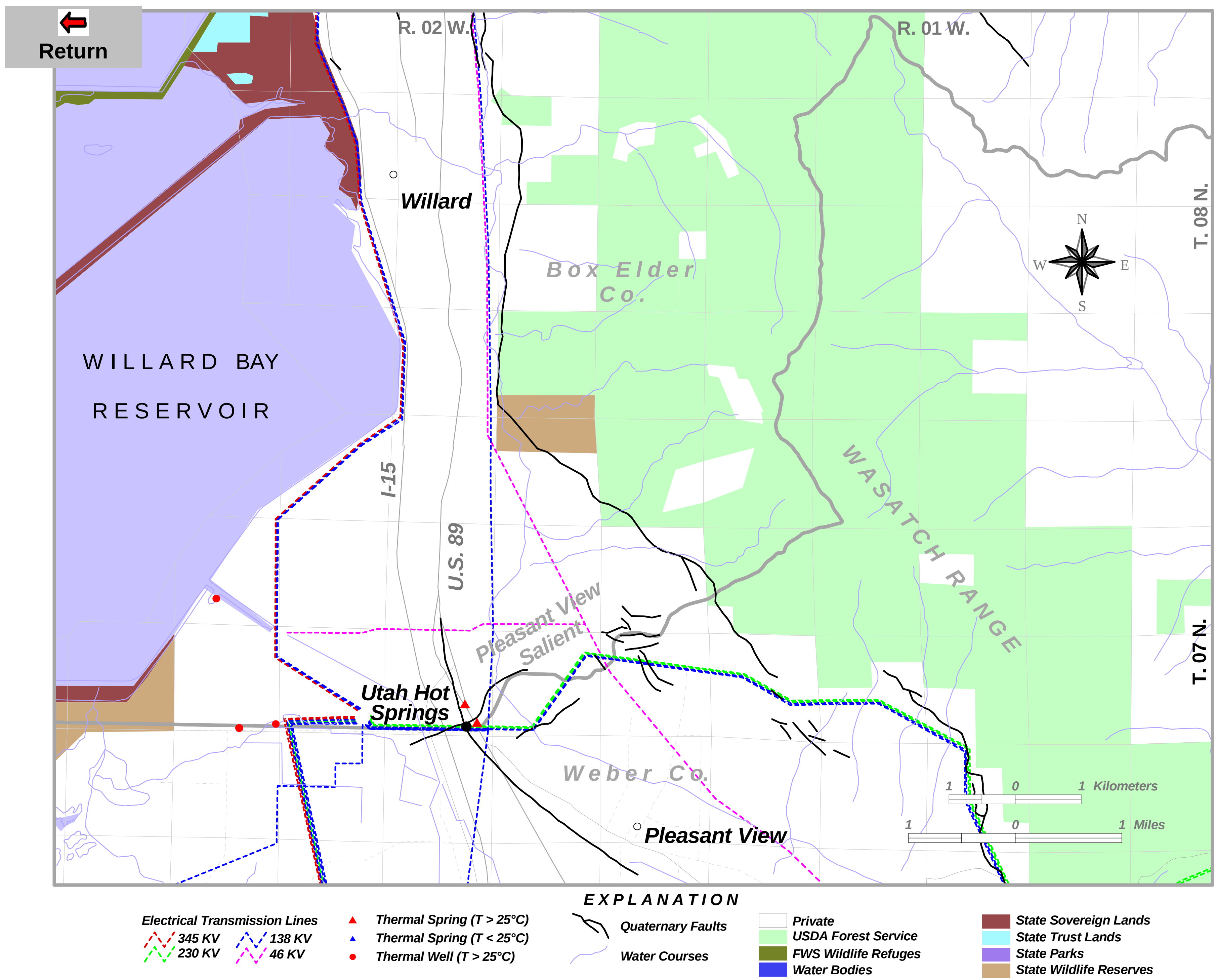

Figure 7. Utah Hot Springs and vicinity showing land ownership, thermal wells and springs, and Quaternary faults.

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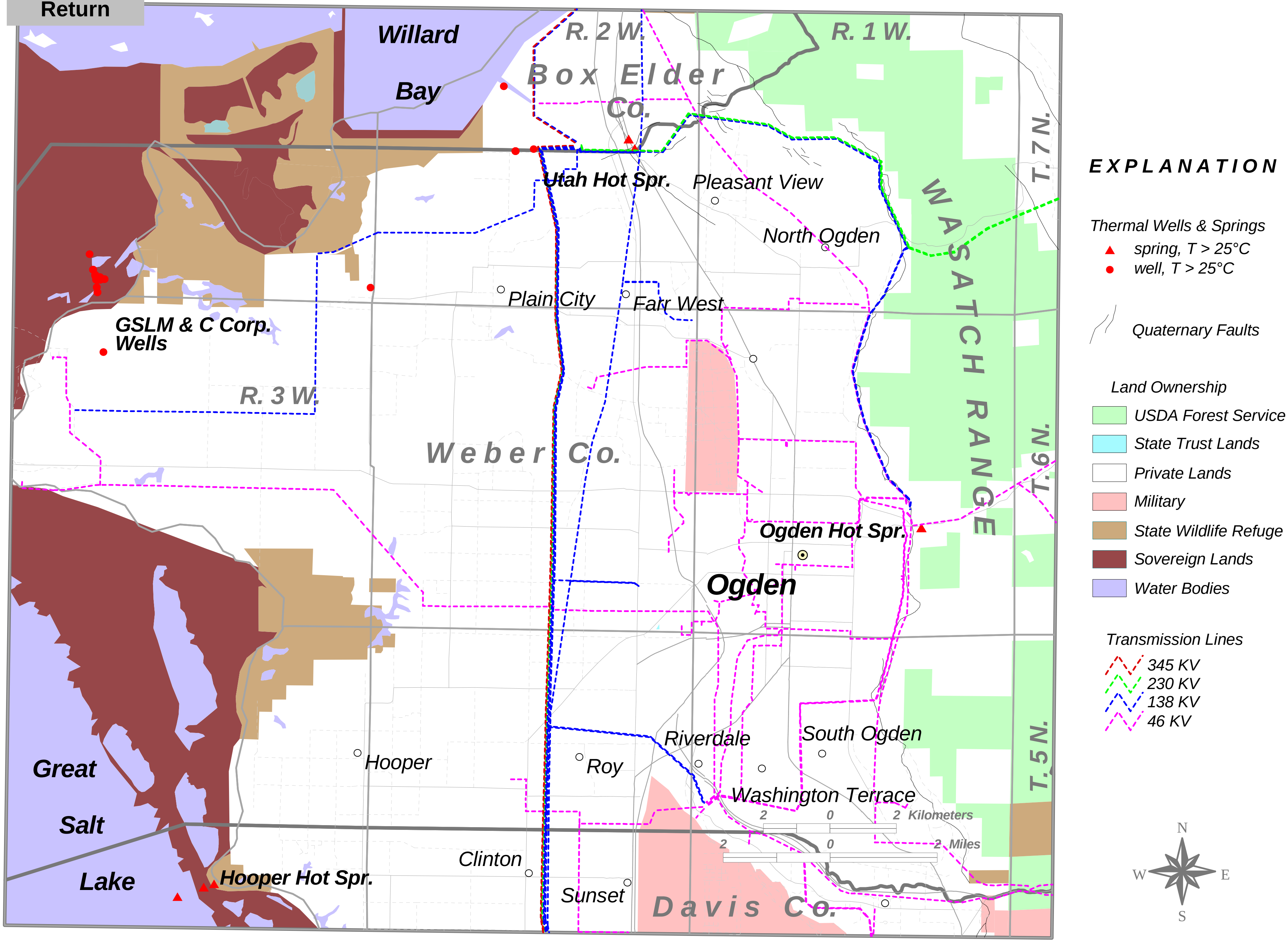

Figure 8. Ogden, Utah, and Hooper hot springs and surrounding areas showing thermal wells & springs, Quaternary faults, powerlines, roads, water courses, and land ownership.

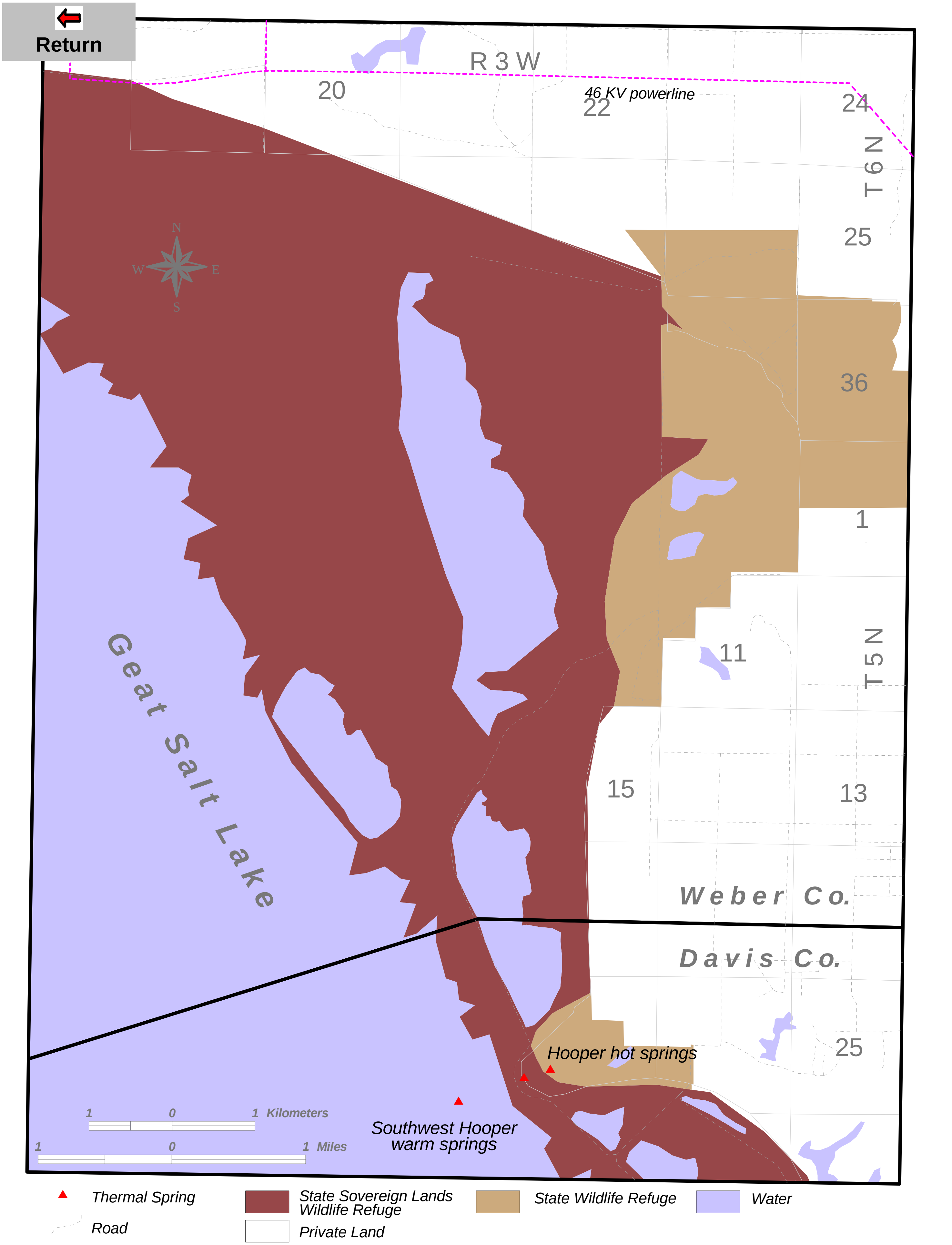

Figure 9. Hooper Hot Springs area showing land ownership, thermal springs, powerlines, and roads.

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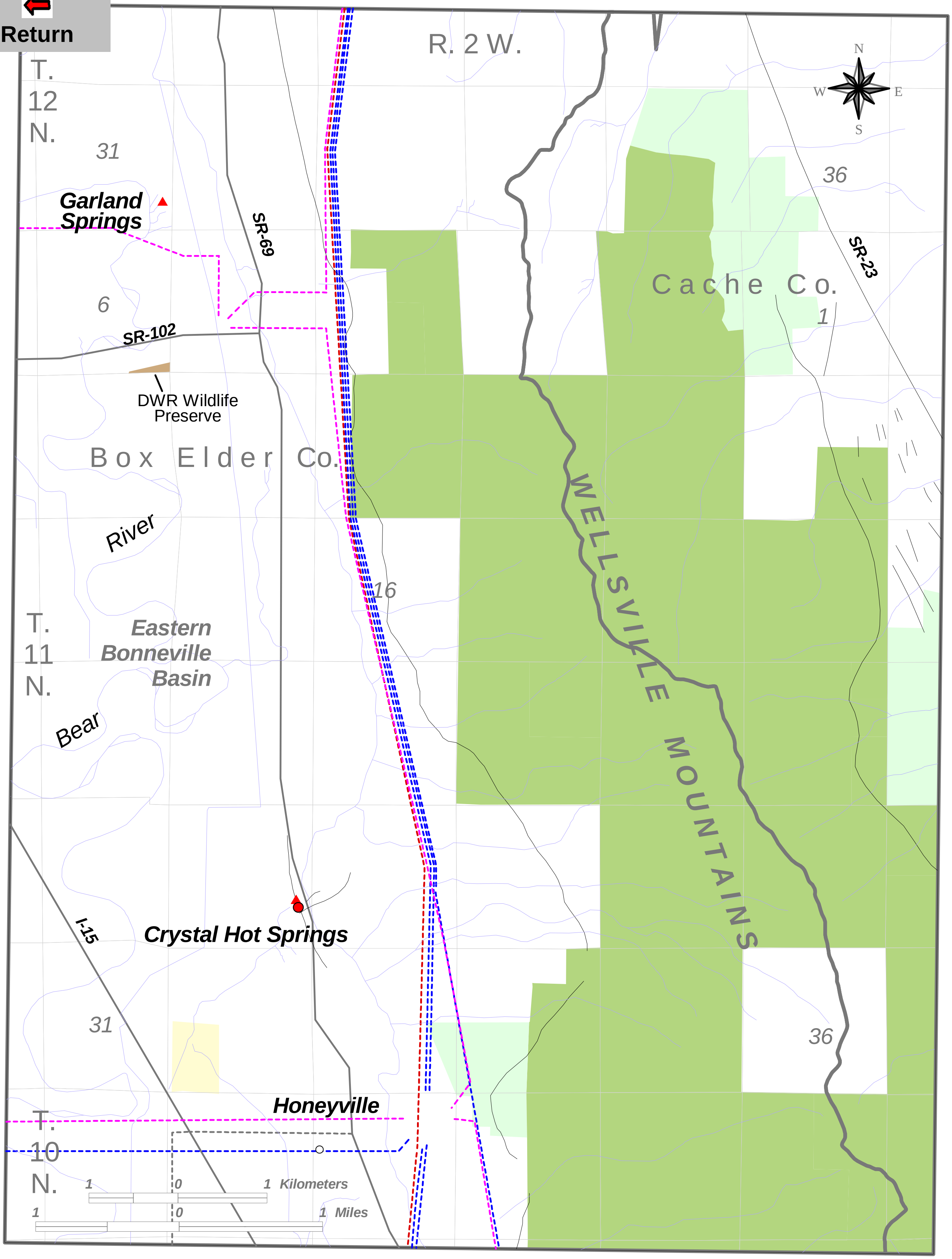

EXPLANATION

Transmission Lines	Thermal Springs	Geologic Symbols	Land Status	
345 KV	spring, T > 25°C	Quaternary faults	USDA Forest Ser.	Private Land
138 KV	spring, 20° < T < 25°C		USFS Wilderness	Bureau of Land Mgmt.
46 KV				

Figure 10. Crystal-Madsen hot springs and vicinity, showing land ownership, transmission lines, thermal springs, and Quaternary faults.

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Table 1. General parameters for selected geothermal areas in Utah.

Geothermal Area	Location	Lat_North	Long_West	County	Meas T[1]	Res T[2]	Res Depth[3]	TDS[4]
	Twn, Rng, Sec	(Degrees)	(Degrees)		(°C)	(°C)	(m)	(mg/L)
Geothermal Areas Analyzed								
Newcastle	T.36S., R.15W., sec. 20	37.6591	113.5651	Iron	118	130	150-270	1000-1100
Thermo	T.30S., R12W., sec 28	38.1731	113.2036	Beaver	174	160-217	2200	1300-3300
Roosevelt	T.26S., R.09W., sec. 34	38.5019	112.8503	Beaver	270	270	1000-2000	7000-7800
Cove Fort	T.26S., R06W., sec. 07	38.5685	112.5668	Beaver-Millard	150	150	180-900	9400
Ogden HS	T.06N, R.01W., sec. 23	41.2356	111.9233	Weber	57	190	1800?	8800
Utah HS	T.07N., R.02W., sec.14	41.3375	112.0278	Box Elder-Weber	59	192	1800?	22000
Hooper HS	T.05N., R.03W., sec. 27	41.1370	112.1753	Davis	57	135	1500?	8600
Crystal-Madsen	T.11N., R.02W., sec. 29	41.6600	112.0864	Box Elder	54	153	1800?	43600
Drum Mtns	T.14-16S., R.11-13W.	39.4900	113.1533	Juab-Millard	NA	200?	800?	NA
Geothermal Areas Considered, Not Analyzed								
Beryl	T.34S., R.16W., sec. 18	37.8390	113.6870	Iron	149	~150	2134	~4000
Meadow-Hatton	T.22S., R.06W., sec. 35	38.8500	112.4900	Millard	29-66	~110	NA	4450
Monroe-Joseph	T.25S., R.03W., sec. 10	38.6330	112.1070	Sevier	70-76	94-110	NA	2650
N. Sanpete Valley	T.07S., R.03W., sec. 03	39.3628	111.5653	Sanpete	38	~200?	NA	8260
Crater Springs	T.14S., R.08W., sec. 10	39.6125	112.7281	Juab	75-85	87-116	NA	3600-4000
Uinta Basin	T.05S., R.22E., sec. 23	40.3650	109.4160	Uintah	40-56	NA	1300	2000

NA = Not Available

1. Meas T = Measured Temperature in degrees Celsius

2. Res T = Estimated Resource Temperature in degrees Celsius

3. Res Depth = Estimated Resource Depth in Meters

4. TDS = total dissolved solids

Return

Table 2. Levelized cost comparison of natural gas power versus selected renewable technologies (California Energy Commission, 2003).

Technology	***Fuel***	***Operative Mode***	***Economic Lifetime (years)***	***Gross Capacity (MW)***	***Direct Cost Levelized (cents/kWh)***
Combined Cycle	Natural Gas	Baseload	20	500	4.58
Simple Cycle	Natural Gas	Peaking	20	100	14.06
Wind	None	Variable	30	100	5.44
Hydropower	Water	Load-Following	30	100	7.20
Geothermal Flash	Water	Baseload	30	50	4.71
Geothermal Binary	Water	Baseload	30	35	7.64

Return

Table 3. Cost comparison of alternative technologies for additional power generating capacity at PacifiCorp's Blundell geothermal plant (PacifiCorp, 2003).

Technology	***Fuel***	***Real Levelized Cost*** *(CY 2002 cents/kWh)*	
		Low	High
Combined Cycle	Natural Gas	3.83	4.68
Simple Cycle	Natural Gas	8.93	14.07
Wind	None	3.38	5.74
Geothermal Flash w/ Bottoming Cycle	Water	3.49	
Pulverized Coal	Coal	2.75	3.68

Return

Table 4. Electric Power Generation from Blundell Geothermal Power Plant, Roosevelt Hot Springs KGRA, 1992-2003.

Year	Megawatt-Hours
1992	186,369
1993	148,148
1994	194,804
1995	139,742
1996	191,912
1997	168,518
1998	160,057
1999	155,530
2000	151,843
2001	152,742
2002	184,447
2003	198,465

Return

Table 5. Electric power generation from the Cove Fort Geothermal Power Plant, Cove Fort-Sulphurdale KGRA, 1992-2002.

Year	Megawatt-Hours
1992	47,024
1993	38,727
1994	37,827
1995	28,422
1996	31,399
1997	34,657
1998	34,500
1999	30,396
2000	34,618
2001	33,247
2002	29,681

Return

Table 6. Summary of land ownership in the study areas.

Site	***Ownership***
Cove Fort-Sulphurdale	USFS, Private, SITLA, BLM, Tribal
Crystal-Madsen Hot Springs	Private
Hooper Hot Springs	FFSL/DWLR, Private
Newcastle	Private, BLM
Ogden Hot Springs	Private, USFS
Roosevelt Hot Springs	Private, SITLA, BLM
Thermo Hot Springs	Private, BLM, SITLA
Utah Hot Springs	Private
Drum Mountains	BLM, SITLA

USFS = U.S. Forest Service
BLM = U.S. Bureau of Land Management
SITLA = Utah School & Institutional Trust Lands Administration
FFSL = Utah Division of Forestry, Fire, & State Lands
DWLR = Utah Division of Wildlife Resources

Return

Table 7. Surface-area ownership in Utah KGRAs.

KGRA Name	***Total Acres***	***BLM***	***State***	***Private***	***USFS***	***Tribal***
Crater Springs	8,320	6,120	1,280	920	-	-
Roosevelt Hot Springs	25,600	10,632	200	5,161	8,450	1,157
Cove Fort-Sulphurdale	24,960	20,680	1,800	2,480	-	-
Thermo Hot Springs II	640	640	-	-	-	-
Total Acres	59,520	38,072	3,280	8,561	8,450	1,157

Return

Table 8. Federal geothermal leases in Utah (written communication, James Fouts, U.S. BLM Utah State Office, September 2000)[1].

Serial Number	***Area***	***Proprietor***	***Twp/Rng (SL)***	***Acres***
Non-competitive				
71373	Thermo	Lewis Katz	30S/12W	1,760.79
78044	Newcastle	New Castle Irr. Co.	36S/15W	228.04
Subtotal (acres)				*1,988.83*
Competitive				
14990	Roosevelt	R.L. Wright	27S/09W	40.00
27386	Roosevelt	Intermountain Geo	26-27S/09W	963.45
27388	Roosevelt	Intermountain Geo	27S/09W	200.00
27389	Roosevelt	Intermountain Geo	27S/09W	680.00
27392	Roosevelt	Intermountain Geo	27S/09W	440.00
29557	Cove Fort	UMPA/City of Provo	26S/06-07W	2,594.37
Subtotal (acres)				*4,877.82*
Total				***6,866.65***

[1] The Utah State Office of the BLM held a geothermal lease sale on December 9, 2003 within all Utah KGRAs. They reportedly leased nearly 2,670 ha (6,600 ac.) within the Roosevelt Hot Springs and the Cove Fort-Sulphurdale KGRAs.

Return

Table 9. Geothermal areas showing identified threatened or endangered species or their potential habitat.

Geothermal Area	***T & E Species (Common Name)***	***Number of T & E Species***
Cove Fort-Sulphurdale	Greater Sage-Grouse, Burrowing Owl, Ferruginous Hawk	3
Newcastle	Burrowing Owl, Ferruginous Hawk, Long-billed Curlew	3
Thermo Hot Springs	Burrowing Owl, Ferruginous Hawk, Swainson's Hawk, Greater Sage-Grouse	4
Crystal-Madsen Hot Springs	Bluehead Sucker, Bonneville Cutthroat Trout, Long-billed Curlew, Wolverine	4
Roosevelt Hot Springs	Burrowing Owl, Ferruginous Hawk, Greater Sage-Grouse, Wolverine, Least Chub, Brazilian Free-tailed Bat	6
Utah Hot Springs	American White Pelican, Blue Grosbeak, Brazilian Free-tailed Bat, Lewis's Woodpecker, Pacific Treefrog, Bald Eagle, Burrowing Owl, Long-billed Curlew, Osprey, Short-eared Owl	10
Ogden Hot Springs	Bluehead Sucker, Common Yellowthroat, June Sucker, Pacific Treefrog, Ute Ladies' Tresses, Yellow-billed Cuckoo, American White Pelican, Blue Grosbeak, Brazilian Free-tailed Bat, Lewis's Woodpecker	10
Hooper Hot Springs	American White Pelican, Bald Eagle, Ferruginous Hawk, Long-billed Curlew, Mountain Plover, Peregrine Falcon, Short-eared Owl, Bobolink, Common Yellowthroat, Grasshopper Sparrow, Townsend's Big-eared Bat	11
Drum Mountains	Townsend’s Big-eared Bat	1

Return

APPENDIX A: CHEMICAL GEOTHERMOMETRY

Geothermometers, or geoindicators, are computations applied to natural waters from springs or wells based on empirically derived formulas using dissolved chemical species. Geothermometers in geothermal exploration are used to estimate temperature and composition of the original reservoir fluid prior to cooling by conduction and mixing with shallow ground water at the sample collection point (well or spring). Geothermometers indicate a hotter geothermal fluid reservoir somewhere in the system, usually at greater depth.

Some constituents in natural fluids are unstable and change significantly with time following sample collection. Others are relatively stable, or can be fixed using proper sampling methods. Assumptions include:

- Temperature-dependent reactions involving rock and water fix the amounts of dissolved “indicator” constituents in water.
- There is an adequate supply of all reactants.
- There is equilibrium in the reservoir or aquifer with respect to the “indicator” reaction.
- No re-equilibration of the “indicator” constituents occurs after the water leaves the reservoir.
- Either no mixing of different waters occurs during movement to the surface or evaluation of the results of such mixing is possible.

<u>Chemical reactions used in major element geothermometry include</u>:

silica dissolution

Quartz	150 - 230ºC
Chalcedony	below 150ºC

feldspar dissolution/cation exchange

Na – K – Ca	150 - 280ºC
Na – K – Ca – Mg	70 - 250ºC
K – Mg	--

<u>Equations for SiO_2 solubility include (concentrations expressed in mg/kg ~ mg/L)</u>:

Quartz (steam loss) $T^{o}C = [1522/(5.75 - \log SiO_2)] - 273.15$

Quartz (conductive) $T^oC = [1309/(5.19 – \log SiO_2)] – 273.15$

Chalcedony $T^oC = [1032/(4.69 – \log SiO_2)] – 273.15$

Equations for alkaline earth exchange include (concentrations expressed in mg/kg ~ mg/L):

Sodium-Potassium-Calcium

Na-K-Ca; $T^oC = [1647/(\log (Na/K) + ß(\log (vCa/Na) + 2.06) +2.47] – 273.15$

(Where ß = 4/3 for T < 100, or ß = 1/3 for T > 100) (Fournier, 1981)

Na-K-Ca, Mg correction (in ºC to be subtracted from the Na-K-Ca calculated temp)

Where

$R = [Mg/(Mg + Ca + K)] \times 100$ (with concentrations expressed in equivalents).

and

T = Na-K-Ca calculated temperature in kelvin.

for,

$5 < R < 50$ $? t_{Mg} = 10.66 – 4.7415R + 325.87(\log R)^2 – 1.032 \times 10^5 (\log R)^2 /T - 1.968 \times 10^7 (\log R)^2 /T^2 + 1.605 \times 10^7 (\log R)^3 /T^2$,

$R < 5$ $? t_{Mg} = - 1.03 + 59.971x \log R + 145.05 (\log R)^2 /T – 1.67x10^7 - 1.67 \times 10^7 \log R/T^2$,

Potassium-Magnesium

K–Mg; $T^oC = [4410/(13.95 – \log (K^2/Mg))] – 273.15$ (Giggenbach, 1988)

Return

APPENDIX B: Results of Geothermometers

MAPNO	SOURCE	AREA	TYPE	Concentrations					Geothermometers						Meas. T.
				SiO2	NA	K	CA	MG	Qtz-Max	Qtz-Cond.	Chalc	Na-K-Ca	Na-K-Ca-Mg	K-MG	
			units	mg/L	mg/L	mg/L	mg/L	mg/L	°C	°C	°C	°C	°C	°C	°C
BE-001	Utah State 42-7 Well	CFS	W	180.0	3460.0	225.0	26.4	12.0	162	173	151	211	136	**154**	**178**
BE-005	Roosevelt Hot Spr.	RHS	S	400.0	2100.0	470.0	19.0	3.3	210	233	221	292	283	**210**	**85**
BE-011	Thermal Power 14-2	RHS	W	383.0	2200.0	410.0	6.9	0.1	207	229	217	292	202	**298**	**268**
BE-012	Phillips 54-3	RHS	W	263.0	2320.0	461.0	8.0	2.0	184	199	181	297	296	**221**	**260**
BE-013	Phillips 3-1	RHS	W	590.0	1950.0	400.0	7.0	0.1	238	268	265	297	208	**296**	*******
BE-018	Phillips 9-1	RHS	W	178.0	1780.0	440.0	69.1	1.0	162	172	150	278	276	**236**	**225**
BE-021	Utah State 72-16	RHS	W	244.0	2000.0	400.0	12.2	0.3	179	194	175	288	260	**263**	**243**
BE-022	Utah State 52-21	RHS	W	65.0	1900.0	216.0	107.0	4.0	113	114	86	219	209	**173**	**204**
BE-068	Escalante 57-29	THS	W	440.0	961.0	75.0	36.3	0.7	217	241	231	193	***	**166**	**160**
BO-008	Utah Hot Spr.	UHS	S	35.0	6580.0	935.0	1020.0	39.0	89	86	55	236	213	**186**	**58**
BO-029	Crystal Hot Spr. (Madsen)	CHS	S	22.0	15800.0	720.0	840.0	130.0	72	67	35	186	112	**153**	**54**
DA-012	Hooper Hot Spr.	HHS	S	24.0	2463.0	204.0	459.0	72.0	75	70	39	191	102	**121**	**57**
DA-013	SW Hooper Warm Spr.	HHS	S	48.0	8290.0	803.0	536.0	458.0	101	100	70	223	29	**135**	**32**
IR-024	Hildebrande	NCA	W	79.2	273.3	15.2	64.6	0.8	122	125	97	99	***	**111**	**77**
IR-026	Troy Hygro	NCA	W	69.4	290.2	17.0	78.7	0.7	116	118	89	99	***	**116**	**63**
IR-027	Christensen Bros.	NCA	W	110.0	260.0	14.0	52.0	1.3	137	143	116	148	***	**101**	**100**
IR-027	Christensen Bros.	NCA	W	140.0	240.0	14.0	36.0	0.6	149	157	133	154	***	**112**	**97**
SA-003	J. Paulsen	SSV	W	15.0	3600.0	77.0	1.0	0.1	60	53	21	179	162	**207**	**38**
WE-011	Ogden Hot Spr.	OHS	S	47.0	2730.0	360.0	360.0	4.9	100	99	69	223	***	**190**	**57**
WE-022	Utah Hot Spr.	UHS	S	28.0	6588.0	821.0	974.0	23.0	89	86	55	236	213	**192**	**59**

RHS = Roosevelt KGRA; CFS = Cove Fort-Sulfurdale KGRA; SSV = Sanpete-Sevier Valley; THS = Thermo HS KGRA; NCA = Newcastle

HHS = Hooper Hot Springs; OHS = Ogden Hot Springs; UHS = Utah Hot Springs

Type field refers to source of fluid: W = well; S = spring

Return

APPENDIX C

Geothermal Resource Legislation and Regulation
In Selected Western States
(adapted from Bloomquist, 1992; Bloomquist and Lund, 1998; and Battocletti, 2003)

FEDERAL

DEFINITION OF GEOTHERMAL: Statute and No.: Geothermal Steam Act of 1970 (Public Law 91 - 581) "Geothermal steam and associated resources" means (i) all products of geothermal processes, embracing indigenous steam, hot water, and hot brines, (ii) steam and other gases, hot water, and hot brines resulting from water, gas, or other fluids artificially introduced into geothermal formation; (iii) heat or other associated energy found in geothermal formation; and (iv) by-products derived from them.

GEOTHERMAL IS CHARACTERIZED AS: Mineral

OWNERSHIP: Statute and No.: U.S. Court of Appeals for the Ninth Circuit, Ottobonite vs the United States of America, 549F .2d 1271 (9th Circ.) The federal government claims ownership of all geothermal resources underlying federal lands or where mineral rights have been maintained.

AGENCY RESPONSIBLE FOR LEASING: Statute and No.: Geothermal Steam Act of 1970 (Public Law 91-581) Bureau of Land Management, State Office. Indian Lands 25 CFR Parts 131.171.172,173. For information concerning the leasing of Indian Lands, contact the Bureau of Indian Affairs or the governing body of the Indian Nation.

LEASING: Competitive leases are available on Known Geothermal Resource Areas (KGRA) lands. Non-Competitive leases are available on all other lands. Exploration permits are also available on all lands including those under lease. For leasing state, county, or municipal lands, contact the appropriate officials in the jurisdiction of interest.

LEASE TERMS: Bureau of Land Management, State Office

Primary: 10 years, 5-year extension available if drilling or have power purchase agreement.*

Renewable: For as long as producing in commercial quantities, 40 year maximum,

Rentals: $2/acre KGRA lands, $l/acre non-KGRA lands but increasing in year 6-10 and $12/acre in years 10-15.

Royalties: (% of gross sales): 10 to 15% plus up to 5% of by-products.

DILIGENCE REQUIREMENTS: Bureau of Land Management, State Office

AGENCY RESPONSIBLE FOR GROUNDWATER REGULATIONS: Groundwater regulation is the responsibility of the surface management agency or, in most instances, the state agency responsible for groundwater regulation.

AGENCY RESPONSIBLE FOR REGULATING DRILLING: Statute and No.: Geothermal Steam Act of 1970 (Public Law 91 - 581). Bureau of Land Management, State Office

INJECTION REQUIREMENTS: Statute and No.: Geothermal Steam Act of 1970 (Public Law 91-581). Bureau of Land Management. State Office

ENVIRONMENTAL STATUTE PERTAINING TO EXPLORATION, DEVELOPMENT, AND INJECTION: National Environmental Policy Act 42 U.S.C. 4321 ct. seg., and Geothermal Steam Act of 1970. 43 C.F.R., Part 3200 and 30 C.F.R., Part 270

AGENCY RESPONSIBLE FOR ENVIRONMENTAL PROTECTION: Environmental Protection Agency; Bureau of Land Management, State Office

ADDITIONAL INFORMATION: For the regulation of geothermal leasing, exploration, and development contact the appropriate state office of the Bureau of Land Management or see 30 U.S.C. 1001 and the following one, 43 C.F.R., Part 3200, and 30 C.F.R., Part 270.

* Legislation passed and signed into law in 1988 (PI 100.443) provides for three 5-year extension of the primary lease term if special circumstances exist. PI 100.443 also extended protection for units of the National Park System.

ARIZONA

DEFINITION OF GEOTHERMAL: Statute and No.: Arizona Revised Statutes (ARS) 27-651

a. "Geothermal resource" means all products of geothermal processes embracing indigenous steam, hot water, and hot brines;

b. Steam and other gases, hot water, and hot brines resulting from water, other fluids, or gas artificially introduced into geothermal formations;

c. Heat or other associated energy found in geothermal formations including any artificial stimulation or induction thereof; and

d. Any mineral or minerals, exclusive of fossil fuels and helium gas, which may be present in solution or in association with geothermal steam, water, or brines.

GEOTHERMAL IS CHARACTERIZED FOR LEASING AS: Steam, hot water, heat, or mineral.

OWNERSHIP: The geothermal resource is included in the ownership of the land.

AGENCY RESPONSIBLE FOR LEASING: Statute and No.: ARS 27-668. State Lands Department, For Public Lands: Bureau of Land Management

LEASING: ARS 27-670 Leasing is on a competitive basis.

LEASE TERMS: ARS 27-671 State Land Department

Primary;	10 years
Renewable:	As long as production is maintained.
Rentals:	$ 1.00/acre/year
Royalties:	(% of sales): Not less than 12.5% of gross value at the wellhead.

DILIGENCE REQUIREMENTS: None

AGENCY RESPONSIBLE FOR GROUNDWATER REGULATIONS: See ARS 27-667. Department of Water Resources

AGENCY RESPONSIBLE FOR DRILLING/REGULATING: Statute and No.: ARS 27-656. Arizona Geological Survey

INJECTION REQUIREMENTS: Arizona Administrative Code Rule Title 12 Chapter 7-175

STATE ENVIRONMENTAL STATUTE PERTAINING TO EXPLORATION, DEVELOPMENT, AND INJECTION: ARS 27-652

AGENCY RESPONSIBLE FOR ENVIRONMENTAL PROTECTION: Department of Environmental Quality

ADDITIONAL INFORMATION REGARDING PERMITTING, REGULATING, OR MONITORING:

Arizona Geological Survey
(Lead Agency)
416 W. Congress #100
Tucson, AZ 85701
(520) 770-3500

State Land Department
1616 W. Adams, Rm. 329
Phoenix, AZ 85007
(602) 542-4631

Dept. of Environmental Quality
3033 N. Central
Phoenix, AZ 85012
(602) 207-2300

Department of Water Resources
500 N. 3rd
Phoenix, AZ 85004
(602) 417-2400

CALIFORNIA

DEFINITION OF GEOTHERMAL: Statute and No.: Public Resources Code (PRC), Section 6903. For purposes of this chapter, "geothermal resources" shall mean the natural heat of the earth, the energy in whatever form below the surface of the earth present in, resulting from, or created by, or which may be extracted from, such as natural heat, and all minerals in solution or other products obtained from naturally heated fluids, brines, associated gases and steam, in whatever form, found below the surface of the earth, but excluding oil, hydrocarbon gas, or other hydrocarbon substances.

"Low-temperature geothermal well" means a well drilled for the purpose of providing geothermal resources as defined in Section 6903 from which fluids can be produced which have value by virtue of the heat contained therein and have a temperature that is not more than the boiling point of water at the altitude of the occurrence.

GEOTHERMAL IS CHARACTERIZED AS: Mineral

OWNERSHIP: Statute and No.: PRC. Paragraph 6904. Also see Pariani vs California (CA Court of Appeals, 1981). The state claims ownership whenever it owns the mineral estate, otherwise the resource is the property of the owner of the mineral estate.

AGENCY RESPONSIBLE FOR LEASING: Statute and No.: PRC, Paragraph 6904, 6911, and 6916. California State Lands Commission

LEASING: Leasing in a Geothermal Resource Areas (GRA) is by competitive bid. Exploration permits are available in non-GRA areas.

LEASE TERMS: State Lands Commission

Primary: 10 years and so long as geothermal resources are being produced or utilized or are capable of being produced or utilized in commercial quantities but not to exceed 99 years.

Renewable: Yes

Rentals: Not less than $ 1/acre on up

Royalties: (% of sales): Minimum of 10% of gross revenue and not higher than 16-2/3%.

DILIGENCE REQUIREMENTS: California State Lands Commission

AGENCY RESPONSIBLE FOR GROUNDWATER REGULATING: Division of Oil, Gas and Geothermal Resources

AGENCY RESPONSIBLE FOR REGULATING DRILLING: Statute and No.: PRC, Paragraph 6911. Division of Oil, Gas and Geothermal Resources

INJECTION REQUIREMENTS: Statute and No.: PRC, Paragraph 6921, Chapter 4, commencing with Section 3700 of Division 3. Division of Oil, Gas and GeothermaL Resources

STATE ENVIRONMENTAL STATUTE PERTAINING TO EXPLORATION, DEVELOPMENT, AND INJECTION: Statute and No.: PRC, Section 3715.5. Division of Oil, Gas and Geothermal Resources

AGENCY RESPONSIBLE FOR ENVIRONMENTAL PROTECTION: Division of Oil, Gas and Geothermal Resources

ADDITIONAL INFORMATION:

California State Lands Comm.
Mineral Resources Mgmt. Division
200 Oceangate, 12th Floor
Long Beach, CA 90802
(562) 590-5201

Div. Oil, Gas and Geothermal Res.
801 K Street, MS 20-20
Sacramento, CA 95814-3530
(916) 323-1788

California Energy Commission
1516 9th Street
Sacramento. CA 95814
(916) 654-287

COLORADO

DEFINITION OF GEOTHERMAL: Statute and No.: Colorado Geothermal Resources Act, Colorado Revised Statutes CRS 37-90.5-103

"Geothermal resource" means the natural heat of the earth and includes:

a. The energy that may be extracted from the natural heat;

b. The material medium used to extract the energy from a geothermal resource; and

c. Geothermal by-products.

"Geothermal fluid" means naturally occurring groundwater, brines, vapor, and steam associated with a geothermal resource.

"Geothermal by-products" means dissolved or entrained minerals and gases that may be obtained from the material medium, excluding hydrocarbon substances and carbon dioxide.

GEOTHERMAL IS CHARACTERIZED AS: Water

OWNERSHIP: Statute and No.: Colorado Revised Statutes 37.90.5-104. Where a geothermal resource is found in association with geothermal fluid which is tributary groundwater, such geothermal resource is declared to be a public resource to which usufructuary rights only may be established according to the procedures of this article. No correlative property right to such a geothermal resource in place is recognized as an incidence of ownership of an estate in land. The property rights to a hot dry rock resource is an incident of the ownership of the overlying surfaces unless severed, reserved, or transferred with the subsurface estate expressly. Nothing in this section shall be deemed to derogate valid, existing property rights to geothermal resource which has vested prior to July 1, 1983. However, such property rights shall not be deemed vested absent the award of a decree for an application filed prior to the effective date of this article pursuant to existing water law or the entering into a geothermal lease prior to the effective date of this article or unless utilizing facilities are actually in existence prior to July 1, 1983. A facility for utilization of geothermal resources shall be considered to be in existence if it is in actual operation or is undergoing significant construction activities prior to operation. Nothing in this section shall be deemed to derogate the rights of a landowner to non-tributary groundwater.

AGENCY RESPONSIBLE FOR LEASING: Statute and No.: "Special Rules and Regulation Relating to Geothermal Resource Leases," (Form 248-1)1972, Lease Form (Form 248-2)1972. State Board of Land Commissioners

LEASING: Leases may be awarded by the State Board of Land Commissioners for lands under its jurisdiction through negotiation or by competitive bidding.

LEASE TERMS: State Board of Land Commissioners

Primary: Set in the lease.

Renewable: As long as production continues; if no production. State Board of Land Commissioner decides.

Rentals: Set in the lease.

Royalties: (% of sales): Set in the lease.

DILIGENCE REQUIREMENTS: Water Quality Control Commission and the State Board of Land Commissioners - To continue injection and/or discharge and maintain lease

AGENCY RESPONSIBLE FOR GROUNDWATER REGULATIONS: Department of Natural Resources, Division of Water Resources

AGENCY RESPONSIBLE FOR REGULATING DRILLING: Statute and No.: Colorado Revised Statutes 37-90-138, 37-90.5-106,37-91. Department of Natural Resources, Division of Water Resources

INJECTION REQUIREMENTS: Statute and No.: Colorado Geothermal Resources Act 37-90.5-106. Department of Natural Resources, Oil & Gas Conservation Commission, and/or Division of Water Resources

STATE ENVIRONMENTAL STATUTE PERTAINING TO EXPLORATION, DEVELOPMENT, AND INJECTION: Title 37, Colorado Revised Statutes, Article 90.5

AGENCY RESPONSIBLE FOR ENVIRONMENTAL PROTECTION: U S. Environmental Protection Agency

ADDITIONAL INFORMATION:

Dept. of Natural Resources
Oil & Gas Conservation Comm.
1580 Logan Street
Denver. CO 80203
(303) 894-2100

Dept. of Natural Resources
Division of Water Resources
818 Centennial Building
1313 Sherman Street
Denver, CO 80203
(303) 866-3581
Info Desk: 866-3587

Water Quality Control Comm.
Department of Health
4210 E. 11th Avenue
Denver, CO 80220
(303) 692-3500

IDAHO

DEFINITION OF GEOTHERMAL: Statute and No.: Geothermal Resource Act, Idaho Code, Paragraph 42-4002. "The natural heat energy of the earth, the energy, in whatever form, which may be found in any position and at any depth below the surface of the earth present in, resulting from, or created by, or which may be extracted from, such natural heat, and all minerals in solution or other products obtained from the material medium of any geothermal resource. Ground water having a temperature of two hundred twelve (212) degrees Fahrenheit or more in the bottom of a well shall be classified as a geothermal resource. Geothermal resources are found and hereby declared to be *sui generis*, being neither a mineral resource nor a water resource, but they are also found and hereby declared to be closely related to and possibly affecting and affected by water and mineral resources in many instances" (1C § 42-002).

Section 42-230 Idaho Code

(a) "ground water" is all water under the surface of the ground whatever may be the geological structure in which it is standing or moving.

(1) All ground water having a temperature of greater than eighty-five (85) degrees Fahrenheit and less than two hundred twelve (212) degrees Fahrenheit in the bottom of a well shall be classified and administered as a low temperature geothermal resource pursuant to section 42-233, Idaho Code.

(2) All ground water having a temperature of two hundred twelve (212) degrees Fahrenheit or more in the bottom of a well shall be classified as a geothermal resource pursuant to section 42-4002, Idaho Code, and shall be administered as a geothermal resource pursuant to chapter 40, title 42, Idaho Code.

Section 42-233 Idaho Code

Low temperature geothermal resource. The right to the use of low temperature geothermal resources of the state shall be acquired by appropriation. The appropriation may be perfected by means of the application, permit and license procedure as provided for in chapter 4.

GEOTHERMAL IS CHARACTERIZED AS: *Sui generis*

OWNERSHIP: Statute and No.: Idaho Code, Chapter 16, Section 47-1602. State claims ownership of all geothermal resources underlying state and school lands.

AGENCY RESPONSIBLE FOR LEASING: Statute and No.: Idaho Code, Chapter 16, Section 47-1603. Idaho State Board of Land Commissioners

LEASING: Leasing is by competitive bid in areas designated by Director of the Department of State Lands or where competitive interest. Other areas are available for a lease upon submittal of application to the Department of State Lands.

LEASE TERMS: Idaho State Department of Lands

Primary: 10 years.
Renewable: So long as commercial production or drilling continues to minimum of 1,000 ft, maximum 40 years with preferential right to renew.
Rental: $1 /acre first 5 years, $2/acre second 5 years, $3/acre thereafter.
Royalties: (% of sales): 10%

DILIGENCE REQUIREMENTS: N/A

AGENCY RESPONSIBLE FOR GROUNDWATER REGULATIONS: Idaho Department of Water Resources

AGENCY RESPONSIBLE FOR REGULATING DRILLING: Statute and No.: Idaho Code, Chapter 40, Sec. 42-238 and Sec. 42-4001 through 42-4015. See Drilling/or Geothermal Resources Rules and Regulations and Minimum Well Construction Standards, and/or contact the Idaho Department of Water Resources.

INJECTION REQUIREMENTS: Statute and No.: Idaho Code, Title 42, Chapter 39 and Chapter 40, Section 42. See A Guide to the Idaho Well Program and Rules and Regulations, Drilling for Geothermal Resources, and/or contact the Idaho Department of Water Resources.

STATE ENVIRONMENTAL STATUTE PERTAINING TO EXPLORATION, DEVELOPMENT, AND INJECTION: Statute and No.: Idaho Code, Chapter 40, Section 42-4003 through 42-4009

AGENCY RESPONSIBLE FOR ENVIRONMENTAL PROTECTION: Idaho Department of Health & Welfare, Environmental Division, and/or Idaho Department of Water Resources

ADDITIONAL INFORMATION: Drilling for Geothermal Resources Rules and Regulations. Minimum Well Construction Standards, and Low-Temperature Geothermal Resources, June 1988. A Guide to the Idaho Injection Well Program, April 1986; Rules and Regulations, Construction and Use of Injection Wells, June 1993; Rules and Regulations, Water Well Driller's Licenses, March 1985 Geothermal Energy Development: A Guide So the Federal and State Regulating Process in Idaho, Montana, Oregon, and Washington. 1991, Geothermal Energy Development, A Guide to the Federal and State Regulating Process in Idaho, Montana, Oregon, and Washington, 1991.

Idaho State Dept. of Lands
Statehouse
Boise, ID S3720
(208) 334-0200

Idaho Dept. of Water Res.
Statehouse
Boise, ID 83720
(208) 327-7900

Idaho Dept. of Health & Welfare
Environmental Division
Statehouse
Boise, ID 83720
(208) 334-5000

MONTANA

DEFINITION OF GEOTHERMAL: Statute and No.: Leasing Statute 77-4-102(1) Montana Code Annotated (M.C.A.). "Geothermal resource" means the natural heat energy of the earth, including the energy, in whatever form, which may be found in any position and at any depth below the surface of the earth, either present in, resulting from, created by, or which may be extracted from, such natural heat, and all minerals in solution or other products obtained from the material medium of any geothermal resource.

GEOTHERMAL IS CHARACTERIZED AS: *Sui generis* but governed by law as to groundwater.

OWNERSHIP: Statute and No.: Leasing Statute 7-4-102(1) M.C.A. On state lands geothermal resources are owned by the state as part of their mineral reservation. However, state water laws also apply to all geothermal development involving production and diversion of geothermal fluids.

AGENCY RESPONSIBLE FOR LEASING: Statute and No.: Administrative Rules of Montana (ARM) 26-26(2)-S60120, State Board of Land Commissioners

LEASING: All leasing is by competitive bid. However, if only one bid is received, the applicant may negotiate a lease with the Department of Natural Resources and Conservation

LEASE TERMS: State Board of Land Commissioners

Primary:	10 years.
Renewable:	As long as resources are produced in paying quantity.
Rentals:	Minimum of $ 1/acre; $2/acre after discovery.
Royalties:	(% of sales): 10% of gross revenue from the sale of heat energy, steam, brine, or associated gas on the fair market value of such heat energy or steam.

DILIGENCE REQUIREMENTS: Department of Environmental Quality

AGENCY RESPONSIBLE FOR GROUNDWATER REGULATIONS: Department of Natural Resources & Conservation, Water Resources Division

AGENCY RESPONSIBLE FOR REGULATING DRILLING: Statute and No.: 37-43-101 et seq., ARM40.3.106(6)-S10620 Department of Natural Resources and Conservation

INJECTION REQUIREMENTS: Department of Environmental Quality

STATE ENVIRONMENTAL STATUTE PERTAINING TO EXPLORATION, DEVELOPMENT, AND INJECTION:

a. Air Pollution Discharge Permit 75-2-101 et seq. M.C.A. Regulation at l6-2.14(l)-S1400.;

b. Water Pollution Discharge Permit/Pre-treatment standards for waste water discharged into municipal sewer system; 40 C.F.R. Parts 128,403;

c. Permit requirements for discharge into state water: 75-5-101 et. seq. M.C.A. Regulation at ARM 16-2.14(10)-S14460;

d. Underground Injection Control/Standard for geothermal injection well permits: 40 C.F.R. Parts 122, 123,124,146; 44 Fed. Reg. 34267 et seq. and 44 Fed. Reg. 23738; and

e. Environmental Impact Statements, Montana Environmental Policy Act: 75-1-101 et. seq. M.C.A.

AGENCY RESPONSIBLE FOR ENVIRONMENTAL PROTECTION: Department of Natural Resources & Conservation, Water Resources; Environmental Quality and/or Fish, Wildlife, and Parks

ADDITIONAL INFORMATION: Bloomquist, R.G., 1991, A regulatory guide to leasing, permitting, and licensing in Idaho, Montana, Oregon, and Washington: Olympia, Washington State Energy Office, report number DOE/BP-00425-2, 275 p.

Dept. of Natural Resources
& Conservation
Water Management Bureau
48 N. Last Chance Gulch
PO Box 201601
Helena, MT 59620
Ph: (406) 444-6637

Dept. of Natural Resources
& Conservation
Water Operations Bureau
48 N. Last Chance Gulch
PO Box 201601
Helena, MT 59620
Ph: (406) 444-6610

Dept. of Environmental
Quality
Permitting & Compliance Div.
1520 E. Sixth Street
Helena, MT 59620
Ph: (406) 444-4323
Fax: (406) 444-5275

State-Owned Lands
Dept. of Natural Resources
& Conservation
Trustland Mgmt. Div.
1625 11th Avenue
Helena, MT 59620
Ph: (406) 444-2074

NEVADA

DEFINITION OF GEOTHERMAL: Statute and No.: Nevada Revised Statute (NRS) 534A.010 Geothermal resources are defined as the natural heat of the earth and the energy associated with that natural heat, but excluding hydrocarbons and helium. In addition, geothermal resources are divided into classes for purposes of regulation as follows:

Domestic Class: This type of geothermal resource is developed for dwellings with common ownership on a single parcel of land, and uses not more than an annual average of 1800 gallons per day. A geothermal resource developed for a community's usage that does not produce geothermal heat for sale or for the generation of power is also considered as a domestic well.

Commercial Class: A commercial well is primarily used to provide geothermal resources on a commercial basis for purposes other than generation of power.

Industrial Class: This type of geothermal resource is used primarily to generate power.

GEOTHERMAL IS CHARACTERIZED AS: Mineral if use is only for heat content. For low temperature uses and where there is consumptive use, the resource would be characterized as both water and mineral and would fall under the jurisdiction of the State Engineer, Division of Water Resources (water) and the State Division of Minerals (heat).

OWNERSHIP: Statute and No.: NRS 534A.050 Geothermal resources in Nevada belong to the owner of the surface estate, unless they have been reserved by or conveyed to another person,

AGENCY RESPONSIBLE FOR LEASING: Contact Office of State Lands. For federal lands, contact the Bureau of Land Management.

LEASING: Leases are negotiated.

LEASE TERMS: Office of State Lands

Primary:	N/A
Renewable:	N/A
Rentals:	N/A
Royalties:	(% of sales): N/A

DILIGENCE REQUIREMENTS: Nevada Administrative Code (NAC) 534A.210

AGENCY RESPONSIBLE FOR CROUNDWATER REGULATING: Department of Conservation and Natural Resources, Division of Environmental Protection

AGENCY RESPONSIBLE FOR REGULATING DRILLING: Statute and No.: NRS 534A. Department of Minerals

INJECTION REQUIREMENTS: Statute and No.: NAC 534A.410 and Chapter 445 Nevada Administrative Code, Section 2596 inclusive. State Department of Conservation and Natural Resources, Division of Environmental Protection and Division of Minerals

STATE ENVIRONMENTAL STATUTE PERTAINING TO EXPLORATION. DEVELOPMENT, AND INJECTION: NRS 534A, Department of Minerals

AGENCY RESPONSIBLE FOR ENVIRONMENTAL PROTECTION: State Department of Conservation and Natural Resources, Division of Environmental Protection, and Division of Minerals.

ADDITIONAL INFORMATION:

State Lands Division
333 West Nye Lane
Carson City, NV 89710
(702) 687-4363
Pamela Wilcox

Department of Conservation
123 West Nye Lane
Carson City, NV 89710
(702) 687-4670, ext. 3150
Russ Land

Division of Minerals
400 West King Street, #106
Carson City, NV 89703
(702) 687-5050
Fax: (702) 687-395
John Snow
Ndom@govmail.state.nv.us
Http://www.state.nv.us/b&i/minerals

NEW MEXICO

DEFINITION OF GEOTHERMAL: Statute and No.: New Mexico Statutes Annotated (NMSA) 1978 71-5-3 and NMSA 1978 72-2-17. "Geothermal resource" means the natural heat of the earth, or the energy, in whatever form, below the surface of the earth present in, resulting from, creating by or which may be extracted from, this natural heat, and all minerals in solution or other products obtained from naturally heated fluids, brines, associated gases and steam, in whatever form, found below the surface of the earth, but excluding oil, hydrocarbon gas and other hydrocarbon substances. "Geothermal fluid" means naturally occurring steam or hot water which is at a temperature of at least 95°F in the natural state of free-flowing springs or pumped from wells.

GEOTHERMAL IS CHARACTERIZED AS: Mineral

OWNERSHIP: Statute and No.; NMSA 1978, 19-13-3 and NMSA 1978, 71-5-2. The state claims ownership of geothermal resources whenever it holds the mineral rights.

AGENCY RESPONSIBLE FOR LEASING: Statute and No.: NMSA 1978,19-13-5. State Land Office

LEASING: Leasing is competitive in geothermal resource fields and non-competitive in all other areas.

LEASE TERMS: NMSA 1978, 19-13-7 and 19-13-11. State Land Office

Primary: 5 years.

Renewable: 5 years and for so long as resources are produced.

Rentals: $1/acre for first 5 years or when in production. $5/acre second 5 years and no production.
Royalties: (% of sales): 10% of gross revenues minus transportation costs or royalty of 8% of the net revenue received from the operation of an energy producing plant.

DILIGENCE REQUIREMENTS: N/A

AGENCY RESPONSIBLE FOR GROUNDWATER REGULATIONS: Office of the State Engineer

AGENCY RESPONSIBLE FOR REGULATING DRILLING: Statute and No.: NMSA 1978, 71-5-6,71-6-8,72-12-3,72-12-26. Oil Conservation Division and/or Office of the State Engineer

INJECTION REQUIREMENTS: Statute and No.: NMSA 1978,71-5-6. Oil Conservation Division, Office of the State Engineer; and New Mexico Environment Department

STATE ENVIRONMENTAL STATUTE PERTAINING TO EXPLORATION, DEVELOPMENT, AND INJECTION: NMSA 1978, 71-5-6 and 74-6-1 through 12. -Note: All NMSA numbers are being revised.

AGENCY RESPONSIBLE FOR ENVIRONMENTAL PROTECTION: New Mexico Environment Department

ADDITIONAL INFORMATION: Southwest Technology Development Institute, NMSU, Las Cruces, NM (505) 646-1846.

Leasing/Land Entry/Archeology
New Mexico State Land Office
Oil, Gas and Mineral Division
310 Old Santa Fe Trail
PO Box 1148
Santa Fe, NM 87504-1148
Sam Taylor
(505) 827-5750

Drilling, Injection, Production
Oil Conservation Division (OCD)
New Mexico, Mineral, and
Natural Resources Dept.
2040 South Pacheco
PO Box 6429
Santa Fe, NM 87505-5472
Roy Johnson
(505) 827-8198
Rjohnson@emnrdsf.state.nm.us

Water Rights, Drilling, Prod., Inject.
New Mexico State Engineer Office
Water Rights Division
Bataan Memorial Building
PO Box 25102
Santa Fe, NM 87504-5102
(505) 827-6120
(800) 928-3766

Environmental, Discharge, Injection
New Mexico Environment Dept.
Water and Waste Management Div.
Ground Water Bureau
Harold S. Runnels Building
1190 St. Francis Drive
Santa Fe, NM 87505-4182
(505) 827-2855
(800) 879-3421

Geothermal Resources, Development and Uses
Southwest Technology
Development Institute
New Mexico State University
Box 30001, Dept. 3 SOL
Las Cruces, NM 88003-0001
James C. Witcher
(505) 646-3949
jwitcher@nmsu.edu

Geologic Reports and Maps
New Mexico Bur. of Mines & Mineral Resources
New Mexico Inst. of Mining & Tech.
801 Leroy Place
Socorro, NM 87801-4796
(505) 835-5410

OREGON

DEFINITION OF GEOTHERMAL: Statute and No.: Oregon Revised Statute (ORS) 522.005(11); ORS 577.090 Subsection (II): "Geothermal resources" means the natural heat of the earth, the energy in whatever form, below the surface of the earth present in, resulting from, or created by, or which may be extracted from the natural heat, and all minerals in solution or other products obtained from naturally heated fluids, brines, associated gases, and steam, in whatever form, found below the surface of the earth, exclusive of helium or of oil, hydrocarbon gas or other hydrocarbon substances, but including, specifically:

a. All products of geothermal process, embracing indigenous steam, hot water, and hot brines;
b. Steam and other gases, hot water and hot brines resulting from water, gas, or other fluids artificially introduced into geothermal formation;
c. Heat or other associated energy found in geothermal formations; and
d. Any by-product derived from them.

Subsection (12): "Geothermal well" includes any excavation made for producing geothermal resources and any geothermal reinjection well as defined in subsection (10) of this subsection.

Subsection (13): "Geothermal reinjection well" means any well or converted well constructed to dispose of geothermal fluids derived from geothermal resources into an underground reservoir.

GEOTHERMAL IS CHARACTERIZED AS: Water if the temperature is (less than 250°F; and under the jurisdiction of the Department of Water Resources. If it is above 250°F, it is considered mineral and under the jurisdiction of the Department of Geology and Mineral Resources. Also, if exploration for geothermal resources of any temperature at depth greater than 2,000 feet, it is under the jurisdiction of the Department of Geology and Mineral Resources.

OWNERSHIP: Statute and No.: ORS 522,035; ORS 537.090. Owner of the surface estate, unless otherwise reserved or conveyed.

AGENCY RESPONSIBLE FOR LEASING: Statute and No.: ORS 273.551; Oregon Administrative Rules, Chapter 141 75-010 through 141-75-575. Division of State Lands

LEASING: Leases are available on a non-competitive as well as competitive basis.

LEASE TERMS: Division of State Lands

Primary: 10 years.
Renewable: 5 years if discovery has been made or is imminent. Leases are renewable every 10 years. No lease shall exceed 50 years except the lessee shall have a right of first refusal if the Division decides to continue leasing.
Rentals: $1 /acre (1st, 2nd, and 3rd year); $3/acre (4th year); $5/acre all subsequent years.
Royalties: (% of sales): 10% of production value of resource produced.

DILIGENCE REQUIREMENTS: Division of State Lands

AGENCY RESPONSIBLE FOR GROUNDWATER REGULATIONS: ORS 537, Department of Water Resources (<250°F) and/or ORS 522, Department of Geology & Mineral Industries (>250°F)

AGENCY RESPONSIBLE FOR REGULATING DRILLING: Same as above

INJECTION REQUIREMENTS: Same as above, plus Oregon Administrative Rules, Chapter 690, Division 65-055-Water Resources Department/Low Temperature Geothermal Effluent Disposal.

STATE ENVIRONMENTAL STATUTE PERTAINING TO EXPLORATION, DEVELOPMENT, AND INJECTION: Statute and No.: ORS 522 and Oregon Administrative Rules, Chapter 141-75-265. Department of Geology and Mineral Industries; Department of Water Resources and/or Department of Environmental Quality

AGENCY RESPONSIBLE FOR ENVIRONMENTAL PROTECTION: Department of Environmental Quality

UTAH

DEFINITION OF GEOTHERMAL: Statute and No.: Geothermal Resource Conservation Act, Section 73-22-3, Utah Code Annotated (UCA) 1953. "Geothermal resources" means:

a. The natural heat of the earth at temperatures greater than 120°C; and

b. The energy, in whatever form, including pressure, present in, resulting from, created by, or which may be extracted from the natural heat, directly or through a material medium. Geothermal resource does not include geothermal fluids.

"Geothermal fluid" means water and steam at temperatures greater than 120°C naturally present in a geothermal system.

GEOTHERMAL IS CHARACTERIZED AS: Water

OWNERSHIP: Statute and No.: Geothermal Resource Conservation Act, UCA, Section 73-21-4. Ownership of a geothermal resource derives from an interest in land and not from an appropriated right to geothermal fluids. This chapter shall apply to all lands in the state of Utah, including federal and Indian lands to the extent allowed by law. In effect, the right to geothermal resource is based on ownership of the mineral rights or surface rights, which are usually obtained by direct ownership or by leasing. Because of the potential relationship between geothermal fluids and groundwater resource, however, an approved application to appropriate geothermal fluids is required prior to the production of geothermal fluids from a well (UCA, Section 73-21-8). The appropriations process for geothermal fluids is similar to that of water appropriations, and includes provisions for advertisement of the application and the filing of protests, Utah Division of Water Rights

AGENCY RESPONSIBLE FOR LEASING: Statute and No.: UCA, Section 65-1-18. Utah School and Institutional Trust Lands Administration (SITLA). Hydrothermal resources at low and moderate temperatures (<120°C) are regulated by the Department of Natural Resources, Division of Water Rights under Utah Water Law.

LEASING: Competitive leasing involves lands that have newly become available for lease because of new purchase, relinquished leases, or any other reason and are leased under the simultaneous filing procedures. Applications for non-competitive leases are filed with the SITLA Board of Trustees.

LEASE TERMS:

Primary: 10 years.

Renewable: For as long as land is in production.

Rentals: $1 /acre per year.

Royalties: (% of sales): 10% of gross proceeds received from sale of those products, or 10% of the fair market value when the products are utilized but not directly sold.

DILIGENCE REQUIREMENTS: Currently a drilling requirement by the end of the first 5 years. SITLA is considering dropping the 5-year drilling requirement.

AGENCY RESPONSIBLE FOR GROUNDWATER REGULATIONS: Utah Division of Water Rights

AGENCY RESPONSIBLE FOR REGULATING DRILLING: Statute and No.: UCA, Section 73-21 -5. Utah Division of Water Rights

INJECTION REQUIREMENTS: Statute and No.: UCA, Section 73-21-5. Utah Division of Water Rights and/or Division of Water Quality; injection may be required in order to maintain water levels in heavily used aquifers.

STATE ENVIRONMENTAL STATUTE PERTAINING TO EXPLORATION, DEVELOPMENT, AND INJECTION: Statute and No,: UCA, Section 73-21-2 and UCA 26-11, Section 1-20

AGENCY RESPONSIBLE FOR ENVIRONMENTAL PROTECTION: Department of Environmental Quality, Division of Water Quality

ADDITIONAL INFORMATION: Wagstaff, L.W., and Green, Stanley, 1982, Utah geothermal handbook: a user's guide of agencies, regulations, permits and aids for geothermal development: Idaho Falls, U.S. Department of Energy report DOE/ID/12016-2, 84 p.

Dept. of Natural Resources
Division of Water Rights
PO Box 146300
Salt Lake City, UT 84116-6300
(801) 538-7240
http://www.waterrights.utah.gov/

Dept. of Environmental Quality
Division of Water Quality
PO Box 144870
Salt Lake City, UT 84114-4870
(801) 538-6146
(801) 538-6016 (fax)
http://waterquality.utah.gov/

Utah School and Institutional Trust
Lands Administration
675 E. 500 S, Suite 500
Salt Lake City, UT 84102
(801)538-5100
(801) 355-0922 (fax)
http://wwwtl.state.ut.us/

Department of Natural Resources
Utah Geological Survey
1594 W. North Temple, Suite 3110
Box 146100
Salt Lake City, UT 84114-6100
(801) 537-3300
(801) 537-3400 (fax)
http://geology.utah.gov/

Department of Natural Resources
Utah Geological Survey
Southern Regional Office
Southern Utah University
Electronic Learning Center, Rm 116
(435) 865-8139
(435) 865-8180
http://geology.utah.gov/

WASHINGTON

DEFINITION OF GEOTHERMAL: Statute and No.: Geothermal Resources Act. Revised Code Washington (RCW), Chapter 79.76(3). "Geothermal resource" means only that natural heat energy of the earth from which it is <u>technologically practical to produce electricity commercially</u> and the medium by which such heat energy is extracted from the earth, including liquids or gases, as well as any mineral contained in any natural or injected fluids, brines, and associated gas, but excluding oil, hydrocarbon gas, and other hydrocarbon substances. All direct-use geothermal resources are considered to be groundwater and regulated accordingly. (Emphasis added)

GEOTHERMAL IS CHARACTERIZED AS: *Sui generis*. Direct use resources are characterized as groundwater.

OWNERSHIP: Statute and No.: Geothermal Resource Act, RCW, Chapter 79.76. Geothermal resources are the property of the surface owner. Water Rights: Chapters 18.104,43.27A, 90,14,90.16,90.22,90,44 and 90.54 RCW; Chapters 173-100, 173-136,173-50, 173-154, 173-166, 173-500, and 173-590 WAC.

AGENCY RESPONSIBLE FOR LEASING: Statute and No.: Geothermal Resources Act, RCW, Chapter 79.76. Department of Natural Resources, Division of Lands

LEASING: All leases are negotiated.

LEASE TERMS: All terms are negotiated.

DILIGENCE REQUIREMENTS: All terms are negotiated.

AGENCY RESPONSIBLE FOR GROUNDWATER REGULATIONS: Department of Ecology. Groundwater Management Areas: Chapter 90.44 RCW; Chapter 173-100 WAC.

AGENCY RESPONSIBLE FOR REGULATING DRILLING: Department of Ecology, RCW 18.104, Chapter 173-160 WAC. Chapter 173-162 WAC.

INJECTION REQUIREMENTS: Statute and No.: Geothermal Resources Act, RCW, Chapter 79.76, Department of Natural Resources, Division of Geology & Earth Resources. Department of Ecology, Chapter 90.48 RCW, Chapter 173-218 WAC - Underground Injection control program.

STATE ENVIRONMENTAL STATUTE PERTAINING TO EXPLORATION, DEVELOPMENT, AND INJECTION: State Environmental Policy Act 1971 and Geothermal Resources Act, RCW, Chapter 79.76

AGENCY RESPONSIBLE FOR ENVIRONMENTAL PROTECTION: Department of Ecology, RCW 43.21A.040

ADDITIONAL INFORMATION:

Bloomquist, R.G., 1986, Geothermal energy development in Washington State, a guide to the federal, state and local regulatory process: Olympia, Washington State Energy Office, ISBN 8944935, 66 p.

Bloomquist, R.G., 1991, Geothermal - a regulatory guide to leasing, permitting, and licensing in Idaho, Montana, Oregon, and Washington: Olympia, Washington State Energy Office, report number DOE/BP-00425-2, 275 p.

Department of Natural Resources
Division of Lands
1111 Washington Street SE
PO Box 47001
Olympia. WA 98504-7001
(360) 902-1000

Department of Ecology
300 Desmond Drive
PO Box 47600
Lacey, WA 98504-7600
(360) 407-6000

Department of Natural Resources
Division of Geology & Earth Resources
1111 Washington Street NE
PO Box 47001
Olympia, WA 98504-7001
(360) 902-1450

Washington State University Energy Program
925 Plum Street, Bldg. 4
Olympia, WA 98504-3165
(360) 956-2016

WYOMING

DEFINITION OF GEOTHERMAL: Statute and No.: Wyoming Statutes (WS) Chapter XI Rules and Regulations Governing the Issuance of Geothermal Permits and Leases. "Geothermal resources" shall mean the natural heat in the subsurface of the earth, its energy, in whatever form, resulting from, or created by, or which may be extracted from, such natural heat and all minerals in solution or other products obtained from naturally heated fluids, brines, associated gases, and steam, in whatever form, found below the surface of the earth, but excluding oil, hydrocarbon gas, other hydrocarbon substances or miscellaneous minerals.

GEOTHERMAL IS CHARACTERIZED AS: Water

OWNERSHIP: Statute and No.: Nature of Water Rights and Beneficial Use, Article 1, §41-3-101 Wyoming Statutes (WS). Geothermal is a public resource available for appropriation.

AGENCY RESPONSIBLE FOR LEASING: Article 1. § 41-3-101: Rules and Regulations Governing the Issuance of Geothermal Resource Permits and Leases, Wyoming State Lands Office

LEASING: Leasing in Known Geothermal Resource Areas (KGRA) is by competitive bid. Other lands are available through a non-competitive permit which may be converted to a lease within 50 days should the area be classified as a KGRA.

LEASE TERMS: Wyoming State Lands Office

Primary: 10 years.

Renewable: As long as geothermal resources are being produced or utilized, or are capable of being produced or utilized in commercial quantities.

Rentals: $2/year.

Royalties: (% of sales): 10% of gross revenue as determined by a reasonable value received from the sale of steam, brine, from which no minerals have been extracted, and associated gases at the point of delivery to purchaser thereof. In such a case where the resource is used by the lessee and not sold, the gross revenue therefrom to be determined as those said geothermal resources had been sold to a third person and then primarily market price in the same market area and under the same market conditions.

DILIGENCE REQUIREMENTS: Drilling must commence within two (2) years. State Board of Land Commissioners

AGENCY RESPONSIBLE FOR GROUNDWATER REGULATIONS: State Engineer - a permit must be obtained from the State Engineer's Office prior to drilling any water well (Wyoming Statue 41-3-930)

AGENCY RESPONSIBLE FOR REGULATING DRILLING: Statute and No.: Rules and Regulations Governing the Issuance of Geothermal Resource Permits and Leases. State Board of Land Commissioners and State Engineer

INJECTION REQUIREMENTS: Surface disposal may be approved by the Wyoming Game and Fish Department, State Engineer or Department of Environmental Quality.

STATE ENVIRONMENTAL STATUTE PERTAINING TO EXPLORATION, DEVELOPMENT, AND INJECTION: State Engineer or Department of Environmental Quality, Section 12, Board of Land Commissioners Permit to Prospect for Geothermal Resources

AGENCY RESPONSIBLE FOR ENVIRONMENTAL PROTECTION: Department of Environmental Quality

ADDITIONAL INFORMATION:

Wyoming State Lands Office
and/or State Board of Land
Commissioners
3rd Floor West
Herschler Building
Cheyenne, WY 82002
(307) 777-6638

Dept. of Environmental Quality
4th Floor West
Herschler Building
Cheyenne, WY 82002
(307) 777-7781

University of Wyoming
Department of Geology
and Geophysics
16th & Gibbon Street
PO Box 3006
Laramie, WY 82071
(307) 766-3389

State Engineer's Office
4th Floor East
Herschler Building
Cheyenne, WY 82002
(307) 777-6159

Return

Appendix D: Overall comparison matrix of geothermal sites studied.

Site	Long: (W)	Lat: (N)	T, R, S SLB&M	County:	Meas Temp (°C):	Res Temp (°C):	Depth (m):	Resource Type:	TDS (mg/L)	Dist to KV-46 or Greater (mi)	Line Label	Dist to Road (mi)	Road Label	Land Ownership	T & E Species	No. T & E Species	Ground Water Basin(s) and Status[1]	2000 Population[2]	2000 Income[3]
Roosevelt Hot Springs	112.8503	38.5019	T26S, R9W, sec 34	Beaver	270	270	1000 - 2000	high-temp liquid	7,000-7,800	0.2	KV-138	7.7	hwy 257	Private, State, BLM	Burrowing Owl, Ferruginous Hawk, Greater Sage-Grouse, Wolverine, Least Chub, Brazilian Free-tailed Bat	6	Basin 71 = Closed, Restricted; Basin 77 = Closed	6024	21,339
Cove Fort-Sulphurdale	112.5668	38.5685	T26S, R6W, sec 07	Beaver	150	150	180 - 900	dry steam in shallow reservoir, high-temp liquid in deep reservoir	9,400	0.7	KV-46	4.6	I-70	USDA Forest Service, Private, State, BLM, Tribal	Greater Sage-Grouse, Burrowing Owl, Ferruginous Hawk	3	Basin 71 = Closed, Restricted; Basin 67 = Closed; Basin 63 = Closed	6024	21,339
Thermo Hot Springs	113.2036	38.1731	T30S, R12W, sec 28	Beaver	160	160-217	2200	high-temp liquid	1,300-3,300	12.3	KV-46	13.3	hwy 130	Private, BLM, State	Burrowing Owl, Ferruginous Hawk, Swainson's Hawk, Greater Sage-Grouse	4	Basin 71 = Closed	6024	21,339
Newcastle	113.5651	37.6591	T36S, R15W, S20	Iron	118	130	150 - 270	moderate-temp liquid	1000-1100	0.5	KV-138	1.0	hwy 56	Private, BLM	Burrowing Owl, Ferruginous Hawk, Long-billed Curlew	3	Basin 71 = Closed	33960	16,104
Hooper Hot Springs	112.1753	41.1370	T5N, R3W, S27	Davis	57	135	1500?	low- to mod-temp liquid	8600	6.2	KV-46	3.5	unknown	SOV/Wildlife Management Area, Private	American White Pelican, Bald Eagle, Ferruginous Hawk, Long-billed Curlew, Mountain Plover, Peregrine Falcon, Short-eared Owl, Bobolink, Common Yellowthroat, Grasshopper Sparrow, Townsend's Big-eared Bat	11	Basin 31 = Restricted; Basin 35 = Restricted	240,259	24,100
Utah Hot Springs	112.0278	41.3375	T7N, R2W, S14	Weber	59	192	1800?	high-temp liquid (?)	22000	0.0	KV-230	0.1	hwy 89	Private	American White Pelican, Blue Grosbeak, Brazilian Free-tailed Bat, Lewis's Woodpecker, Pacific Treefrog, Bald Eagle, Burrowing Owl, Long-billed Curlew, Osprey, Short-eared Owl	10	Basin 29 = Open; Basin 35 = Restricted	197,264	22,757

[1] Ground water basin number and status as classified by the Utah Division of Water Rights.
[2] United States 2000 Census county population estimates.
[3] United States 2000 Census county average per-capita income.

Appendix D: Overall comparison matrix of geothermal sites studied (continued).

Site	Long:	Lat:	T, R, S	County:	Meas Temp (°C):	Res Temp (°C):	Depth (m):	Resource Type:	TDS (mg/L)	Dist to KV-46 or Greater (mi)	Line Label	Dist to Road (mi)	Road Label	Land Ownership	T & E Species	No. T & E Species	Ground Water Basin(s) and Status[1]	2000 Population[2]	2000 Income[3]
Ogden Hot Springs	111.9233	41.2356	T6N, R1W, S23	Weber	57	190	1800?	high-temp liquid (?)	8800	0.1	KV-46	0.1	hwy 39	Private, USDA Forest Service	Bluehead Sucker, Common Yellowthroat, June Sucker, Pacific Treefrog, Ute Ladies' Tresses, Yellow-billed Cuckoo, American White Pelican, Blue Grosbeak, Brazilian Free-tailed Bat, Lewis's Woodpecker	10	Basin 35 = Restricted, Closed; Basin 31 = Restricted, Closed	197,264	22,757
Crystal-Madsen Hot Springs	112.0864	41.6600	T11N, R2W, S29	Box Elder	54	153	1800?	mod- to high-temp liquid	43600	0.9	KV-345	0.1	hwy 69	Private	Bluehead Sucker, Bonneville Cutthroat Trout, Long-billed Curlew, Wolverine	4	Basin 29 = Open; Basin 25 = Open	42,872	22,321
Drum Mountains	113.1533	39.4900	T14-15S, R12-13W	Juab and Millard	?	200?	800?	?	?	22.3	KV-230	10.0	unknown	State, BLM	Townsend's Big-Eared Bat	1	Basin 18 = Open; Basin 16 = Open; Basin 68 = Closed, Open; Basin 67 = Restricted; Basin 69 = Open;	Juab: 8,285; Millard: 12,416	Juab: 15,206; Millard: 16,880

[1] Ground water basin number and status as classified by the Utah Division of Water Rights.
[2] United States 2000 Census county population estimates.
[3] United States 2000 Census county average per-capita income.

Return

Appendix E: County Economic Profiles, 1969-1984 (Part 1)

County/Area Name	Geothermal Site(s)	Line Title	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
State of Utah Total	All	Personal income (thousands of dollars)	3248701	3614045	4026202	4514470	5056616	5685997	6354904	7301818	8330509	9605627	11026413	12464137	14078428	15281825	16480744	18223095
State of Utah Total	All	Nonfarm personal income	3171217	3531224	3942720	4417395	4918669	5582092	6281886	7221918	8261281	9528073	10934630	12400366	14038301	15237117	16444753	18162534
State of Utah Total	All	Farm income	77484	82821	83482	97075	137947	103905	73018	79900	69228	77554	91783	63771	40127	44708	35991	60561
State of Utah Total	All	Net earnings 1/	2603649	2851564	3149962	3527845	3945870	4408397	4867179	5614235	6426276	7394348	8360537	9225811	10236826	10847298	11504562	12807248
State of Utah Total	All	Transfer payments	244494	297221	353692	402578	469040	532767	659432	721675	789717	876118	993070	1174053	1367801	1575799	1712261	1734846
State of Utah Total	All	Income maintenance 2/	23946	32158	38597	45340	47096	49316	59397	66984	69451	73496	78889	107635	118796	125236	141781	140026
State of Utah Total	All	Unemployment insurance benefit payments	12774	17107	23841	27600	24159	31583	65390	58154	48121	40075	47418	73765	83872	151512	151100	78783
State of Utah Total	All	Retirement and other	207774	247956	291254	329638	397785	451868	534645	596537	672145	762547	866763	992653	1165133	1299051	1419380	1516037
State of Utah Total	All	Dividends, interest, and rent	400558	465260	522548	584047	641706	744833	828293	965908	1114516	1335161	1672806	2064273	2473801	2858728	3263921	3681001
State of Utah Total	All	Population (number of persons) 3/	1047000	1065672	1100733	1134601	1168784	1198793	1233935	1272365	1316421	1364235	1416094	1472595	1515472	1558314	1594943	1622342
State of Utah Total	All	Per capita personal income	3103	3391	3658	3979	4326	4743	5150	5739	6328	7041	7786	8464	9290	9807	10333	11233
State of Utah Total	All	Per capita net earnings	2487	2676	2862	3109	3376	3677	3944	4412	4882	5420	5904	6265	6755	6961	7213	7894
State of Utah Total	All	Per capita transfer payments	234	279	321	355	401	444	534	567	600	642	701	797	903	1011	1074	1069
State of Utah Total	All	Per capita income maintenance	23	30	35	40	40	41	48	53	53	54	56	73	78	80	89	86
State of Utah Total	All	Per capita unemployment insurance benefits	12	16	22	24	21	26	53	46	37	29	33	50	55	97	95	49
State of Utah Total	All	Per capita retirement and other	198	233	265	291	340	377	433	469	511	559	612	674	769	834	890	934
State of Utah Total	All	Per capita dividends, interest, and rent	383	437	475	515	549	621	671	759	847	979	1181	1402	1632	1835	2046	2269
State of Utah Total	All	Earnings by place of work ($000)	2689024	2944667	3254963	3649328	4102809	4589353	5062150	5833799	6674556	7680630	8705375	9600046	10702046	11358149	12064105	13443522
State of Utah Total	All	Wage and salary disbursements	2197216	2417436	2647808	2947696	3296545	3695919	4042778	4580311	5212653	6037064	6874319	7649819	8644254	9190546	9673365	10717817
State of Utah Total	All	Other labor income	137393	162691	203253	235983	267343	331110	417068	514756	636745	742804	864035	1007797	1160874	1282734	1379222	1483307
State of Utah Total	All	Proprietors' income	354415	364540	403902	465649	538921	562324	602304	738732	825158	900762	967021	942430	896918	884869	1011518	1242398
State of Utah Total	All	Nonfarm proprietors' income	296816	301125	339192	385646	421908	482093	554187	686646	785331	863346	918738	924416	902077	891804	1023995	1228930
State of Utah Total	All	Farm proprietors' income	57599	63415	64710	80003	117013	80231	48117	52086	39827	37416	48283	18014	-5159	-6935	-12477	13468
State of Utah Total	All	Total full-time and part-time employment	443666	454613	466945	494083	522552	544692	552712	580314	612701	651347	678982	688713	699156	709116	721291	764375
State of Utah Total	All	Wage and salary jobs	382639	392894	404533	428335	452582	470229	474773	495605	523245	559278	581762	584431	592740	596724	603694	641912
State of Utah Total	All	Number of proprietors	61027	61719	62412	65748	69970	74463	77939	84709	89456	92069	97220	104282	106416	112392	117597	122463
State of Utah Total	All	Number of nonfarm proprietors 5/	46651	47837	48921	52701	57307	61824	65231	71892	76447	78954	83829	90616	92486	98274	102516	107487
State of Utah Total	All	Number of farm proprietors	14376	13882	13491	13047	12663	12639	12708	12817	13009	13115	13391	13666	13930	14118	15081	14976
State of Utah Total	All	Average earnings per job (dollars)	6061	6477	6971	7386	7851	8426	9159	10053	10894	11792	12821	13939	15307	16017	16726	17588
State of Utah Total	All	Average wage and salary disbursements	5742	6153	6545	6882	7284	7860	8515	9242	9962	10794	11816	13089	14584	15402	16024	16697
State of Utah Total	All	Average nonfarm proprietors' income	6362	6295	6933	7318	7362	7798	8496	9551	10273	10935	10960	10201	9754	9075	9989	11433
Beaver	Roosevelt, Cove Fort, Thermo	Personal income (thousands of dollars)	9929	10884	12172	13756	15316	16871	17446	20254	22812	25062	27120	29752	33160	36385	40600	45681
Beaver	Roosevelt, Cove Fort, Thermo	Nonfarm personal income	8738	9617	10982	12332	13537	15164	16544	19052	21632	23745	26040	29419	32263	34403	39261	43783
Beaver	Roosevelt, Cove Fort, Thermo	Farm income	1191	1267	1190	1424	1779	1707	902	1202	1180	1317	1080	333	897	1982	1339	1898
Beaver	Roosevelt, Cove Fort, Thermo	Net earnings 1/	7408	7972	8835	10012	11013	11788	11293	13386	15178	16571	17396	18325	19811	20985	23224	26296
Beaver	Roosevelt, Cove Fort, Thermo	Transfer payments	1305	1531	1795	2039	2347	2670	3452	3814	4142	4546	4985	5662	6607	7538	8201	8434
Beaver	Roosevelt, Cove Fort, Thermo	Income maintenance 2/	52	72	65	100	85	107	147	209	220	261	249	359	398	421	479	484
Beaver	Roosevelt, Cove Fort, Thermo	Unemployment insurance benefit payments	65	66	79	88	67	87	341	214	179	148	177	194	206	348	346	219
Beaver	Roosevelt, Cove Fort, Thermo	Retirement and other	1188	1393	1651	1851	2195	2476	2964	3391	3743	4137	4559	5109	6003	6769	7376	7731
Beaver	Roosevelt, Cove Fort, Thermo	Dividends, interest, and rent	1216	1381	1542	1705	1956	2413	2701	3054	3492	3945	4739	5765	6742	7862	9175	10951
Beaver	Roosevelt, Cove Fort, Thermo	Population (number of persons) 3/	3900	3798	3830	3864	3993	3976	4064	4074	4064	4194	4240	4408	4518	4678	4771	4969
Beaver	Roosevelt, Cove Fort, Thermo	Per capita personal income	2546	2866	3178	3560	3836	4243	4293	4972	5613	5976	6396	6750	7340	7778	8510	9193
Beaver	Roosevelt, Cove Fort, Thermo	Per capita net earnings	1899	2099	2307	2591	2758	2965	2779	3286	3735	3951	4103	4157	4385	4486	4868	5292
Beaver	Roosevelt, Cove Fort, Thermo	Per capita transfer payments	335	403	469	528	588	672	849	936	1019	1084	1176	1284	1462	1611	1719	1697
Beaver	Roosevelt, Cove Fort, Thermo	Per capita income maintenance	13	19	17	26	21	27	36	51	54	62	59	81	88	90	100	97
Beaver	Roosevelt, Cove Fort, Thermo	Per capita unemployment insurance benefits	17	17	21	23	17	22	84	53	44	35	42	44	46	74	73	44

County/Area Name	Geothermal Site(s)	Line Title	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Beaver	Roosevelt, Cove Fort, Thermo	Per capita retirement and other	305	367	431	479	550	623	729	832	921	986	1075	1159	1329	1447	1546	1556
Beaver	Roosevelt, Cove Fort, Thermo	Per capita dividends, interest, and rent	312	364	403	441	490	607	665	750	859	941	1118	1308	1492	1681	1923	2204
Beaver	Roosevelt, Cove Fort, Thermo	Earnings by place of work ($000)	7765	8364	9291	10558	11614	12430	11762	13868	15682	17125	18021	19113	20379	21797	24706	28318
Beaver	Roosevelt, Cove Fort, Thermo	Wage and salary disbursements	5278	5780	6565	7370	8020	8651	8381	9520	10832	11982	13025	14617	15521	15939	18760	20661
Beaver	Roosevelt, Cove Fort, Thermo	Other labor income	254	310	386	454	517	641	671	823	1045	1243	1359	1573	1641	1731	2252	2586
Beaver	Roosevelt, Cove Fort, Thermo	Proprietors' income	2233	2274	2340	2734	3077	3138	2710	3525	3805	3900	3637	2923	3217	4127	3694	5071
Beaver	Roosevelt, Cove Fort, Thermo	Nonfarm proprietors' income	1307	1284	1431	1578	1643	1834	2252	2836	3174	3366	3452	3580	3323	3346	3542	4384
Beaver	Roosevelt, Cove Fort, Thermo	Farm proprietors' income	926	990	909	1156	1434	1304	458	689	631	534	185	-657	-106	781	152	687
Beaver	Roosevelt, Cove Fort, Thermo	Total full-time and part-time employment	1781	1711	1779	1799	1800	1866	1808	1880	1939	1947	1874	1876	1906	1888	1984	2080
Beaver	Roosevelt, Cove Fort, Thermo	Wage and salary jobs	1238	1189	1259	1306	1317	1343	1284	1347	1383	1369	1268	1243	1277	1241	1309	1430
Beaver	Roosevelt, Cove Fort, Thermo	Number of proprietors	543	522	520	493	483	523	524	533	556	578	606	633	629	647	675	650
Beaver	Roosevelt, Cove Fort, Thermo	Number of nonfarm proprietors 5/	293	285	294	278	278	324	322	328	346	368	393	417	409	423	435	409
Beaver	Roosevelt, Cove Fort, Thermo	Number of farm proprietors	250	237	226	215	205	199	202	205	210	210	213	216	220	224	240	241
Beaver	Roosevelt, Cove Fort, Thermo	Average earnings per job (dollars)	4360	4888	5223	5869	6452	6661	6506	7377	8088	8796	9616	10188	10692	11545	12453	13614
Beaver	Roosevelt, Cove Fort, Thermo	Average wage and salary disbursements	4263	4861	5214	5643	6090	6442	6527	7068	7832	8752	10272	11759	12154	12844	14332	14448
Beaver	Roosevelt, Cove Fort, Thermo	Average nonfarm proprietors' income	4461	4505	4867	5676	5910	5660	6994	8646	9173	9147	8784	8585	8125	7910	8143	10719
Box Elder	Crystal-Madsen HS	Personal income (thousands of dollars)	88089	95061	102450	114118	125738	139763	146135	163561	179756	205156	236679	271516	307918	333428	366268	403079
Box Elder	Crystal-Madsen HS	Nonfarm personal income	78202	83578	91949	103285	109459	121927	136743	155640	175723	199259	230737	268135	308303	333042	366520	401367
Box Elder	Crystal-Madsen HS	Farm income	9887	11483	10501	10833	16279	17836	9392	7921	4033	5897	5942	3381	-385	386	-252	1712
Box Elder	Crystal-Madsen HS	Net earnings 1/	72760	76977	81471	90742	99969	110760	112744	126137	137745	157293	180508	201733	224607	239165	262426	289197
Box Elder	Crystal-Madsen HS	Transfer payments	5576	6826	8400	9445	10847	11960	14224	15704	17208	18915	20826	24804	29199	32733	34540	35774
Box Elder	Crystal-Madsen HS	Income maintenance 2/	361	514	782	1062	1068	907	1029	1306	1215	1288	1124	1767	2097	2403	2515	2541
Box Elder	Crystal-Madsen HS	Unemployment insurance benefit payments	324	493	703	593	761	893	1441	1479	1244	950	1111	1344	1479	2377	1603	848
Box Elder	Crystal-Madsen HS	Retirement and other	4891	5819	6915	7790	9018	10160	11754	12919	14749	16677	18591	21693	25623	27953	30422	32385
Box Elder	Crystal-Madsen HS	Dividends, interest, and rent	9753	11258	12579	13931	14922	17043	19167	21720	24803	28948	35345	44979	54112	61530	69302	78108
Box Elder	Crystal-Madsen HS	Population (number of persons) 3/	27600	28185	28535	29133	29228	29181	29623	30247	30844	31547	32441	33455	34313	34805	35223	35829
Box Elder	Crystal-Madsen HS	Per capita personal income	3192	3373	3590	3917	4302	4790	4933	5408	5828	6503	7296	8116	8974	9580	10399	11250
Box Elder	Crystal-Madsen HS	Per capita net earnings	2636	2731	2855	3115	3420	3796	3806	4170	4466	4986	5564	6030	6546	6872	7450	8072
Box Elder	Crystal-Madsen HS	Per capita transfer payments	202	242	294	324	371	410	480	519	558	600	642	741	851	940	981	998
Box Elder	Crystal-Madsen HS	Per capita income maintenance	13	18	27	36	37	31	35	43	39	41	35	53	61	69	71	71
Box Elder	Crystal-Madsen HS	Per capita unemployment insurance benefits	12	17	25	20	26	31	49	49	40	30	34	40	43	68	46	24
Box Elder	Crystal-Madsen HS	Per capita retirement and other	177	206	242	267	309	348	397	427	478	529	573	648	747	803	864	904
Box Elder	Crystal-Madsen HS	Per capita dividends, interest, and rent	353	399	441	478	511	584	647	718	804	918	1090	1344	1577	1768	1968	2180
Box Elder	Crystal-Madsen HS	Earnings by place of work ($000)	64574	69273	73625	85984	96279	107948	111354	125550	139193	161116	189260	212690	245880	268024	303532	341830
Box Elder	Crystal-Madsen HS	Wage and salary disbursements	47205	49876	53457	63516	67338	74995	83368	94791	107684	125516	150498	172591	204199	221643	250112	282493
Box Elder	Crystal-Madsen HS	Other labor income	3319	3753	4495	5760	6190	7676	9626	11649	14879	16885	19659	23682	29375	34074	38477	39407
Box Elder	Crystal-Madsen HS	Proprietors' income	14050	15644	15673	16708	22751	25277	18360	19110	16630	18715	19103	16417	12306	12307	14943	19930
Box Elder	Crystal-Madsen HS	Nonfarm proprietors' income	6323	6305	7258	7787	8816	10109	11731	14245	15801	17167	17658	17551	16977	16592	19525	22366
Box Elder	Crystal-Madsen HS	Farm proprietors' income	7727	9339	8415	8921	13935	15168	6629	4865	829	1548	1445	-1134	-4671	-4285	-4582	-2436
Box Elder	Crystal-Madsen HS	Total full-time and part-time employment	11072	11213	11017	11899	12134	12293	12500	12827	13370	14148	15064	15530	15935	15643	16259	17150
Box Elder	Crystal-Madsen HS	Wage and salary jobs	8285	8425	8417	9288	9580	9611	9801	10124	10684	11498	12297	12626	13066	12757	13267	14074
Box Elder	Crystal-Madsen HS	Number of proprietors	2787	2788	2600	2611	2554	2682	2699	2703	2686	2650	2767	2904	2869	2886	2992	3076
Box Elder	Crystal-Madsen HS	Number of nonfarm proprietors 5/	1329	1368	1205	1248	1219	1332	1422	1480	1499	1496	1626	1776	1730	1787	1819	1908
Box Elder	Crystal-Madsen HS	Number of farm proprietors	1458	1420	1395	1363	1335	1350	1277	1223	1187	1154	1141	1128	1139	1099	1173	1168
Box Elder	Crystal-Madsen HS	Average earnings per job (dollars)	5832	6178	6683	7226	7935	8781	8908	9788	10411	11388	12564	13695	15430	17134	18669	19932
Box Elder	Crystal-Madsen HS	Average wage and salary disbursements	5698	5920	6351	6839	7029	7803	8506	9363	10079	10916	12239	13669	15628	17374	18852	20072
Box Elder	Crystal-Madsen HS	Average nonfarm proprietors' income	4758	4609	6023	6240	7232	7589	8250	9625	10541	11475	10860	9882	9813	9285	10734	11722
Davis	Hooper HS	Personal income (thousands of dollars)	289316	317694	366188	402818	446382	511016	575002	666920	764347	889464	1027212	1177454	1344319	1486355	1624788	1819599

County/Area Name	Geothermal Site(s)	Line Title	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Davis	Hooper HS	Nonfarm personal income	286064	314479	362751	398506	441443	507407	572081	663243	761144	885551	1021227	1171317	1340187	1481994	1620556	1815395
Davis	Hooper HS	Farm income	3252	3215	3437	4312	4939	3609	2921	3677	3203	3913	5985	6137	4132	4361	4232	4204
Davis	Hooper HS	Net earnings 1/	245980	266019	305973	336018	370433	422889	471915	548579	629841	732709	832977	934022	1049711	1141472	1236369	1387461
Davis	Hooper HS	Transfer payments	14324	17201	20438	23149	27536	31474	39576	43862	49434	54160	64304	77190	91507	106509	114545	118630
Davis	Hooper HS	Income maintenance 2/	1086	1462	1617	1771	1974	2004	2334	2899	3152	2733	4036	5508	5930	6546	7427	7549
Davis	Hooper HS	Unemployment insurance benefit payments	962	1105	1452	1620	1711	2160	4424	3663	3416	3053	3708	5999	7220	9827	8891	4780
Davis	Hooper HS	Retirement and other	12276	14634	17369	19758	23851	27310	32818	37300	42866	48374	56560	65683	78357	90136	98227	106301
Davis	Hooper HS	Dividends, interest, and rent	29012	34474	39777	43651	48413	56653	63511	74479	85072	102595	129931	166242	203101	238374	273874	313508
Davis	Hooper HS	Population (number of persons) 3/	97000	99760	103665	105296	110035	112078	117173	120786	126880	133807	140324	147884	152924	158043	162239	165723
Davis	Hooper HS	Per capita personal income	2983	3185	3532	3826	4057	4559	4907	5522	6024	6647	7320	7962	8791	9405	10015	10980
Davis	Hooper HS	Per capita net earnings	2536	2667	2952	3191	3367	3773	4028	4542	4964	5476	5936	6316	6864	7223	7621	8372
Davis	Hooper HS	Per capita transfer payments	148	172	197	220	250	281	338	363	390	405	458	522	598	674	706	716
Davis	Hooper HS	Per capita income maintenance	11	15	16	17	18	18	20	24	25	20	29	37	39	41	46	46
Davis	Hooper HS	Per capita unemployment insurance benefits	10	11	14	15	16	19	38	30	27	23	26	41	47	62	55	29
Davis	Hooper HS	Per capita retirement and other	127	147	168	188	217	244	280	309	338	362	403	444	512	570	605	641
Davis	Hooper HS	Per capita dividends, interest, and rent	299	346	384	415	440	505	542	617	670	767	926	1124	1328	1508	1688	1892
Davis	Hooper HS	Earnings by place of work ($000)	296844	327971	395745	407227	435885	501528	554725	628546	708863	797573	886226	967311	1094266	1176837	1243184	1387182
Davis	Hooper HS	Wage and salary disbursements	257938	284309	335432	340070	362994	411137	442988	490149	541619	615802	679009	734024	833549	894840	934451	1026348
Davis	Hooper HS	Other labor income	19604	23489	36975	38861	41638	55995	72029	86572	108567	118854	138979	161359	189541	208059	222683	254122
Davis	Hooper HS	Proprietors' income	19302	20173	23338	28296	31253	34396	39708	51825	58677	62917	68238	71928	71176	73938	86050	106712
Davis	Hooper HS	Nonfarm proprietors' income	17117	18025	20953	24949	27469	32126	38097	49541	56883	60869	64323	68018	69286	72181	84330	105043
Davis	Hooper HS	Farm proprietors' income	2185	2148	2385	3347	3784	2270	1611	2284	1794	2048	3915	3910	1890	1757	1720	1669
Davis	Hooper HS	Total full-time and part-time employment	40762	41222	42601	44673	46079	47740	48746	50947	53916	56972	59584	59978	61778	62848	63953	68004
Davis	Hooper HS	Wage and salary jobs	36837	37239	38452	40189	41152	42285	42851	44339	46871	49659	51709	51370	52888	53497	54196	57479
Davis	Hooper HS	Number of proprietors	3925	3983	4149	4484	4927	5455	5895	6608	7045	7313	7875	8608	8890	9351	9757	10525
Davis	Hooper HS	Number of nonfarm proprietors 5/	3331	3411	3596	3950	4410	4936	5356	6050	6468	6719	7262	7976	8243	8684	9047	9822
Davis	Hooper HS	Number of farm proprietors	594	572	553	534	517	519	539	558	577	594	613	632	647	667	710	703
Davis	Hooper HS	Average earnings per job (dollars)	7282	7956	9290	9116	9460	10505	11380	12337	13148	13999	14874	16128	17713	18725	19439	20399
Davis	Hooper HS	Average wage and salary disbursements	7002	7635	8723	8462	8821	9723	10338	11055	11556	12401	13131	14289	15761	16727	17242	17856
Davis	Hooper HS	Average nonfarm proprietors' income	5139	5284	5827	6316	6229	6509	7113	8189	8795	9059	8857	8528	8405	8312	9321	10695
Iron	Newcastle	Personal income (thousands of dollars)	33299	34682	40061	44976	49989	55327	61433	71515	83237	94197	107497	119436	126260	137268	151499	168799
Iron	Newcastle	Nonfarm personal income	30234	32258	37626	41928	45844	51902	59526	68964	80265	92410	104626	117136	125040	136032	150839	166291
Iron	Newcastle	Farm income	3065	2424	2435	3048	4145	3425	1907	2551	2972	1787	2871	2300	1220	1236	660	2508
Iron	Newcastle	Net earnings 1/	26576	26687	30881	34491	37988	41224	44731	52331	61654	69114	76698	81019	83508	87357	95570	109086
Iron	Newcastle	Transfer payments	2526	3041	3614	4183	4855	5643	7292	8304	9139	10294	11944	15186	16971	18959	20381	20799
Iron	Newcastle	Income maintenance 2/	149	191	205	202	193	232	294	383	414	484	532	810	1043	1315	1665	1769
Iron	Newcastle	Unemployment insurance benefit payments	124	145	157	286	256	257	633	729	556	416	479	1281	1069	1568	1316	839
Iron	Newcastle	Retirement and other	2253	2705	3252	3695	4406	5154	6365	7192	8169	9394	10933	13095	14859	16076	17400	18191
Iron	Newcastle	Dividends, interest, and rent	4197	4954	5566	6302	7146	8460	9410	10880	12444	14789	18855	23231	25781	30952	35548	38914
Iron	Newcastle	Population (number of persons) 3/	11900	12314	12846	13236	13718	14110	14722	15172	15546	16244	16840	17429	17714	18294	18704	19273
Iron	Newcastle	Per capita personal income	2798	2816	3119	3398	3644	3921	4173	4714	5354	5799	6383	6853	7128	7503	8100	8758
Iron	Newcastle	Per capita net earnings	2233	2167	2404	2606	2769	2922	3038	3449	3966	4255	4555	4649	4714	4775	5110	5660
Iron	Newcastle	Per capita transfer payments	212	247	281	316	354	400	495	547	588	634	709	871	958	1036	1090	1079
Iron	Newcastle	Per capita income maintenance	13	16	16	15	14	16	20	25	27	30	32	46	59	72	89	92
Iron	Newcastle	Per capita unemployment insurance benefits	10	12	12	22	19	18	43	48	36	26	28	73	60	86	70	44
Iron	Newcastle	Per capita retirement and other	189	220	253	279	321	365	432	474	525	578	649	751	839	879	930	944
Iron	Newcastle	Per capita dividends, interest, and rent	353	402	433	476	521	600	639	717	800	910	1120	1333	1455	1692	1901	2019
Iron	Newcastle	Earnings by place of work ($000)	27548	27565	32050	35799	39530	43096	46843	54728	64635	72937	81103	85102	88972	92965	101602	115305

County/Area Name	Geothermal Site(s)	Line Title	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Iron	Newcastle	Wage and salary disbursements	19082	19889	23191	25245	27474	30646	34177	38682	44942	53510	60225	63936	69185	72903	79228	87130
Iron	Newcastle	Other labor income	1054	1221	1520	1775	2051	2498	3191	3998	5314	6436	7506	8228	8611	9323	10547	11368
Iron	Newcastle	Proprietors' income	7412	6455	7339	8779	10005	9952	9475	12048	14379	12991	13372	12938	11176	10739	11827	16807
Iron	Newcastle	Nonfarm proprietors' income	5022	4702	5560	6333	6598	7366	8458	10496	12470	12661	12066	12271	11569	11313	12915	16049
Iron	Newcastle	Farm proprietors' income	2390	1753	1779	2446	3407	2586	1017	1552	1909	330	1306	667	-393	-574	-1088	758
Iron	Newcastle	Total full-time and part-time employment	5170	5202	5571	5762	5939	6168	6449	6624	6854	7171	7434	7376	7456	7635	8022	8341
Iron	Newcastle	Wage and salary jobs	4039	4078	4440	4620	4781	4930	5144	5252	5474	5798	6022	5910	5973	6104	6423	6712
Iron	Newcastle	Number of proprietors	1131	1124	1131	1142	1158	1238	1305	1372	1380	1373	1412	1466	1483	1531	1599	1629
Iron	Newcastle	Number of nonfarm proprietors 5/	692	710	737	769	805	885	951	1016	1020	1009	1040	1087	1094	1137	1181	1216
Iron	Newcastle	Number of farm proprietors	439	414	394	373	353	353	354	356	360	364	372	379	389	394	418	413
Iron	Newcastle	Average earnings per job (dollars)	5328	5299	5753	6213	6656	6987	7264	8262	9430	10171	10910	11538	11933	12176	12665	13824
Iron	Newcastle	Average wage and salary disbursements	4724	4877	5223	5464	5746	6216	6644	7365	8210	9229	10001	10818	11583	11943	12335	12981
Iron	Newcastle	Average nonfarm proprietors' income	7257	6623	7544	8235	8196	8323	8894	10331	12225	12548	11602	11289	10575	9950	10936	13198
Juab	Drum Mountains	Personal income (thousands of dollars)	11254	12034	12906	14489	16461	18290	19517	22182	25914	28183	33945	38421	45539	43738	46390	52321
Juab	Drum Mountains	Nonfarm personal income	10181	10853	11919	13286	15040	17036	18679	20940	24201	27696	33501	37905	45031	43346	45994	51106
Juab	Drum Mountains	Farm income	1073	1181	987	1203	1421	1254	838	1242	1713	487	444	516	508	392	396	1215
Juab	Drum Mountains	Net earnings 1/	8809	9145	9586	10804	12143	13307	13722	15589	18340	19318	23343	25650	31182	25700	26582	31183
Juab	Drum Mountains	Transfer payments	1324	1624	1947	2187	2579	2916	3462	3705	4088	4644	5244	6342	6756	8505	9301	9080
Juab	Drum Mountains	Income maintenance 2/	131	157	183	165	165	231	249	286	283	295	281	428	385	433	539	540
Juab	Drum Mountains	Unemployment insurance benefit payments	71	130	197	196	161	191	253	213	236	231	238	485	307	1457	1456	757
Juab	Drum Mountains	Retirement and other	1122	1337	1567	1826	2253	2494	2960	3206	3569	4118	4725	5429	6064	6615	7306	7783
Juab	Drum Mountains	Dividends, interest, and rent	1121	1265	1373	1498	1739	2067	2333	2888	3486	4221	5358	6429	7601	9533	10507	12058
Juab	Drum Mountains	Population (number of persons) 3/	4500	4577	4645	4776	4922	4884	4972	5010	5144	5317	5442	5547	5607	5711	5863	6027
Juab	Drum Mountains	Per capita personal income	2501	2629	2778	3034	3344	3745	3925	4428	5038	5301	6238	6926	8122	7659	7912	8681
Juab	Drum Mountains	Per capita net earnings	1958	1998	2064	2262	2467	2725	2760	3112	3565	3633	4289	4624	5561	4500	4534	5174
Juab	Drum Mountains	Per capita transfer payments	294	355	419	458	524	597	696	740	795	873	964	1143	1205	1489	1586	1507
Juab	Drum Mountains	Per capita income maintenance	29	34	39	35	34	47	50	57	55	55	52	77	69	76	92	90
Juab	Drum Mountains	Per capita unemployment insurance benefits	16	28	42	41	33	39	51	43	46	43	44	87	55	255	248	126
Juab	Drum Mountains	Per capita retirement and other	249	292	337	382	458	511	595	640	694	774	868	979	1082	1158	1246	1291
Juab	Drum Mountains	Per capita dividends, interest, and rent	249	276	296	314	353	423	469	576	678	794	985	1159	1356	1669	1792	2001
Juab	Drum Mountains	Earnings by place of work ($000)	11382	11633	11947	12853	14157	15263	15186	16282	18456	18888	23849	26707	33985	24320	24021	26113
Juab	Drum Mountains	Wage and salary disbursements	8203	8297	8502	8735	9792	10784	10876	11207	12342	13596	17722	20570	27674	18698	17815	18986
Juab	Drum Mountains	Other labor income	552	570	643	664	773	920	999	1121	1302	1452	1935	2212	2777	2141	2174	2295
Juab	Drum Mountains	Proprietors' income	2627	2766	2802	3454	3592	3559	3311	3954	4812	3840	4192	3925	3534	3481	4032	4832
Juab	Drum Mountains	Nonfarm proprietors' income	1737	1758	1975	2390	2333	2473	2685	2980	3408	3791	4253	3972	3610	3783	4306	4291
Juab	Drum Mountains	Farm proprietors' income	890	1008	827	1064	1259	1086	626	974	1404	(L)	-61	(L)	-76	-302	-274	541
Juab	Drum Mountains	Total full-time and part-time employment	2215	2136	2092	2087	2144	2251	2200	2199	2312	2313	2350	2416	2579	2219	2166	2190
Juab	Drum Mountains	Wage and salary jobs	1723	1663	1639	1628	1682	1771	1707	1676	1775	1763	1797	1858	1987	1636	1569	1601
Juab	Drum Mountains	Number of proprietors	492	473	453	459	462	480	493	523	537	550	553	558	592	583	597	589
Juab	Drum Mountains	Number of nonfarm proprietors 5/	257	242	226	235	241	250	258	282	290	302	309	318	348	350	350	346
Juab	Drum Mountains	Number of farm proprietors	235	231	227	224	221	230	235	241	247	248	244	240	244	233	247	243
Juab	Drum Mountains	Average earnings per job (dollars)	5139	5446	5711	6159	6603	6781	6903	7404	7983	8166	10149	11054	13178	10960	11090	11924
Juab	Drum Mountains	Average wage and salary disbursements	4761	4989	5187	5365	5822	6089	6371	6687	6953	7712	9862	11071	13928	11429	11354	11859
Juab	Drum Mountains	Average nonfarm proprietors' income	6759	7264	8739	10170	9680	9892	10407	10567	11752	12553	13764	12491	10374	10809	12303	12402
Millard	Drum Mountains	Personal income (thousands of dollars)	18919	19952	22706	25752	29596	31683	31629	34793	36330	42273	48183	53151	59998	69695	95576	135586
Millard	Drum Mountains	Nonfarm personal income	15554	15458	17830	19200	20274	23538	26903	29234	31936	36011	41736	49046	57913	66809	92877	129923
Millard	Drum Mountains	Farm income	3365	4494	4876	6552	9322	8145	4726	5559	4394	6262	6447	4105	2085	2886	2699	5663
Millard	Drum Mountains	Net earnings 1/	14598	14986	17037	19302	22243	22983	21657	23390	23497	27472	30590	31575	34637	40024	61774	96436

County/Area Name	Geothermal Site(s)	Line Title	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Millard	Drum Mountains	Transfer payments	2034	2325	2684	3109	3602	4209	4863	5381	5708	6476	7165	8337	9424	11048	11910	12551
Millard	Drum Mountains	Income maintenance 2/	80	101	106	162	165	238	225	322	323	399	390	574	658	699	817	829
Millard	Drum Mountains	Unemployment insurance benefit payments	84	102	114	128	124	154	265	235	166	160	142	302	253	755	830	575
Millard	Drum Mountains	Retirement and other	1870	2122	2464	2819	3313	3817	4373	4824	5219	5917	6633	7461	8513	9594	10263	11147
Millard	Drum Mountains	Dividends, interest, and rent	2287	2641	2985	3341	3751	4491	5109	6022	7125	8325	10428	13239	15937	18623	21892	26599
Millard	Drum Mountains	Population (number of persons) 3/	7000	7026	7258	7555	7611	7625	7985	8230	8377	8450	8874	9080	9498	10166	11052	12554
Millard	Drum Mountains	Per capita personal income	2703	2840	3128	3409	3889	4155	3961	4228	4337	5003	5430	5854	6317	6856	8648	10800
Millard	Drum Mountains	Per capita net earnings	2085	2133	2347	2555	2922	3014	2712	2842	2805	3251	3447	3477	3647	3937	5589	7682
Millard	Drum Mountains	Per capita transfer payments	291	331	370	412	473	552	609	654	681	766	807	918	992	1087	1078	1000
Millard	Drum Mountains	Per capita income maintenance	11	14	15	21	22	31	28	39	39	47	44	63	69	69	74	66
Millard	Drum Mountains	Per capita unemployment insurance benefits	12	15	16	17	16	20	33	29	20	19	16	33	27	74	75	46
Millard	Drum Mountains	Per capita retirement and other	267	302	339	373	435	501	548	586	623	700	747	822	896	944	929	888
Millard	Drum Mountains	Per capita dividends, interest, and rent	327	376	411	442	493	589	640	732	851	985	1175	1458	1678	1832	1981	2119
Millard	Drum Mountains	Earnings by place of work ($000)	14751	15035	17262	19601	22587	23540	22511	24151	24307	28644	32307	33942	37303	43936	73995	120739
Millard	Drum Mountains	Wage and salary disbursements	8980	7937	9410	9650	9751	11314	13436	13915	15091	18017	20350	23445	27972	33249	59654	97475
Millard	Drum Mountains	Other labor income	440	462	587	647	723	958	1206	1350	1547	1871	2312	2887	3593	4063	6828	10695
Millard	Drum Mountains	Proprietors' income	5331	6636	7265	9304	12113	11268	7869	8886	7669	8756	9645	7610	5738	6624	7513	12569
Millard	Drum Mountains	Nonfarm proprietors' income	2769	2978	3242	3571	3852	4367	4883	5625	5987	6550	7085	7087	6743	6821	7672	9657
Millard	Drum Mountains	Farm proprietors' income	2562	3658	4023	5733	8261	6901	2986	3261	1682	2206	2560	523	-1005	-197	-159	2912
Millard	Drum Mountains	Total full-time and part-time employment	3555	3383	3529	3495	3358	3436	3620	3615	3662	3730	3680	3787	4021	4148	5226	6701
Millard	Drum Mountains	Wage and salary jobs	2176	2037	2203	2173	2121	2163	2374	2410	2415	2462	2424	2540	2734	2821	3869	5300
Millard	Drum Mountains	Number of proprietors	1379	1346	1326	1322	1237	1273	1246	1205	1247	1268	1256	1247	1287	1327	1357	1401
Millard	Drum Mountains	Number of nonfarm proprietors 5/	559	540	529	538	463	483	498	488	551	595	593	594	630	698	691	744
Millard	Drum Mountains	Number of farm proprietors	820	806	797	784	774	790	748	717	696	673	663	653	657	629	666	657
Millard	Drum Mountains	Average earnings per job (dollars)	4149	4444	4891	5608	6726	6851	6219	6681	6638	7679	8779	8963	9277	10592	14159	18018
Millard	Drum Mountains	Average wage and salary disbursements	4127	3896	4271	4441	4597	5231	5660	5774	6249	7318	8395	9230	10231	11786	15418	18392
Millard	Drum Mountains	Average nonfarm proprietors' income	4953	5515	6129	6638	8320	9041	9805	11527	10866	11008	11948	11931	10703	9772	11103	12980
Weber	Utah HS, Ogden HS	Personal income (thousands of dollars)	419352	467766	523430	553008	594785	652918	719274	807296	887383	1004774	1134418	1267559	1411706	1533666	1659758	1818560
Weber	Utah HS, Ogden HS	Nonfarm personal income	415393	463622	518909	547098	587020	649321	716612	804047	884981	1001747	1131494	1265815	1411237	1532621	1659132	1817059
Weber	Utah HS, Ogden HS	Farm income	3959	4144	4521	5910	7765	3597	2662	3249	2402	3027	2924	1744	469	1045	626	1501
Weber	Utah HS, Ogden HS	Net earnings 1/	337310	370496	411762	429218	455881	494840	539373	605016	661586	745286	827243	901828	982169	1042713	1109733	1225976
Weber	Utah HS, Ogden HS	Transfer payments	31995	39335	46669	52050	61424	69682	83215	90650	98514	109859	123094	143599	166152	187829	204876	205548
Weber	Utah HS, Ogden HS	Income maintenance 2/	3527	4807	5717	6474	7155	7689	7570	8377	8706	10171	11118	15102	16393	17304	20254	19302
Weber	Utah HS, Ogden HS	Unemployment insurance benefit payments	2087	2897	3790	3771	3989	4978	9531	9222	8300	6769	7626	9773	11265	16556	16551	9092
Weber	Utah HS, Ogden HS	Retirement and other	26381	31631	37162	41805	50280	57015	66114	73051	81508	92919	104350	118724	138494	153969	168071	177154
Weber	Utah HS, Ogden HS	Dividends, interest, and rent	50047	57935	64999	71740	77480	88396	96686	111630	127283	149629	184081	222132	263385	303124	345149	387036
Weber	Utah HS, Ogden HS	Population (number of persons) 3/	125500	126703	129153	132700	132016	134174	135455	137696	139002	140822	143225	145405	148229	150858	153305	154831
Weber	Utah HS, Ogden HS	Per capita personal income	3341	3692	4053	4167	4505	4866	5310	5863	6384	7135	7921	8717	9524	10166	10827	11745
Weber	Utah HS, Ogden HS	Per capita net earnings	2688	2924	3188	3234	3453	3688	3982	4394	4760	5292	5776	6202	6626	6912	7239	7918
Weber	Utah HS, Ogden HS	Per capita transfer payments	255	310	361	392	465	519	614	658	709	780	859	988	1121	1245	1336	1328
Weber	Utah HS, Ogden HS	Per capita income maintenance	28	38	44	49	54	57	56	61	63	72	78	104	111	115	132	125
Weber	Utah HS, Ogden HS	Per capita unemployment insurance benefits	17	23	29	28	30	37	70	67	60	48	53	67	76	110	108	59
Weber	Utah HS, Ogden HS	Per capita retirement and other	210	250	288	315	381	425	488	531	586	660	729	817	934	1021	1096	1144
Weber	Utah HS, Ogden HS	Per capita dividends, interest, and rent	399	457	503	541	587	659	714	811	916	1063	1285	1528	1777	2009	2251	2500
Weber	Utah HS, Ogden HS	Earnings by place of work ($000)	271961	293466	316323	340192	365994	391725	435437	499078	549126	627905	711071	782352	852924	904096	964478	1081069
Weber	Utah HS, Ogden HS	Wage and salary disbursements	226852	246517	261193	277940	298989	319377	348980	392348	426531	491584	560477	620898	683369	725609	764987	858130
Weber	Utah HS, Ogden HS	Other labor income	13156	15554	19895	21666	23183	28066	36157	44912	54620	62370	72472	85228	97936	107213	116158	126952
Weber	Utah HS, Ogden HS	Proprietors' income	31953	31395	35235	40586	43822	44282	50300	61818	67975	73951	78122	76226	71619	71274	83333	95987

County/Area Name	Geothermal Site(s)	Line Title	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Weber	Utah HS, Ogden HS	Nonfarm proprietors' income	28957	28208	31655	35537	37114	41912	48782	59728	66701	72362	76829	76270	72972	72399	84754	96482
Weber	Utah HS, Ogden HS	Farm proprietors' income	2996	3187	3580	5049	6708	2370	1518	2090	1274	1589	1293	(L)	-1353	-1125	-1421	-495
Weber	Utah HS, Ogden HS	Total full-time and part-time employment	47439	47599	47535	49009	49992	50720	51246	53308	54445	57359	59822	60822	61122	61452	62320	66424
Weber	Utah HS, Ogden HS	Wage and salary jobs	41879	41873	41674	42851	43298	43756	44077	45484	46350	49186	51495	52131	52471	52291	52919	56654
Weber	Utah HS, Ogden HS	Number of proprietors	5560	5726	5861	6158	6694	6964	7169	7824	8095	8173	8327	8691	8651	9161	9401	9770
Weber	Utah HS, Ogden HS	Number of nonfarm proprietors 5/	4903	5082	5226	5536	6081	6350	6497	7101	7324	7360	7481	7811	7746	8218	8397	8778
Weber	Utah HS, Ogden HS	Number of farm proprietors	657	644	635	622	613	614	672	723	771	813	846	880	905	943	1004	992
Weber	Utah HS, Ogden HS	Average earnings per job (dollars)	5733	6165	6655	6941	7321	7723	8497	9362	10086	10947	11886	12863	13954	14712	15476	16275
Weber	Utah HS, Ogden HS	Average wage and salary disbursements	5417	5887	6268	6486	6905	7299	7918	8626	9202	9994	10884	11910	13024	13876	14456	15147
Weber	Utah HS, Ogden HS	Average nonfarm proprietors' income	5906	5551	6057	6419	6103	6600	7508	8411	9107	9832	10270	9764	9421	8810	10093	10991

Source: Regional Economic Information System (REIS), U.S. Department of Commerce, Economics and Statistics Administration, Bureau of Economic Analysis

Appendix E: County Economic Profiles, 1985-2000 (Part 2)

County/Area Name	Geothermal Site(s)	Line Title	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
State of Utah Total	All	Personal income (thousands of dollars)	19462380	20367186	21208237	22224834	23842737	25938559	27749681	29788209	31950465	34578711	37278220	40354052	43695891	46771866	49148488	52532150
State of Utah Total	All	Nonfarm personal income	19400797	20275972	21085261	22017100	23641088	25692701	27525972	29526244	31641474	34366221	37116278	40192059	43511260	46536619	48906190	52318277
State of Utah Total	All	Farm income	61583	91214	122976	207734	201649	245858	223709	261965	308991	212490	161942	161993	184631	235247	242298	213873
State of Utah Total	All	Net earnings 1/	13647979	14186701	14799019	15686779	16723250	18305764	19625711	21301865	22951182	24869336	26778451	28999948	31422210	33802393	35965210	38442052
State of Utah Total	All	Transfer payments	1864706	2038776	2210780	2300466	2515027	2811912	3145696	3507806	3819046	3907690	4206303	4445237	4695143	4857465	5053197	5329154
State of Utah Total	All	Income maintenance 2/	146606	161093	172031	189101	212210	232577	268861	317561	335255	346800	372156	377285	395795	393364	396748	407578
State of Utah Total	All	Unemployment insurance benefit payments	90880	107549	104433	72506	62984	65138	83532	125815	115311	80726	70379	78072	81895	94618	103769	119195
State of Utah Total	All	Retirement and other	1627220	1770134	1934316	2038859	2239833	2514197	2793303	3064430	3368480	3480164	3763768	3989880	4217453	4369483	4552680	4802381
State of Utah Total	All	Dividends, interest, and rent	3949695	4141709	4198438	4237589	4604460	4820883	4978274	4978538	5180237	5801685	6293466	6908867	7578538	8112008	8130081	8760944
State of Utah Total	All	Population (number of persons) 3/	1642910	1662833	1678120	1689372	1705865	1731223	1779780	1836799	1898404	1960446	2014177	2067976	2119784	2165960	2203482	2241555
State of Utah Total	All	Per capita personal income	11846	12248	12638	13156	13977	14983	15592	16217	16830	17638	18508	19514	20613	21594	22305	23436
State of Utah Total	All	Per capita net earnings	8307	8532	8819	9286	9803	10574	11027	11597	12090	12686	13295	14023	14823	15606	16322	17150
State of Utah Total	All	Per capita transfer payments	1135	1226	1317	1362	1474	1624	1767	1910	2012	1993	2088	2150	2215	2243	2293	2377
State of Utah Total	All	Per capita income maintenance	89	97	103	112	124	134	151	173	177	177	185	182	187	182	180	182
State of Utah Total	All	Per capita unemployment insurance benefits	55	65	62	43	37	38	47	68	61	41	35	38	39	44	47	53
State of Utah Total	All	Per capita retirement and other	990	1065	1153	1207	1313	1452	1569	1668	1774	1775	1869	1929	1990	2017	2066	2142
State of Utah Total	All	Per capita dividends, interest, and rent	2404	2491	2502	2508	2699	2785	2797	2710	2729	2959	3125	3341	3575	3745	3690	3908
State of Utah Total	All	Earnings by place of work ($000)	14363975	14956180	15615284	16601314	17722796	19394299	20822512	22589636	24338474	26394365	28445169	30776565	33341511	35818914	38115200	40714426
State of Utah Total	All	Wage and salary disbursements	11442061	11855636	12344083	13168597	14083691	15277156	16392118	17706893	18846698	20504109	22469839	24498371	26653006	28613569	30463491	32670915
State of Utah Total	All	Other labor income	1584194	1648868	1747979	1823135	2000625	2236417	2509524	2779614	3022283	3230501	3280752	3382190	3320431	3523262	3661973	3852293
State of Utah Total	All	Proprietors' income	1337720	1451676	1523222	1609582	1638480	1880726	1920870	2103129	2469493	2659755	2694578	2896004	3368074	3682083	3989736	4191218
State of Utah Total	All	Nonfarm proprietors' income	1322398	1402555	1440904	1448728	1487765	1694980	1755930	1900573	2228349	2532437	2622062	2820982	3279036	3545348	3844398	4088276
State of Utah Total	All	Farm proprietors' income	15322	49121	82318	160854	150715	185746	164940	202556	241144	127318	72516	75022	89038	136735	145338	102942
State of Utah Total	All	Total full-time and part-time employment	792763	805392	835108	870184	903052	944622	967063	985619	1033804	1111548	1160232	1228442	1281882	1321435	1358714	1394198
State of Utah Total	All	Wage and salary jobs	667222	677082	686385	711736	743563	778448	798411	822026	861598	910656	960116	1010602	1052591	1083329	1111003	1138088
State of Utah Total	All	Number of proprietors	125541	128310	148723	158448	159489	166174	168652	163593	172206	200892	200116	217840	229291	238106	247711	256110
State of Utah Total	All	Number of nonfarm proprietors 5/	110609	113697	134483	144652	145847	152403	154835	149820	157209	186089	184868	202817	214246	222821	232006	240410
State of Utah Total	All	Number of farm proprietors	14932	14613	14240	13796	13642	13771	13817	13773	14997	14803	15248	15023	15045	15285	15705	15700
State of Utah Total	All	Average earnings per job (dollars)	18119	18570	18699	19078	19625	20531	21532	22919	23543	23746	24517	25053	26010	27106	28052	29203
State of Utah Total	All	Average wage and salary disbursements	17149	17510	17984	18502	18941	19625	20531	21541	21874	22516	23403	24241	25321	26413	27420	28707
State of Utah Total	All	Average nonfarm proprietors' income	11956	12336	10714	10015	10201	11122	11341	12686	14174	13609	14183	13909	15305	15911	16570	17005
Beaver	Roosevelt, Cove Fort, Thermo	Personal income (thousands of dollars)	50148	47596	49485	52882	55903	59556	63048	65353	72310	70839	74316	84288	92686	100830	110193	128549
Beaver	Roosevelt, Cove Fort, Thermo	Nonfarm personal income	49694	46449	45216	46544	50359	52958	58044	60044	65823	66222	70144	75696	80471	84573	87176	91463
Beaver	Roosevelt, Cove Fort, Thermo	Farm income	454	1147	4269	6338	5544	6598	5004	5309	6487	4617	4172	8592	12215	16257	23017	37086
Beaver	Roosevelt, Cove Fort, Thermo	Net earnings 1/	28396	25511	27397	30714	31722	34600	36886	37194	40045	41212	42241	50618	56813	63476	71888	87656
Beaver	Roosevelt, Cove Fort, Thermo	Transfer payments	8909	9206	9876	10422	11644	12629	13452	15998	16586	16782	18190	18956	19760	19726	20369	21612
Beaver	Roosevelt, Cove Fort, Thermo	Income maintenance 2/	423	544	558	633	728	873	751	1054	971	1124	1133	1323	1454	1333	1353	1435
Beaver	Roosevelt, Cove Fort, Thermo	Unemployment insurance benefit payments	448	256	247	182	150	148	183	279	284	181	183	270	283	272	229	283
Beaver	Roosevelt, Cove Fort, Thermo	Retirement and other	8038	8406	9071	9607	10766	11608	12518	14665	15331	15477	16874	17363	18023	18121	18787	19894
Beaver	Roosevelt, Cove Fort, Thermo	Dividends, interest, and rent	12843	12879	12212	11746	12537	12327	12710	12161	15679	12845	13885	14714	16113	17628	17936	19281
Beaver	Roosevelt, Cove Fort, Thermo	Population (number of persons) 3/	5087	4968	4876	4739	4726	4769	4798	4929	5001	5159	5394	5687	5851	5883	5978	6024
Beaver	Roosevelt, Cove Fort, Thermo	Per capita personal income	9858	9581	10149	11159	11829	12488	13140	13259	14459	13731	13778	14821	15841	17139	18433	21339
Beaver	Roosevelt, Cove Fort, Thermo	Per capita net earnings	5582	5135	5619	6481	6712	7255	7688	7546	8007	7988	7831	8901	9710	10790	12025	14551
Beaver	Roosevelt, Cove Fort, Thermo	Per capita transfer payments	1751	1853	2025	2199	2464	2648	2804	3246	3317	3253	3372	3333	3377	3353	3407	3588
Beaver	Roosevelt, Cove Fort, Thermo	Per capita income maintenance	83	110	114	134	154	183	157	214	194	218	210	233	249	227	226	238
Beaver	Roosevelt, Cove Fort, Thermo	Per capita unemployment insurance benefits	88	52	51	38	32	31	38	57	57	35	34	47	48	46	38	47
Beaver	Roosevelt, Cove Fort, Thermo	Per capita retirement and other	1580	1692	1860	2027	2278	2434	2609	2975	3066	3000	3128	3053	3080	3080	3143	3302
Beaver	Roosevelt, Cove Fort, Thermo	Per capita dividends, interest, and rent	2525	2592	2505	2479	2653	2585	2649	2467	3135	2490	2574	2587	2754	2996	3000	3201
Beaver	Roosevelt, Cove Fort, Thermo	Earnings by place of work ($000)	31539	27926	29753	33638	35841	38585	41616	41639	44551	46190	48230	57658	63739	70410	78803	94475
Beaver	Roosevelt, Cove Fort, Thermo	Wage and salary disbursements	24140	20057	19087	20659	23591	24288	27820	27374	28655	31854	35566	40196	43334	46322	47181	48939
Beaver	Roosevelt, Cove Fort, Thermo	Other labor income	3168	2956	3052	2984	3406	3737	4386	4497	4703	5094	5278	5801	6134	6666	6687	6977
Beaver	Roosevelt, Cove Fort, Thermo	Proprietors' income	4231	4913	7614	9995	8844	10560	9410	9768	11193	9242	7386	11661	14271	17422	24935	38559
Beaver	Roosevelt, Cove Fort, Thermo	Nonfarm proprietors' income	5021	4954	4546	4941	4599	5406	5740	5750	6833	8060	7596	8038	8274	7576	8222	8706

County/Area Name	Geothermal Site(s)	Line Title	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Beaver	Roosevelt, Cove Fort, Thermo	Farm proprietors' income	-790 (L)		3068	5054	4245	5154	3670	4018	4360	1182	-210	3623	5997	9846	16713	29853
Beaver	Roosevelt, Cove Fort, Thermo	Total full-time and part-time employment	2169	1936	1949	2028	2040	2123	2208	2213	2301	2591	2690	2968	3146	3140	3202	3279
Beaver	Roosevelt, Cove Fort, Thermo	Wage and salary jobs	1554	1361	1379	1421	1446	1480	1575	1577	1684	1822	1934	2140	2300	2247	2276	2328
Beaver	Roosevelt, Cove Fort, Thermo	Number of proprietors	615	575	570	607	594	643	633	636	617	769	756	828	846	893	926	951
Beaver	Roosevelt, Cove Fort, Thermo	Number of nonfarm proprietors 5/	373	335	336	379	367	413	401	405	372	532	517	595	617	660	687	712
Beaver	Roosevelt, Cove Fort, Thermo	Number of farm proprietors	242	240	234	228	227	230	232	231	245	237	239	233	229	233	239	239
Beaver	Roosevelt, Cove Fort, Thermo	Average earnings per job (dollars)	14541	14425	15266	16587	17569	18175	18848	18816	19362	17827	17929	19427	20260	22424	24611	28812
Beaver	Roosevelt, Cove Fort, Thermo	Average wage and salary disbursements	15534	14737	13841	14538	16315	16411	17663	17358	17016	17483	18390	18783	18841	20615	20730	21022
Beaver	Roosevelt, Cove Fort, Thermo	Average nonfarm proprietors' income	13461	14788	13530	13037	12531	13090	14314	14198	18368	15150	14692	13509	13410	11479	11968	12228
Box Elder	Crystal-Madsen HS	Personal income (thousands of dollars)	432649	461149	500624	515130	539625	556631	575118	616676	645666	670993	715955	779332	823607	855999	894346	956967
Box Elder	Crystal-Madsen HS	Nonfarm personal income	431459	454815	482020	490748	517768	529765	549476	583325	606480	643989	690652	753013	794659	828740	864123	934753
Box Elder	Crystal-Madsen HS	Farm income	1190	6334	18604	24382	21857	26866	25642	33351	39186	27004	25303	26319	28948	27259	30223	22214
Box Elder	Crystal-Madsen HS	Net earnings 1/	310926	330642	368186	383386	398005	410351	423680	460259	480243	497675	527986	571765	605804	628348	658786	701304
Box Elder	Crystal-Madsen HS	Transfer payments	38622	41873	44758	46156	49477	55266	59854	67148	74922	75923	82749	89870	95533	97458	102141	107852
Box Elder	Crystal-Madsen HS	Income maintenance 2/	2580	2847	2862	3081	3448	3597	3977	4755	5335	5486	5845	5875	6270	6453	6634	7027
Box Elder	Crystal-Madsen HS	Unemployment insurance benefit payments	1334	1094	1108	922	831	1017	1053	1931	2118	1439	1247	1320	1335	1617	1613	1934
Box Elder	Crystal-Madsen HS	Retirement and other	34708	37932	40788	42153	45198	50652	54824	60462	67469	68998	75657	82675	87928	89388	93894	98891
Box Elder	Crystal-Madsen HS	Dividends, interest, and rent	83101	88634	87680	85588	92143	91014	91584	89269	90501	97395	105220	117697	122270	130193	133419	147811
Box Elder	Crystal-Madsen HS	Population (number of persons) 3/	35948	36259	36562	36875	36542	36568	36864	37317	37882	38541	39077	39802	40751	41571	42378	42872
Box Elder	Crystal-Madsen HS	Per capita personal income	12035	12718	13692	13970	14767	15222	15601	16525	17044	17410	18322	19580	20211	20591	21104	22321
Box Elder	Crystal-Madsen HS	Per capita net earnings	8649	9119	10070	10397	10892	11222	11493	12334	12677	12913	13511	14365	14866	15115	15545	16358
Box Elder	Crystal-Madsen HS	Per capita transfer payments	1074	1155	1224	1252	1354	1511	1624	1799	1978	1970	2118	2258	2344	2344	2410	2516
Box Elder	Crystal-Madsen HS	Per capita income maintenance	72	79	78	84	94	98	108	127	141	142	150	148	154	155	157	164
Box Elder	Crystal-Madsen HS	Per capita unemployment insurance benefits	37	30	30	25	23	28	29	52	56	37	32	33	33	39	38	45
Box Elder	Crystal-Madsen HS	Per capita retirement and other	966	1046	1116	1143	1237	1385	1487	1620	1781	1790	1936	2077	2158	2150	2216	2307
Box Elder	Crystal-Madsen HS	Per capita dividends, interest, and rent	2312	2444	2398	2321	2522	2489	2484	2392	2389	2527	2693	2957	3000	3132	3148	3448
Box Elder	Crystal-Madsen HS	Earnings by place of work ($000)	378980	414655	480950	514435	531164	548881	562507	607965	623622	641112	666135	699107	729856	768043	740577	765200
Box Elder	Crystal-Madsen HS	Wage and salary disbursements	318326	344794	391680	417804	432200	439306	447577	474005	474386	496863	513197	540051	576130	614951	588107	615367
Box Elder	Crystal-Madsen HS	Other labor income	41555	45578	54547	56877	61829	65527	71929	80379	84509	85170	84231	77429	74250	81964	74483	77310
Box Elder	Crystal-Madsen HS	Proprietors' income	19099	24283	34723	39754	37135	44048	43001	53581	64727	59079	68707	81627	79476	71128	77987	72523
Box Elder	Crystal-Madsen HS	Nonfarm proprietors' income	21924	21541	19520	19409	19768	22588	22734	25752	32055	40503	52498	64387	60740	54391	58123	62136
Box Elder	Crystal-Madsen HS	Farm proprietors' income	-2825	2742	15203	20345	17367	21460	20267	27829	32672	18576	16209	17240	18736	16737	19864	10387
Box Elder	Crystal-Madsen HS	Total full-time and part-time employment	17937	18218	19635	20741	21000	20853	20940	20799	21003	22305	22693	23596	24751	25424	24915	24689
Box Elder	Crystal-Madsen HS	Wage and salary jobs	14818	15070	16185	17046	17285	17059	17092	17091	17188	17902	18165	18783	19714	20155	19480	19122
Box Elder	Crystal-Madsen HS	Number of proprietors	3119	3148	3450	3695	3715	3794	3848	3708	3815	4403	4528	4813	5037	5269	5435	5567
Box Elder	Crystal-Madsen HS	Number of nonfarm proprietors 5/	1953	2005	2338	2613	2636	2700	2744	2604	2603	3198	3279	3575	3788	4000	4132	4263
Box Elder	Crystal-Madsen HS	Number of farm proprietors	1166	1143	1112	1082	1079	1094	1104	1104	1212	1205	1249	1238	1249	1269	1303	1304
Box Elder	Crystal-Madsen HS	Average earnings per job (dollars)	21128	22761	24495	24803	25294	26321	26863	29230	29692	28743	29354	29628	29488	30209	29724	30994
Box Elder	Crystal-Madsen HS	Average wage and salary disbursements	21482	22879	24200	24510	25004	25752	26186	27734	27600	27755	28252	28752	29224	30511	30190	32181
Box Elder	Crystal-Madsen HS	Average nonfarm proprietors' income	11226	10744	8349	7428	7499	8366	8285	9889	12315	12665	16010	18010	16035	13598	14067	14576
Davis	Hooper HS	Personal income (thousands of dollars)	1991743	2105604	2205358	2337478	2539963	2832394	3025646	3210340	3419869	3670142	3957324	4280028	4712698	5056497	5381520	5790266
Davis	Hooper HS	Nonfarm personal income	1990283	2104312	2198073	2323832	2527298	2815629	3010400	3189604	3398571	3657389	3946499	4271653	4704202	5044962	5372961	5783863
Davis	Hooper HS	Farm income	1460	1292	7285	13646	12665	16765	15246	20736	21298	12753	10825	8375	8496	11535	8559	6403
Davis	Hooper HS	Net earnings 1/	1515426	1594006	1664108	1776063	1915199	2171705	2315978	2474218	2639789	2809132	3013727	3263771	3583701	3837938	4128798	4452568
Davis	Hooper HS	Transfer payments	132025	144223	158170	167593	187083	214882	239846	266468	292705	309582	334878	355639	385909	405311	428618	456734
Davis	Hooper HS	Income maintenance 2/	8489	8653	9949	11178	12560	15075	17989	21755	22594	24341	26128	25743	27672	27505	27187	27911
Davis	Hooper HS	Unemployment insurance benefit payments	6731	6163	6732	5203	4692	4971	6390	9722	8941	6302	5692	6222	6702	7511	8260	9507
Davis	Hooper HS	Retirement and other	116805	129407	141489	151212	169831	194836	215467	234991	261170	278939	303058	323674	351535	370295	393171	419316
Davis	Hooper HS	Dividends, interest, and rent	344292	367375	383080	393822	437681	445807	469822	469654	487375	551428	608719	660618	743088	813248	824104	880964
Davis	Hooper HS	Population (number of persons) 3/	169887	174267	179746	181733	185236	188841	193773	199199	204936	210164	214622	219687	224871	230937	235912	240259
Davis	Hooper HS	Per capita personal income	11724	12083	12269	12862	13712	14999	15614	16116	16687	17463	18439	19482	20957	21896	22812	24100
Davis	Hooper HS	Per capita net earnings	8920	9147	9258	9773	10339	11500	11952	12421	12881	13366	14042	14856	15937	16619	17501	18532
Davis	Hooper HS	Per capita transfer payments	777	828	880	922	1010	1138	1238	1338	1428	1473	1560	1619	1716	1755	1817	1901
Davis	Hooper HS	Per capita income maintenance	50	50	55	62	68	80	93	109	110	116	122	117	123	119	115	116
Davis	Hooper HS	Per capita unemployment insurance benefits	40	35	37	29	25	26	33	49	44	30	27	28	30	33	35	40

County/Area Name	Geothermal Site(s)	Line Title	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Davis	Hooper HS	Per capita retirement and other	688	743	787	832	917	1032	1112	1180	1274	1327	1412	1473	1563	1603	1667	1745
Davis	Hooper HS	Per capita dividends, interest, and rent	2027	2108	2131	2167	2363	2361	2425	2358	2378	2624	2836	3007	3305	3522	3493	3667
Davis	Hooper HS	Earnings by place of work ($000)	1514344	1569922	1569745	1649483	1789780	1916949	2026353	2103826	2216813	2318010	2496635	2614576	2809806	2990375	3179032	3470007
Davis	Hooper HS	Wage and salary disbursements	1132416	1179554	1169925	1234937	1343644	1435023	1509243	1562834	1643028	1732139	1896159	2008640	2126747	2261484	2406941	2636588
Davis	Hooper HS	Other labor income	275887	279116	280400	287810	317500	334864	356733	369154	375594	378412	392877	401370	413013	427345	446703	491240
Davis	Hooper HS	Proprietors' income	106041	111252	119420	126736	128636	147062	160377	171838	198191	207459	207599	204566	270046	301546	325388	342179
Davis	Hooper HS	Nonfarm proprietors' income	107173	112429	114641	116008	119160	134090	148857	154898	181325	200373	202839	202175	268239	296912	323610	343579
Davis	Hooper HS	Farm proprietors' income	-1132	-1177	4779	10728	9476	12972	11520	16940	16866	7086	4760	2391	1807	4634	1778	-1400
Davis	Hooper HS	Total full-time and part-time employment	71365	73535	75538	77868	81765	85921	86149	87139	90736	97566	99485	105344	110734	113682	116752	120350
Davis	Hooper HS	Wage and salary jobs	60219	61760	61384	62520	66204	69487	69562	71241	75148	77669	80123	84176	88098	89870	92079	94880
Davis	Hooper HS	Number of proprietors	11146	11775	14154	15348	15561	16434	16587	15898	15588	19897	19362	21168	22636	23812	24673	25470
Davis	Hooper HS	Number of nonfarm proprietors 5/	10447	11093	13492	14714	14941	15817	15976	15291	14942	19272	18730	20556	22034	23201	24045	24842
Davis	Hooper HS	Number of farm proprietors	699	682	662	634	620	617	611	607	646	625	632	612	602	611	628	628
Davis	Hooper HS	Average earnings per job (dollars)	21220	21349	20781	21183	21889	22311	23521	24143	24431	23758	25096	24819	25374	26305	27229	28833
Davis	Hooper HS	Average wage and salary disbursements	18805	19099	19059	19753	20296	20652	21696	21937	21864	22302	23666	23862	24141	25164	26140	27789
Davis	Hooper HS	Average nonfarm proprietors' income	10259	10135	8497	7884	7975	8478	9318	10130	12135	10397	10830	9835	12174	12797	13459	13831
Iron	Newcastle	Personal income (thousands of dollars)	175936	182259	188851	200246	224627	249388	262479	288034	317916	347590	377388	403954	465152	501265	518171	546902
Iron	Newcastle	Nonfarm personal income	174252	179683	184426	191983	216865	240368	255980	279913	305039	337112	371448	401420	452845	485467	504999	535023
Iron	Newcastle	Farm income	1684	2576	4425	8263	7762	9020	6499	8121	12877	10478	5940	2534	12307	15798	13172	11879
Iron	Newcastle	Net earnings 1/	111593	114135	119170	130001	145742	164814	168520	188591	212357	234446	254064	271598	316394	341058	356400	370901
Iron	Newcastle	Transfer payments	23019	25319	28158	30339	33956	39068	44826	50843	55240	56658	61651	65015	71575	76176	78919	86489
Iron	Newcastle	Income maintenance 2/	1923	2325	2328	2649	2926	3005	3601	4355	4857	5566	5736	5797	6435	6487	6341	6655
Iron	Newcastle	Unemployment insurance benefit payments	1143	983	960	634	577	644	784	889	984	726	663	836	876	1020	1076	1183
Iron	Newcastle	Retirement and other	19953	22011	24870	27056	30453	35419	40441	45599	49399	50366	55252	58382	64264	68669	71502	78651
Iron	Newcastle	Dividends, interest, and rent	41324	42805	41523	39906	44929	45506	49133	48600	50319	56486	61673	67341	77183	84031	82852	89512
Iron	Newcastle	Population (number of persons) 3/	19970	20057	20058	20123	20495	20927	21688	22626	24227	25791	27707	28981	30171	31653	32883	33960
Iron	Newcastle	Per capita personal income	8810	9087	9415	9951	10960	11917	12102	12730	13122	13477	13621	13939	15417	15836	15758	16104
Iron	Newcastle	Per capita net earnings	5588	5691	5941	6460	7111	7876	7770	8335	8765	9090	9170	9372	10487	10775	10838	10922
Iron	Newcastle	Per capita transfer payments	1153	1262	1404	1508	1657	1867	2067	2247	2280	2197	2225	2243	2372	2407	2400	2547
Iron	Newcastle	Per capita income maintenance	96	116	116	132	143	144	166	192	200	216	207	200	213	205	193	196
Iron	Newcastle	Per capita unemployment insurance benefits	57	49	48	32	28	31	36	39	41	28	24	29	29	32	33	35
Iron	Newcastle	Per capita retirement and other	999	1097	1240	1345	1486	1693	1865	2015	2039	1953	1994	2014	2130	2169	2174	2316
Iron	Newcastle	Per capita dividends, interest, and rent	2069	2134	2070	1983	2192	2175	2265	2148	2077	2190	2226	2324	2558	2655	2520	2636
Iron	Newcastle	Earnings by place of work ($000)	117116	119581	124891	135995	151863	171449	173471	196506	220017	241692	262948	280784	327492	351678	367736	381719
Iron	Newcastle	Wage and salary disbursements	89765	90282	93105	98949	113295	127451	129571	146040	159885	181426	206348	225160	250960	271371	286700	299604
Iron	Newcastle	Other labor income	11918	12432	13254	14106	16772	19758	21267	24618	27506	30639	32505	34546	35598	38814	40993	42109
Iron	Newcastle	Proprietors' income	15433	16867	18532	22940	21796	24240	22633	25848	32626	29627	24095	21078	40934	41493	40043	40006
Iron	Newcastle	Nonfarm proprietors' income	15538	15982	15807	16586	16059	17572	18398	19991	22704	23319	22966	23658	34671	31905	33005	35062
Iron	Newcastle	Farm proprietors' income	-105	885	2725	6354	5737	6668	4235	5857	9922	6308	1129	-2580	6263	9588	7038	4944
Iron	Newcastle	Total full-time and part-time employment	8367	8174	8638	9163	9676	10265	10461	11211	12159	13906	14774	15713	17084	17968	18497	19071
Iron	Newcastle	Wage and salary jobs	6738	6542	6837	7162	7766	8229	8425	9188	9930	10828	11816	12458	13520	14155	14516	14956
Iron	Newcastle	Number of proprietors	1629	1632	1801	2001	1910	2036	2036	2023	2229	3078	2958	3255	3564	3813	3981	4115
Iron	Newcastle	Number of nonfarm proprietors 5/	1217	1231	1413	1626	1539	1663	1662	1649	1824	2681	2552	2857	3171	3414	3571	3705
Iron	Newcastle	Number of farm proprietors	412	401	388	375	371	373	374	374	405	397	406	398	393	399	410	410
Iron	Newcastle	Average earnings per job (dollars)	13997	14629	14458	14842	15695	16702	16583	17528	18095	17380	17798	17870	19170	19572	19881	20016
Iron	Newcastle	Average wage and salary disbursements	13322	13800	13618	13816	14589	15488	15379	15895	16101	16755	17463	18074	18562	19171	19751	20032
Iron	Newcastle	Average nonfarm proprietors' income	12767	12983	11187	10200	10435	10566	11070	12123	12447	8698	8999	8281	10934	9345	9243	9463
Juab	Drum Mountains	Personal income (thousands of dollars)	53411	53697	54056	58760	62138	67872	73777	78992	84289	87756	93348	101254	107048	118432	121570	125979
Juab	Drum Mountains	Nonfarm personal income	53144	52937	51679	55047	58303	63779	70769	75287	79675	85159	91344	100234	106610	114246	117249	124638
Juab	Drum Mountains	Farm income	267	760	2377	3713	3835	4093	3008	3705	4614	2597	2004	1020	438	4186	4321	1341
Juab	Drum Mountains	Net earnings 1/	32369	31438	31857	37373	38970	43147	47365	52095	54982	56968	59943	65032	68166	78003	80177	82195
Juab	Drum Mountains	Transfer payments	8895	9898	10761	10848	11560	13133	14676	15839	18210	18538	19676	21111	22541	22930	23933	24761
Juab	Drum Mountains	Income maintenance 2/	437	495	531	584	617	675	803	1004	1137	1153	1380	1517	1718	1646	1646	1626
Juab	Drum Mountains	Unemployment insurance benefit payments	621	993	859	490	346	330	472	922	840	488	454	421	454	543	655	631
Juab	Drum Mountains	Retirement and other	7837	8410	9371	9774	10597	12128	13401	13913	16233	16897	17842	19173	20369	20741	21632	22504

County/Area Name	Geothermal Site(s)	Line Title	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Juab	Drum Mountains	Dividends, interest, and rent	12147	12361	11438	10539	11608	11592	11736	11058	11097	12250	13729	15111	16341	17499	17460	19023
Juab	Drum Mountains	Population (number of persons) 3/	6245	6196	5950	5742	5798	5820	5911	5978	6141	6477	6813	7213	7460	7832	8076	8285
Juab	Drum Mountains	Per capita personal income	8553	8666	9085	10233	10717	11662	12481	13214	13726	13549	13701	14038	14350	15122	15053	15206
Juab	Drum Mountains	Per capita net earnings	5183	5074	5354	6509	6721	7414	8013	8714	8953	8795	8798	9016	9138	9960	9928	9921
Juab	Drum Mountains	Per capita transfer payments	1424	1597	1809	1889	1994	2257	2483	2650	2965	2862	2888	2927	3022	2928	2963	2989
Juab	Drum Mountains	Per capita income maintenance	70	80	89	102	106	116	136	168	185	178	203	210	230	210	204	196
Juab	Drum Mountains	Per capita unemployment insurance benefits	99	160	144	85	60	57	80	154	137	75	67	58	61	69	81	76
Juab	Drum Mountains	Per capita retirement and other	1255	1357	1575	1702	1828	2084	2267	2327	2643	2609	2619	2658	2730	2648	2679	2716
Juab	Drum Mountains	Per capita dividends, interest, and rent	1945	1995	1922	1835	2002	1992	1985	1850	1807	1891	2015	2095	2190	2234	2162	2296
Juab	Drum Mountains	Earnings by place of work ($000)	25457	23869	25459	31560	32974	35803	42827	45070	46946	48710	50892	55778	59423	69306	71993	74170
Juab	Drum Mountains	Wage and salary disbursements	19689	18255	18877	21810	23790	25679	32190	33251	33747	36458	38576	43660	47199	51384	53275	57739
Juab	Drum Mountains	Other labor income	2387	2304	2519	2879	3251	3646	4604	5087	5310	5641	5595	6160	6448	6824	6783	7092
Juab	Drum Mountains	Proprietors' income	3381	3310	4063	6871	5933	6478	6033	6732	7889	6611	6721	5958	5776	11098	11935	9339
Juab	Drum Mountains	Nonfarm proprietors' income	3794	3197	2341	3906	2899	3321	3933	3947	4218	5070	5694	5767	6122	7718	8408	8910
Juab	Drum Mountains	Farm proprietors' income	-413	113	1722	2965	3034	3157	2100	2785	3671	1541	1027	191	-346	3380	3527	429
Juab	Drum Mountains	Total full-time and part-time employment	2161	2116	2126	2285	2320	2500	2700	2726	2833	3045	3125	3338	3412	3585	3625	3685
Juab	Drum Mountains	Wage and salary jobs	1587	1554	1545	1688	1756	1884	2054	2076	2172	2259	2304	2445	2494	2608	2623	2667
Juab	Drum Mountains	Number of proprietors	574	562	581	597	564	616	646	650	661	786	821	893	918	977	1002	1018
Juab	Drum Mountains	Number of nonfarm proprietors 5/	333	327	355	379	349	401	431	438	425	551	575	648	671	727	745	761
Juab	Drum Mountains	Number of farm proprietors	241	235	226	218	215	215	215	212	236	235	246	245	247	250	257	257
Juab	Drum Mountains	Average earnings per job (dollars)	11780	11280	11975	13812	14213	14321	15862	16533	16571	15997	16285	16710	17416	19332	19860	20128
Juab	Drum Mountains	Average wage and salary disbursements	12406	11747	12218	12921	13548	13630	15672	16017	15537	16139	16743	17857	18925	19702	20311	21649
Juab	Drum Mountains	Average nonfarm proprietors' income	11393	9777	6594	10306	8307	8282	9125	9011	9925	9201	9903	8900	9124	10616	11286	11708
Millard	Drum Mountains	Personal income (thousands of dollars)	165616	147368	128703	132753	139313	152603	161868	157281	170791	167111	167419	180858	185875	203345	206461	209576
Millard	Drum Mountains	Nonfarm personal income	164354	141788	118836	115870	120631	128456	138852	136770	142965	151125	155445	164960	171413	177826	180524	191742
Millard	Drum Mountains	Farm income	1262	5580	9867	16883	18682	24147	23016	20511	27826	15986	11974	15898	14462	25519	25937	17834
Millard	Drum Mountains	Net earnings 1/	122096	102923	86024	91217	94892	106383	113905	107986	118691	112111	108050	117553	119043	134189	137471	135785
Millard	Drum Mountains	Transfer payments	13914	15297	16167	16172	17094	19293	21370	24018	27311	28387	30858	32738	33341	34184	35153	36779
Millard	Drum Mountains	Income maintenance 2/	707	917	911	977	1082	1285	1530	1981	2194	2695	3044	3202	3291	3182	3141	3147
Millard	Drum Mountains	Unemployment insurance benefit payments	920	1204	1001	625	508	471	616	999	921	589	548	535	548	642	638	725
Millard	Drum Mountains	Retirement and other	12287	13176	14255	14570	15504	17537	19224	21038	24196	25103	27266	29001	29502	30360	31374	32907
Millard	Drum Mountains	Dividends, interest, and rent	29606	29148	26512	25364	27327	26927	26593	25277	24789	26613	28511	30567	33491	34972	33837	37012
Millard	Drum Mountains	Population (number of persons) 3/	13626	13518	12399	11759	11508	11310	11471	11571	11783	11932	12167	12187	12284	12295	12416	12416
Millard	Drum Mountains	Per capita personal income	12154	10902	10380	11289	12106	13493	14111	13593	14495	14005	13760	14840	15131	16539	16629	16880
Millard	Drum Mountains	Per capita net earnings	8961	7614	6938	7757	8246	9406	9930	9332	10073	9396	8881	9646	9691	10914	11072	10936
Millard	Drum Mountains	Per capita transfer payments	1021	1132	1304	1375	1485	1706	1863	2076	2318	2379	2536	2686	2714	2780	2831	2962
Millard	Drum Mountains	Per capita income maintenance	52	68	73	83	94	114	133	171	186	226	250	263	268	259	253	253
Millard	Drum Mountains	Per capita unemployment insurance benefits	68	89	81	53	44	42	54	86	78	49	45	44	45	52	51	58
Millard	Drum Mountains	Per capita retirement and other	902	975	1150	1239	1347	1551	1676	1818	2053	2104	2241	2380	2402	2469	2527	2650
Millard	Drum Mountains	Per capita dividends, interest, and rent	2173	2156	2138	2157	2375	2381	2318	2185	2104	2230	2343	2508	2726	2844	2725	2981
Millard	Drum Mountains	Earnings by place of work ($000)	158347	127088	99785	104237	108816	122264	132779	122343	133489	127244	123050	133346	133734	148206	151418	150454
Millard	Drum Mountains	Wage and salary disbursements	133853	99970	71211	70341	73602	80054	90197	82006	84121	89490	90988	96396	97076	98745	100143	106467
Millard	Drum Mountains	Other labor income	15152	12717	9979	9542	10085	11443	13462	12943	13843	14491	13653	13957	13530	13965	13961	14616
Millard	Drum Mountains	Proprietors' income	9342	14401	18595	24354	25129	30767	29120	27394	35525	23263	18409	22993	23128	35496	37314	29371
Millard	Drum Mountains	Nonfarm proprietors' income	10735	11191	10957	10550	10241	11557	11292	12524	13850	14673	13802	13928	15804	17328	18619	19801
Millard	Drum Mountains	Farm proprietors' income	-1393	3210	7638	13804	14888	19210	17828	14870	21675	8590	4607	9065	7324	18168	18695	9570
Millard	Drum Mountains	Total full-time and part-time employment	7644	6484	5573	5408	5351	5571	5509	5415	5445	5799	5728	6028	6249	6196	6266	6233
Millard	Drum Mountains	Wage and salary jobs	6210	5028	3956	3778	3809	4023	4003	3930	3956	4086	4037	4208	4294	4201	4219	4147
Millard	Drum Mountains	Number of proprietors	1434	1456	1617	1630	1542	1548	1506	1485	1489	1713	1691	1820	1955	1995	2047	2086
Millard	Drum Mountains	Number of nonfarm proprietors 5/	782	822	1000	1033	952	951	906	885	824	1045	993	1123	1250	1279	1311	1350
Millard	Drum Mountains	Number of farm proprietors	652	634	617	597	590	597	600	600	665	668	698	697	705	716	736	736
Millard	Drum Mountains	Average earnings per job (dollars)	20715	19600	17905	19275	20336	21947	24102	22593	24516	21942	21482	22121	21401	23920	24165	24138
Millard	Drum Mountains	Average wage and salary disbursements	21554	19883	18001	18619	19323	19899	22532	20867	21264	21902	22539	22908	22607	23505	23736	25673
Millard	Drum Mountains	Average nonfarm proprietors' income	13728	13614	10957	10213	10757	12152	12464	14151	16808	14041	13899	12402	12643	13548	14202	14667
Weber	Utah HS, Ogden HS	Personal income (thousands of dollars)	1979621	2072003	2114558	2190755	2320952	2562783	2720462	2878273	3018807	3203297	3410810	3633060	3843310	4078260	4218755	4489107

County/Area Name	Geothermal Site(s)	Line Title	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Weber	Utah HS, Ogden HS	Nonfarm personal income	1977919	2069088	2108949	2181870	2312653	2550961	2711510	2868226	3006527	3193498	3407021	3629143	3841440	4073480	4215148	4488366
Weber	Utah HS, Ogden HS	Farm income	1702	2915	5609	8885	8299	11822	8952	10047	12280	9799	3789	3917	1870	4780	3607	741
Weber	Utah HS, Ogden HS	Net earnings 1/	1338546	1396093	1429391	1488687	1572513	1756591	1864634	1981671	2073588	2180070	2327703	2470853	2616177	2793569	2946045	3144221
Weber	Utah HS, Ogden HS	Transfer payments	220989	236406	243766	257166	275690	305902	337122	376564	411975	415608	440039	464804	485824	496404	514897	535686
Weber	Utah HS, Ogden HS	Income maintenance 2/	20488	21101	22038	24015	27016	29797	34411	39468	42450	44026	46385	45584	47039	46395	46430	47010
Weber	Utah HS, Ogden HS	Unemployment insurance benefit payments	10550	9966	10709	8530	7521	8387	10240	18280	16874	11294	9640	11248	11370	12729	12756	15134
Weber	Utah HS, Ogden HS	Retirement and other	189951	205339	211019	224621	241153	267718	292471	318816	352651	360288	384014	407972	427415	437280	455711	473542
Weber	Utah HS, Ogden HS	Dividends, interest, and rent	420086	439504	441401	444902	472749	500290	518706	520038	533244	607619	643068	697403	741309	788287	757813	809200
Weber	Utah HS, Ogden HS	Population (number of persons) 3/	156087	156913	157605	157228	157847	158860	162186	166479	171055	176032	180546	184584	188334	190846	193697	197264
Weber	Utah HS, Ogden HS	Per capita personal income	12683	13205	13417	13934	14704	16132	16774	17289	17648	18197	18892	19682	20407	21369	21780	22757
Weber	Utah HS, Ogden HS	Per capita net earnings	8576	8897	9069	9468	9962	11057	11497	11903	12122	12385	12893	13386	13891	14638	15210	15939
Weber	Utah HS, Ogden HS	Per capita transfer payments	1416	1507	1547	1636	1747	1926	2079	2262	2408	2361	2437	2518	2580	2601	2658	2716
Weber	Utah HS, Ogden HS	Per capita income maintenance	131	134	140	153	171	188	212	237	248	250	257	247	250	243	240	238
Weber	Utah HS, Ogden HS	Per capita unemployment insurance benefits	68	64	68	54	48	53	63	110	99	64	53	61	60	67	66	77
Weber	Utah HS, Ogden HS	Per capita retirement and other	1217	1309	1339	1429	1528	1685	1803	1915	2062	2047	2127	2210	2269	2291	2353	2401
Weber	Utah HS, Ogden HS	Per capita dividends, interest, and rent	2691	2801	2801	2830	2995	3149	3198	3124	3117	3452	3562	3778	3936	4130	3912	4102
Weber	Utah HS, Ogden HS	Earnings by place of work ($000)	1199647	1270454	1312667	1382911	1460732	1601302	1730190	1877112	1988653	2113483	2254471	2479411	2655138	2781313	2948589	3024872
Weber	Utah HS, Ogden HS	Wage and salary disbursements	955137	1014284	1047611	1108466	1169344	1266616	1357428	1467884	1544107	1653371	1782283	1991035	2160388	2262064	2396578	2458289
Weber	Utah HS, Ogden HS	Other labor income	144521	154246	164039	173181	190824	216875	245578	276189	296428	306448	310202	317426	310882	317429	335135	339648
Weber	Utah HS, Ogden HS	Proprietors' income	99989	101924	101017	101264	100564	117811	127184	133039	148118	153664	161986	170950	183868	201820	216876	226935
Weber	Utah HS, Ogden HS	Nonfarm proprietors' income	100270	100830	97195	94478	94590	108766	120985	125782	138896	147534	161919	170507	185683	200844	217003	230503
Weber	Utah HS, Ogden HS	Farm proprietors' income	-281	1094	3822	6786	5974	9045	6199	7257	9222	6130	67	443	-1815	976	-127	-3568
Weber	Utah HS, Ogden HS	Total full-time and part-time employment	70802	73292	75635	78519	80483	82696	84168	85224	86655	93380	97698	104422	108241	108580	111097	111863
Weber	Utah HS, Ogden HS	Wage and salary jobs	60821	63102	63769	65772	67874	69765	71079	72653	74173	77513	82275	87852	91288	91173	93052	93245
Weber	Utah HS, Ogden HS	Number of proprietors	9981	10190	11866	12747	12609	12931	13089	12571	12482	15867	15423	16570	16953	17407	18045	18618
Weber	Utah HS, Ogden HS	Number of nonfarm proprietors 5/	8995	9230	10933	11827	11681	11978	12114	11579	11409	14816	14347	15516	15906	16344	16952	17526
Weber	Utah HS, Ogden HS	Number of farm proprietors	986	960	933	920	928	953	975	992	1073	1051	1076	1054	1047	1063	1093	1092
Weber	Utah HS, Ogden HS	Average earnings per job (dollars)	16944	17334	17355	17612	18150	19364	20556	22026	22949	22633	23076	23744	24530	25615	26541	27041
Weber	Utah HS, Ogden HS	Average wage and salary disbursements	15704	16074	16428	16853	17228	18155	19097	20204	20818	21330	21663	22664	23666	24811	25755	26364
Weber	Utah HS, Ogden HS	Average nonfarm proprietors' income	11147	10924	8890	7988	8098	9080	9987	10863	12174	9958	11286	10989	11674	12289	12801	13152

Source: Regional Economic Information System (REIS), U.S. Department of Commerce, Economics and Statistics Administration, Bureau of Economic Analysis

Footnotes for Table CA30 Regional Economic Profiles

1. Total earnings less personal contributions for social insurance adjusted to place of residence.
2. Consists largely of supplemental security income payments, family assistance, general assistance payments, food stamp payments, and other assistance payments, including emergency assistance.
3. Census Bureau midyear population estimates.
4. Type of income divided by population yields a per capita measure for that type of income.
5. Excludes limited partners.

(L) Less than $50,000 or less than 10 jobs, as appropriate, but the estimates for this item are included in the totals.
(N) Data not available for this year.

TERRESTRIAL HEAT FLOW IN UTAH

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ABSTRACT

New heat flow determinations have been made at 88 sites in Utah using information from oil and gas wells. These sites fill many gaps in the previous heat flow coverage and allow us to better delineate the thermal transition between the Colorado Plateau and the Basin and Range provinces in central Utah.

A thermal relaxation method for correcting oil well bottom hole temperatures (BHTs) was applied to 511 BHTs from 181 wells grouped into 88 sites. Depth to the corrected temperatures ranges from 1 to 5 km. At these depths, the thermal field is minimally affected by surface perturbations caused by topographic relief, microclimate, or near surface (< 500m) hydrologic effects. Fifty-seven new and nearly 2,000 previously determined thermal conductivity values were used with lithologic well logs and regional stratigraphic studies to estimate the thermal conductivity structure for each borehole. Heat flow was determined by calculating a one-dimensional, steady-state geotherm that accounts for volumetric heat production and that minimizes the difference between corrected BHTs and calculated formation temperatures. Errors in heat flow determinations were calculated for clusters of boreholes in the Colorado Plateau and Basin and Range provinces using a Monte Carlo analysis. The probable error of the heat flow was typically 15 percent in the Colorado Plateau compared to 12 percent in the Basin and Range, the primary source of error being the generalizations necessary in prescribing the thermal properties of each borehole.

Previous heat flow studies have determined the mean heat flow for the Basin and Range to be 107 *m*W $^{-2}$ (standard error of mean (SEM) 8 *m*W $^{-2}$) and the mean heat flow for the Colorado Plateau to be 59 *m*W $^{-2}$ (SEM 4 *m*W $^{-2}$). Corresponding mean heat flow values for the new sites are 91 *m*W $^{-2}$ (SEM 8 *m*W $^{-2}$)in the Basin and Range and 62 *m*W $^{-2}$ (SEM 2 *m*W $^{-2}$) in the Colorado Plateau. The lateral heat flow gradient from the interior Colorado Plateau to the interior Basin and Range is about 0.3 *m*W $^{-2}$ km $^{-1}$. With the addition of these new data, the 75 *m*W $^{-2}$ contour, which marks the thermal boundary between the Colorado Plateau and Basin and Range, is shifted only slightly but located with greater confidence.

INTRODUCTION

Heat flow studies are critical to understanding many basic geological and geophysical phenomena. The large scale processes that shape the earth leave thermal signatures that may prove crucial to deeper understanding of processes like plate tectonics and crustal magmatism. Heat flow also provides information on the maturation of hydrocarbons, groundwater flow, and displacement rates on faults.

The tectonic evolution of the Colorado Plateau (CP), Basin and Range (B&R), and the Transition Zone (TZ) between them has long been associated with various thermal processes. Explanations for the uplift history of the CP include different modes of plateau uplift, including thermal expansion of the lithosphere due to mantle plumes, subducted ridges and shear heating effects (McGetchin, 1979; McGetchin and others, 1980). McGetchin (1979) also discusses other mechanisms of uplift, such as volumetric expansion due to partial melting, density changes due to dehydration, introduction of volatiles, and density reduction due to iron depletion. Wilson (1973) examined mantle plumes and hotspots and their role in plate tectonics on a global scale, paying special attention to the possibility of the CP uplift being the result of a mantle plume. Anderson and Perkins (1975) examined the irregular patterns seen in the magmatic activity of the CP and attributed them to eddy currents in the large magmatic plume to which the uplift is attributed. Bird (1979) examined the possibility of delamination of the mantle portion of the lithosphere beneath the CP, subsequent replacement of the delaminated section with low density asthenospheric material, causing the observed uplift. Sbar and Sykes (1973) examined the current state of stress fields in the CP and speculated on the tectonic driving forces that would produce them. Thompson and Zoback (1979) studied the idea of lithosphere thinning below the CP due to assimilation of the Farallon plate. Keller and others (1979) examined different seismic velocities and correlated the higher velocities with lower heat flow and vice-versa. The current geological and geophysical state of the CP is summarized in Hunt (1956), Thompson and Zoback (1979), and Stokes (1986).

Many studies have examined the B&R and different aspects of its formation. Lachenbruch (1978) proposed that the high heat flow seen in the B&R could be due to differential strain rates on regional and local scales, and that anomalous conductive heat flow was not necessary to produce the observed heat flow. Hamilton (1987) examined the differing nature of extension at varying depths within the B&R. The upper crust deforms brittle, the middle deforms through ductile discontinuous shear and the bottom of the crust deforms ductile. Lachenbruch and others (1994) reported mean heat flow values in the northern B&R of 92 ±9 mW^{-2} and mean heat flow in the southern B&R of 82 ±3 mW^{-2}. Lachenbruch and others (1994) also showed that either delamination or magmatic additions could produce the observed results. Klemperer and others (1986) determined that the Moho of the B&R was at a depth of 9-11 s (two-way travel time). Catchings and Mooney (1991) examined velocity contrasts in the B&R of Nevada and concluded that there was a thicker crust in the B&R of 30-35 km thick, up from 22-30 km; that estimate was due to misinterpretation of the Moho in the B&R. Ehlers and Chapman (1999) examined conductive and hydrothermal heat transfer surrounding the Wasatch Fault. Eaton (1982) gives a thorough examination of the geophysical state of the B&R.

Studies of the TZ geology include general regional geology and geomorphology by Hunt (1956) and Stokes (1986). Smith (1978) examined the differences in the crustal thickness between the CP and B&R. Seismic data from the TZ were studied by Loeb (1986) and Pechmann and others (1992) to examine subsurface structures that effect seismic velocities. Wong and Humphrey (1989) defined the state of stress in the CP and TZ. Changes in the stresses in the upper crust of the TZ were examined by Thompson and Zoback (1979), and Zoback and Zoback (1980). Lowry and Smith (1995) determined the effective elastic thickness across the TZ and correlated it to different geophysical characteristics, like heat flow, lithosphereic age, seismic properties, stress orientations, and earthquake focal depths. The TZ plays a crucial role in the geology of Utah because it forms the tectonically active hinge line between the B&R to the west and the CP to the east (Hunt, 1956). Therefore, a better understanding of the thermal state of the TZ will provide greater insight into the tectonic processes that control it.

The thermal state of the B&R, CP and TZ (figure 1) have been the subject of several regional heat flow studies conducted in Utah. These studies include two different methodologies, the shallow borehole or classical method, and the oil and gas well BHT method. The classical method uses high resolution temperature data in relatively shallow holes (< 500 meters) and a tightly constrained thermal conductivity profile. Previous classical heat flow studies in Utah include Roy and others (1968), Sass and others (1971a), Costain and Wright (1973) at various sites around Utah; Reiter and others (1979) in the Four Corners area of the CP;

and Chapman and others (1981) and Clement (1981) in the Escalante Desert, Bodell (1981) and Bodell and Chapman (1982) in the north-central CP; Carrier and Chapman (1981) in southwestern Utah; Bauer (1984) and Bauer and Chapman (1986) at the Stillwater dam site; Powell and Chapman (1990) and Powell (1997) in the TZ; and Moran (1991) at the Jordanelle dam site. Two of the primary difficulties associated with the classical method are perturbation of the temperature field by groundwater flow and topography. The topographic perturbations can be accounted for mathematically (Lachenbruch, 1968; Powell and others, 1988) in the heat flow calculations, but the perturbations due to groundwater circulation are difficult to quantify.

The BHT method utilizes a large body of less reliable and lower precision data found on oil and gas well logs. Once a transient BHT is obtained (from the well log header), it must be corrected to account for the thermal perturbation due to drilling. Thermal conductivity information must be constructed from lithologic or electrical logs or regional stratigraphic studies. Heat flow studies in Utah, based on the BHT method, include Chapman and others (1984) and Keho (1987) in the Uinta Basin, Deming and Chapman (1988a,b) and Deming (1988) in the Utah -Wyoming thrust belt, as well as regional studies of varying extent (Reiter and Mansure, 1982; Eggleston and Reiter, 1984). In addition to the heat flow studies, Willett (1988) modeled the spatial variability in the thermal properties of the Uinta Basin, using stochastic inversion and statistical techniques.

This work presents a number of new heat flow determinations in Utah based on the BHT method mentioned above. New data are combined with previously published Utah heat flow data to create the most complete heat flow map of Utah to date.

This paper starts with a brief review of the geology encountered in the CP, B&R, and TZ. Methods for correcting transient BHTs, assembling thermal conductivity profiles of rocks, and calculating heat flow are described. The resulting heat flow data are then qualitatively compared to previous studies. Finally, the center of the TZ is identified, with the 75 $m\mathrm{W}^{-2}$ contour on a map of all existing heat flow data for Utah and comparisons between the new and old datasets are made.

METHODS

Temperature Data

A transient BHT is recorded by a maximum temperature thermometer on an oil or gas well logging tool. Temperatures are least perturbed by drilling at the bottom of the well. As these temperatures are recorded, the length of the shut-in time (t_s) is also recorded as either clock time or the length of time elapsed since the circulation of drilling mud ceased. If multiple transient BHTs are recorded at the same depth in a well, then the thermal relaxation of the well and, in particular, the steady-state BHT can be calculated (Bullard, 1947; Lachenbruch and Brewer, 1959).

The dataset of transient BHTs is freely available and very large, numbering near 100,000 recorded temperatures in Utah alone. The questionable nature of the dataset results from a variety of circumstances including, but not limited to, frequently broken thermometers and misrecording of the data. When examining the log headers, one must be careful, as errant data are not always obvious. Spurious data can be caught at the source by checking to see that, for each well, the temperature at a given depth increases with the shut-in time. Frequently the recorded temperatures for one well-depth are identical for all shut-in times, indicating inadvertent misrecording of data. The wells can also be reconditioned (by recirculation drilling fluid) without mention on the headers. This reconditioning results in widely varying temperature data which appear nonsensical.

The transient BHTs are corrected using methods found in Bullard (1947) and Lachenbruch and Brewer (1959). The method is sometimes referred to as the "Horner plot method" because of the similarity to pressure recovery in a well (Horner, 1951). The thermal recovery method is a convenient and moderately accurate method of estimating formation steady-state temperatures (Deming and Chapman, 1988b; Beck and Balling, 1988; Funnell and others, 1996). The thermal recovery method does have weaknesses, such as minimum shut-in times and certain aspects of drilling that are overlooked. These weaknesses are examined in Luheshi (1983), who mentions that many of the data (mud properties and circulation time) needed to calculate the steady-state BHT are not normally recorded on the well log header.

These problems are avoided in this study by assuming a fixed circulation time and using an approximation which does not rely upon the material properties of the drilling mud. While this approach doesn't eliminate the problem, it does minimize the unseen variability and creates a uniform point from which to correct the transient BHTs.

The transient temperature field ($T(t_s)$) in a well was first described mathematically by Bullard (1947) using the equation

$$T(t_s) = T_\infty - (Q/4\pi k)[Ei(-r^2/4st_s) - Ei(-r^2/4s(t_s+t_c))], \qquad (1)$$

where T_∞ is a steady-state BHT, Q is the line source strength, k is thermal conductivity, Ei is the exponential integral, r is borehole radius, s is system thermal diffusivity, t_s is shut-in time, and t_c is circulation time. When the condition

$$r^2/4st_s << 1 \qquad (2)$$

is met, (1) can be simplified to

$$T(t_s) = T_\infty - (Q/4\pi k)[\ln(t_s/(t_s + t_c)], \qquad (3)$$

as was shown by Bullard (1947). For this study, the portions of equations (1) and (3) that are enclosed in square brackets are referred to as the thermal recovery factor.

Circulation times are almost never recorded in the U.S., but for this study a value of 5 hours is used because it is an intermediate value between the mean of 8 hours and median of 3 hours circulation time found by Scott (1982) in a study of 301 oil wells.

Transient BHTs from a particular depth are plotted against the thermal recovery factor in constructing a thermal recovery plot (figure 2). A linear least-squares fit is applied to the plotted transient BHTs and the resulting line is extrapolated to the T-intercept, which represents infinite shut-in time and therefore the steady-state formation temperature. Thermal recovery plots that used two transient BHTs are called two-point data and the thermal recovery plots that used three or more data points are called three-point data.

The slope of the least-squares line on the thermal recovery plot also provides information about the area being examined. The greater the slope, the higher the rate of recovery and therefore, the greater the initial perturbation. For example, in figure 2, the wells State of Utah "L" and State of Utah "K" both have very high rates of thermal recovery for their respective depths. These are typical of the Great Salt Lake area, and reflect the high thermal gradients observed beneath the Great Salt Lake.

Unfortunately, the exponential integral, or exact, solution (equation (1)) requires information on the thermal diffusivity of the borehole-country rock system. Thermal diffusivity is seldom measured and variability in the factors involved in calculating the system thermal diffusivity can cause large unknown variations in the thermal recovery factor. The variation in thermal recovery factor causes corresponding errors in the calculated steady-state temperature. With a fixed diffusivity, for example, the thermal recovery factor from the exact solution was shown to differ by as much as 12 percent from the thermal recovery factor of the logarithmic approximation (3) for the data used in this study (figure 3 A). Fortunately, this rather large shift in the thermal recovery factor alters the slope of the thermal recovery curve, but has only a small affect (1-2 percent) on the final calculated steady-state temperature (figure 3 B). The difference between the approximation and exact solution decreases as the shut-in time increases. This convergence over time of the exact solution and the approximation, and the high degree of variability introduced by the diffusivity term in the exact solution, provides adequate reason to use the approximation.

Equation (3) thus provides a convenient basis for estimating a steady-state BHT if two or more transient BHTs are measured at a given depth. In many wells, unfortunately, only a single transient BHT is determined. We now investigate empirical predictions of the thermal recovery rate in order to extract steady-state BHT estimates from single point data.

Wells are grouped according to diameter because the diameter appears to have a first-order effect on the rate of thermal recovery. The oil and gas wells are organized into three groups: 150-154 mm (5.9-6.0 in) diameters are labeled as 150 mm, 180-250 mm (7.1-9.8 in) are labeled as 205 mm, 311-365 mm (12.2-14.4 in) are labeled as 311mm, and 365-475 mm (14.4-18.7 in) wells are labeled as 445 mm. These labels reflect the diameters of the majority of the boreholes in any specific group.

When oil wells are drilled, the first section to be drilled is the widest. As the well deepens the diameter of the hole decreases. Many of the well logs are run during the breaks in drilling when the drill bits are being changed or replaced. This narrowing of the well is important to remember when considering the location and likely role of a well of a given diameter. For example, the narrowest (150 mm, 5.9 in) holes are generally the very deepest sections of oil or gas wells, although they also are used for shallow exploration. As a result of the limited role of the 150 mm (5.9 in) diameter wells, they are less common than the other wells and only 29 of them are included in this study. The sizes 205 and 311 mm (8.1 and 12.2 in) are more common, with 140 and 60 wells in each group, respectively. Oddly, the 311 mm (12.2 in) wells had very little near-surface data, probably the result of them being used as a second-stage for still larger diameter wells. The largest wells (445 mm [17.5 in] and larger) are relatively rare and almost all are very shallow, probably because they are used only as a first stage for very deep wells.

Depth-dependent correction equations for each of the above mentioned diameter groups were determined by graphing slopes from individual thermal recovery plots against their respective depths (figure 4). The data presented suggest a nonlinear trend that was quantified by fitting a quadratic function to the dataset using the least-squares method. The best-fit quadratics for the two-point data show a slight systematic shift to the right of the three-point data best fit line. The quadratic function gives a predicted rate of thermal recovery for any individual well as a function of depth. From this rate of recovery, the formation steady-state temperature can be estimated for wells with a single temperature depth measurement.

The criterion (2) for using the approximation (3) requires the shut-in times of the wells to be of a required minimum duration. The minimum shut-in time depends on the diameter of the well. For wells with diameters of 445 mm (17.5 in), 311 mm (12.2 in), 205 mm (8.1 in) and 150 mm (5.9 in), minimum shut-in times are 8, 7, 5 and 4 hours respectively (Funnell and others, 1996). In the context of the condition (2), the ratios of well diameter and shut-in time are not all equal. However, in order to make use of the data from larger diameter oil wells, the minimum shut-in time standard had to be reduced, relative to the well diameter. The error in the calculated steady-state BHT associated with these minimum shut-in times can be as large as 5 percent, but is usually less (Funnell and others, 1996). This criterion effectively removed the 445 mm wells from this study because none of the wells had sufficient shut-in times.

The quadratic trendlines are constrained to have a zero intercept based on the assumption that the drilling fluid has the same temperature as the ground surface at the drilling site, and are of the form

$$A = az + bz^2 , \qquad (4)$$

where A is the slope of the thermal recovery plot and z is depth (table 1). The result is a predicted depth-dependent rate of recovery for any well that has been shut in for an adequate period of time as described above.

The deviations of the two-point data from the curve compared to the deviation of the three-point data from the curve were quantified by calculating root mean square (rms) residuals (table 2). As expected, the three-point data, being more tightly constrained than the two-point data, better fit the trendline than the two-point data. The purpose of this analysis was to determine if the two-point data and the three-point data were sufficiently similar to be used together. As expected, the less constrained two-point data exhibited greater scatter, but the best fit curves of both the three and two-point data are similar (figure 4). The improvement in the curve-fit of the data from two-point to three-point was not uniform for the different well groups. The rms residual for the smallest wells improved by about 5°C (41°F), for the 205 mm (8.1 in) wells about 4°C (39°F), for the 311 mm (12.2 in) wells by 3°C (37°F) (table 2).

A common problem when using the thermal recovery method is a lack of the multiple transient BHTs at a single depth required to construct a thermal recovery plot. The majority of the data in this study have multiple transient BHTs and thus yield heat flow values directly. An additional 64 heat flow values were obtained in wells having single transient BHTs at a given depth by employing the correction equations (table 1). The search for these additional data was based on geographic density of data points for any given region, with the greatest attention being paid to regions with little or no temperature-depth data. The additional data improved the spatial coverage of the data, but there are regions of Utah where oil and gas wells are absent. Therefore, there are large regions with few deep thermal data.

A group of 447 measured transient BHTs from 117 different wells were initially used in the thermal recovery method to determine 174 new, corrected BHTs. The ratio of transient BHTs to corrected BHTs is approximately 3:1. Because the thermal recovery method relies on a best-fit line to determine the corrected BHT, the 3:1 ratio further constrains the best-fit line, resulting in a greater degree of confidence in the corrected BHTs. The data from the above mentioned 110 corrected BHTs were then used to create the correction equations. Using the correction equations, an additional 64 uncorrected BHTs, which brought the total uncorrected BHTs to 511, in 64 separate wells were corrected to bring the total number of corrected BHTs to 240 in a total of 181 different wells.

All of the temperature-depth data generated by this study are plotted in figure 5. The majority of the oil and gas wells examined in Utah have average thermal gradients between 18 and 45°C km^{-1} (0.99 and 2.5°F/100 ft). This range reflects the various tectonic settings across the state, from the cool interior of the CP (Bodell, 1981) to the relatively hot Great Salt Lake area. The high thermal gradients below the Great Salt Lake area were initially viewed with skepticism. However, because of the uniform nature of the geothermal gradient in the area, the Great Salt Lake is treated as a geographically bounded anomaly and the wells therein are kept separate from the other groups of wells.

The surface temperatures (T_0) used in the heat flow calculation were determined by taking the average annual air temperature of a nearby weather station and adjusting for air-ground temperature differences and elevation. We assumed that ground temperature is on average 2.9°C (37.2°F) warmer than the air temperature and that temperature decreases with elevation at a rate of -7°C km^{-1} (-0.4°F/100 ft) (Powell and others, 1988).

Thermal Conductivity Measurements

Thermal conductivity measurements were made on 57 rock samples from five different formations (table 3). Hand specimens greater than 12 cm (4.7 in) in diameter and thicker than 5 cm (2 in) from the Simonson Dolomite, Sevy Dolomite, Guilmette Formation and Hermosa Group, were measured with a TK04 line source instrument using methods outlined in Sass and others (1984). The Hermosa Shale was measured, in crushed form, in cells on the University of Utah divided bar using equipment and methods outlined in Sass and others (1971a) and Bodell (1981). Results are shown in table 3.

The number of samples collected for a formation reflects the magnitude of the thermal resistance (thickness/thermal conductivity) of the formation and thus the overall impact of the formation on the heat flow calculation. Therefore, the greater the thermal resistance of the formation, the more times we sampled the unit. All measurements from an individual formation were averaged to account for the heterogeneities inherent in the rocks. However, the anisotropy and friable nature of shale makes reliable laboratory measurements difficult. Gallardo and Blackwell (1999) showed that the in-situ measured thermal conductivity of shale can be almost half that of the laboratory measurements of the same formation. Unfortunately, the methods described in Gallardo and Blackwell (1999), whereby conductivites are inferred from the ratio of thermal gradients through multiple formations in a single well, require resources that were unavailable for this project.

The proximity of nearest-neighbor wells, however, affords a different kind of field calibration for thermal conductivity of shales. We consider pairs of heat flow sites which penetrate the Mancos Shale with nearest-neighbor sites which do not encounter the Mancos. The matrix conductivity of the Mancos Shale was adjusted so that these sets of proximal sites would have identical heat flow. The matrix thermal conductivity values necessary to produce equivalent heat flow values are given for each well in table 4. A weighted mean of matrix conductivity based on the percentage of the stratigraphic column occupied by the Mancos Shale resulted in a matrix conductivity of 1.7 W m^{-1} K^{-1} , which in turn resulted in an average in-situ thermal conductivity of 1.5 W m^{-1} K^{-1}. These values are consistent with the shale conductivity values reported in Gallardo and Blackwell (1999). Heat flow calculations that involved the Mancos Shale (laboratory measured at 2.48 W m^{-1} K^{-1}) were recalculated using a matrix thermal conductivity of 1.7 W m^{-1} K^{-1} (table 4).

This study also makes extensive use of previously published thermal conductivity measurements of rocks from Utah (Bodell, 1981; Carrier and Chapman, 1981; Keho, 1987; Deming, 1988; Deming and Chapman, 1988b; Moran, 1991; and Powell, 1997). For formations for which there are no measured or published conductivity data, values were used from measurements of lithologically similar formations. These are referred to as assumed thermal conductivity values.

Matrix thermal conductivities in table 3 are converted to in situ conductivity by accounting for porosity and temperature effects. Thermal conductivity (k) of a porous medium can be expressed as

$$k = k_s^{(1 - \phi)} k_w^{\phi}, \qquad (5)$$

where k is the in situ thermal conductivity, ϕ is porosity, k_s is conductivity of the solid matrix, and k_w is conductivity of the pore-filling fluid, in this case water. The porosity values used in this study are calculated using exponential compaction trends

$$\phi_z = \phi_0 \, e^{(-z/d)}, \qquad (6)$$

described in Sclater and Christie (1980), Rieke and Chilingarian (1974), and Bond and Kominz (1984), where ϕ_z is porosity at depth (z), ϕ_0 is porosity at zero depth and d is a compaction constant.

Surface porosity varied based upon lithology and local geology. Typical values measured for ϕ_0 were 0.4 for valley fill, 0.08 for limestones and dolomites, and 0.22 for sandstone (Bodell, 1981; Carrier and Chapman, 1981; Keho, 1987; Deming, 1988; Deming and Chapman, 1988b; and Powell, 1997). The porosity of the shale samples could not be measured because the shale lacked sufficient cohesion to survive water saturation intact. These surface porosity values reflect burial, compaction, and subsequent exhumation (figure 6). The compaction curves (figure 6) (Sclater and Christie, 1980) were used to determine shale porosity. Porosity values measured by previous workers were used in conjunction with those in table 3 to determine the surface porosity values used in the model. Current surface porosity reflects the maximum depth of burial, and subsequent exhumation, assuming no reopening of pores due to exhumation. However, some porosity values were adjusted for the near-surface ($\leq$500 m) increase in porosity of uplifted CP strata described in Jarrard and others (1999). Based on measured porosities, the sediments of the CP were assumed to have been exhumed 3,500 m (11,500 ft) and the older rocks in the B&R were exhumed 3,000 m (9,840 ft). These empirically derived porosity values agree reasonably well (±10 percent) with the laboratory measured values of Powell (1997) and Bodell (1981).

Adjustment of the matrix conductivity (k) values for temperature was accomplished by using the relation given by Chapman and Furlong (1992)

$$k = k_{20} \, [1/(1 + 0.0005\,(T))], \qquad (7)$$

where k_{20} is the matrix conductivity at 20°C and T is the temperature in degrees Celsius. The total effect of the temperature adjustment is less than 1 percent, which falls within the expected bounds of error for this study.

The conductivity of the pore water was calculated using the polynomial, relating temperature to conductivity, given by Deming and Chapman (1988b) based on data from Touloukian and others (1970). No adjustments were made for the salinity of the pore water.

Heat production in the rocks of the CP and B&R is a minor factor in calculating heat flow. Values of 0.5 $\mu W\ m^{-3}$ were assigned to sandstone and limestone strata, 1.0 $\mu W\ m^{-3}$ to valley fill, and 1.8 $\mu W\ m^{-3}$ to shale, based on values from Funnell and others (1996) and Rybach (1986). The heat production of the rock layers involved in the calculation typically contributed 5 percent or less of the total surface heat flow.

When making regional heat flow calculations it is not always practical to sample rocks for thermal conductivity measurements every few vertical meters in every borehole as suggested by Chapman and others (1984). The bulk of the conductivity data that are available are organized by geological groups, formations, and members. With data in this structure, thermal conductivity profiles are created by determining the most likely stratigraphy for a borehole, or cluster of boreholes, down to the required depth, and by applying the thermal conductivity data to the stratigraphic profile. Ideally this is accomplished using lithological well logs. However, few such logs are available for oil and gas wells. More prevalent are SP and neutron log interpretations of the lithology, typically given as percentages of sand, limestone, or shale. Because the thermal conductivity data are based on stratigraphic units, this end-member knowledge is not an adequate substitute for knowledge of the actual stratigraphy.

Although the conductivity of a given formation has been shown to vary up to 25 percent laterally, as in the case of the Navajo-Nugget sandstone, with the exception of Chapman and others (1984) and Willett (1988) lateral variation of thermal conductivity within a formation has not been addressed in detail. The structure of the rocks and thicknesses of the beds used in the calculations are based on regional stratigraphic studies (Hintze, 1988) and, whenever possible, lithology logs. The possible errors in conductivity that are outlined above are analyzed using a Monte Carlo error analysis discussed later.

Computation of Present-Day Surface Heat Flow

The variation of temperature with depth (T(z)) for steady-state heat conduction through a horizontally layered Earth that includes heat production is given by

$$T(z) = T_0 + \sum_{i=1}^{n}[(q_{i-1}\Delta z_i)/k_i - (A_i\Delta z_i^2)/2k_i], \qquad (8)$$

where

$$q_i = q_{i-1} - A_i\Delta z_i \qquad (9)$$

T_0 is the surface temperature; q_i is the heat flow into the base of layer i; q_{i-1} is the heat flow out of the top of the ith layer; Δz_i, k_i, and A_i are the thickness, thermal conductivity and heat production, respectively, for the ith depth interval in a well.

Equation (8) leads directly to the "Bullard" method of calculating heat flow (Bullard, 1947) assuming negligible heat production and therefore constant q_i. This simplification results in

$$T(z) = T_0 + q_0 \sum_{i=1}^{n} \Delta z_i/ki, \qquad (10)$$

where q_0 is the surface heat flow. In practice, heat flow is determined from the Bullard method and equation (10) as the slope of a line when temperature is plotted against summed thermal resistance ($\Delta z_i/\Delta k_i$).

In this study, equations (8) and (9) were used for the primary heat flow calculations. Steady-state BHT data are combined with ground surface temperatures, and thermal conductivity data as input to equations (8) and (9). This is accomplished using a spreadsheet which creates a temperature-depth profile for each heat flow site using equations (8) and (9), based on heat production, porosity, temperature effects, steady-state BHT, and thermal conductivity data. In equations (8) and (9), once the layer thicknesses, heat production and thermal conductivity profile have been determined, a temperature at any given depth can be calculated by assuming a surface heat flow. In this calculation the only value that is not predetermined is the heat flow, so by iterating through various surface heat flow magnitudes, alteration of the calculated geothermal gradient is possible. An optimum surface heat flow value is found that minimizes the differences between a calculated temperature for the approximate depth and the corrected BHT.

Wells that were within 0.1° longitude and 0.1° latitude (about 11 km; 6.8 mi) of each other or in an area of uniform geology were grouped and treated as a single location. This clustering resulted in an increase in the number of corrected BHTs used in each heat flow calculation.

Error Analysis

The uncertainty in heat flow values determined by the "Bullard" method depends on uncertainties in formation thicknesses and thermal conductivities, surface temperature, and corrected BHTs. The effects of these errors on the heat flow calculation were evaluated using a Monte Carlo analysis and equation (10).

In the Monte Carlo analysis, perturbations were applied to thermal conductivity, formation steady-state temperatures, mean surface temperature, and the positions of the rock layer interfaces which govern layer thicknesses for as many as 10 formations (table 5). These parameters were perturbed in each heat flow realization using a random number generator that produces values in a Gaussian distribution with a mean of zero and a variance of one. We scaled the magnitude of each perturbation in a realization by multiplying each random number by the estimated variability for that specific parameter.

Thermal conductivity was perturbed according to the magnitude of the standard deviation of the thermal conductivity of each formation. If a formation in the stratigraphic column was not measured in the lab and there were no preexisting thermal conductivity data for it, a standard deviation of 0.15 of its assumed conductivity was assigned. The standard deviation of the mean, annual surface temperature was assumed to be 1°C, based on meteorological records that typically represent 100 years of data. The corrected BHTs were randomized by 10 percent, a magnitude based on a likely error associated with the thermal recovery method.

Monte Carlo analyses are presented here for two sites, one each from the CP and B&R (figure 7 and figure 8, respectively). Each analysis produced a scatter plot of temperature difference (T(z)-T 0) versus thermal resistance and a histogram showing the distribution of computed heat flow values per 1,000 realizations.

For the area on the CP, the analysis was performed on the well “Salt Valley #1” (figure 7). The corrected BHT is 78.3°C (172.9°F) at a depth of 3,448 m (11,312 ft), the assumed surface temperature is 14.7°C and the mean value of the summed thermal resistance is 1,056 m^2°CW^{-1}, yielding a deterministic heat flow value of 61 *m*W $^{-2}$. The Monte Carlo simulation produced extreme perturbations of 37 and 94°C (99 and 201°F) for $T(z)-T_0$ and 785 and 1,420 m^2 KW^{-1} for the summed thermal resistance. Heat flow values for these extremes vary from 35 to 90 *m*W m^{-2}. The standard deviation of the 1,000 realizations for this well is 8.7 *m*W $^{-2}$, or 15 percent of the mean heat flow of 60 *m*W $^{-2}$.

For the area on the B&R, the analysis was performed on the well “State of Utah N#1” (figure 8) the corrected BHT is 111°C (232°F) at a depth of 2,000 m (6,562 ft), the assumed surface temperature is 13.9°C (57.0°F) and the mean value of the summed thermal resistance is 773 m^2 °CW^{-1} , yielding a deterministic heat flow value of 127 *m*W $^{-2}$. The Monte Carlo simulation produced extreme perturbations of 80 and 117°C (176 and 243°F) for $T(z)-T_0$ and 600 and 1,200 m^2 KW^{-1} for the summed thermal resistance. Heat flow values for these extremes vary from 75 to 175 *m*W $^{-2}$. The standard deviation of the 1,000 realizations for this well is 15.7 *m*W m^{-2}, or 12 percent of the mean heat flow of 127 *m*W $^{-2}$.

DISCUSSION

The thermal resistance method relies on temperature data and thermal properties to compute heat flow. Each well was not necessarily restricted to a single corrected BHT at a single depth. Therefore, in some cases, a temperature-depth series could be used to constrain the geothermal gradient and reduce random error. Each iteration of the spreadsheet served to minimize the differences between the corrected BHT data and the calculated temperature for that depth. In an attempt to reduce the overall random error, wells were grouped together, based on distance apart and continuity of local geology. Generally, the wells grouped together are within 11 km, although that range was extended or restricted based on the uniformity of local geology. The benefit of grouping is that the random error associated with the corrected BHTs is more likely to cancel out with the increase in the number of corrected BHTs used for each heat flow calculation.

The new heat flow values for Utah are plotted in figure 9 and consist of two numbers. The upper bold number is the heat flow for that well or cluster of wells. The lower of the two numbers represents the number of transient BHTs used to make the heat flow determination. The larger the number of transient BHTs used in the thermal recovery plots, and therefore the thermal gradient calculations, the greater the confidence in the calculated thermal gradient.

Figure 10 shows the updated heat flow data for Utah. The bold numbers with solid circles represent new heat flow determinations from this study. Plain numbers with open circles represent heat flow values from previous studies. In some cases a number of heat flow values from previous studies have been averaged to facilitate legibility. The number in parentheses indicates the number of heat flow values that were averaged.

The overall pattern of the new heat flow map is higher values in the west and lower values in the east, although there are exceptions. The new data presented in figure 9 yield an average heat flow for the B&R of 91 *m*W $^{-2}$ (standard error of the mean (SEM) 8 *m*W $^{-2}$). Previous studies (Roy and others, 1968; Costain and Wright, 1973; Reiter, and others, 1979; Carrier and Chapman, 1981; Chapman, and others, 1981, Eggleston and Reiter, 1984; Moran, 1991; Powell, 1997) yield an average heat flow value of 107 *m*W m^{-2} (SEM 8 *m*W m^{-2}) for the B&R. Due to the fact that the two SEM do overlap, these values can not be considered statistically different. Some of the previously existing heat flow data in the B&R came from studies conducted for geothermal resources exploration. These geothermal studies produced some extremely high (500 - 3,000 *m*W $^{-2}$) heat flow values that were not included in the calculation of the mean of previously published data. However, it is likely that the data, none the less, were biased toward higher values and the mean of that data is not representative of the entire region. In contrast, BHT values are from oil and gas wells drilled in sedimentary basins. These values are likely to be cooler due to the depression of the geotherms in the sedimentary basin (Gallardo and Blackwell, 1999; Sclater and Christie, 1980), and more uniform than those drilled for geothermal exploration. The mean of all known heat flow data for the B&R, excepting the geothermal exploration data, is 105 *m*W m^{-2} , SEM 5 *m*W m^{-2}.

The average heat flow in the CP as determined by this study is 62 *m*W m^{-2} (SEM 2 *m*W m^{-2}). Previous studies (Costain and Wright, 1973; Reiter and others, 1979; Bodell, 1981; Bodell and Chapman, 1982; Reiter and Mansure, 1982; Eggleston and Reiter, 1984; Powell, 1997) yield an average heat flow value of 59 mW m^{-2} (SEM 4 mW m^{-2}) for the CP. The overlap in the SEM of these mean values indicates that they are not statistically different. The mean of all known heat flow data for the CP in Utah is 60 mW m^{-2} with a SEM of 1 mW m^{-2}.

An ideal comparison between two sets of heat flow data would be point by point, comparing heat flow determinations in a single borehole or oil well by multiple studies. Unfortunately, no such groupings exist. Instead, a nearest-neighbor approach is used. Scatter plots (figure 11) show the nearest-neighbor comparison between the old and new data from figure 10. In the B&R (figure 11 A) the previously published heat flow values are slightly higher than the new data, indicated by the slope of 1.03 of the least-squares best fit line. In figure 11 B the trend is slightly higher heat flow values from this study compared to the previously published data in the CP, indicated by the slope of 0.92 of the least-squares best fit line. It should be noted that the removal of the outliers seen in figure 11B does not change the slope of the best-fit line appreciably. The scatter seen in the data does not increase with increased distance from the nearest-neighbor. This is not surprising considering the difficulty encountered in contouring heat flow data. These scatter plots are consistent with the provincial means discussed earlier in this section.

There are some interesting aspects to the new data (figure 9), starting from the north: two data points which straddle the TZ, representing 43 transient BHTs, which average 75 mW $^{-2}$, are marginally higher than the surrounding heat flow values. These are located on the Utah-Wyoming thrust belt at approximately 111.3°W, 41.3°N. The heat production in the thrust sheet could account for most of this modest increase in heat flow, provided the thrust sheet was 3 km thick when emplaced and produces heat at a rate of 2 μW m^{-3} (Deming, 1988). This heat production rate is slightly higher than any used in this study, but is not unreasonable and would explain roughly 6 mW m^{-2} of the observed difference in heat flow.

Farther south and astride the TZ east of Nephi around 111°W, 39.6°N, there are two new values of 54 and 72 mW m^{-2} representing 18 transient BHTs which are in close proximity to two other values of 88 and 89 mW m^{-2}. The two high values are from Eggelston and Reiter (1984) and are based on BHT data. However, for their thermal conductivity data, they assigned the average of previously published thermal conductivity values, corresponding to the lithologies encountered by the lithology logs. Most of the thermal conductivity data for rocks in Utah that now exist did not exist in 1984, so the values they were employing were not from rocks in Utah.

They used these foreign values in their calculations instead of an actual formation-based conductivity structure. Eggelston and Reiter (1984) estimate their error to be 10 percent to 15 percent. This would suggest a minimum heat flow of 76 *m*W m^{-2}. Assuming an error of 12-15 percent shown by the Monte Carlo analysis, the values from this study could be as high as 63 and 88 *m*W m^{-2}. While the probable error bars do overlap, the disagreement between the 54 *m*W m^{-2} and the previously published values can also be explained through the foreign nature of the thermal conductivity values used by Eggelston and Reiter (1984).

The thermal transition from the CP to the B&R has traditionally been defined as the 75 *m*W m^{-2} contour (Powell, 1997) (figure 10). However, there is a great deal of scatter in the heat flow determinations. This degree of scatter is common in heat flow studies and is a primary reason that data from regional heat flow studies are rarely contoured. The position of the 75 *m*W m^{-2} contour that delineates the TZ is seen in figure 10 as the solid curved line running from the Idaho border near 111°W longitude to the Nevada border near 38°N latitude.

The transition in heat flow between the B&R and CP reflects a number of factors. When a warm province abuts a colder province, the zone that thermally separates them will blur as heat diffuses laterally from higher to lower temperature rocks. Differences in thermal conductivity cause refraction of heat from the lower to higher conductivity. For example, the thicker, cooler granitic crust that supports the CP (Keller and others, 1979; Thompson and Zoback, 1979; Benz and others, 1990) probably acts to draw heat away from the edge of the warmer B&R. This theory is supported by the velocity profiles found in Benz and others (1990). Using a simple thermal length calculation, the warm thermal signal from the B&R would have conducted 44 km (27 mi) into the cooler CP in the 15 Ma since the extension began. This length scale coincides fairly well with the 50 km (31 mi) average width of the thermal transition.

Another process that can affect the surface heat flow is volcanism. At first glance, volcanism seems to appear in Utah as modest heat flow highs around the Marysvale area. Using a thermal-length argument presented in Lachenbruch and others (1976), we have determined that the apparent heat flow highs in the area of the Marysvale volcanics are not related to the volcanic activity of the last 15-30 Ma. The activity was too small in scale and too long ago to leave any discernible signal.

Also important to remember are mechanisms that may serve to focus or disperse heat in certain areas. One candidate source is near-surface groundwater flow. For example, Chapman and others (1984), Keho (1987), and Willett (1988) describe the effects of near-surface groundwater effects on the heat flow in the Uinta Basin. The CP and B&R both have relatively porous rocks in positions of relatively high relief that can result in strong groundwater circulation.

Topographic relief was not considered a factor in this study because the topographic relief was generally small, relative to the depth of measurement and the horizontal distance to the depth of measurement (Lachenbruch, 1968).

The thermal transition in figure 10 generally agrees with previously published CP-B&R thermal transition zones (Bodell, 1981; Blackwell and Steele, 1992; Lowry and Smith, 1995; Powell, 1997). Blackwell and Steele (1992) mapped regional heat flow and interpolated the transition. Their estimation is surprisingly close to the TZ determined in this study, especially considering the sparse data from the region at the time. Lowry and Smith (1995) examined the relationship between the elastic thickness of the TZ and heat flow, seismicity and focal mechanisms. Integrating these data resulted in a transition zone that is located to the east of the geomorphic transition. Lowry and Smith (1995) do not map their transition. Instead, they present a series of west to east cross sections, showing the geophysical properties across the Transition Zone that they investigated in that area. Their series of cross sections does follow the same trend that this study found. The Powell (1997) thermal TZ in southern Utah matches the thermal transition produced by this study, but it diverges to the east near the Uinta Basin, probably because of sparse data.

The Monte Carlo error analysis provided probable bounds for the error associated with the calculations performed, based on rock layer interfaces, known errors in thermal conductivity, and temperature gradients. The errors employed in the calculation were as realistic as possible, and sometimes intentionally overestimated to examine worst-case scenarios. However, the errors used may in fact be much too small and future studies could further refine the TZ. The heat flow in Utah is represented to within 15 percent by the data presented here.

CONCLUSIONS

New heat flow determinations have been made at 88 sites in Utah using information from oil and gas wells. These sites fill many gaps in the previous heat flow coverage and allow us to better delineate the thermal transition between the CP and the B&R in central Utah. Thermal gradients are determined from oil and gas well steady-state BHTs and weather station data. Measured thermal conductivity for five formations and previously published data from approximately 80 additional Utah formations were used in the calculations.

The new heat flow values were combined with previously published data to create a heat flow map for Utah and to define the thermal TZ more accurately. The following conclusions were reached:

1. The mean heat flow of newly determined sites for the B&R in Utah is 91 $m\text{W m}^{-2}$ with a standard error of the mean (SEM) of 8 $m\text{W m}^{-2}$. This heat flow for the B&R is somewhat lower than determined in previous studies, many of which were geothermal exploration projects that focused on anomalously high heat flows. The mean of all known heat flow data for the Utah B&R (excluding geothermal resource exploration) is 105 $m\text{W m}^{-2}$ with SEM 5 $m\text{W m}^{-2}$.

2. The mean heat flow for the CP in Utah is 62 $m\text{W m}^{-2}$ with SEM 2 $m\text{W m}^{-2}$. This heat flow for the CP is not significantly different from previous studies. The mean of all known heat flow sites on the CP is 60 $m\text{W m}^{-2}$ with SEM 1 $m\text{W m}^{-2}$.

3. The thermal transition for B&R to CP is better delineated. It is 50 to 100 km east of the geomorphic transition. The systematic changes in the heat flow values from east to west across Utah reflect the different tectonic provinces contained therein and 15 to 20 Ma of conductive heat transport between them.

4. Monte Carlo analyses indicate that the heat flow values determined by the BHT method are reliable to 12-15 percent, provided the thermal conductivity structure is well constrained.

The tectonic differences between the B&R and CP are manifested in numerous ways, not least of which is a contrast in heat flow. The transition between the two are marked by the geomorphic, stratigraphic, and tectonic transitions. Geomorphology, stratigraphy, and tectonics all affect the thermal transition in some way, but a systematic lateral heat flow gradient of about 10 *m*W m^{-2} per degree longitude is a generally observable characteristic.

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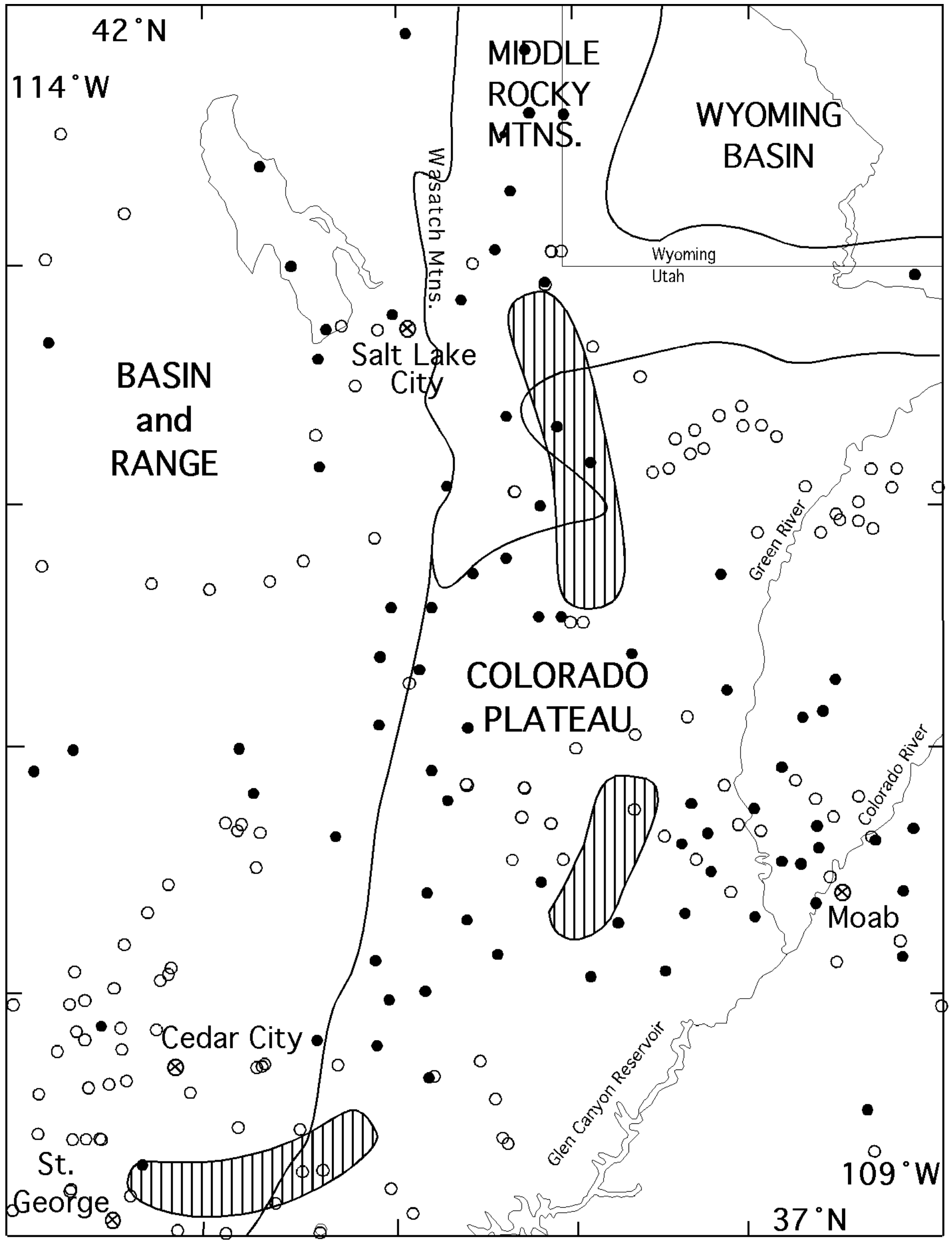

Figure 1. Locations of the new heat flow sites. Solid circles indicate new data, open circles are previously published. Major physiographic boundaries are indicated by fine lines (from Fenneman, 1946). Hatched areas are the thermal transition as defined by Powell (1997).

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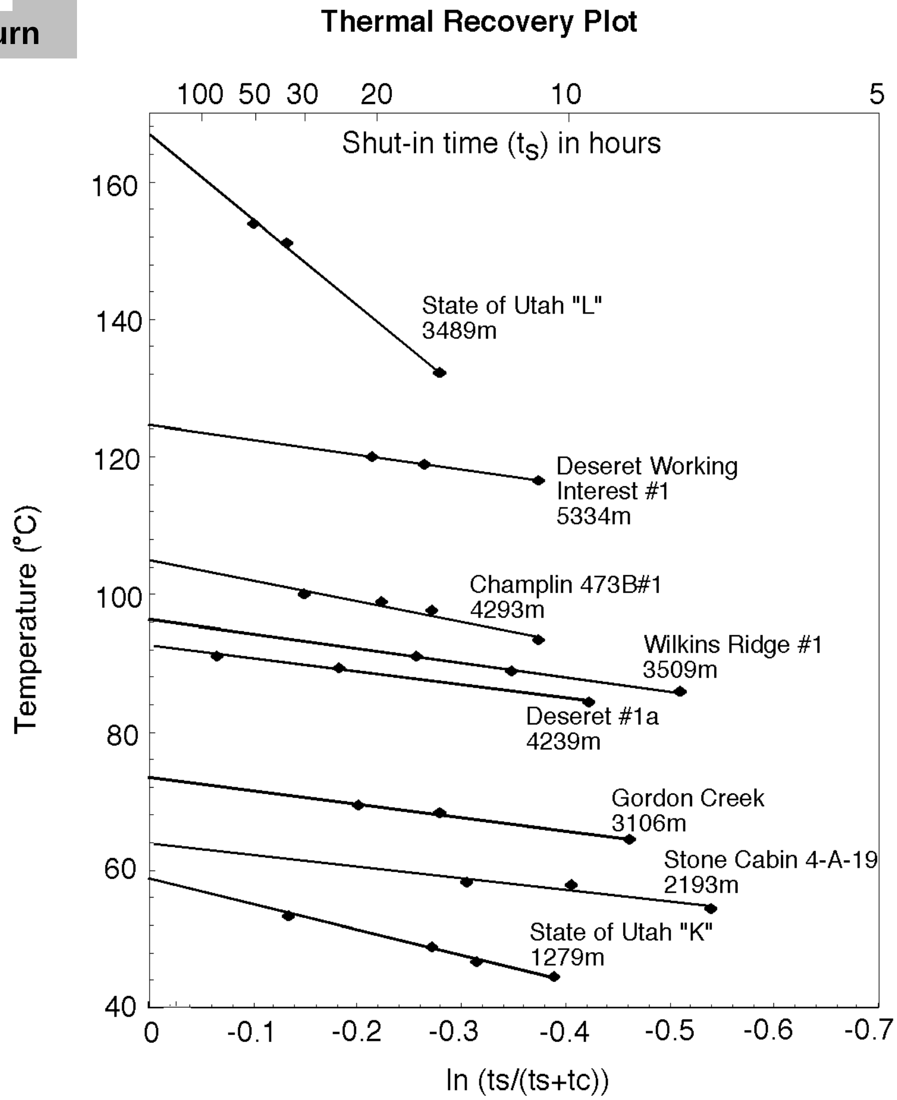

Figure 2. Thermal recovery plot for a representative selection of wells. Various depths and geographical regions are represented. The temperature-intercept of each line indicates the steady-state temperature for that depth in that well.

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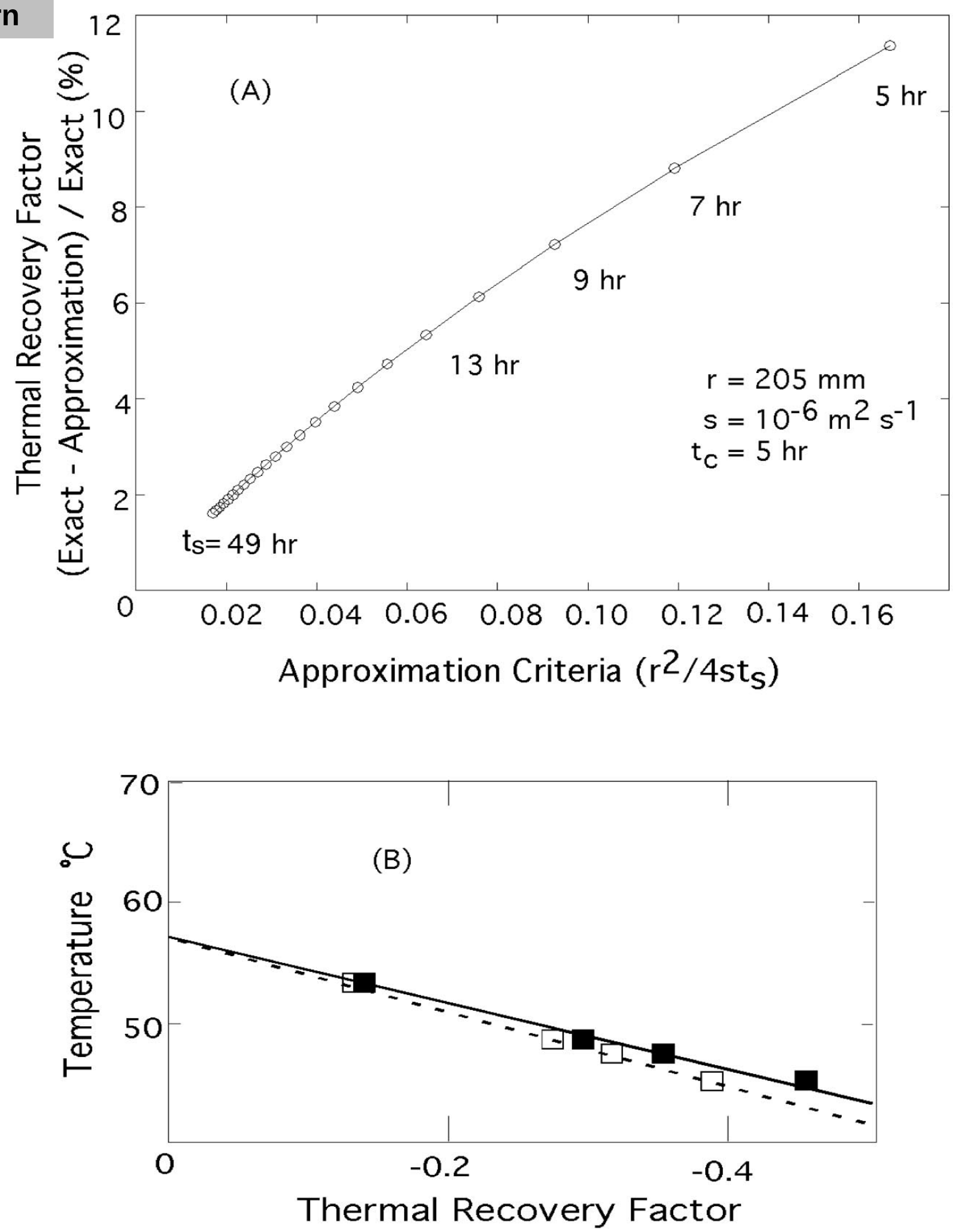

Figure 3. Borehole thermal recovery. (A) shows the difference between the thermal recovery factors of the exact solution and the approximation plotted against the criterion for using the approximation. The approximation criterion is changing with the shut-in times, in this case 5-49 hours in 2 hour intervals. (B) shows the relative insensitivity of calculated steady-state temperature in spite of large differences in thermal recovery factors between the approximation (dashed line, open symbols) and the exact solution (solid line, closed symbols).

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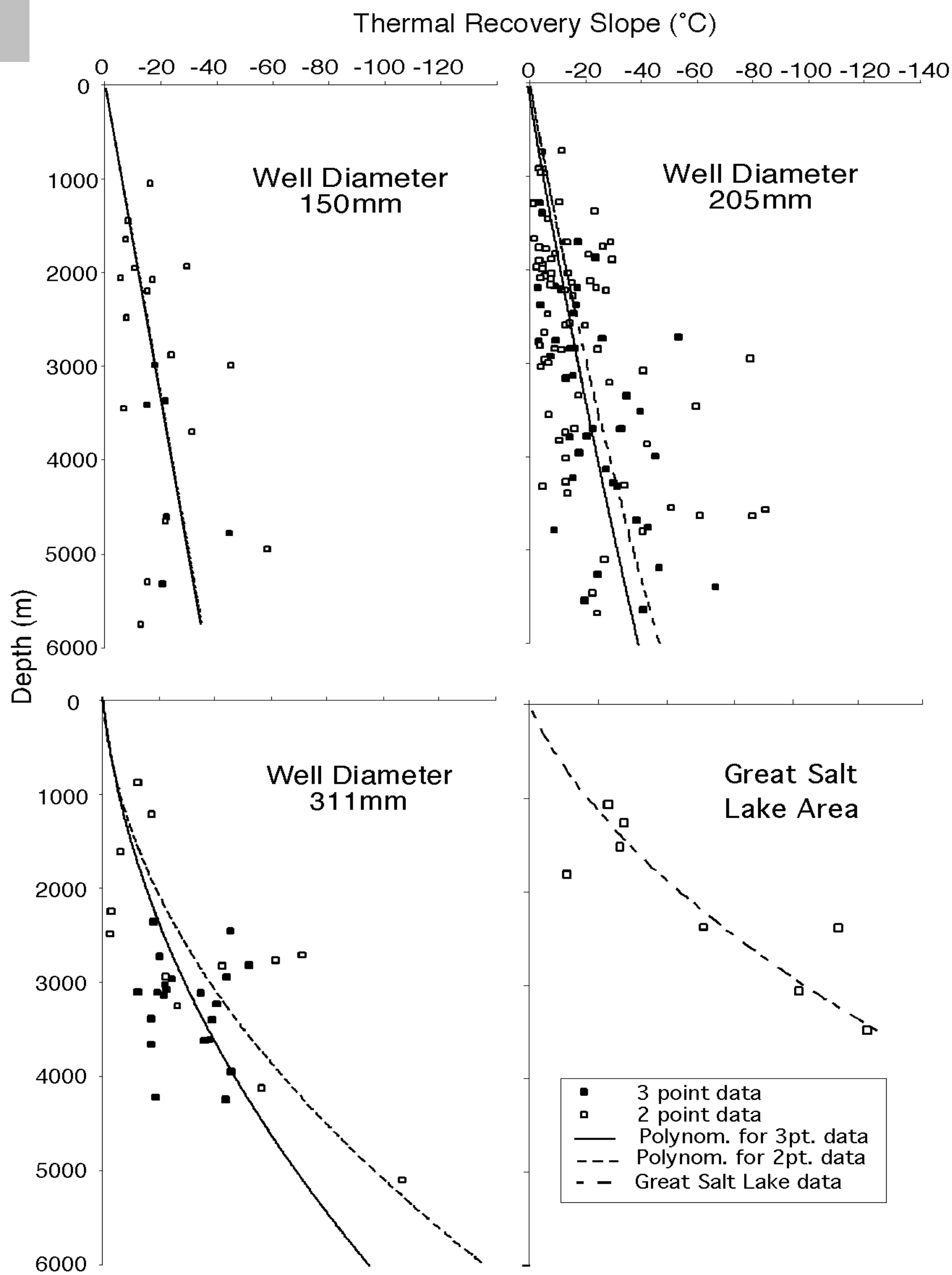

Figure 4. Depth dependence of thermal recovery slopes. The slopes of each thermal recovery plot are plotted as a function of depth with each well diameter group plotted separately. The data from the Great Salt Lake area are plotted as a separate group.

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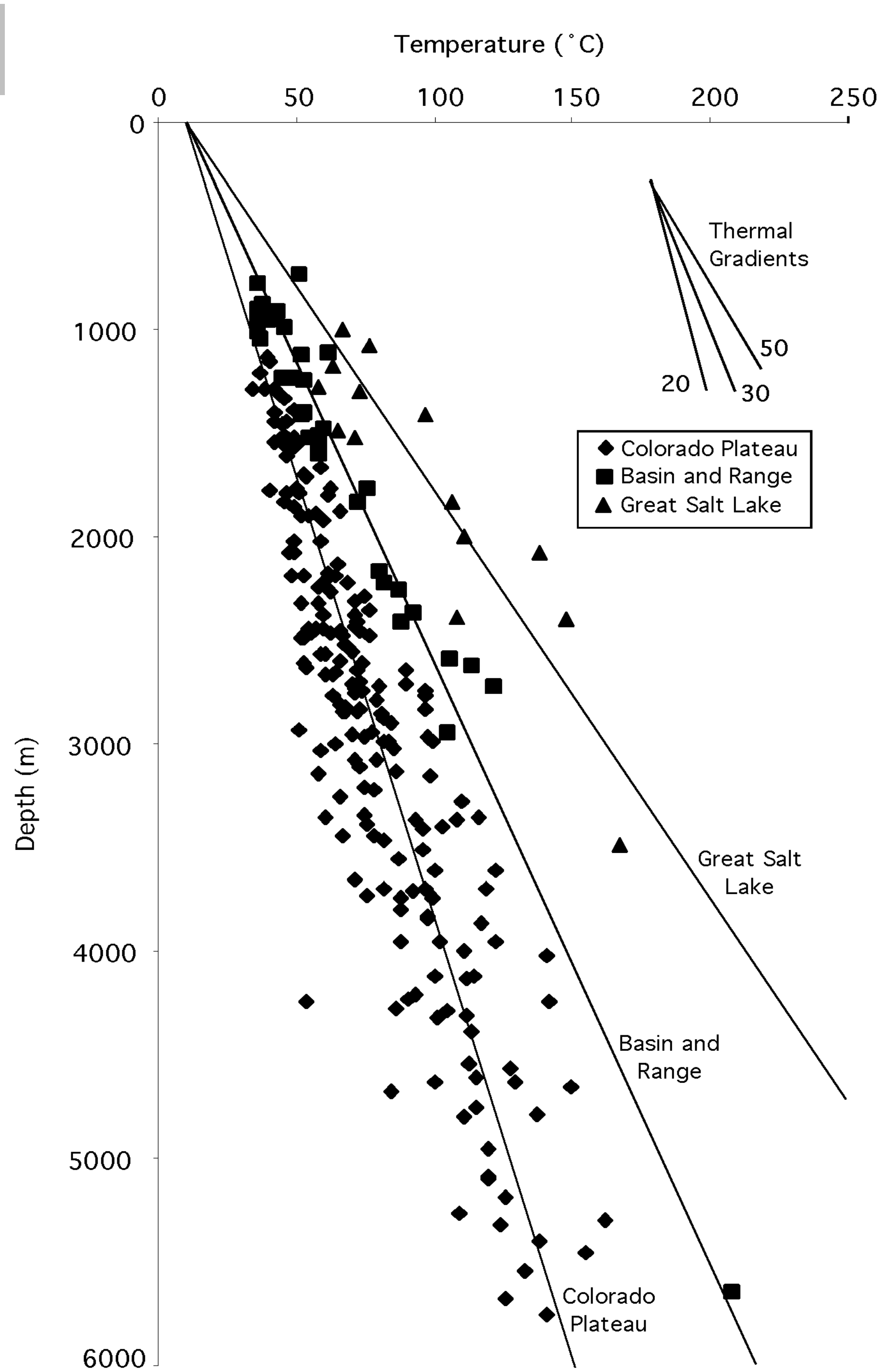

Figure 5. Temperature versus depth for all of the data collected in this study. Average thermal gradients projected on the figure are for the Great Salt Lake (60°C km^{-1}), Basin and Range (35°C km^{-1}) and Colorado Plateau (26°C km^{-1}). The Basin and Range and Colorado Plateau are separated according to the geomorphic transition.

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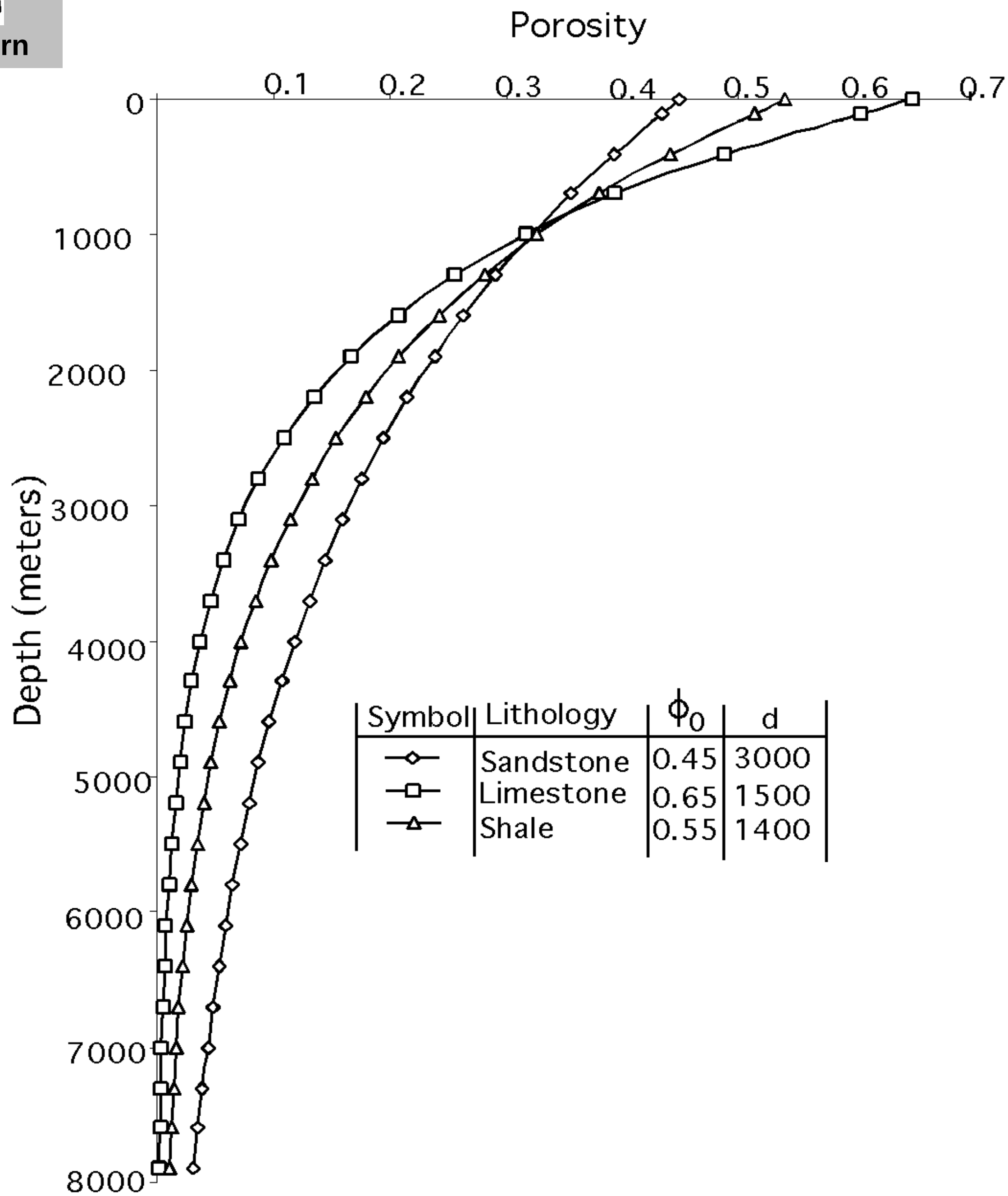

Figure 6. Porosity-depth compaction curves. Three categories of sediments are used to determine porosity and burial-exhumation magnitudes.

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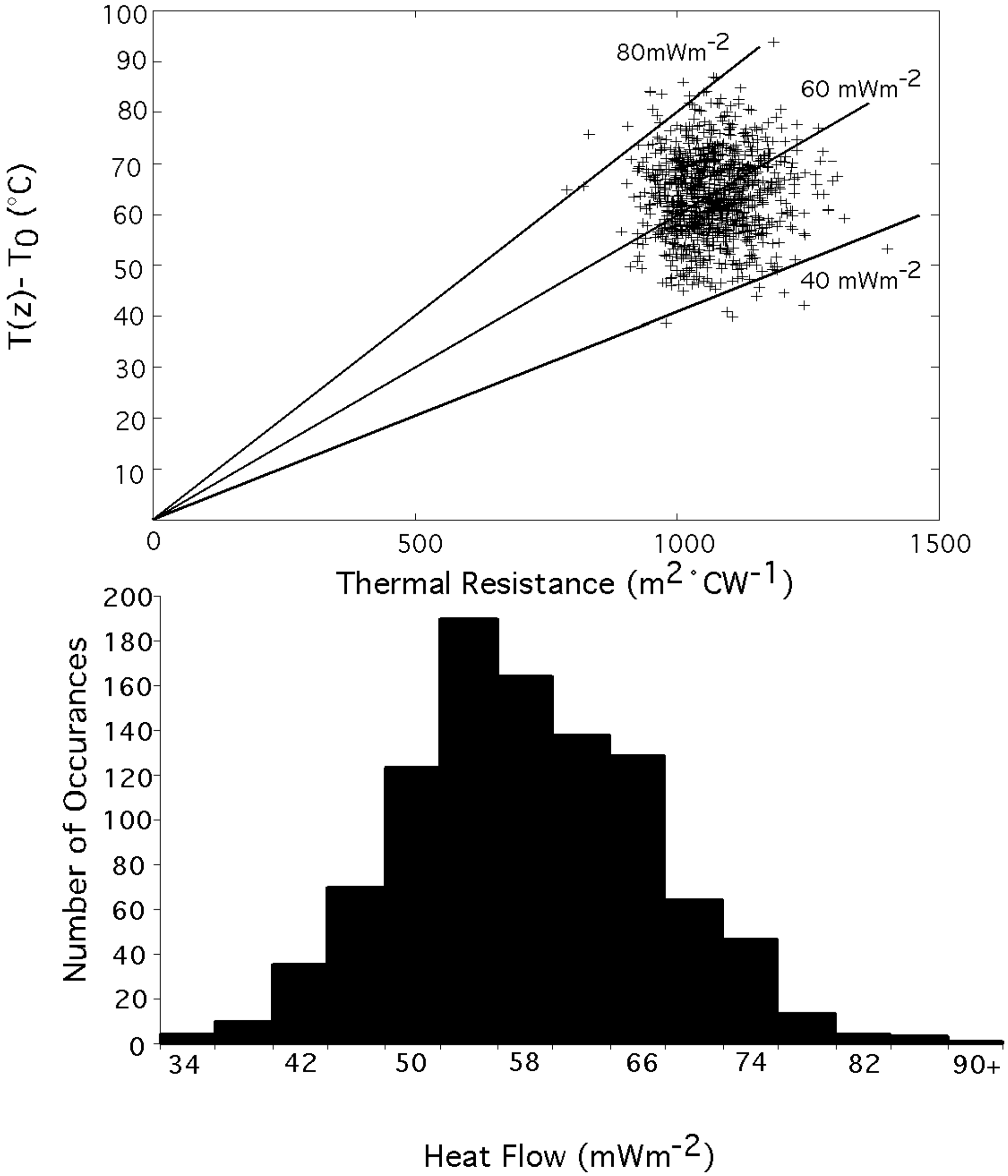

Figure 7. Monte-Carlo analysis for Salt Valley #1 on the Colorado Plateau near Moab, Utah.

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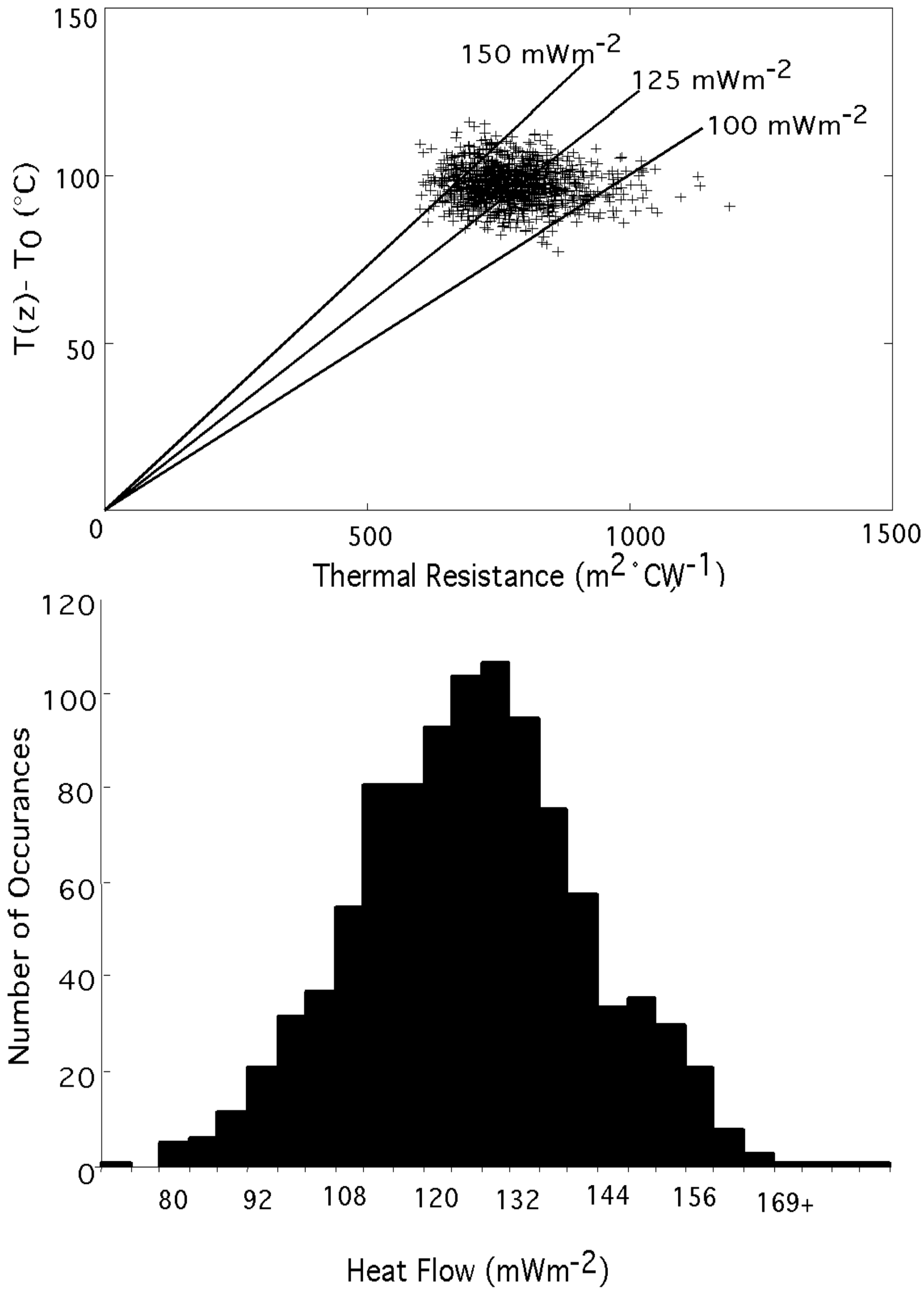

Figure 8. Monte Carlo analysis of "State of Utah N#1" in the Basin and Range, near the Great Salt Lake.

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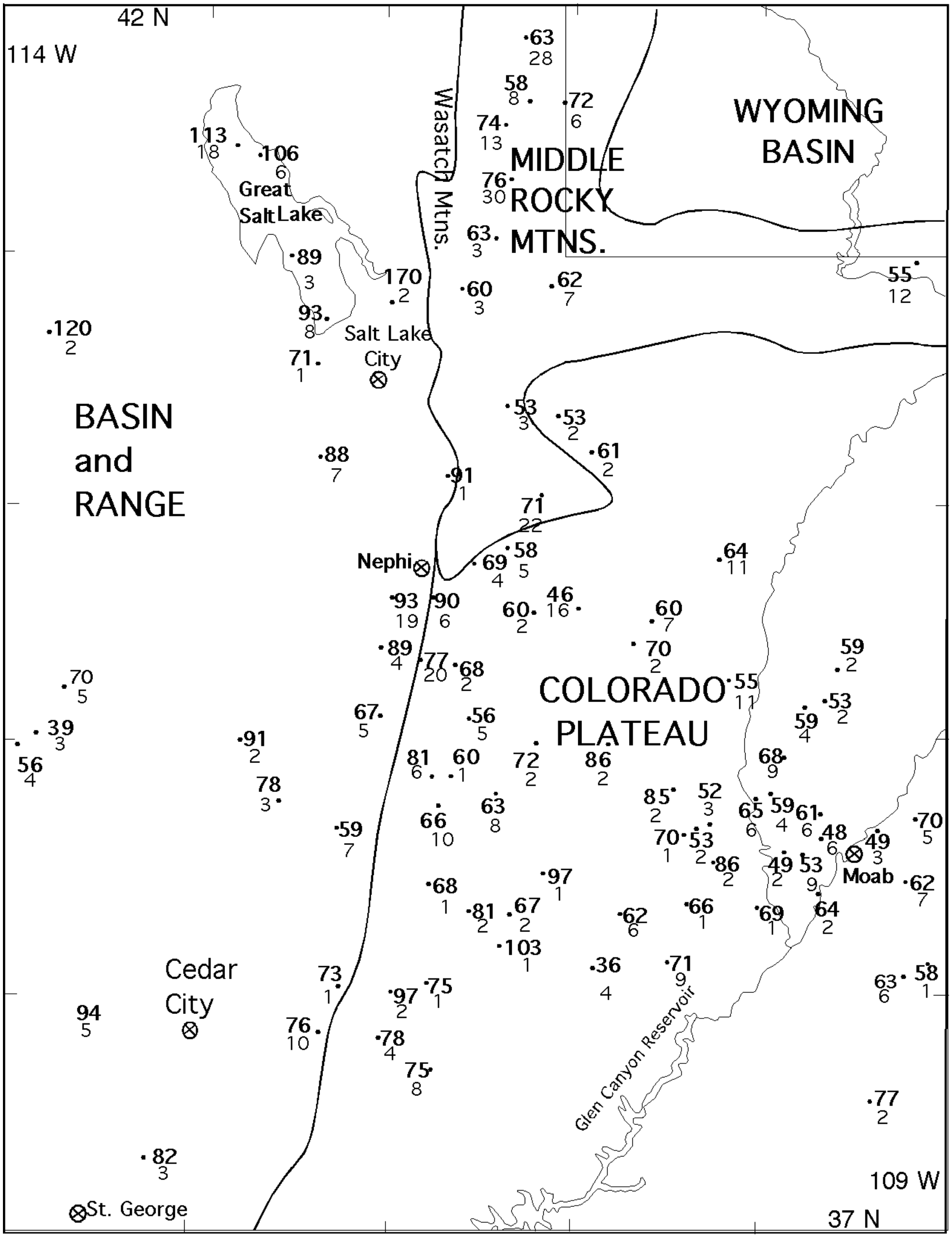

Figure 9. New heat flow values from oil and gas well data. The bold upper numbers are heat flow in mW m^{-2} and the lower numbers represent the number of transient BHTs used in the heat flow calculation.

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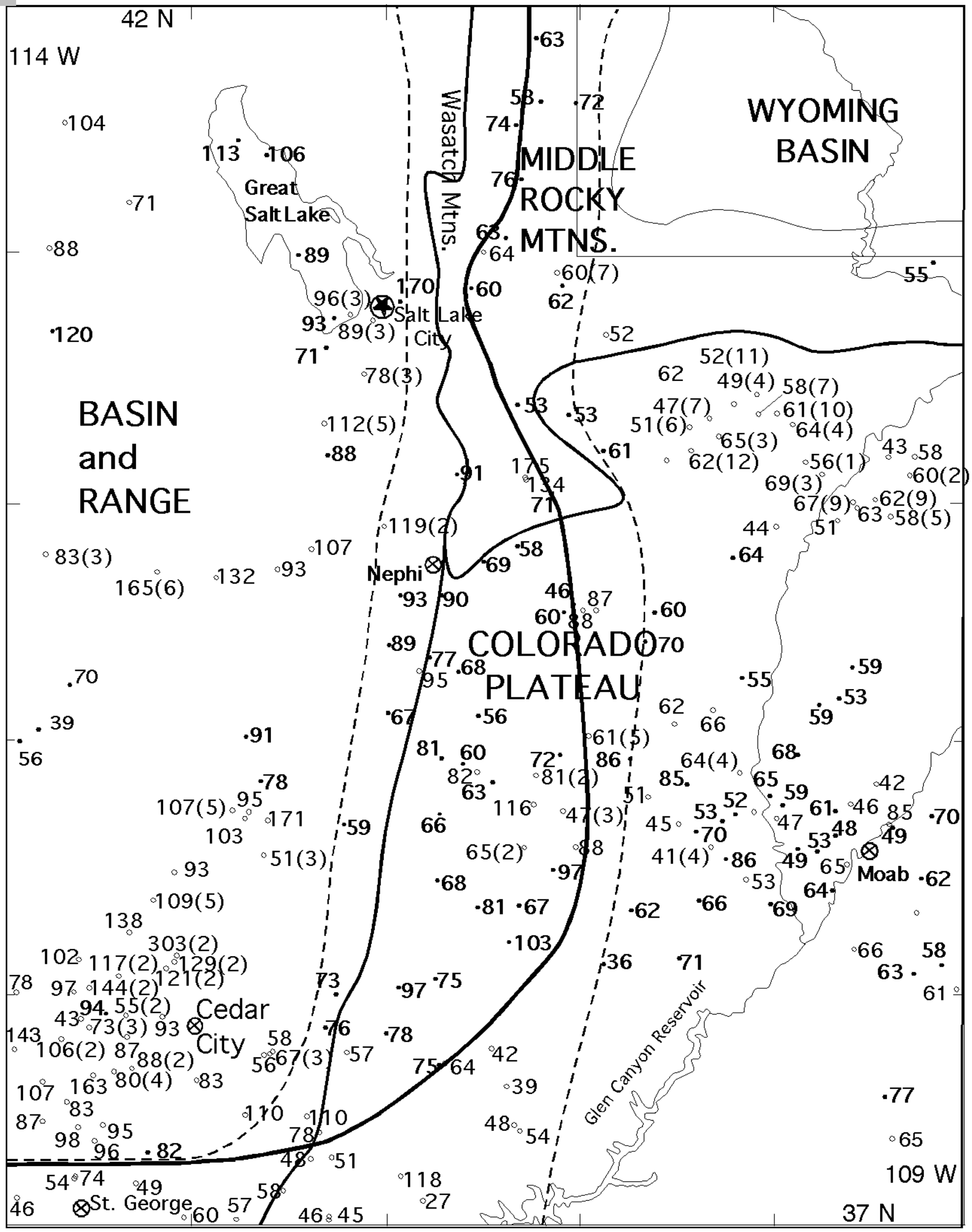

Figure 10. Heat flow data for Utah. The values in bold are from this study, other values are from previous studies and the numbers in parenthesis indicate the number of heat flow values averaged together to facilitate legibility. The thermal transition is shown as a single heavy line. The dashed lines delineate the areas used in the mean heat flow calculations. Values are in milliwatts per square meter.

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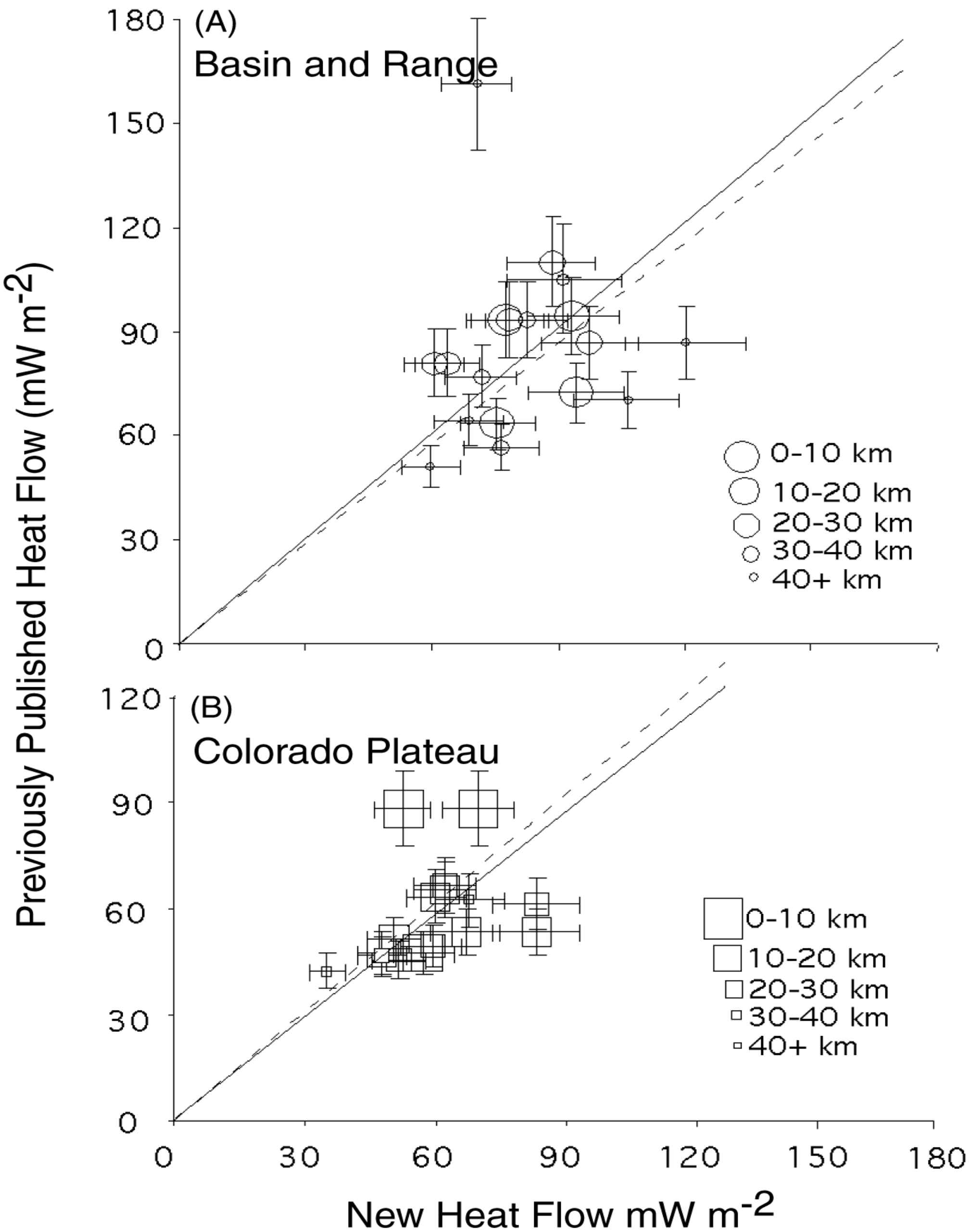

Figure 11. Comparison of new data with nearest-neighbor previously published data. The size of the symbol in the plot indicates the inverse relative distance between two points. The error bars represent the error calculated in the Monte Carlo analyses. The solid line represents the least-squares best-fit line to the data. The dashed line indicates a 1:1 correlation between old and new data.

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Table 1. Thermal recovery coefficients.

Well Group	*a* x10 $^{-3}$ °C m^{-1}	*b* x 10^{-6} °C m^{-2}	slope error estimate (%)
150 mm	5.9	0	16
205 mm	6.0	0.2	19
311 mm	4.1	2.0	24
Great Salt Lake	1.5	6.0	25

Coefficients for equations describing the best fit thermal recovery plots, as shown in Figure 4. The slope error is the quotient of the standard deviation of the slopes used to calculate the coefficients and the average slope.

Return

Table 2. Results of rms residual for thermal recovery slopes.

Well Group	2 datapoint mean rms residual (°C)	3 or more datapoint mean rms residual (°C)	all data mean rms residual (°C)
150 mm	13.7	8.5	12.6
205 mm	16.0	11.9	14.6
311 mm	20.1	17.4	18.4
Great Salt Lake			19.7

The Great Salt Lake data were not included in this analysis because the dataset for the GSL is too small. Note that the higher confidence data have the lower residual.

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Table 3. New thermal conductivity and porosity data.

Formation	Lith.	N	Matrix Conductivity ($W\ m^{-1}K^{-1}$)	Std. Deviation ($W\ m^{-1}K^{-1}$)	Porosity (%)	Std Deviation n (%)
Hermosa	Sh	9	1.63	0.14		
Hermosa	Ss	5	4.78	0.08	22.0	0.5
Mancos	Sh	24	*1.7			
Simonson	Ls	9	2.91	0.17	2.2	0.96
Sevy	Dol	1	6.41		1.0	
Guilmette	Ls	9	2.46	0.35	10.3	4.18

N is the number of samples measured for each formation.
*The thermal conductivity of the Mancos Shale used in the heat-flow calculations is based on nearest-neighbor field calibration discussed in text.

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Table 4. Matrix thermal conductivity of Mancos Shale.

Well name	Thermal Conductivity[1]	Mancos Shale as % of section penetrated	% change[2]
Price Area	2.8	43	17
Federal 41-33	1.7	37	20
Bogart Cyn.	1.3	33	11
Range Creek	2.7	8	16
Federal 1-26	1	7	4
Rattlesnake Cyn.	1.3	49	17
One Eye State	1.4	44	15

1. Matrix conductivity for the Mancos Shale required for the specific well to have heat flow identical to its nearest-neighbors. 2. Percentage change between heat flow calculated using a laboratory average matrix conductivity of 2.48 W $m^{-1}K^{-1}$ and the field calibrated matrix conductivity of 1.7 W $m^{-1}K^{-1}$.

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Table 5. Factors in the Monte Carlo error analysis.

Parameter	Factor variability	Typical variability (%)	Typical perturbation
Thermal conductivity (k)	St.dev.of (k)	10	0.3W $m^{-1} K^{-1}$
Surface temp (T_0)	Instrument error	10	1°C
BHT (T(z))	Instrument error	10	8°C
Depth of layer interfaces	Lithological variability	15	20-150 m

GEOTHERMAL RESOURCES BIBLIOGRAPHY OF UTAH

Modified from:
Utah Geological (and Mineral) Survey Bulletin 121
"*Annotated Geothermal Bibliography of Utah*"

by

Karin E. Budding and Miriam H. Bugden
compilers, 1986

Updated to include publications to 2000

Utah Geological Survey
Salt Lake City, Utah

March 2002

CONTENTS

INTRODUCTION

The bibliography of geothermal-related publications for Utah was compiled initially by Karin E. Budding and Miriam H. Bugden formerly of the Utah Geological (and Mineral) Survey and published as UGMS Bulletin 121 (Budding and Bugden, 1986). The work was completed for the U.S. Department of Energy. The following bibliography contains the original references from Budding and Bugden (1986) augmented with references to publications relating to geothermal resources in Utah since 1986. Sources used in compiling the bibliography include: 1) Utah Geological Survey Bibliography of Utah Geology, 2) the American Geologic Institute database - GEOREF, 3) U.S. Department of Energy - Energy Data Base, 4) Annotated and Indexed Bibliography of Geothermal Phenomena, 5) University of Utah publications, 6) U.S. Geological Survey publications, 7) Utah Geological Survey publications, 8) graduate theses, 9) Geothermal Resources Council publications, 10) United Nations symposia, and 11) private industry publications. Geological, geophysical, and tectonic maps and reports are included if they cover one of the primary thermal areas of Utah.

Many references directly pertaining to geothermal resources in Utah are annotated. The annotations are intended to inform the reader of the information contained in the article, not to summarize the results.

The following organizations maintain information and publications pertaining to geothermal resources in Utah:

- Three division within the Utah Department of Natural Resources -- Utah Geological Survey (UGS), Division of Water Rights, and Office of Energy and Resource Planning.
- The Utah Department of Community and Economic Development, Office of Energy Services.
- U.S. Department of the Interior, U.S. Geological Survey
- U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Energy Information Administration
- The University of Utah, Energy and Geoscience Institute(EGI)

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Memorandum of agreement signed that provides for review of proposals to inject geothermal and heat pumping water into natural channels; regulatory agencies named.

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Bid received for one of 12 geothermal steam housing tracts; amount paid and location of tract; temperature ranges of existing springs in area.

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Two ton tomato crop from a geothermal Utah farm; layout of greenhouses and tomato plant arrangements; temperatures of wells and total dissolved solids content of thermal waters; cost savings; location of area; future geothermal power development plans.

—1980d, Wells completed at Utah prison site: Geothermal Resources Council Bulletin, v. 9, no. 11, p. 15.

State of Utah completed two exploratory wells for a space-heating project at Crystal Hot Springs; project funding and purpose; depth and temperatures of first well.

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Geothermal Conservation Act of 1981 established to assign regulatory authority of geothermal energy to the Division of Water Rights; other conditions stated in the act.

—1981b, Roosevelt Hot Springs geothermal pact gets approval: Geothermal Resources Council Bulletin, v. 10, no. 1, p. 16.

Utah Public Service Commission approved a contract between Phillips Petroleum Company and Utah Power and Light Company for producing electricity with geothermal steam; Phillips to supply the steam for Utah Power and Light 20 MWe plant.

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Application for funds to study the feasibility of using geothermal energy for powering the MX system; feasibility study to be completed March 1981; consideration of other energy sources.

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Open house held for Utah Roses, Inc. geothermal greenhouses; water temperatures and well depth; estimated cost of heating operation; long range construction plans; permitting delay for the discharge of geothermal production fluid into the Jordan River.

—1981e, Utah geothermal bill passes: Geothermal Resources Council Bulletin, v. 10, no. 2, p. 13.

Utah Senate and House passed a bill establishing guidelines for development of Utah's geothermal energy; Division of Water Rights named as the regulatory agency.

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Completion of a 1005 foot exploratory well; location and water temperatures of well; source of funds for the geothermal space-heating prison project.

—1981g, Geothermists participate in CATMECS meeting: Geothermal Resources Council Bulletin, v. 10, no. 3, p. 13.

Forty attendees to the tenth meeting of the Centers for the Analysis of Thermal-Mechanical Energy Conversion Concepts; topics addressed; availability of meeting report.

—1981h, Utah PUC gives approval to power plant: Geothermal Resources Council Bulletin, v. 10, no. 3, p. 13-14.

Utah Public Service Commission approves a contract between Phillips Petroleum Company and Utah Power and Light for use of geothermal steam to produce electricity.

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Release of the draft environmental assessment on the proposed 20 MWe geothermal power plant at Roosevelt Hot Springs; construction schedule; environmental concerns; six commercial wells drilled at Roosevelt.

—1981j, Utah geothermal unit approved: Geothermal Resources Council Bulletin, v. 10, no. 9, p. 21.

Utah Division of State Lands approval of the formation of the Drum Mountains Geothermal Unit; location and size of the unit; unit agreement provisions.

—1981k, Biphase unit installed at Roosevelt Hot Springs: Geothermal Resources Council Bulletin, v. 10, no. 11, p. 13-14.

Equipment for Biphase Energy Systems mobile generating plant prepared for operation at Roosevelt Hot Springs in September of 1981; expected production; Utah Power and Light plans to study economic and technical feasibility of a 7 MWe and a 20 MWe steam turbine system; endurance test scheduled for spring 1982 depending on success of tests.

—1982a, Roosevelt Hot Springs produces power, Utah Power and Light customers get their first geothermally produced electricity: Geothermal Resources Council Bulletin, v. 11, no. 1, p. 3-4.

Date first geothermal generating unit at Roosevelt Hot Springs began supplying electricity to Utah Power and Light; cooperative project of Utah Power and Light, Phillips Petroleum Company, Biphase Energy Systems, and Electrical Power Research Institute.

—1982b, WESTEC gets start-up contract: Geothermal Resources Council Bulletin, v. 11, no. 2, p. 23.

Westec Services, Inc. to provide start-up services for

Utah Power and Light Company's Rotary Separator Turbine geothermal project at Roosevelt Hot Springs; total cost of contract and duration of project.

—1982c, Utah lease sale gets no bids; Geothermal Resources Council Bulletin, v. 11, no. 2, p. 23.

No bids submitted for geothermal lease sale units in Box Elder and Millard Counties, Utah.

—1982d, Phillips plans Utah exploration: Geothermal Resources Council Bulletin, v. 11, no. 4, p. 22.

Phillips Petroleum Company plans exploratory geothermal drilling in the Drum Mountains unit of Utah; location of area; previously reported geothermal gradients.

—1982e, Crystal Hot Springs water rights studied: Geothermal Resources Council Bulletin, v. 11, no. 5, p. 16.

Hearing held in 1982 to investigate the administration of water rights in Crystal Hot Springs area; successful drilling and test results in the area.

—1982f, Phillips to drill new Roosevelt Hot Springs well: Geothermal Resources Council Bulletin, v. 11, no. 5, p. 17.

Plans for Phillips to drill more wells for the 20 MWe geothermal power plant; well locations and projected depths.

—1982g, Union is sole bidder for Utah geothermal leases: Geothermal Resources Council Bulletin, v. 11, no. 5, p. 17.

Total bonus paid by Union Oil Company of California for 1314.57 acres of land for geothermal leasing from the State of Utah; location of lands acquired.

—1982h, Hunt bid tops Utah lease sale: Geothermal Resources Council Bulletin, v. 11, no. 7, p. 19.

Location of tract and amount of W. H. Hunt's bid for leasing unit 4 in the Cove Fort-Sulphurdale KGRA; bids on four other tracts.

—1982i, Utah State Prison well to be tested: Geothermal Resources Council Bulletin, v. 11, no. 8, p. 14-15.

Plans for a 30-day pump test on a well at the Utah State Prison; recovery monitoring to last seven to ten days; management and interpretation plans for the tests.

—1982j, Hunt Oil plans four Utah wells: Geothermal Resources Council Bulletin, v. 11, no. 8, p. 15.

Hunt Oil Company plans to drill up to four 7000-ft-deep geothermal wells in Iron County, Utah; availability of a copy of the plan of operation.

—1982k, Drilling confirms Roosevelt Hot Springs geothermal potential: Geothermal Resources Council Bulletin, v. 11, no. 1 0, p. 19.

Combined flow capacity of two Phillips Petroleum Company wells; list of participating resource companies at Roosevelt.

—1983a, Roosevelt Hot Springs power plant on target: Geothermal Resources Council Bulletin, v. 12, no. 1, p. 23.

Completion of two of four stages of a Utah Power and Light 20 MWe power plant at Roosevelt Hot Springs; schedule of completion of fourth stage; results of Phillips Petroleum's recent drilling projects; electrical power tests conducted at Roosevelt.

—1983b, Roosevelt Hot Spring activity update: Geothermal Resources Council Bulletin, v. 12, no. 2, p. 26.

Testing of a 1.6 MWe Transamerica Delaval Biphase Rotary Separator Turbine at Roosevelt Hot Springs; total electrical production during the test; construction schedule of a 20 MWe single-flash power plant.

—1983c, Geothermal to warm prisoners: Geothermal Resources Council Bulletin, v. 12, no. 10, p. 14-15.

Development and construction costs for converting the Utah State Prison minimum security building to a geothermal heating system; breakdown of DOE and State's costs; future plans.

—1984a, Biphase turbine to operate for UP&L: Geothermal Resources Council Bulletin, v. 13, no. 6, p. 1.

A wellhead geothermal power unit to be installed at Roosevelt, Utah; expected power generation; unique features of unit; Utah Power and Light production history at Roosevelt.

—1984b, Dry steam discovery/blowout: Geothermal

Resources Council Bulletin, v. 13, no. 1, p. 27-28.

Discovery of a dry steam well near Cove Fort, Utah; estimated flow of dry steam and well head temperature; new well drilled in area-, new development and plans for sale of power.

—1984c, Dry steam discovery/blow out: Geothermal Resources Council Bulletin, v. 13, no. 2, p. 21-22.

Location and field operator for Olga's Well No. 34-7; initial drilling program for 34-7; time and date of blowout; estimated flow of "dry steam" from the blowout; efforts made to contain the well; equipment used; successful containment; power sale contract between the operator and Provo City; future development plans of the operator.

—1984d, Second well completed at Cove Fort: Geothermal Resources Council Bulletin, v. 13, no. 4, p. 26.

Completion of a dry steam well at Cove Fort, Utah; location and depth of well; plans for further drilling.

—1984e, Unidyne to acquire geothermal division of Amax: Geothermal Resources Council Bulletin, v. 13, no. 4, p. 27.

Preliminary agreement between Amax and Unidyne for Unidyne's purchase of Steam Reserve Corporation; terms of the agreement; properties involved in the agreement.

—1984f, Roosevelt Hot Springs plant goes on line: Geothermal Resources Council Bulletin, v. 13, no. 11, p. 24.

Utah Power and Light's $35 million, 20 MWe power plant start up; plant designers and construction company-, further Utah Power and Light plans.

—1984g, Provo to purchase geothermal power: Geothermal Resources Council Bulletin, v. 13, no. 11, p. 24.

Plans underway for Provo City to purchase geothermal power from wells at Cove Fort, Utah; developer of the wells; estimated power output from the Cove Fort area; approximate cost for Provo citizens.

—1985a, UP&L wins award for energy innovation: Geothermal Resources Council Bulletin, v. 14, no. 1, p. 21-22.

Utah Power and Light Company wins an award for research and development of a high-efficiency turbine generator for the Roosevelt Hot Springs area; characteristics of the power plant, cost comparisons and projected savings.

—1985b, UP&L subsidiary organized to explore energy resources: Geothermal Resources Council Bulletin, v. 14, no. 1, p. 22.

Organization of Energy National, Inc.; purpose of new company; maximum equity financing for Energy National, Inc.

—1985c, First power plant dedicated at Cove Fort, Utah: Geothermal Resources Council Bulletin, v. 14, no. 10, p. 5-6.

Date and location of dedication ceremonies; speakers at the ceremonies; capacity and design of power plant; terms of agreement for Provo City's purchase of power; geothermal exploration history of the Cove Fort and Sulphurdale areas; production drilling; lifetime expectations of the field.

Geothermex, Incorporated, 1977, Geothermal potential of the lands leased by Geothermal Power Corporation in the Mineral Mountains, Beaver and Millard Counties: Earth Science Laboratory/University of Utah Research Institute Open-File Report UT/RHS/GPC-2, 43 p.

Stratigraphy and structure of study area; gravity and aeromagnetic data interpretation; interpretations based on geoelectrical, seismic, and heat flow surveys; hydrology of surface and ground waters; geothermal regime; exploration history; maps of geology, gravity, aeromagnetics, and temperature gradients.

Geotronics, Incorporated, 1976, Magnetotelluric resistivity cross sections - Roosevelt Hot Springs: Geotronics Corporation, scale: 1:24,000.

Magnetotelluric resistivity cross section from Roosevelt Hot Springs; magnetotelluric survey fence diagram of subsurface resistivities; magnetotelluric survey resistivities at 2000 feet below sea level.

Gertson, R.C., and Smith, R.B., 1979, Interpretation of a seismic refraction profile across the Roosevelt Hot Springs, Utah and vicinity: Earth Science Laboratory/University of Utah Research Institute

Report DOE/ET/28392, 109 p.

Seismic study defines fault locations and assesses the source of the thermal anomaly at Roosevelt Hot Springs; geology and geophysics of study area; seismic data computations; interpretations of P-wave travel times and construction of velocity-depth models to fit observed data; computer analysis of seismic refraction data; interpretation of amplitude variations of seismic diffraction data; two-dimensional gravity modeling from refraction data.

Getty Oil Company, 1978a, Getty well 52-21, Roosevelt Hot Springs - water analysis: Earth Science Laboratory/University of Utah Research Institute Open-File Report UT/RHS/GOC-3, unpaginated.

Water analyses for well 52-21 and Jefferson well; rework history; charts and water analyses taken from depth.

—1978b, Getty well 52-21, Roosevelt Hot Springs - well report: Earth Science Laboratory/University of Utah Research Institute Open-File Report UT/RHS/GOC-2, unpaginated.

Well history; bit record; lithologic log; temperature and pressure logs; subsurface temperature survey.

Gilbert, G.K., 1890, Lake Bonneville: U.S. Geological Survey Monograph, v. 1, p. 332-335.

Location and geomorphology of Fumarole Butte; temperature ranges of steam issuing from fissures; temperature ranges of a group of local hot springs; geologic history of area; persistence of volcanic heat in study area; other basalt localities of Lake Bonneville.

Glenn, W.E., Chapman, D.S., Foley, Duncan, Capuano, R.M., Sibbett, B.S., Cole, D.R., and Ward, S.H., 1980, Geothermal exploration at Hill Air Force Base, Ogden, Utah: Earth Science Laboratory/University of Utah Research Institute Report DOE/ET/28392-42, 89 p.; also, (abs.), Geological Society of America Abstracts with Programs, v. 12, no. 6, p. 274.

Identifies and tests favorable geologic structures for thermal fluids; survey of mercury concentration in soil profiles and soil traverses; fluid geochemical analyses of thermal waters, wells, and cold surface waters; application of geothermometers to water analysis; ground water model of fluid path from source regions to spring and well locations; gravity and reflection seismic surveys and interpretations; thermal gradient drilling and well log data interpretation; seismic sections and gravity profiles; plates showing well logs with natural gamma, resistivity, temperature gradient, temperature, and caliper readings.

Glenn, W.E., and Hulen, J.B., 1979a, A study of well logs from Roosevelt Hot Springs KGRA, Utah (abs.): Society of Petroleum Well Log Analysts, Transcripts, v. 2, paper no. ZZ, p. 1.

See Glenn and Hulen (1979b).

—1979b, Interpretation of well log data from four drill holes at Roosevelt Hot Springs KGRA: Earth Science Laboratory/University of Utah Research Institute Report DOE/ET/28392-27, 74 p.

Determination of geothermal reservoir characteristics based on well log data from four drill holes; lithologic, temperature, caliper, porosity, density, resistivity, natural gamma, and spontaneous potential logs for each drill hole; estimates of rock properties of alluvial material and igneous and metamorphic rocks based on geophysical logs; heat flow and fluid entries; plates of geologic log composites and coinciding geophysical logs.

Glenn, W.E., Hulen, J.B., and Nielson, D.L., 1980, A comprehensive study of LASL well C/T-2 (Phillips 9-1) Roosevelt Hot Springs KGRA, Utah, with applications to geothermal well logging: Los Alamos Scientific Laboratory Report LA-8686-MS, 175 p.

General geology and structure of area; petrographic study of drill hole cuttings to identify rock types and alteration phases of lithologic units; chemical analyses of composite samples from well C/T-2; analysis of oxygen and carbon isotopes to estimate temperature of deposition of hydrothermal minerals; measurement of bulk density, magnetic susceptibility, and thermal conductivity of cuttings; geophysical interpretation based on description and data from temperature, caliper, acoustic, neutron, density, electrical conductivity, SP, and gamma ray logs; use of cross plots from log data to identify distinct lithologies and estimate porosity values; tables of petrographic summaries of cuttings, whole rock analyses versus well depth, neutron activation analyses, and oxygen isotope values versus well depth; plates of geophysical logs, and chemical, radiometric, and X-ray fluorescence data.

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Map of survey area showing major geographic features and location of Monroe and Joseph; purpose of study; location of regional gravity survey; previous investigations; maps showing total ground magnetic intensity anomalies of the Red Hill Hot Springs and Joseph Hot Springs detailed grid; stratigraphy, Tertiary volcanic history, and structure of the study area; density and magnetic susceptibility measurements from rock samples; instrumentation used;

regional and detailed gravity and ground magnetic data; gravity data reduction and terrain corrections; ground magnetic data reduction; error analysis; complete Bouguer gravity anomaly map of the survey area; polynomial surface filtering; methods of interpretation; interpretative geologic cross sections; gravity and magnetic profiles; summary and conclusions.

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Location of Monroe City, Utah; surface characteristics of the Monroe KGRA; dissolved solids concentration of the Monroe Springs discharge; structural control of the geothermal system; 21 line-km of 100 m dipole-dipole resistivity survey; resistivity trends; eight thermal gradient and test holes drilled and tested; graphs of temperature profiles in test holes; chemical analysis of waters; drilling problems, procedures, and temperature logs from a production test well; results of a 70 hour drawdown test; summary and conclusions.

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Results of elemental analyses of travertine mounds; model of circulation of thermal waters.

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—1981, Helium and mercury concentrations in the Roosevelt Hot Springs area, Utah (abs.), *in* Geological Survey Research 1981: U.S. Geological Survey Professional Paper 1275, p. 19.

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Monroe KGRA and their value in predicting resources; stratigraphy and structure of area; alteration and spring geochemistry; interpretation of gravity, magnetic, and resistivity surveys; temperature and lithologic logs from 11 shallow holes; test and production well drilling; maps of heat flow, gravity, magnetic, and resistivity surveys; gravity and magnetic profiles; resistivity models; isotherm cross sections; lithologic, temperature, and gamma ray logs for test wells; tables of spring geochemical data.

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Overview of potential use of geothermal energy as a power source; geothermal potential of Utah; two dipole-dipole continuous sounding profiling resistivity IP lines across Fumarole Butte; map showing location of Fumarole Butte, geology, and hydrology; previous work in area; regional geology, stratigraphy, volcanic history, geothermal gradient, and hydrology; table showing chemical analyses of lavas from area; table showing chemical analyses of water from Abraham Hot Springs; resistivity arrays used; data results; conclusions.

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—1979, Forced convective heat transfer in the Monroe Hot Springs geothermal system: Journal of Volcanology and Geothermal Research, v. 6, no. 3-4, p. 257-277.

Definition of problem and purpose of study; mathematical and conceptual models of heat transfer; general numerical solution of the energy equation; organization of numerical algorithm to accept ground-water flows, thermal conductivities, and boundary conditions; accuracy and rate of convergence of the algorithm; problems associated with estimating the film coefficient from wind speeds; dimensionless energy equation; origination and migration of thermal waters in model of a fault-controlled geothermal system; application of convective heat transfer theory to model; graph showing relationship between heat flow enhancement directly over a fracture and the Peclet number of the model; geology and hydrology of study area; hot springs occurrences, temperatures, and salinity; graph showing temperature-depth curves at Monroe Hot Springs and Red Hill Hot Springs; mixing of hot and cold waters and speculation on mixing location; fault permeability estimates; graph of numerically determined curves of heat-flow enhancement as a function of distance from the hot springs; implications for Monroe-Red Hill springs.

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Objectives of study; distribution of known high-temperature resources in the Basin and Range; methods of geophysical exploration; problems with geophysical methods in geothermal applications; table comparing values of Poisson's ratio for Roosevelt Hot Springs with other geothermal systems; brief reports on geology and geophysics of several known geothermal resource areas; map showing geology of Roosevelt Hot Springs KGRA and vicinity; alteration and mineral assemblages of the Roosevelt system; thermal studies map of Roosevelt; map showing first separation resistivity from 300 m dipole-dipole survey; map of the CSMAT 32 Hz apparent resistivity; self-potential map and map showing microearthquakes occurring during July 1981 swarm at Roosevelt; Wadati diagram derived from earthquakes occurring during July 1981 swarm; evaluation of the contribution made by each of 14 methods used to understand reservoirs at each of 13 geothermal projects in the Basin and Range.

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White, K.L., Hill, A.C., and Ursenbach, W.O., 1978, Environmental overview report on Utah geothermal resource areas, Roosevelt Hot Springs, Cove Fort-Sulphurdale, Thermo Hot Springs-Lund KGRAS: University of Utah Research Institute/Environmental Studies Laboratory Report UCRL-13955, v. 1, 9.47 p.

Willis, C.P., 1980, Radium and uranium determination in samples of Utah Roses geothermal water: National Technical Information Service Report EGGPHYS-5169, 11 p.

Analysis of Utah Roses geothermal well waters for uranium and radium by direct alpha counting on separated elements; tables of uranium and radium fractions; appendix of chemical and radiochemical procedures used in study.

Wilson, W.R., 1980, Thermal studies in a geothermal areaSalt Lake City, University of Utah, unpublished Ph.D. thesis, 145 p.

Purpose of study; map of location and general geology of Roosevelt Hot Springs; methods used to measure temperatures in 53 drill holes in study area; graphs of temperature-depth curves; procedures for determining thermal conductivity and histogram of results; thermal conductivity values for major geologic units; heat transfer characteristics; plot showing magnitude of conductive lateral heat transfer; map showing surface conductive heat flow for area; map of downward continuation of the surface heat flow; appendix showing downward continuation formulas; graph of two-dimensional power spectrum of gridded surface heat flow; appendix of temperature-depth curves for Roosevelt Hot Springs; shallow heat flow surveys across normal fault geothermal systems providing fault geometry and fluid flow information; temperature-depth results from five drill holes at the Monroe KGRA; investigation of heat flow data for geometric properties of the Monroe geothermal system; datum correction for heat flow measurements made on an arbitrary surface.

Wilson, W.R., and Chapman, D.S., 1978, Interpretation of heat flow results at Roosevelt Hot Springs, Utah (abs.): EOS Transactions, American Geophysics Union, v. 59, no. 12, p. 1201.

Use of 47 drill holes to determine temperature gradients and thermal conductivity of lithologic units; configuration of near surface hydrothermal system; downward continuation model.

—1979, Heat flow mapping at Roosevelt Hot Springs, Utah as a geothermal exploration method (abs.): Geophysics, v. 44, no. 3, p. 405.

Use of drill holes to obtain thermal conductivity measurements of lithologic units; conductive heat flow calculated for upper 30 meters of holes; heat flow pattern; downward continuation model.

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Wright, P.M., Blackett, R.E., and Ross, H.P., 1990, Geothermal resource development in Utah: Utah Geological Association Publication 18, p. 27-43.

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Yearsley, E., 1994, Roosevelt Hot Springs reservoir model applied to forecasting remaining field potential: Geothermal Resources Council, Transactions, v. 18, p. 617-622.

Reservoir Engineering; Roosevelt; reservoir models; boundary conditions; forecast; initial state; TETRAD; wellhead pressure constraint; bottom hole pressure constraint.

Young, C.Y., Ward, R.W., and Lin, T.L., 1979, Seismic attenuation observations across Roosevelt Hot Springs, KGRA (abs.): EOS Transactions, American Geophysical Union, v. 60, no. 46, p. 946.

Program design for mapping travel-time delays beneath geothermal areas; procedures used to digitize the seismographs of 41 teleseisms for quantitative attenuation analysis; inversion technique used to obtain three-dimensional Q mode for the region.

Young, R.A., and Carpenter, C.H., 1965, Ground-water conditions and storage in the central Sevier Valley, Utah: U.S. Geological Survey Water-Supply Paper, no. 1787, 95 p.

Yusas, M.R., 1979a, Stress history of the Mineral Mountains pluton, southwestern Utah (abs.): Geological Society of America Abstracts with Programs, v. 11, no. 6, p. 306.

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Purpose of study; map showing general geology of the Mineral Mountains area; geology and tectonic setting of the Mineral Mountains; procedures used in mapping structure; analysis of structure and fracture systems; table showing tensile strengths of rocks; development of fracture permeability; procedures used in strain relief measurements; orientations and magnitudes of principal strains; table showing results of strain relief measurements; depth of producing geothermal reservoirs; formation of the geothermal reservoir; appendices showing unreduced strain relief test results and results of uniaxial compression tests.

Yusas, M.R., and Bruhn, R.L., 1979, Structural fabric and in-situ stress analyses of the Roosevelt Hot Springs KGRA: University of Utah, Department of Geology and Geophysics Report DOE/ET/28392-31, 62 p.

Geometry and origin of fractures used to develop a structural model of the geothermal reservoir at the Roosevelt KGRA; geologic and tectonic setting; field mapping and structural analysis of joints, dikes, and shear zones; genesis and development of fracture permeability in the geothermal reservoir; measurement of strain relief to determine active and residual stresses; possible mechanisms of strain relief.

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Analytical procedures; geographic orientation of Raft River and Roosevelt KGRAs in the Intermountain Seismic Belt; background seismicity; microearthquake swarm detected in the Mineral Mountains; techniques for locating hypocenters; geological interpretation of data; conclusions of microearthquake information; equipment used and logistics involved in study at Roosevelt; appendix describing method used for calibration of induced- seismicity network at Roosevelt.

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GEOGRAPHIC INDEX

Best and Brimhall, 1974
Blackwell, 1983
Blackwell and Chapman, 1977
Bortz, 1983
Brown and Nash, 1978
Bucher, 1971
Corwin and Hoover, 1979
Costain, 1973
Crowley, 1977, 1978
Edmiston, 1979, 1982
Edmiston and Benoit, 1985
Evans, 1978
Fiore, 1980
Fishman, 1976
Fleck and others, 1975
Glenn and others, 1982
Greider, 1976
Hogg, 1972a
Holmes, 1979
Koenig and McNitt, 1983
Lachenbruch and Sass, 1978
Leeman and Rogers, 1970
Liaw and Suyenaga, 1982
Loring, 1972
Mabey and others, 1983
Mackin, 1960a
Mainzer, 1978
Mariner, Presser, and Evans, 1983
Meinzer, 1924
Meyer and others, 1979
Mifflin, 1983
Nehring and Mariner, 1979
Nielson, 1980
Osmond, 1958
Overton and Hanold, 1977
Ritzma, 1972
Rowan and others, 1983
Rowley and others, 1978
Scholz and others, 1971
Smith, R.B., 1977b
Smith and Sbar, 1974
Stewart, 1971, 1983
Stewart and others, 1977
Stringfellow, 1982
Tischler and others, 1964
Wannamaker, 1983
Ward, 1983b
Ward and others, 1979, 1980, 1981
White and Heropoulos, 1983
Zoback and Anderson, 1983

Colorado Plateau Province

Best and Brimhall, 1974
Bodell, 1981
Bucher, 1971
Diment and others, 1975
Feltis, 1966
Henrickson, 2000
Mainzer, 1978
Sill and others, 1977

UTAH

Ames and Sand, 1959
Anno and others, 1978
Batty and others, 1975
Blackett, 1993
Blackett, 1994a, 1994b
Bliss, 1983
Bowen, 1975
Brown, 1982a
Cleary, 1978
Cole, 1983
Cook and others, 1975
Costain and Wright, 1969
Department of Geology and Geophysics, University of Utah, 1979
England and Johnson, 1976
Evans, 1979
Geothermal Resources Council, 1980a, 1980b, 1981a, 198le, 1981g, 1985b
Goode, 1978
Green, 1979
Green and Wagstaff, 1979
Hanny and Lunis, 1979
Hewitt and others, 1972
Heylmun, 1966
Kaliser and Grey, 1970
Klauk, 1982, 1985
Kolesar and Degraff, 1977
McNitt, 1965
Milligan, 1967
Milligan and others, 1966
Mundorff, 1970
Olson and Smith, 1977
Parry and Cleary, 1978
ReMillard and others, 1991
Renner and Galyardt, 1976
Rogers, 1978
Rowley and others, 1975
Rush, 1983
Sandquist and others, 1972
Selk, 1976
Smith, M.R., 1979, 1982
Smith and Sharda, 1978
Sprinkel, 1999
Stowe, 1977
Swanberg, 1974
Utah Department of Natural Resources, 1976
Utah Geological and Mineral Survey, 1980, 1983
Ward, Cook, Nash, and others, 1974
Ward, Cook, Parry and others, 1974
Ward, Nash, and others, 1974
Whelan, 1970
White, 1980
Wright, 1966
Wright and others, 1990
Zeitz and others, 1976

UTAH - Central

Snow, 1978

UTAH - Northern

Gilbert, 1890
Khattab, 1969

UTAH - Southern

Wechsler and Smith, 1979

UTAH - Southwestern

Best and others, 1980
Blackett and Moore, 1994
Blackett and Ross, 1992
Crosby, 1973
Mabey and Budding, 1987, 1994
Mackin, 1960b
Ross and others, 1991a, 1991b, 1995
Rowley and others, 1979
Sill and others, 1977
Sommer and Budding, 1994
Wannamaker and others, 1983

UTAH - Wasatch Front

Anderson, 1978
Cole, 1981, 1982, 1983
Pack, 1927
Talmage, 1929

UTAH - Western

Evans, 1980, 1982
Evans and Brown, 1980, 1981
Geothermal Resources Council Bulletin, 1981c
Goode, 1979
Mehnert and others, 1978
Montgomery, 1973
Nash and others, 1978
Rush, 1977
Turley and others, 1979

COUNTIES

Beaver

Abou-Sayed and others, 1977
Adhidjaja, 1981
Aerial Surveys, 1978a, 1978b
Aleinkoff and others, in press
Allen, 1983
Ash and others, 1979
Asten, 1983
Atkinson, 1981
Atkinson and Meyer, 1980
Ballantyne, G.H., 1978
Ballantyne, J.M., 1978, 1980
Ballantyne and Parry, 1978, 1979
Bamford, 1978
Bamford and Christensen, 1979
Bamford and others, 1980
Barosh, 1960
Batzle and Simmons, 1976
Berge and others, 1976, 1977
Berge and others, 1981
Best and Grant, in press
Best and Keith, 1983
Best and others, in press
Bowers, 1978
Bowman, 1979
Bowman and others, 1982
Bowman and Rohrs, 1981
Brown, 1977
Brown, 1982b, 1983
Brown and Mansure, 1981
Brumbaugh, 1978
Brumbaugh and Cook, 1977
Bryant, 1977
Bryant and Parry, 1977
Burbank City Public Service Department, 1977
Butz, 1980
Butz and Plooster, 1979
Cady, 1983
Campbell and others, 1984
Campbell and Flanigan, 1982
Capuano and Bamford, 1978
Capuano and Cole, 1982
Carlston, 1982
Carson and Livesay, 1981
Carter, 1978
Carter and Cook, 1978
Carter and others, 1977
Case, 1977
Caskey and Shuey, 1975
Cassel and others, 1978
Christensen, 1982
Christensen and others, 1980
Christensen and others, 1983
Chu, 1980
Chu and others, 1979
Ciancanelli, 1977
Ciancanelli and Corman, 1978
Clark, 1977
Cole, 1983
Combs and others, 1982
Combs and others, 1983
Condie, 1960
Condie and Barsky, 1972
Conrad, 1969
Cook and Carter, 1978
Cook, Serpa, and Pe, 1980
Cook, Serpa, Pe, and Brumbaugh, 1980
Cook and others, 1981
Cook and others, 1984
Cordova and Mower, 1976
Crebs, 1975
Crebs and Cook, 1976
Crebs and others, 1977
Cremer, 1980
Crowley, 1977, 1978
Cunningham and Steven, 1979b
Cunningham and others, 1983
Cunningham and others, 1984
Denton, 1977
DiPippo, 1985
Douze and Laster, 1979
Durham, 1977
Durham and Hoops, 1977
Earth Science Laboratory/University of Utah Research Institute, 1979
East, 1981
Edmiston and Benoit, 1985
Erickson, 1973
Erickson and Dasch, 1963
Evans, 1977
Evans and Nash, 1975 1978
Evans and Nielson, 1982
Evans and Steven, 1982
Flanigan and Campbell, 1981
Foley, 1982
Forrest, 1980
Frangos and Ward, 1980
Gabbert, 1980
Gardner, Williams, and Long, 1976
Geonomics, Incorporated, 1976b
Geothermal Power Corporation, 1978a, 1978b, 1982
Geothermal Resources Council Bulletin, 1981b, 1981h, 1981i, 1981k, 1982a, 1982b, 1982f, 1982g, 1982h, 1982k, 1983a, 1983b, 1984a, 1984b, 1984c, 1984d, 1984e, 1984f, 1984g, 1985a, 1985c
GeothermEx, Incorporated, 1977
Geotronics Incorporated, 1976
Gertson and Smith, 1979
Getty Oil Company, 1978a, 1978b
Glenn and Hulen, 1979a, 1979b
Glenn, Hulen, and Nielson, 1980
Glenn and Ross, 1982
Glenn and others, 1982
Hahl and Mundorff, 1968
Haugh, 1978a
Helton Engineering and Geological Services, Incorporated, 1978
Hewitt and others, 1972
Hinkle, 1980, 1981
Hinkle and Harms, 1978
Hinkle and others, 1978
Hoover, 1974
Huertas, 1979
Hughes, 1983
Hulen, 1978
Iyer, 1980
lyer and others, 1980
Jamin, 1982
Jensen and Qidwai, 1980?
Katz, 1977
Katzenstein and Jacobson, 1976
Kellogg and Cook, 1979

Keys, 1979
Koenig and others, 1976
Koenig and Petersen, 1977
Kruger and Semprini, 1983
Laster and Douze, 1978
Lee, 1907
Leitner, 1978
Lenzer and others, 1976
Liaw and Suyenaga, 1982, 1983
Liese, 1957
Lin, 1981
Lipman and others, 1975
Lipman and others, 1978
Lovell and others, no date
Luth and Hardee, 1980
Lynch and Nash, 1980
Mabey and Budding, 1987, 1994
Mabey and Virgin, 1980
Machette, 1982
Machette and others, 1984
Mariner and others, 1978
Mariner, Presser, and Evans, 1983
Mathews, 1979
Mathews and LaDelfe, 1981
Matlick and Shiraki, 1981
McHugh, Ficklin, and Miller, 1980, 1981
McHugh, Ficklin, Miller, and Preston, 1981
McHugh and Miller, 1981, 1982
McHugh, Miller, and Ficklin, 1984
McHugh, Motooka, and Tucker, 1980
McKinney, 1978
Micro Geophysics, 1977
Moore, 1980a, 1980b
Mooore and others, 1979
Moore and others, 1983
Mower, 1978
Mower and Cordova, 1973, 1974
Mudgett, 1964
Murphy and Entingh, 1981
Nash, 1976, 1981
Nash and Crecraft, 1982
Nash and Evans, 1978
Nash and others, 1978
Nash and others, 1980
Nathenson and Muffler, 1975
Nelson and Bromfield, 1979
Nielson, 1978, 1980
Nielson and Moore, 1979
Nielson and others, 1978
Nielson and others, 1979
Nielson and others, 1980
Nielson and others, in press
Olson, 1976
Olson and Smith, 1976
Olson and others, 1976
Parry, 1978
Parry, Ballantyne, and Bryant, 1980
Parry, Ballantyne, Bryant, and Dedolph, 1980
Parry, Nash, and Ward, 1977
Parry, Nash, Bowman, and others, 1977
Parry and others, 1976
Parry and others, 1978
Pera, 1978a
Petersen, 1973, 1975a, 1975b
Peterson, 1972, 1974
Petrick, 1976
Phillips Petroleum Company, 1979, 1980
Phoenix Geophysics, Incorporated, 1976
Pushkar and Condie, 1973
Rasband, 1981, 1982, 1983
Reimer, 1979
Robinson and Iyer, 1979, 1981
Rodriguez, 1960
Rohrs, 1980
Rohrs and Bowman, 1980
Rohrs and Parry, 1978
Ross, 1979
Ross and Moore, 1985
Ross, Moore, and Christensen, 1982
Ross, Nielson, and Moore, 1982
Ross and others, 1981
Ross and others, 1991a
Rowley, 1978
Rowley and Lipman, 1975
Roxlo, 1980
Rudisill, 1978
Sandberg, 1980
Savino and others, 1982
Sawyer, 1977
Sawyer and Cook, 1977
Schaff, 1981
Schmoker, 1972
Seismic Exploration Incorporated, 1977
Serpa, 1980
Serpa and Cook, 1979
Shannon, Goff, and others, 1983
Shannon, Pettitt, and others, 1983
Sibbett and Nielson, 1980
Sill, 1981, 1982
Sill and Bodell, 1977
Sill, Chapman, and others, 1977
Sill and Johng, 1979
Sill and Ward, 1978
Sill, Ward, and others, 1977
Smith, G.E., 1977
Smith, R.B., 1977a
Smith, J.L., 1980
Steven, Cunningham, and Anderson, 1984
Steven and Morris, 1983a, 1984
Steven, Rowley, and Cunningham, 1978, 1984
Steven and others, 1979
Stringfellow, 1982
Thangsuphanich, 1976
Thermal Power Company, 1976, 1977a, 1977b
Tripp, 1978
Tripp and others, 1976
Tucker and others, 1980
U.S. Geological Survey, 1972b, 1976, 1979a
Union Oil Company, 1973, 1974, 1976a, 1976b, 1977, 1978a, 1978b, 1978c, 1978d, 1978e, 1978f, 1978g, 1979a, 1979b
University of Denver, Denver Research Institute, 1978
Wannamaker, 1978
Wannamaker and Hohmann, 1980
Wannamaker and others, 1978
Wannamaker and others, 1979
Wannamaker and others, 1980, 1983
Ward, 1983a, 1983b
Ward, Bowman, and others, 1978
Ward, Cook, Nash, and others, 1974
Ward, Glenn, and others, 1975
Ward, Parry, and others, 1978
Ward, Rijo, and Petrick, 1975
Ward and Sill, 1976a, 1976b, 1984
Ward and others, 1977

Box Elder

Cache

Carbon

Davis

Duschene

Emery

Garfield

Grand

Iron

Juab

Turley and Nash, 1980

Kane

Lowder, 1973
Sargent and Hansen, 1976
Smedley and others, 1976
Whelan, 1976

Millard

Adhidjaja, 1981
Aerial Surveys, 1978a, 1978b
Ash and others, 1979
Bamford and Christensen, 1979
Bowman and Rohrs, 1981
Brown, 1975
Brown and Cook, 1982
Brumbaugh, 1978
Brumbaugh and Cook, 1977
Callaghan and Thomas, 1939
Campbell and others, 1984
Carrier, 1979
Carrier and Chapman, 1979, 1980
Carter, 1978
Carter and Cook, 1978
Carter and others, 1977
Case, 1977
Caskey and Shuey, 1975
Cassel and others, 1978
Christensen, 1982
Clark, 1977
Combs and others, 1983
Condie and Barsky, 1972
Conrad, 1969
Cook, Serpa, and Pe, 1980
Cook, Serpa, Pe, and Brumbaugh, 1980
Cook and others, 1981
Cook and others, 1984
Crecraft, 1984
Crecraft and others, 1980a, 1980b, 1981
Crosson, 1964
Crowley, 1977
Cunningham and Steven, 1979b
Cunningham and others, 1983
DiPippo, 1985
Earth Science Laboratory/University of Utah Research Institute, 1979
Emiston and Benoit, 1985
Evans and others, 1980
Foley, 1982
Gabbert, 1980
Galyardt and Rush, 1981
Geothermal Resources Council Bulletin, 1981j, 1982c, 1982d, 1982g, 1982h, 1984b, 1984c, 1984d, 1984g, 1985c
GeothermEx, Incorporated, 1977
Gilbert, 1890
Glenn and Ross, 1982
Glenn and others, 1982
Hahl and Mundorff, 1968
Haugh, 1978b
Hewitt and others, 1972
Hoover, 1974
Hulen, 1978
Isherwood, 1967
Ives, 1947
Johnson, 1975
Laster and Douze, 1978
Lee, 1907
Liese, 1957
Lipman and others, 1975
Lipman and others, 1978
Lynch and Nash, 1980
Mabey and Virgin, 1980
Mariner, Presser, and Evans, 1983
Mariner and others, 1977
Mariner and others, 1978
Mabey and Budding, 1987, 1994
McHugh, Ficklin, Miller, and Preston, 1981
McHugh and others, 1984
Moore, 1980b
Moore and others, 1979
Morris, 1978
Mudgett, 1964
Nash, 1981
Nash and Crecraft, 1982
Nash and Evans, 1978
Nash and others, 1978
Nathenson and Muffler, 1975
Nelson and Bromfield, 1979
Nielson and Moore, 1979
Nielson and others, 1980
Nielson and others, in press
Olson and Smith, 1976
Pampayan, 1984
Parry and others, 1976
Pera, 1978a
Peterson, 1972, 1974
Peterson, 1979
Peterson and Nash, 1980
Peterson and others, 1978
Phillips Petroleum Company, 1979
Phoenix Geophysics, Incorporated, 1976
Price, 1980, 1981
Pushkar and Condie, 1973
Reimer, 1979
Rodriguez, 1960
Ross, 1979
Ross and Moore, 1985
Ross, Moore, and Christensen, 1982
Senterfit and Bedinger, 1976
Serpa, 1980
Serpa and Cook, 1979
Sidle, 1984
Smith, T.B., 1974
Smith, R.B., 1977a
Smith, T.B., and others, 1978
Steven and Morris, 1983a, 1983b, 1984
Steven, Rowley, and Cunningham, 1978, 1984
Steven and others, 1979
Stringfellow, 1982
Turley and Nash, 1980
U.S. Geological Survey, 1972a, 1977, 1979b
Union Oil Company, 1973, 1974, 1976a, 1976b, 1978a, 1978b, 1978c, 1978d, 1978e, 1978f, 1978g, 1979a, 1979b
White and others, 1978
Woodward, 1970
Yusas, 1979a
Zimmerman, 1961

Morgan

Pera, 1978b

Piute

Adhidjaja, 1981
Campbell and others, 1984
Carpenter and Young, 1962, 1963
Cook and others, 1981
Cook and others, 1984
Cunningham and Steven, 1979b
Cunningham and others, 1983

Cunningham and others, 1984
Hahl and Mundorff, 1968
Halliday and others, 1978
Mabey and Virgin, 1980
Machette and others, 1984
McHugh, Ficklin, Miller, and Preston, 1981
McHugh and others, 1984
Nelson and Bromfield, 1979
Pera, 1978a
Reimer, 1979
Richardson, 1907
Rowley and others, 1980
Rowley, Cunningham, and Kaplan, 1981
Rowley, Steven, and Mehnert, 1981
Steven, Cunningham, and Anderson, 1984
Steven and Morris, 1984
Steven, Rowley, and Cunningham, 1978, 1984
Tucker and others, 1980
Wender, 1976
Wender and Nash, 1976, 1979

Rich

Crowley, 1977, 1978

Salt Lake

Adhidjaja and others, 1981
Berge and others, 1981
Blair and Owen, 1981
Childs and others, 1980
Cole, 1982
Energy Services, Incorporated (Idaho Falls), 1982
Felmlee and Cadigan, 1978
Geothermal Resources Council Bulletin, 1980d, 1981d, 1981f, 1982e, 1982i, 1983c
Jensen and Qidwai, 1980?
Karlsson, 1984
Klauk and Darling, 1984
Klauk and others, 1981
Kunze and Gould, 1981
Kunze and Stoker, 1979
Kunze and others, 1980
Marsell, 1951
Meiiji Resource Consultants, 1983
Miller Floral Company, 1977
Morrison-Knudson, 1982
Murphy, 1978, 1981
Murphy and Gwynn, 1979a, 1979c
Pera, 1978b
Richardson, 1906
Shirley, 1984
Skalka, 1979
Smith, Christian, 1980
Terra Tek, 1980a
Utah Energy Office, 1981
Utah Geological and Mineral Survey, 1978, 1981
Utah Roses, Incorporated, 1978
Wagstaff, 1982
Willis, 1980

San Juan

Crowley, 1978
Sass and others, 1983b
Smedley and others, 1976

Sanpete

Brown, 1975
Brown and Cook, 1982
Hahl and Mundorff, 1968
Richardson, 1907

Sevier

Adhidjaja, 1981
Aerial Surveys, 1978a, 1978b
Blair, 1980
Blair and Owen, 1982
Blair and others, 1980
Brown, 1975
Brown and Cook, 1982
Campbell and others, 1984
Carpenter and Young, 1962, 1963
Caskey and Shuey, 1975
Chapman and Harrison, 1978
Chapman and others, 1978a, 1978b
Childs and others, 1980
Cole, 1983
Cook and others, 1981
Cook and others, 1984
Cunningham and Steven, 1979a, 1979b
Cunningham and others, 1983
EG&G, Incorporated, 1979
Earth Science Laboratory/University of Utah Research Institute, 1980
Foley, 1982
Gardner, Williams, and Brougham, 1976
Geothermal Resources Council Bulletin, 1982h
Gornitz, 1979
Hahi and Mundorff, 1968
Halliday, 1978
Halliday and Cook, 1978
Halliday and others, 1978
Harrison, 1980
Harrison and others, 1979
Harrison and others, 1980
Heyl, 1978
Hulen and Sandberg, 1981
Isherwood, 1967
Kilty, 1978
Kilty and others, 1978, 1979
Mabey and Budding, 1987, 1994
Mabey and Virgin, 1980
Mariner and others, 1977
Mariner and others, 1978
Mase, 1979
Mase and Chapman, 1978
Mase and others, 1978
McHugh, Ficklin, Miller, and Preston, 1981
McHugh and others, 1984
Miller, 1976
Monroe City, Utah - Municipality, 1977
Nash, 1981
Nathenson and Muffler, 1975
Nelson and Bromfield, 1979
Nielson and others, 1980
Parry and others, 1976
Pera, 1978a
Price, 1980, 1981
Reimer, 1979
Richardson, 1907
Rowley, Cunningham, and Kaplan, 1981
Rowley and others, 1980
Sandberg, 1980
Skalka, 1979
Smedley and others, 1977
Snow and Madsen, 1978
Steven, 1979

Steven and Morris, 1983b, 1984
Steven, Rowley, and Cunningham, 1978, 1984
Steven and others, 1979
Stringfellow, 1982
Terra Tek, 1980b
Tucker and others, 1980
U.S. Geological Survey, 1979b
Ward and Sill, 1984
Whelan, 1977
Wilson, 1980
Young and Carpenter, 1965

Summit

Crowley, 1977, 1978
Pera, 1978b
Utah Geological and Mineral Survey, 1981

Tooele

Carpenter, 1913
Hogg, 1972b
Ives, 1946
Morris, 1978
Pampayan, 1984
Pera and others, 1977
Whelan and Petersen, 1974

Uintah

Crowley, 1978
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Peterson, 1979
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Murphy and Gwynn, 1979c

Belmont (Udy) Hot Springs

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Utah Geological and Mineral Survey, 1980

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Morrison-Knudson, 1982
Murphy, 1978, 1981
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Shirley, 1984
Skalka, 1979
Smith, Christian, 1980
Terra Tek, 1980a
Utah Energy Office, 1981
Utah Geological and Mineral Survey, 1978
Utah Roses, Incorporated, 1978
Willis, 1980

Crystal (Madsen) Hot Springs

Bjorklund and McGreevey, 1974
Cole, 1981, 1983
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Murphy and Gwynn, 1979b

Joseph Hot Springs

Gardner, Williams, and Brougham, 1976
Geothermal Resources Council Bulletin, 1982h
Halliday, 1978
Halliday and Cook, 1978
Mabey and Budding, 1987, 1994
Mariner and others, 1977
Mariner and others, 1978
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Terra Tek, 1980b

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Gardner, Williams, and Hoover, 1976
White and others, 1978

Meadow-Hatton

Mabey and Budding, 1987, 1994
Ross and others, 1993
Sidle, 1984

Midway Hot Springs

Baker, 1968, 1969
Jensen and Qidwai, 1980?
Kohler, 1979
Kohler and Kolesar, 1979
Ross and others, 1997

Monroe-Red Hill Hot Springs

Blair, 1980
Blair and Owen, 1982
Blair and others, 1980
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Heyl, 1978
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Mabey and Budding, 1987, 1994
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Mase, 1979
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Nielson and others, 1980
Parry and others, 1976
Samberg, 1980
Skalka, 1979
Snow and Madsen, 1978
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Terra Tek, 1980b
Ward and Sill, 1984
Whelan, 1977
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Ross and others, 1990
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Brown, 1982b, 1983, 1987
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Cochrane and others, 1988
Combs and others, 1982
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Denton, 1977
DiPippo, 1984, 1985
Douze and Laster, 1979
Durham, 1977
Earth Science Laboratory/University of Utah Research Institute, 1979
East, 1981
Edmiston and Benoit, 1985
Evans and Nash, 1975
Faulder, 1994
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Jamin, 1982
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Keys, 1979
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Koenig and others, 1976
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Leitner, 1978
Lenzer and others, 1976
Liaw and Suyenaga, 1982, 1983
Lin, 1981
Lovell and others, no date
Luth and Hardee, 1980
Mabey and Budding, 1987, 1994
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Moore, 1980a
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Moore and others, 1983
Murphy and Entingh, 1981
Nash, 1976
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Nielson, 1978, 1980
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Olson, 1976
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Parry, Nash, Bowman, and others, 1977
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Parry and others, 1976
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Phillips Petroleum Company, 1980
Rasband, 1981, 1982, 1983
Robinson and lyer, 1979, 1981
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Ross, Nielson, and Moore, 1982
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Roxlo, 1980
Rudisill, 1978
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Schaff, 1981
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Smith, G.E., 1977
Smith, R.B., 1977a
Smith, J.L., 1980
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U.S. Geological Survey, 1976
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Wannamaker and others, 1978
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Ward, 1983a, 1983b
Ward, Bowman, and others, 1978
Ward, Cook, and others, 1974
Ward, Glen, and others, 1975
Ward, Parry, and others, 1978
Ward, Rijo, and Petrick, 1975
Ward and Sill, 1976a, 1976b, 1984
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White and others, 1978
Wilson, 1980
Wilson and Chapman, 1978, 1979, 1980

Yearsley, 1994
Young and others, 1979
Yusas, 1979b
Yusas and Bruhn, 1979
Zandt and others, 1982

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Cole, 1983
Crowley, 1978
Durham and Hoops, 1977
Edmiston and Benoit, 1985
Gardner, Williams, and Long, 1976
Klauk and Gourley, 1983
Mabey and Budding, 1987, 1994
Mariner and others, 1977
Mariner and others, 1978
Mariner, Presser, and Evans, 1983
Petersen, 1973
Ross and others, 1991a
Rowley and Lipman, 1975
Sawyer, 1977
Sawyer and Cook, 1977
White and others, 1978

Utah Hot Springs

Murphy, 1978
Murphy and Gwynn, 1979b

Wasatch Hot Springs

Cole, 1982
Karlsson, 1984
Murphy, 1981
Murphy and Gwynn, 1979c

Wilson Health Springs

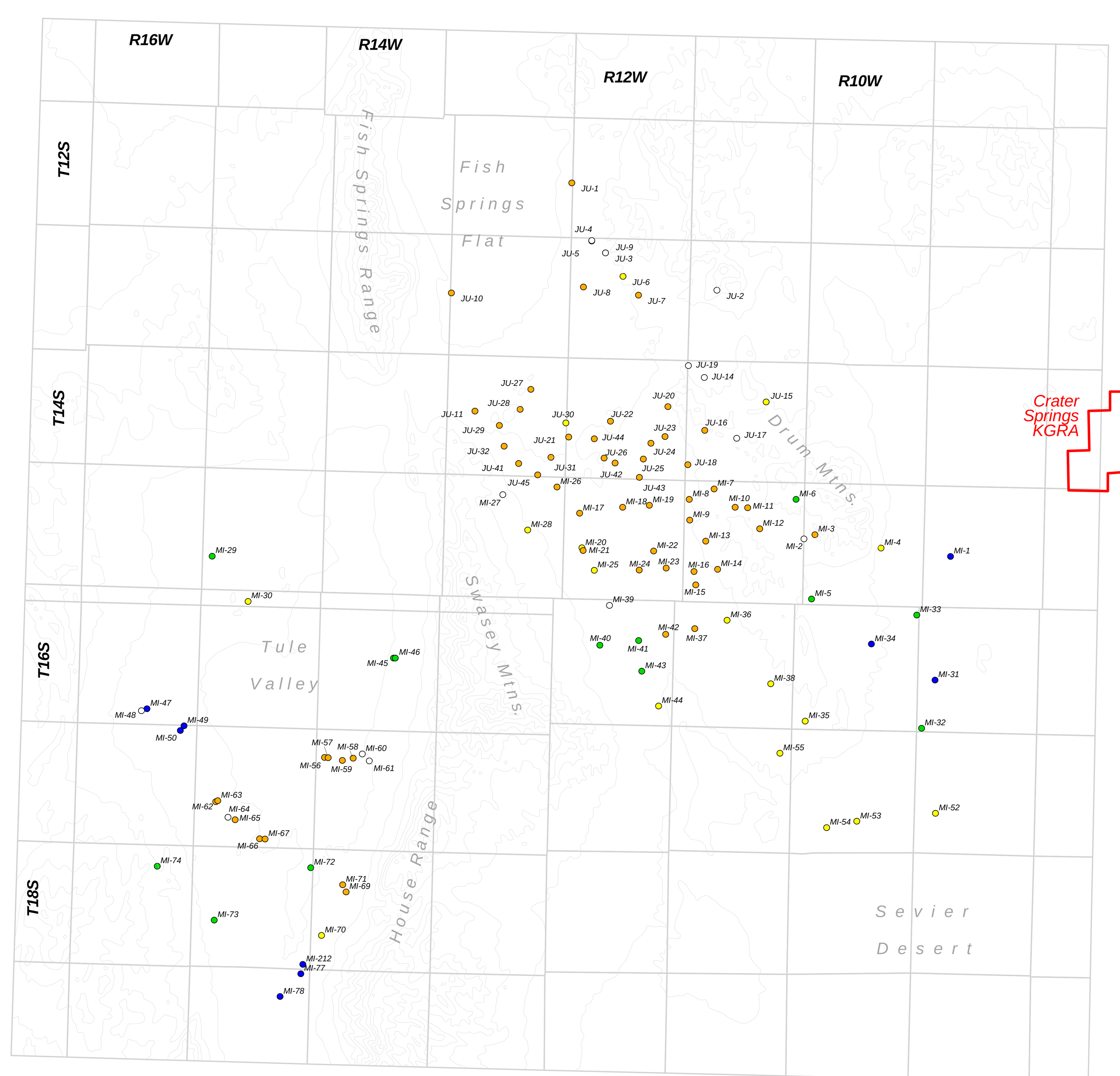
Blackett (1994)

GEOTHERMAL GRADIENT DATA FOR UTAH

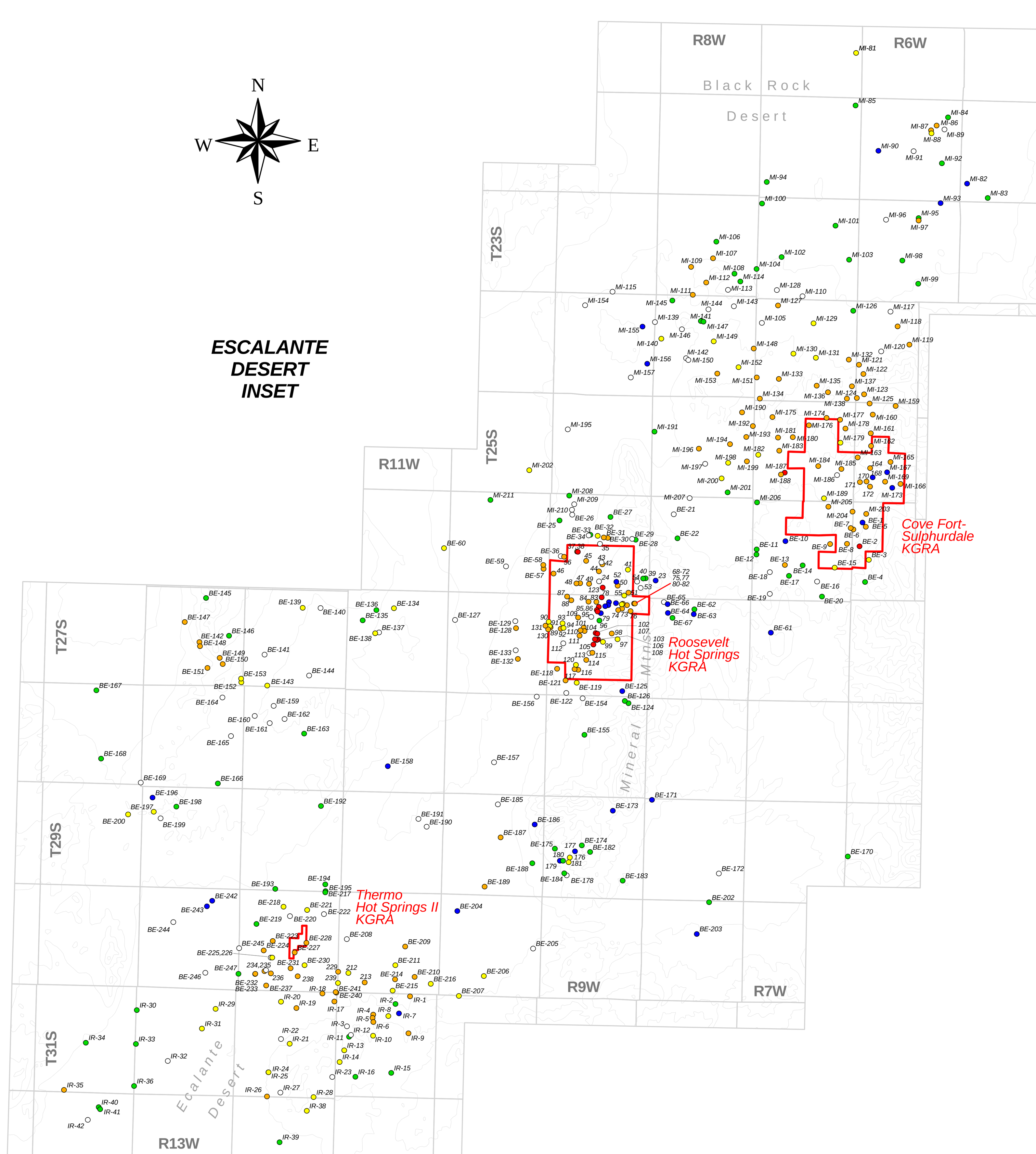
Utah Geological Survey
Open-File Report 431 DM

Plate 1: Thermal-gradient boreholes in Utah.

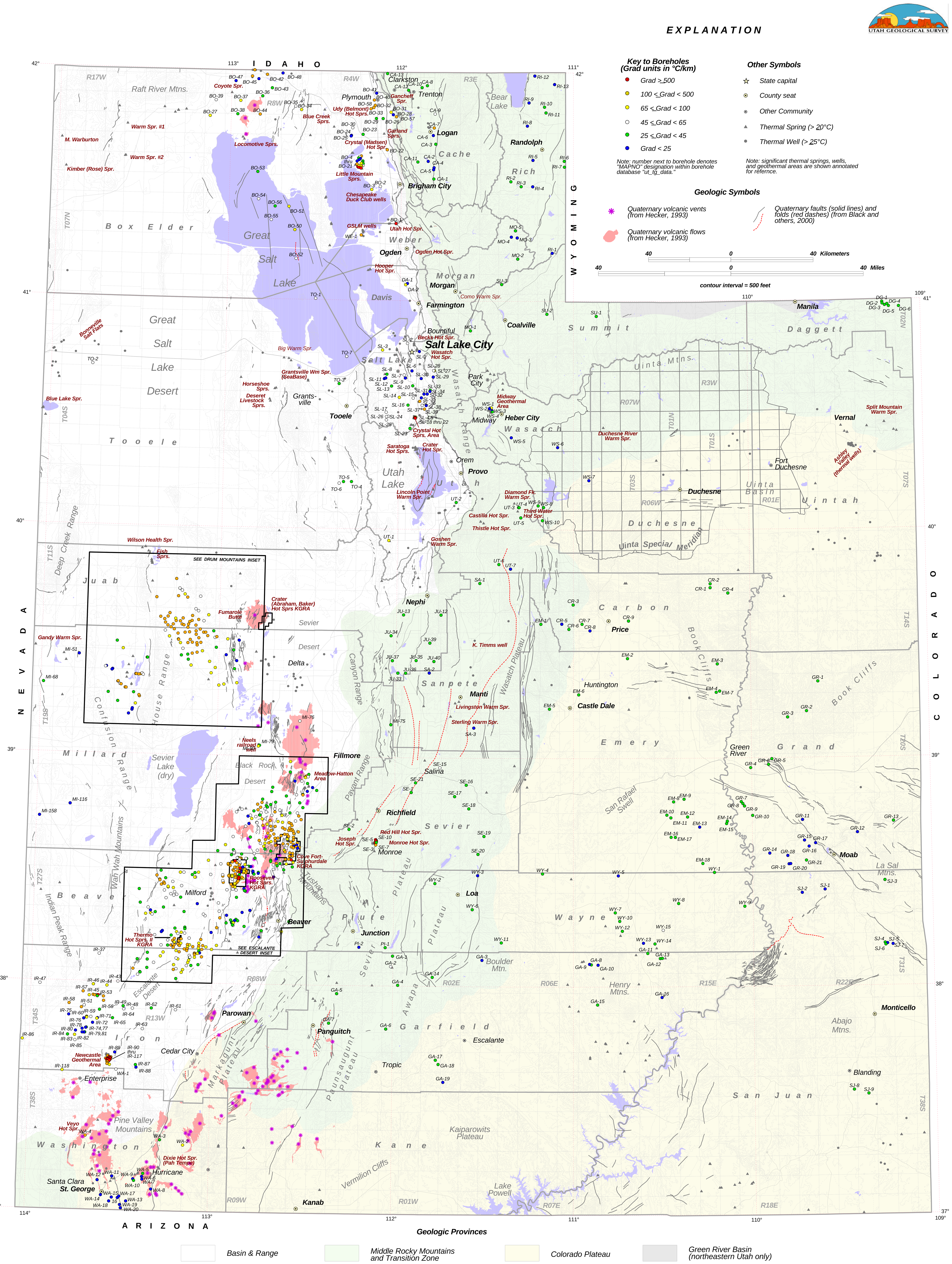
DRUM MOUNTAINS INSET



ESCALANTE DESERT INSET



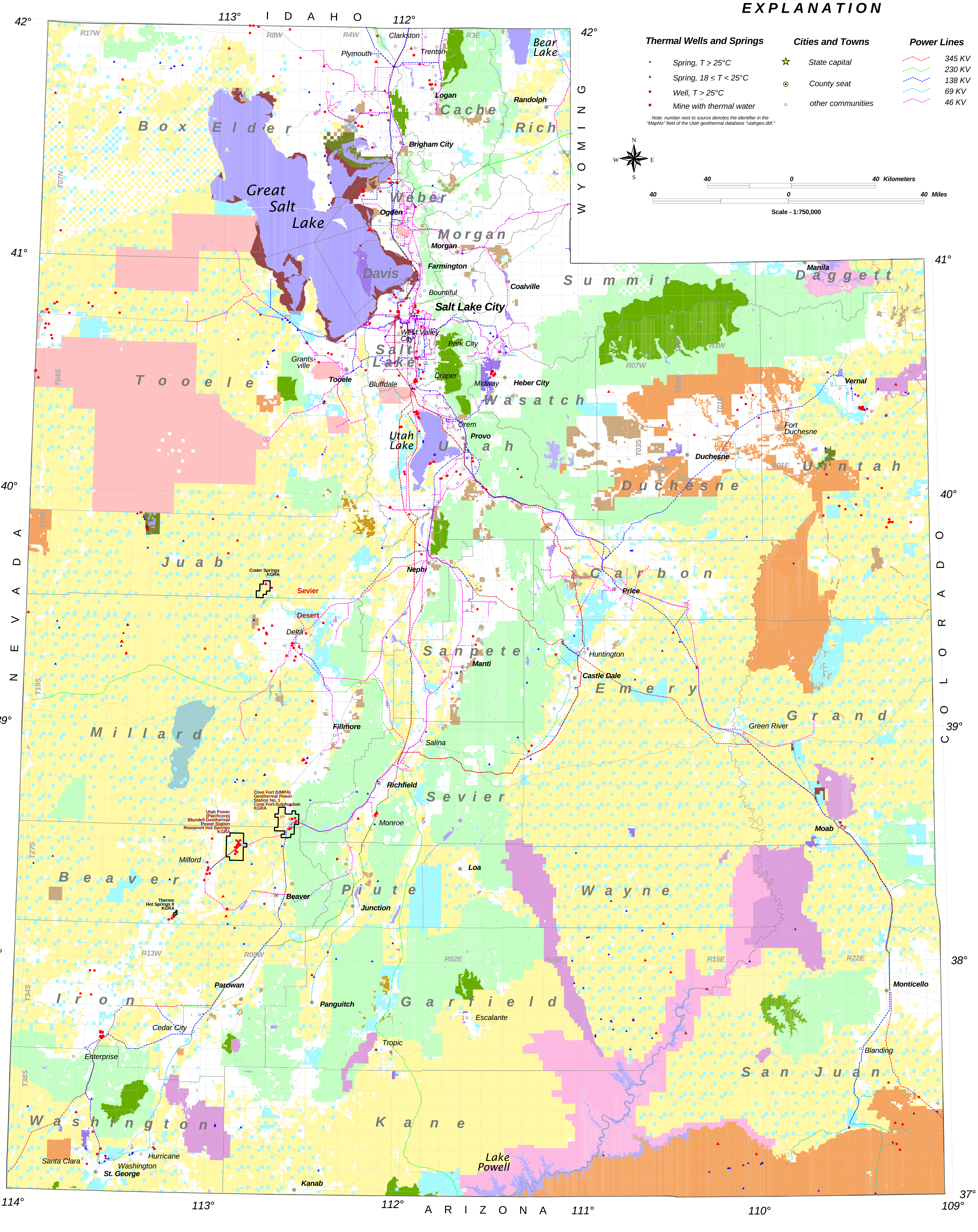
EXPLANATION



GEOTHERMAL RESOURCES OF UTAH

Geothermal Sources and Surface Management Status

UTAH GEOLOGICAL SURVEY



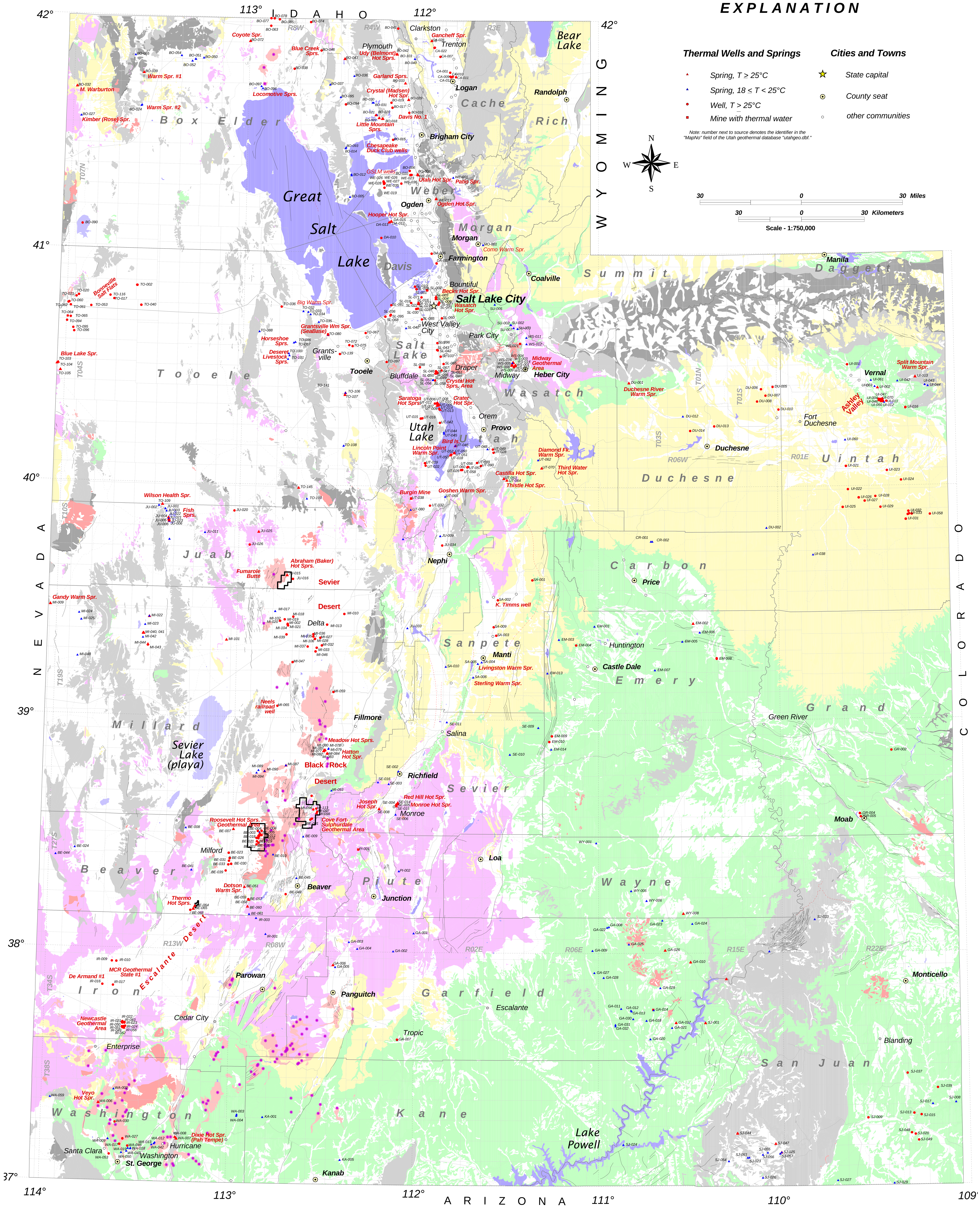
Land Management Units

U.S. Bureau of Land Mgmt.
U.S. Forest Service
Utah State Trust Lands
U.S. National Park Service Parks and Monuments
U.S. National Park Service National Recreation Areas
USFS/BLM Wilderness
Native American Reservations
Private Lands
U.S. Military Reservations
U.S. Fish & Wildlife Service National Wildlife Reserve
State Parks
Utah State Sovereign Lands (includes Great Salt Lake and navigable river beds)
Utah State Wildlife Refuge

GEOTHERMAL RESOURCES OF UTAH

Geothermal Sources and General Geology

UTAH GEOLOGICAL SURVEY



EXPLANATION

Thermal Wells and Springs

- Spring, T > 25°C
- Spring, 18 ≤ T < 25°C
- Well, T > 25°C
- Mine with thermal water

Note: number next to source denotes the identifier in the "MapNo" field of the Utah geothermal database "utahgeo.dbf."

Cities and Towns

- State capital
- County seat
- other communities

N, E, S, W

30 0 30 Miles

30 0 30 Kilometers

Scale - 1:750,000

Geologic Map Units

- Quaternary volcanic vent
- Quaternary faults and folds (dashed)
- Quaternary deposits
- Quaternary volcanic flow
- Tertiary intrusives
- Tertiary volcanics
- Tertiary sediments
- Mesozoic formations
- Paleozoic formations
- Precambrian formations
- water
- playa