Will Stratigraphic Reservoirs Provide the Next Big Increase in U.S. Geothermal Power Generation?

Rick Allis¹, Mark Gwynn¹, Christian Hardwick¹, Greg Mines², and Joseph Moore³

¹Utah Geological Survey, Salt Lake City, Utah
²Idaho National Laboratories, Idaho Falls, Idaho
³Energy and Geoscience Institute, University of Utah, Salt Lake City, Utah

Keywords
Stratigraphic reservoirs, power generation, Great Basin, Pavant Butte, Elko basins, Idaho Thrust Belt, North Steptoe Valley, permeability, levelized cost of electricity

ABSTRACT
Economic and reservoir engineering models show that stratigraphic reservoirs have the potential to contribute significant geothermal power in the U.S. If the reservoir temperature exceeds about 150 – 200 °C at 2 – 4 km depth, respectively, and there is good permeability, then these resources can generate power with a levelized cost of electricity (LCOE) of close to 10 ¢/kWh (without subsidies) on a 100 MW power plant scale. There is considerable evidence from both groundwater geology and petroleum reservoir geology that relatively clean carbonates and sandstones have, and can sustain, the required high permeability to depths of at least 5 km. This paper identifies four attractive stratigraphic reservoir prospects which are all located in the eastern Great Basin, and have temperatures of 160 – 230 °C at 3 – 3.5 km depth. They are the Elko basins (Nevada), North Steptoe Valley (Nevada), Pavant Butte (Utah), and the Idaho Thrust Belt. The reservoir lithologies are Paleozoic carbonates in the first three, and Jurassic sandstone and carbonate in the Idaho Thrust Belt. All reservoir lithologies are known to have high permeability characteristics. At North Steptoe Valley and Pavant Butte, nearby transmission line options allow interconnection to the California power market. Modern techniques for drilling and developing tight oil and gas reservoirs are expected to have application to geothermal development of these reservoirs.

Introduction
Most geothermal power developments in the U.S. have either tapped reservoirs overlying recent magmatic intrusions (Kennedy and Van Soest, 2007), and/or tapped hydrothermal reservoirs notable for permeability enhanced by near-vertical faulting (Faulds and others, 2013). Exploration since the 1970s has located the obvious hydrothermal reservoirs because of surface signatures such as hot springs, thermal ground, hydrothermal alteration, and silica deposits. Most reservoirs that are accessible and have been found to be commercially viable have already been developed; therefore, in recent years the rate of new developments has slowed, and total operating capacity in the U.S. has remained in the range of 2500 to 3500 MWe due to a variety of resource, environmental, and financial constraints (GEA, 2015).

A type of geothermal reservoir that has been investigated in Australia and Europe, but has not been an obvious exploration target in the U.S., is stratigraphic reservoirs. These reservoirs have their main permeability constrained within naturally permeable sedimentary formations, and therefore the reservoirs tend to be sub-horizontal, rather than sub-vertical and associated with fault zones and hydrothermal upflow. In reality, there is a continuum between the two types of reservoir, with faulting and stratigraphic permeability both important factors influencing the total reservoir volume, and therefore the sustainability of a production well field (McNitt, 1995). Two examples of this in the Great Basin of the U.S. are at Soda Lakes, Nevada, and at Cove Fort, Utah (Figure 1). In both cases the reservoirs have surface hydrothermal signatures...
controlled by faults, but the lateral extent of the reservoirs at depth is also clearly stratigraphic (McNitt, 1990; Rowley and others, 2013).

Studying the potential of stratigraphic reservoirs for future power generation has been supported by a U.S. Department of Energy project, with progress reported in series of publications (Allis and others, 2012, 2013; Allis and Moore, 2014). With the project now in its final year, this paper reviews several critical factors influencing the viability of these reservoirs, and then highlights what are the best prospects we have identified so far. The goal of this paper is to show that large-scale geothermal power developments are possible if modern technologies for drilling and permeability enhancement from petroleum exploration can be adapted and applied to stratigraphic geothermal resources. If the geothermal industry focuses on reservoir potential at 3 – 4 km depth, and developments that are 100’s of MWe in scale are considered, then there are economies of scale offsetting the costs of increased reservoir depth, and numerous development opportunities are apparent.

Increased Reservoir Depth Target

Most developed geothermal reservoirs in the U.S. are at 1 – 3 km depth. Sanyal and others (2007) highlighted the change in production technology required at a reservoir temperature of about 190 °C between pumps on wells at lower temperatures, and self-discharging wells at higher temperatures (Figure 2). When considering the temperatures in deep basins, there is a pronounced difference between the temperature – depth character of typical petroleum reservoirs and geothermal reservoirs. A levelized cost of electricity (LCOE) threshold derived from economic modeling provides a temperature-depth guide to the more attractive stratigraphic geothermal reservoirs (derived from Mines and others, 2014). If development of geothermal reservoirs at 3 – 4 km depth is economically viable, then there are many stratigraphic reservoir targets in the northern Great Basin where the heat flow is about 90 mW/m². The economic models do not include any subsidies.

Figure 1. Two cross-section examples (reproduced from the original publications with minor modifications) of developed hydrothermal reservoirs where there is strong stratigraphic control to the permeability. In the case of Soda Lakes, the main permeability is relatively shallow at the base of the Truckee Formation, and lateral flow into the structural high from beneath the adjacent Carson Sink is suspected (McNitt, 1990; 400 °F is close to 200 °C). At Cove Fort, numerous wells have confirmed high permeability within Paleozoic carbonate units (labelled Pq, Pp and IPOu). Overlying Tertiary volcanic units (labelled Ta, Tb, etc.) act as a cap separating groundwater from the reservoir. In both cases, faults locally allow hot fluids to leak to the surface, and there are intrusive rocks at depth beneath the main reservoir.

Figure 2. Contrast in thermal regimes of typical petroleum reservoirs and geothermal reservoirs. A levelized cost of electricity (LCOE) threshold derived from economic modeling provides a temperature-depth guide to the more attractive stratigraphic geothermal reservoirs (derived from Mines and others, 2014). If development of geothermal reservoirs at 3 – 4 km depth is economically viable, then there are many stratigraphic reservoir targets in the northern Great Basin where the heat flow is about 90 mW/m². The economic models do not include any subsidies.
teristics of most petroleum reservoirs, and those of most hydrothermal reservoirs. In high heat-flow settings, especially if there is a significant thickness of low thermal conductivity rocks (such as basin fill or shale), temperatures of about 200 °C can be found at 3 – 4 km depth where the heat flow is more than 90 mW/m². There are large areas in the western U.S. where such heat flows are common, especially in the Great Basin (Blackwell and others, 2011; Williams and DeAngelo, 2011). The high heat flow areas in the Great Basin are one of the largest, if not the largest, high heat-flow land areas in the world (30% of 500 x 500 km area at > 200 °C at 4 km depth; MIT, 2006). The 3 – 4 km depth range is an obvious target for the next generation of geothermal power developments in the U.S.

Can We Find Adequate Permeability at 3 – 4 km Depth?

Evidence from permeability tests in petroleum reservoirs confirms that permeabilities in the range of 30 – 100 mD are not uncommon at depths greater than 3 km (Figure 3). Kirby (2012) compiled permeability measurements from the western U.S. and found the geometric mean permeability between 3 and 5 km depth is 75 mD for carbonates and 30 mD for siliciclastics. There is no evidence in this dataset that permeability decreases with depth between 1 and 6 km depth with these two lithologies. However, there is a strong trend of decreasing permeability with depth in igneous rocks (volcanics and intrusives; most data is less than 2.5 km depth), probably due to the mixed mineralogy of igneous rock and their sensitivity to alteration and plugging of permeability with increasing temperature. Clean sandstones and carbonates appear to be the lithologies most likely to sustain permeability at depth and are an obvious target as possible reservoir rocks.

The effective reservoir thickness with a target permeability of 10 – 100 mD is another important factor influencing the heat sweep efficiency (heat recovery factor) within a reservoir. Modeling of different reservoir-seal “sandwiches” comprising four 25-m-thick horizontal layers with permeabilities of 100 mD within a 300-m-thick host rock of 1 mD showed very different thermal responses over 50 years of production and injection (Roehner and others, 2014). The models utilized a five spot pattern with a 500 m well spacing, with flow rates in producer and injector wells of 63 L/s (1000 gallons per minute). The sandwich model with a cumulative reservoir “pay zone” transmissivity of 10 D-m, had a power density declining from 10 to 4 MWe/km² after 30 years of production, with the thermal rundown starting after about 10 years. Not surprisingly, the more dispersed the flow regime in multiple layers, the better the heat sweep efficiency and the slower the thermal decline. However, when the transmissivity of the reservoir decreases to 3 D-m, the improved heat sweep efficiency is compromised by excessive pressure decline in the production wells. Modeling including the parasitic loads of pumps, and investigating the impacts of varying production flow rate, well spacing and configuration, and reservoir permeability characteristics are continuing.

An important difference between stratigraphic reservoirs and faulted hydrothermal reservoirs commonly developed to date in the Great Basin is reservoir volume and the scale of developments. Reservoir areas of less than several square kilometers for hydrothermal systems in the Great Basin (Blackwell and others, 2012) mean modest sustainable power generation levels, typically less than 50 MWe. With stratigraphic reservoirs, the potential area of the reservoir can be almost basin scale, and therefore hundreds of square kilometers. Once a discovery well verifies the thermal regime, permeability characteristics, and their relationship to the stratigraphy, subsequent step-out wells have much lower risk. Although the main permeability is sub-horizontal, if faults are also present, they may be zones of enhanced permeability that become important targets for wells.

The possibility of laterally extensive, high permeability carbonate units at depth beneath the eastern Great Basin having an effect on regional heat flow has long been recognized (Sass and others, 1971; Lachenbruch and Sass, 1977; Blackwell, 1983). Recent work by the USGS reassessing the hydrogeology of the Great Basin carbonate system has characterized the key hydrological units (Heilweil and Brooks, 2011; Figures 4, 5). Of greatest interest for the geothermal reservoir potential is the “lower carbonate aquifer unit” which comprises mainly Cambrian through Devonian lime-
stone and dolomite, and is prominently exposed in the mountain ranges. The USGS compilation of hydraulic property measurements indicates it has a geometric mean hydraulic conductivity of 4 feet per day (about 150 mD; the average depth of these measurements not stated), and a maximum thickness of 5 km. The cross sections in Figure 5 show there is good connectivity in a north-south direction, but early compressional faulting, followed by extensional faulting in the Cenozoic, has dissected the unit in an east-west direction. Masbruch and others (2012) confirmed that lower heat flow in the southern sector of the carbonate system is due to groundwater recharge and lateral (mostly southern) drainage of cool groundwater at depth. The large “Eureka heat flow” in the southern Great Basin is attributed to this effect (Sass and others, 1971). More important for preserving high temperatures within permeable carbonate units will be the areas of the Great Basin where interbasin flow is more subtle and perhaps directed inwards to hydrologic sinks with no, or minimal, lateral outflow. Numerous examples exist in the northern half of the Great Basin carbonate system.

**Levelized Cost of Electricity (LCOE) With Reservoirs at 3 – 4 km Depth**

The greater depth of these reservoirs raises questions about whether the extra drilling costs still allow a viable project. The effects of many factors were investigated by Mines and others (2014) using the GETEM modeling tool. An important difference from many recent hydrothermal developments in the Great Basin is the scale of development for stratigraphic reservoirs. With potential areas of 100’s to 1000’s km² within basins, rather than 1 – 10 km² for fault-bounded systems, 100+ MW power plants are feasible, and significant economies of scale are possible (for example, drilling costs). The drilling costs assumed by Mines and others (2014) were based on 2013 prices, and the cost of a 3 – 4 km deep well ranged between $5 - $10 million depending on assumptions of “smaller” diameter (7 inch perforated inside 8.5 inch casing) or “larger” diameter (9.625/12.25 inch). Another critical variable was the reservoir productivity/injectivity index (PI/II), which ranged from the GETEM default of 52

**Figure 4.** Shaded relief map (feet above sea level) of the eastern Great Basin and western Colorado Plateau. The Great Basin Carbonate System (Heilweil and Brooks, 2012) occupying the eastern half of the Great Basin is dashed. The hydrogeology beneath two cross sections labeled as A-A’, B-B’ (heavy blue dashes) is shown in Figure 5. Geothermal power plants, and wells referred to in the text, are also highlighted. The four areas promoted here as having the best proven stratigraphic geothermal reservoir potential are Pavant Butte, North Steptoe Valley, the Elko basins, and the Idaho Thrust Belt (black dashed ellipses). Power plant abbreviations are: B, Beowawe; BM, Blue Mountains; Br, Brady; C, Coso; CF, Cove Fort; DP, Desert Peak; DQ, Desert Queen; DV, Dixie Valley; M, Mammoth; MG, McGuinness; Pt, Patau; R, Roosevelt, RR, Raft River; SE, San Emidio; SL, Soda Lakes; St, Stillwater; SW, Salt Wells; Th, Thermo; Tu, Tuscarora; W, Wabuska; WR, Wild Rose. Deep well abbreviations are: BH, Bighorn #2-3 in Wind River Basin; MOC, Mobil O’Connell well in eastern Piceance Basin; RV, Railroad Valley.

**Figure 5.** Cross sections illustrating the three-dimensional hydrogeological framework developed by the USGS for the Great Basin carbonate and alluvial aquifer system (Sweetkind and others, 2011; Masbruch and others, 2012). The deep blue lower carbonate aquifer unit represents potential stratigraphic geothermal reservoirs wherever the temperature is in the range of 150 - 200 °C. The cross-section lines are shown on Figure 4. The red ellipses highlight zones where stratigraphic geothermal reservoir targets have been identified by this project. The volcanic and basin-fill units are Tertiary and younger. Remaining units are Paleozoic and older. There is no TLCAU on these two cross sections.
L/s/bar (mod PI/II) to 104 L/s/bar (Hi PI/II). Although initial modeling runs assumed a reservoir decline rate of 1% per year, based on the reservoir modeling discussed above, the positive cash-flow effect on the LCOE of delayed thermal decline by a decade was also considered. Examples of some of these variables are shown in Figure 6.

The effects on the LCOE from the interplay between the various factors are discussed by Mines and others (2014). Perhaps the most useful guideline for this paper is that if the LCOE is to be close to 10e/kWh, then reservoir temperature has to increase from about 150 °C for a reservoir depth of 2 km, to about 200 °C when the reservoir depth is 4 km (LCOE “threshold” shown on Figure 2). The increasing efficiency of the power conversion with increasing temperature compensates for the increased cost of deeper wells. At 4 km depth all the variables need to be favorable, so a reservoir target not significantly deeper than 3 km and close to the maximum temperature of pumps (~ 190 °C) is considered optimal for a stratigraphic reservoir. Once the viability of these reservoirs is demonstrated, a greater range of reservoir conditions should be a target. A characteristic heat flow geotherm for the northern Great Basin of 90 mW/m² grazes the 10¢/kWh LCOE threshold at reservoir depths between 3 and 4 km (Figure 2).

Four Attractive, Undeveloped Reservoir Prospects

Four areas in the eastern Great Basin are attractive prospects because of evidence for reservoirs having both the required temperature and a stratigraphic, high-permeability target. These are the Elko basins (Nevada), North Steptoe Valley (Nevada), Pavant Butte (Utah), and the Idaho Thrust Belt (Figures 4, 7). Details of the thermal characteristics of each of these can be found in: Elko basins (Gwynn and others, 2014; Kirby and others, 2015); N. Steptoe Valley (Allis and others, 2012; Gwynn, 2015); Pavant Butte (Gwynn and others, 2013; Hardwick and others, 2014; Allis and others, 2015); and the Idaho Thrust Belt (Welhan and others, 2014; Welhan and Gwynn, 2014). Here we summarize the key features that make these prospects attractive. Characteristic cross sections are shown in Figure 8.

The Elko basins comprise the following basins from northeast to southwest: Toano, Marys River, Huntington, and Pine Valley. We suspect Crescent Valley may also be included, but there is insufficient deep well data. On the basis of a small amount of deep well data, the Ruby-Goshute Valleys appear to be significantly cooler. However, in this case, very shallow (typically less than 150 m depth) thermal gradient data in central Ruby Valley (Phillips Geothermal data documented in Sass and others, 1999) suggest the possibility of gradients of 70 – 100 °C/km, so additional thermal information is
Allis, et al.
nEEDED TO RESOLVE THE UNCERTAINTIES. A VERY SIMPLE CROSS SECTION IS SHOWN IN FIGURE 5 (A–A’), BUT THE GEOLOGICAL SETTING IS COMPLEX. LOWER PALEozoIC carBONATES FORM A THICK SECTION AT DEPTH IN THE EAST, BUT IN THE WEST THIS CARBONATE PLATFORM HAS BEEN OVERRIDEN FROM THE WEST BY TYPICALLY MORE SILICICLASTIC, DEEP-WATER MARINE ROCKS OF THE roberts mountain thrust belt. AT Beowawe geothermal field on the west edge of these basins there is a thick sequence of low-permeability, shale-rich Ordovician rock which is inferred to overlie carbonate units at greater depth (Zoback, 1979; Kirby and others, 2015). IN Blackburn oil-field (Pine Valley), the oil reservoir is in devonian dolomite and this is overlain by 2 km of tertiary volcanics and younger basin fill. a substantial gravity low in Marys river Basin suggests over 3 km of basin fill (Heilweil and Brooks, 2011). the reservoir target for geothermal development is the lower Paleozoic carbonate unit (LCAU of Sweetkind and others, 2011), but an integration of the geology with reinterpreted seismic lines and a 3-D gravity survey are needed before deep drilling is justified. there appear to be lateral variations in the thermal regime within and between the basins, so confirmation with some new heat-flow holes is also required. the most attractive area within the Elko basins at the moment is the Marys river Basin. the One Nevada transmission line that is planned to connect renewable energy power projects in northeast Nevada and southern Idaho with southwest Nevada and California was completed as far north as Ely in 2013. the planned route further north passes through the Elko basins, and may be important if large-scale geothermal power generation is viable here.

North Steptoe Valley has both the thermal regime and the reservoir target relatively well-determined. Shell Oil (Shell-1) and Placid Oil (well 17-14) drilled in the center of the valley, and confirmed 2 km of valley fill and predominantly Paleozoic carbonates and shale to at least 3566 m depth. the temperature between 3 and 3.5 km depth ranges between 170 and 200°C. Four carbonate units, the Guilmette Formation, Simonson Dolomite, Sevy Dolomite, and Ely Springs Dolomite, are known elsewhere to have characteristically high permeability. these units represent a potential reservoir section more than 500 m thick. In addition, faults may enhance the permeability in this section of the Placid Oil well. About 20 km to the south, Hunt Energy Corp. conducted some temperature-gradient drilling in the late 1970s and then drilled two geothermal exploration wells (Chovanec, 2003). the deepest well (74-23) had a temperature of 198°C at its total depth of 3308 m. the continuous temperature profile in this well is remarkably similar to the trend of corrected bottom hole temperatures (BHTs) in the two wells in the center of the valley to the north. Well 74-23 penetrated a quartz monzonite intrusion below about 1700 m depth, which confirms the gravity anomalies and suggests the basin is slightly deeper, extending at least 20 km farther north. Based on the present information, the prospective area with attractive temperatures at about 3 km depth extends over at least 200 km². More detailed gravity data is required to better define the base of the surface fill, and some modern seismic reflection surveying is also required to image the lower Paleozoic carbonate section (i.e., beneath the chainman Shale) and faults such as the one suspected at 3200 m in the Placid Steptoe well 17-14 (figure 8). Some oil industry seismic lines have been collected in this valley, but unfortunately the quality of the reflections from beneath the valley fill is poor (Schelling and others, 2013). Based on the known potential reservoir section at 3 km depth in the middle of the valley, and the apparent uniformity of the thermal regime across the basin, even with a conservative power density of 3 MWe/km², Allis and Moore (2014)
suggest this basin should support a power plant of several hundred MWe. Connection to the present northern terminus (Robinson sub-station) of the new One Nevada line is 30 miles from North Steptoe Basin.

Pavant Butte has a well-determined thermal regime based on the Pavant Butte oil exploration well and its re-entry by Phillips Geothermal two years after being plugged and abandoned by Arco. The best-fit geotherm using thermal conductivities measured on cuttings from Pavant Butte 1 (Edwards, 2013) has a heat flow of $140 \pm 20 \text{ mW/m}^2$, and predicts a temperature of 238 °C at 3 km, and 281 °C at 4 km depth. These results suggest some of the highest temperatures in Utah at these depths may exist near Pavant Butte volcano. High-permeability characteristics that could be geothermal reservoir targets are the Quaternary fault zone that traverses the graben, and stratigraphic permeability such as that described by Allis and others (2012) and Allis and Moore (2014). The Pavant Butte 1 well drilled a 400 m section of Lower Cambrian bedrock at the bottom of the well, which is known to be permeable where it outcrops around the basin, but there were no strong indicators of high permeability within the well. The Lower Cambrian section included limestone, phyllite and quartzite (Hintze and Davis, 2003). Allis and others (2012) noted fractures at 3040 m (mud loss of 15 barrels) and possible fractures from 3064 to 3069 m, and from 3266 to 3274 m. Reinterpretation of existing seismic lines (1980s vintage), and some additional shallow heat-flow holes are needed to refine the reservoir target and establish whether the thermal anomaly is centered beneath the axis of the basin, or beneath Pavant Butte volcano. There are several transmission line options close to Pavant Butte that allow easy connection to the California power market.

The Idaho Thrust Belt has the least amount of thermal data of the four prospects, but three deep oil exploration wells have temperatures of 160 to 230 °C at about 3 km depth, suggesting a substantial resource in a 300 km² area. At this stage it is unclear whether the high heat flow is associated with the late Quaternary Blackfoot volcanic field to the southwest, or whether the thermal anomaly is a flank effect of the high heat-flow Snake River Plain to the north. Welhan and others (2014) suggest that limestone and sandstone of Pennsylvanian to Jurassic age at 3 – 5 km depth represent target reservoir rocks (Figure 8). The Jurassic Nugget sandstone is a prolific oil producer further south in the thrust belt; it is known to have permeabilities of about 100 mD (Lindquist, 1988), sufficient for a geothermal reservoir, and occurs at about 3 km depth in the thrust belt. There is some evidence for brines in deeper parts of the thrust belt, and Welhan and others (2014) also suggest that lateral (stratigraphic) movement of pore fluid could be influencing the thermal regime. Additional heat-flow measurements are needed to better delineate the resource before deep drilling is attempted. A high-voltage transmission line runs northwest from Soda Springs and is about 30 km from the high heat flow area (Welhan, pers. comm., 3/30/2015).

Conclusions

The thick, shallow-marine carbonate platform that developed during the early Paleozoic and is now at varying depths below the ground surface of the eastern Great Basin is considered by hydrologists to be an important aquifer contributing to interbasin flow. This aquifer is also a natural geothermal reservoir target where it has the optimal temperature (150 – 200 °C) and depth (3 – 4 km) for economic power generation. The sub-horizontal characteristics of stratigraphic units mean that these reservoirs can have areas of hundreds of square kilometers, and the potential to support power plants of hundreds of MWe. Where these aquifer/reservoir units outcrop or have been used for groundwater developments, their high permeability has been proven. Permeability measurements from drill stem tests in oil reservoir exploration in the western U.S. confirm that clean carbonates and sandstones can have the required high permeability for geothermal wells at depths to at least 5 km.

Four examples of potential stratigraphic geothermal reservoirs at about 3 km depth are identified in this paper. At Pavant Butte the reservoir is Cambrian carbonate, in the Elko basins it is Devonian dolomite, in North Steptoe Valley it is Mississippian carbonate, and in the Idaho Thrust Belt it is Jurassic sandstone and limestone. In all four cases the thermal regime is reasonably well determined, although additional heat-flow measurements are recommended. The greatest risk for development is proving that the necessary permeability is actually present. An exploration well to reservoir depth is still required before planning and scaling up for a power project in these prospects. With tight oil and gas exploration in a new play, a “stiletto” strategy is sometimes used, with the first deep well being near-vertical and used for intensive downhole investigations prior to a program of horizontal drilling. Seismic reflection surveying, which has been of limited value for developing fault-hosted hydrothermal systems in the Great Basin, is considered an essential exploration technique in defining both structure and stratigraphy prior to deep drilling of stratigraphic reservoirs. One advantage of developing these reservoirs is once the optimal drilling and stimulation technique has been established, the rest of the well field should be simple step-out grid drilling, and economies of scale should reduce the cost per MWh. Recent technological advantages in drilling in tight oil and gas fields in the U.S. have shown significant savings with centralized drill pads accommodating more than 20 wells, and skid-mounted rigs that can be slid several meters to their next well head position without dismantling. Acid stimulation techniques, which are common in carbonate oil reservoirs, are also likely to be applicable in these geothermal reservoirs.
Acknowledgements

This paper is part of a project titled: “Novel Geothermal Development of Sedimentary Basins in the United States,” Moore, J.N. and Allis, R.G. (co-Principal Investigators), which is partially funded by the Geothermal Technologies Program of the U.S. Dept. of Energy (Award DE-EE0005128). Many colleagues also contributed to parts of this project and are included in the list of references. We thank Josh Crowell (UND) and Mike Hylland (UGS) for helpful reviews.

References


