Regional Geophysics of the Dixie Valley Area: Example of a Large Basin and Range Geothermal Resource

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Introduction

The Dixie Valley Producing field (DVPF, see Figure 1) was developed between 1979 and 1988. During the last 14 years about 60 MW of electrical power have been produced here, initially by Oxbow Power (since 2000 by Caithness). This geothermal system has been described by Benoit (1992, 1999). The field consists of two groups of production wells in sections 33 and 7, with injection wells in between (section 5) and to the south (section 18 and Lamb Ranch). The DVPF has the highest temperatures (248°C) found in the province in a nonmagmatic producing geothermal system. There are numerous geothermal sites in Dixie Valley in addition to the production area. These include several hot springs - Sou, Seven Devils, Dixie Meadows, Lower Ranch and Hyder; three blind areas- Dixie Comstock Mine, Pirouette Mountain and Eleven Mile Canyon; along with other geothermal areas as shown in Figure 1. In the case of the blind areas, high temperatures were noted in an audit in the Dixie Comstock mine, and two others were located by random areal thermal gradient drilling in southern Dixie Valley- Pirouette Mountain and Eleven Mile Canyon, (Hunt, unpublished data, Western Geothermal Database, 2001). Another nearby blind system, McCoy, was located by temperature logging of an existing stock well (Olsen, *et. al.*, 1979). There are two separate producing regions in the Dixie Valley Producing Field (DVPF) in sections 7 and 33 (see index map in Blackwell, *et. al.*, 2002) and a very hot region in the Dixie Valley Power Partners (DVPP) area immediately to the south where temperatures reach 285°C in well 36-14. Two areas of fumaroles (Senator and section 10, 25N/37E) are associated with the DVPF and DVPP areas. Drilling has confirmed temperatures of at least 198 °C at 2.5 km depth between the Dixie Comstock area to the south and the Senator fumaroles to the north. In spite of all of the evidence of thermal activity throughout the valley, deep wells have only been drilled near the producing field, and at the south end of the valley where Hunt drilled three deep wells in 1979/80.

The number and extent of the thermal anomalies in a setting of active Basin and Range faulting suggests that there are undiscovered resources there. Therefore, the Dixie Valley area is clearly a regional geothermal target. The objective of this paper is to summarize the structural characteristics of the greater Dixie Valley area as an indication of locations and settings that might be favorable for additional exploration of the geothermal potential of this large area.

Geophysical Data

Seismic Data

Seismic reflection data are available for the area of the producing geothermal field and the area to the north. These data are discussed by Blackwell, *et. al.*, (2002) along with the detailed gravity and magnetic studies, and the drilling results. Widely spaced refraction data were described by Thompson, *et. al.*, (1967).

Thermal Gradient Drilling

A large number of wells, to a variety of depths, were drilled in the exploration phase in the late 1970's and early 1980's. Thermal data for many of the wells (223, of which 96 have depth information) are included in the Western Geothermal Database (WGD) (Richards and Blackwell, 2002). There are 53 wells in the depth range of less than 150 m and 31 wells in the depth range of 150 to 650 m in the WGD. There are 7 deep wells, more than 2000 m, outside of the Dixie Valley Producing Field and the Dixie Valley Power Partners areas (Blackwell, *et. al.*, 2000). Four of the wells are in the northern part of the valley. One is located to the north, one to the east, and two to the south (one of them near the Dixie Comstock mine, 45-14). Three deep wells were drilled at the extreme southern end of the valley in the Pirouette Mountain and Eleven Mile Canyon areas. At least some results are available for all of these wells except the southern most pair.

Gravity Data

Gravity is important because it proved key in understanding the nature of the fault system in the producing field (Blackwell, *et. al.*, 1999) and these studies may give information on the possible reservoir structure in other parts of the valley. There have been many gravity studies carried out in the Dixie Valley area. These included widely spaced regional measurements and a study carried out in the southern part of the valley for Hunt Oil in the late 1970's (unpublished report, 1979). Detailed local studies were carried out in the vicinity of the producing field for Sun Oil and Southland Royalty (AMOCO, unpublished, 1979; TransPacific, unpublished, 1979). In 1996, we carried out a detailed study along the range front in the vicinity of the DVPF and the DVPP areas (Blackwell, *et. al.*, 1999). In 2000, we carried out a study to fill in along the range front between the 1996 studies and the Hunt survey to the south. These data have all been combined and are shown in Figure 1 and described for the first time here. A residual Bouguer anomaly map is shown. The residual was calculated by removing a smoothed average gravity value from the regional complete Bouguer gravity anomaly values.

Dixie Valley shows clearly as a region of negative residual gravity (generally about –15 mgal in the lowest areas) due to the low density of the valley fill with respect to the bedrock ranges. The valley essentially terminates near the northern and southern ends of the figure. The gravity in the Stillwater Range is about +15 mgal while in the Clan Alpine Range the residual gravity values range from over +10 to about 0 mgal. The gravity relief is less in the southern half of Dixie Valley, particularly with respect to the areas to the south and east. The Clan Alpine Range has Cenozoic volcanics exposed over most of the surface area and so there is less of a density contrast with the sediments in Dixie Valley. At both the southern and northern ends of the valley there are abrupt changes in the strike of the gravity gradients between the valley and the bedrock. At the north end this change in strike is associated with a change in strike of the mapped young faults (Smith, *et. al.*, 2002).

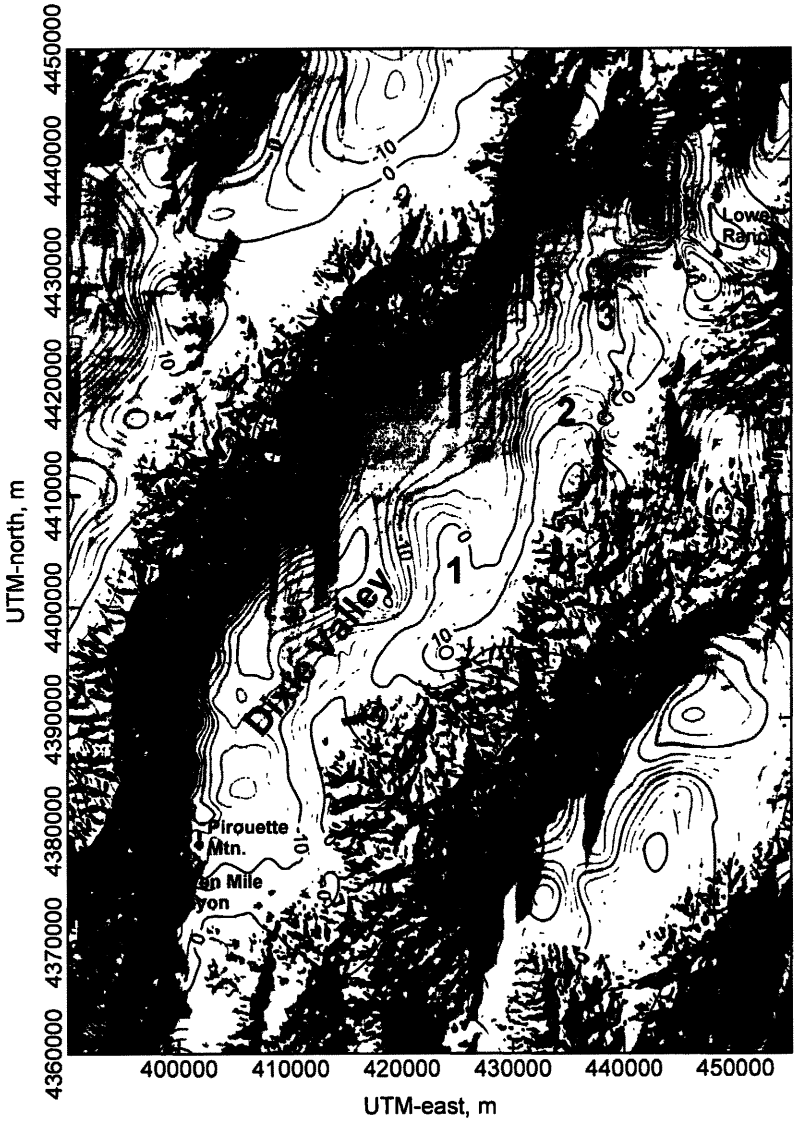

Figure 1. Residual Bouguer gravity anomaly map of the Dixie Valley area. Geothermal sites mentioned in the text are located and named.

Magnetic Data

A very early aeromagnetic survey of the area was described by Smith (1968). Aeromagnetic surveys were also a part of the exploration activities of the late 1970's and early 1980's (AMOCO, unpublished, 1979; Senturian, unpublished, 1979). More recently in early 2002 a high resolution low altitude aeromagnetic study was carried out based on success in imaging shallow expressions of intrabasin faults in the Albuquerque Basin (Grauch, *et. al.*, 2001). That survey is described by Smith, *et. al.*, (2002).

Discussion

The location of the major faults along the boundary between Dixie Valley and the Stillwater Range are of particular interest. At a broad scale the steepness of the gravity contours will outline the regions of greatest density contrast. A way of focusing on the locations of valley bounding faults is to calculate a slope map of the residual gravity anomaly. The steepness of the slope is related to the relief and the geometry of the range/valley contact. The locations of the maximum gravity slope values are shown as a line in Figure 2. The heavy line indicates a very steep gradient while the medium thickness line indicates a shallower, but significant, slope. In addition the range front fault is shown as the dashed line north of Dixie Meadows hot springs and as the location of the 1954 break south of Dixie Meadows.

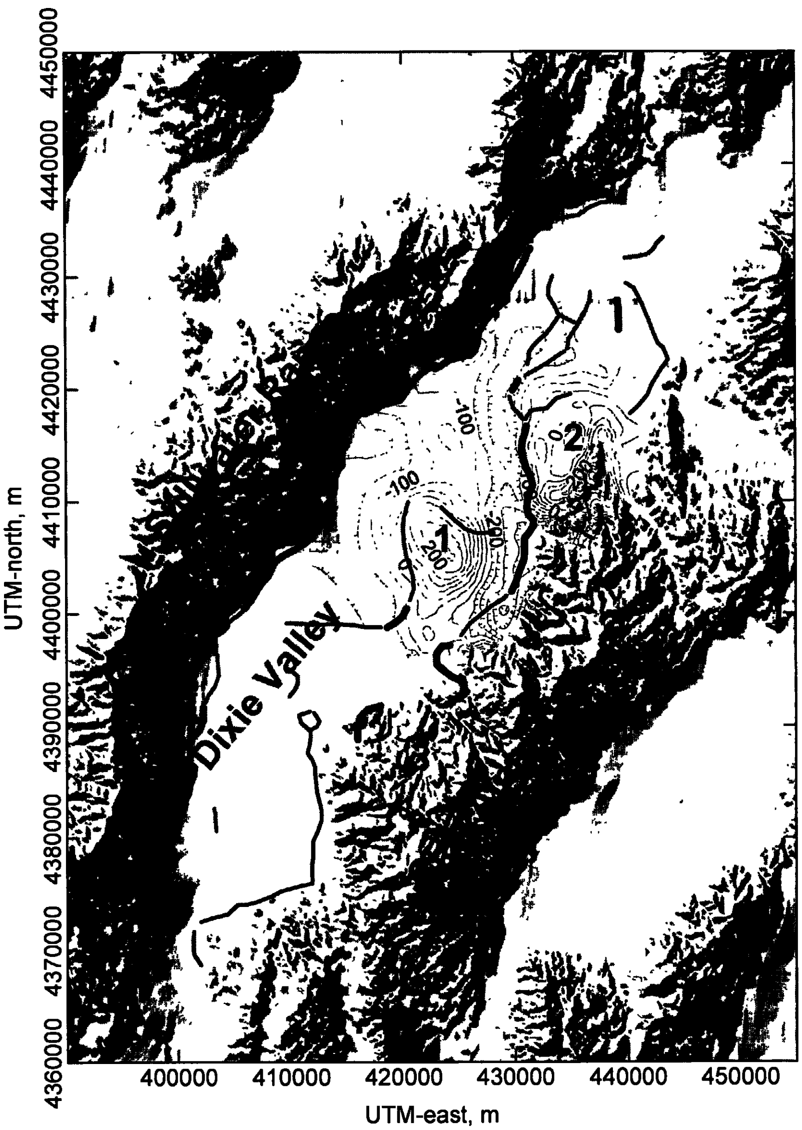

Figure 2. Comparison of the total field magnetic anomaly values to the positions of the steepest gradients of the residual gravity anomaly (see Figure 1).

Also shown on Figure 2 are contours of the magnetic field from the Senturian Survey of 1978 by the thinnest lines. There is a close correlation of the steep gravity gradients within the valley on the east side and the presence of high magnetic field gradients around roughly circular positive total field magnetic field anomalies. In particular, the anomalies marked (1) and (2) on the magnetic map in Figure 2 and the relative positive gravity areas in the valley also marked (1) and (2) on Figure 1 are coincident. The southern area of positive magnetic field values was associated with subcrops of the Jurassic Humboldt lopolith based on an early magnetic survey described by Smith (1968). The anomaly marked (2) is associated with the outcrop of the lopolith in the Clan Alpine Range (Speed, 1976). The area of positive gravity at the northeastern end of Dixie Valley marked (3) on Figure 2 is also characterized by a positive magnetic feature (Smith, *et. al.,* 2002) and lopolith rocks have been encountered at shallow depths beneath valley fill in intermediate depth thermal gradient wells. Thus the two relatively circular areas in Dixie Valley, where the gradients of the gravity field follow the contours of the magnetic field, are clearly related to lopolith bodies that are mostly buried. Clearly the mafic rocks of the lopolith are both dense and magnetic. Weaker positive magnetic anomalies, not so clearly related to gravity, are located along the western side of the valley and high magnetic field values are seen in the Stillwater Range at the edge of the various surveys.

The zone of active normal faulting along the west side of the valley is generally contained between the range front, where most of the topographic offset has occurred, and the steepest gravity gradient, where most of the valley offset has occurred. As shown in Figure 2, these two lines are generally 1 to 2 km apart so that there is generally a wide, shallow, basement block between the main piedmont fault and the range bounding fault. The mapping from aerial photos shows that the piedmont faults are located in places marked at the surface by subtle scarps and by graben structures, considerably removed from the range front, and in general coinciding with the positions of the steepest gravity gradients.

The faults mapped on the basis of aerial photos and from the aeromagnetic survey are discussed by Smith, *et. al.,* (2002). The mapping shows an active west side to the valley where the displacement is on the order of 4 km and some minor distributed faulting in the area between the geographic center of the valley and the eastern side. The pattern of distributed faulting along the east side of the valley is particularly clear from the magnetic data. The net offset, however, based on the gravity data is only a fraction of that along the west side of the valley. The seismic data suggest that the valley started out as a narrow symmetrical graben and then later broadened toward a tilted fault block configuration with the major displacement along the west side of the valley. The gravity and geologic mapping suggest that the geometry of faulting all along the range valley contact is the same as that seen in the DVPF and the DVPP area. The general existence of a fault zone 1 to 2 km wide is well documented. This means that there is a large area of fractured rock for geothermal fluid flow. The recognition that rocks of the Humboldt lopolith underlie a large part of the valley is important from the geothermal resource point of view. The locations where the rocks of the lopolith are along the major normal faults are considered the best reservoir situations for Dixie Valley (Waibel, 1987). If the faulting is like that in the north, the individual faults are steep and will be much more easily located by drilling inclined wells rather than vertical wells.

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