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A GEOPHYSICAL INVESTIGATION OF THE

WARM SPRINGS, MONTANA AREA

by

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APPENDIX A

GEOPHYSICAL STUDY

AT

WARM SPRINGS STATE HOSPITAL.

A GEOPHYSICAL INVESTIGATION
OF THE WARM SPRINGS MONTANA AREA

The Deer Lodge Valley in southwestern Montana is the site of several moderate temperature thermal springs. Of these occurrences, the geothermal system on the grounds of the Warm Springs State Hospital shows considerable potential for the development of the energy source.

During the summer and fall of 1978 a geophysical survey was conducted in the vicinity of the State Hospital to gather information about the geothermal system. Possible targets for the survey included both basement and near-surface geologic features.

It is possible that the placement of the spring is the result of a structural feature in the rock underlying the valley fill. It was hoped that gravity data would reflect the presence of such a feature.

The arrival of water at the surface is accompanied by a deposition of material from solution. This suggests that deposition may also occur in the valley fill along the path of the ascending water. The increased density that would be expected with this deposition became one possible target of a detailed gravity survey in the vicinity of the spring.

It was also expected that the resistivity of the area would be affected by the geothermal water and thus allow mapping of its near-surface lateral extent.

LOCATION

Warm Springs is located in the southern part of the Deer Lodge Valley, west of the Clark Fork River. The Anaconda and Flint Creek mountain ranges create the western boundary of the valley and the

Boulder batholith and the Lowland Creek Volcanics form more gentle topography to the east. The Warm Springs State Hospital is approximately 25 miles from Butte by Interstate Highway 90.

PREVIOUS WORK

The geology and ground water resources of the Deer Lodge Valley are discussed in U.S. Geological Survey Water Supply Paper 1862. Included in the paper is a residual gravity map of the Deer Lodge Valley. Water data from the Warm Springs system and other southwestern Montana thermal springs is given in the U.S. Geological Survey Open File Report 78-438. Montana Bureau of Mines and Geology Special Publication 22 is a geological map of a portion of the Flint Creek Range west of the study area. U.S. Geological Survey Geophysical Publication 538 is an aeromagnetic map that includes the Deer Lodge Valley.

GEOLOGY

The Anaconda and Flint Creek Ranges are composed of Precambrian through Cretaceous sediments and metasediments with numerous igneous intrusives. Three periods of glaciation have occurred in the Flint Creek Range and deposited moraine and outwash material in the Deer Lodge Valley (Mutch, 1960).

Cretaceous quartz monzonite of the Boulder batholith and the Eocene tuffs and lava flows of the Lowland Creek volcanics outcrop a short distance east of the study area.

Valley formation probably began in the early Tertiary, before the Eocene deposition of the Lowland Creek volcanics (Konizeski, 1968). Fault scarps along the western side of the valley indicate relatively recent movement however no surface evidence for faulting along the

eastern valley margin is apparent (Schofield, 1979). Valley fill consists of consolidated and unconsolidated Tertiary sediments and Quaternary alluvium (Konizeski, 1968).

SURVEY METHODS

Figure 1 is a map of the Warm Springs area showing the location of the gravity stations. Station spacing generally did not exceed three-hundred feet. Station elevations were taken from a level net and recorded to the nearest one-hundredth of a foot. Free air, latitude and Bouguer corrections were made upon the data but no terrain corrections were performed.

Resistivity data were gathered with an Eltran array of fifty meter "a" spacing. The survey was designed for profiling the area. Detailed surveys were performed in selected areas using and expanding Wenner array for which the "a" spacings varied from one meter to one hundred meters.

RESULTS

Figure 2(a), (b) and (c) are cross sections constructed utilizing a two-dimensional modeling program (Fleming, 1977). Figures 2(a) and (b) represent an east-west section passing through the spring, beginning approximately 22,000 feet west of the spring and ending approximately 11,000 feet to the east. The location of section 2(c) is shown on figure 1. In all profiles the crosses represent gravity data and the solid lines are the computer-calculated anomalies resulting from the assumed subsurface configuration.

Data for profiles 2(a) and (b) was taken from the U.S. Geological Survey Water Supply Paper 1862. In figure 2(a) a density of 2.2 g/cm^3 was chosen for the valley fill and 2.67 g/cm^3 for the basement material.

These values are in agreement with Burfiend (1967). A density log from a well drilled on the hospital grounds in November of 1979 shows that the average density of the valley fill may be only 2.0 g/cm^3 . Figure 2(b) is a profile modeled to this density contrast. Figures 2(a) and (b), although generally similar in cross sectional shape, clearly show the variation of valley fill depth estimates resulting from the two density contrasts.

The small changes of slope that occur along the gravity profile near the east side of the valley are interpreted to be indicative of changes in the basement configuration. It is possible that these changes could be interpreted as expressions of normal faulting along the eastern edge of the valley.

Data for cross section 2(c) was taken from the residual gravity map shown in figure 3. The profile indicates a highly variable near-surface density distribution with the present-day springs occurring at a boundary between a gravity high and a gravity low.

Other notable features of the residual gravity map are the closed low near the upper-right corner of the map and the high southeast of the spring. The magnitude and area of the closed low probably indicate a small, near surface mass, the center of which may be 100 meters below the surface as calculated by the half-width method (Telford, et.al., 1976).

Applying the half-width method to the gravity high southeast of the spring it can be found that the center of mass may lie 195 meters below the surface. A possible interpretation of the high is that it is the expression of the deposition of materials in the near-surface gravels.

The following calculation is based upon the assumption that valley fill with a density in the range of 2.0 to 2.2 g/cm^3 may undergo a density

increase of 0.3 to 0.4 g/cm³ as the porosity decreases from 20 percent to 5 percent. Applying the increase of 0.4 g/cm³ to a spherical mass of 150 meter radius and center of mass 195 meters below the surface the added attraction becomes:

$$g = \frac{4/3 \pi R^3 d}{z^2} \times G$$

where d = the density
 $4/3 R^3$ = the volume
 z = depth to center of mass
 G = gravitational constant
 $6.67 \times 10^{-8} \frac{\text{dynes-cm}^2}{\text{g}^2}$

$$g = \frac{4/3 \pi (150\text{m} \times 100\text{cm/m})^3 \times 0.4\text{g/cm}^3}{(195\text{m} \times 100\text{cm/m})^2} \times G$$

$$g = 0.000992 \text{ gals or } 0.992 \text{ milligals.}$$

This value is in close agreement with the observed variations of gravity but would vary slightly with different densities or porosities.

Figure 4 is a contour map of the resistivity data taken in the vicinity of the spring. The contours show that the lowest resistivities surround the spring. The northeast trend of the contoured low might be attributed to the natural flow of the water as it reaches the surface. An alternate interpretation is that the northeast trend of the low indicates the position of the water entering the area. However, a free-flowing, warm water spring was encountered while excavation was being done for a basement approximately 800 feet east of the present spring and the occurrence of warm basements in houses southeast of the spring (Painter, 1978) indicates that the warm waters are present southeast of the spring. A distortion in the 10 ohm-meter contour also occurs southeast of the spring in the vicinity of the anomalous gravity high.

DISCUSSION OF RESULTS

Valley cross sections based upon an evaluation of gravity values for the Deer Lodge Valley show that the location of the warm spring seems

to be associated with a change of basement configuration that could be interpreted as faulting along the east side of the valley.

The residual gravity map of the area adjacent to the spring shows a gravity low northeast of the spring and a slight gravity high to the east and southeast of the spring. No present explanation exists for the gravity low other than it is the expression of a near-surface body of low density material. The high, however, may be the expression of a slight density increase resulting from the deposition of materials from migrating geothermal waters as they cool near the surface. Such deposition may block the migrating water and control its dispersion through the gravels. Based upon this hypothesis, the gravity high may indicate that the waters reach the near surface somewhere to the southeast of the present springs.

The resistivity map of the area indicates that a near surface low resistivity zone surrounds the present day spring. The zone broadens to the north and northeast and extends into the region of the previously mentioned gravity low. The resistivity data may be representative of a system in which geothermal water reaches the near-surface and spreads laterally, the northeast elongation being due to the natural hydrologic gradient. Houses with warm basements and the discovery of a small spring indicate that the water may first reach the near-surface southeast of the present spring. A distortion in the 10 ohm-meter contour occurs in the vicinity of the anomalous gravity high.

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BASE MAP FOR GEOPHYSICAL SURVEY OF THE WARM SPRINGS, MONTANA AREA

SOURCE: USGS ANACONDA 3 N.E.
QUADRANGLE

0 500 1000 2000
feet

Figure 1. Map of the Warm Springs area showing gravity station locations and the location of cross section 2(c).

Figure 2. Figures 2(a) and (b) represent an east-west section across the Deer Lodge Valley showing two possible interpretations of the basement configuration resulting from two different valley-fill densities. Figure 2(c) shows the near-surface density distribution within the valley fill. Crosses indicate gravity data and the lines show the computer-calculated anomalies resulting from the assumed subsurface configuration.

BASE MAP FOR GEOPHYSICAL SURVEY OF THE WARM SPRINGS, MONTANA AREA

SOURCE: USGS ANACONDA 3 N.E.
QUADRANGLE

0 500 1000 2000
feet

Figure 3. Residual gravity map of the Warm Springs area. 0.2 milligal contour interval.

Figure 4. Resistivity contour map of the Warm Springs area based upon 50 meter Eltran dipole profiles. 5 ohm-meter contour interval.