A "RESIDUAL TEMPERATURE MAP" OF ARIZONA

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ABSTRACT

I made a "Residual Temperature Map" of Arizona using geothermal gradient measurements. To eliminate problems inherent in thermal gradients the following corrections were made: highly disturbed gradients were eliminated; a straight line was fitted to slightly disturbed gradients and the extrapolated temperature was used; temperatures were taken from the 100-m depth interval and the mean annual temperature was subtracted; measurements in sedimentary rocks were normalized to those in crystalline rocks to eliminate thermal conductivity differences.

On the resulting map, residual temperature zones cross cut major physiographic province boundaries, but show a strong correlation with features on the historical seismicity and major lineament maps of Arizona. Positive anomalies on the residual temperature map are shown on the Geothermal Gradient Map of the Conterminous United States, but negative anomalies generally are not. More confidence can be placed in this map than in a gradient map, although correcting data can be time consuming.

INTRODUCTION

Temperature gradient maps covering large regions are plagued with uncertainties and often contain significant errors. Many of these problems arise from the following conditions: Well depths vary from a few tens to several hundred meters. Some thermal gradients are profoundly affected by hydrologic processes, both natural and human induced. Even within a relatively small area having the same conductive heat flow, thermal conductivities may vary laterally to such an extent that gradients can differ by a factor of two or more. Thus, gradient comparisons over a large area are of questionable value. It is generally recognized that heat flow measurements are more reliable for regional assessments. The trade off, however, is that thermal gradients are relatively abundant and inexpensive to make. Heat flow measurements are not.

I have made a "Residual Temperature Map" of Arizona using published and unpublished thermal gradient measurements (Goldstone and Stone, 1982; Roy and others, 1968a, 1968b; Sass and others, 1971; Sass, 1979, personal commun.; Shearer, 1979). In constructing the map I have applied certain interpretive procedures or corrections to the data set to help eliminate some of the problems associated with thermal gradients. While this method is not rigorous, the corrections and adjustments were consistently and carefully applied. In some areas, final interpretation was guided by knowledge of local geologic or hydrologic conditions.

INTERPRETIVE PROCEDURES

The purpose of this paper is to discuss the interpretive procedures used to correct the data set and to discuss the resultant map itself. The first procedure was to eliminate all wells that showed excessive ground-water disturbance, such as is shown in Figure 1. An accurate formation temperature at any depth is nearly impossible to ascertain under such highly disturbed conditions. Temperature-depth profiles that showed only slight hydrologic disturbance were fitted by a straight line. If extrapolation of the gradient to the land surface approximated the local mean annual temperature (MAT), the temperature predicted by the straight line rather than the measured temperature was used. This procedure increased the temperature for some wells and decreased it for others, depending on whether water was moving down or up the borehole (Figs. 2 and 3). Temperature corrections made in this way varied between about plus or minus 0.5 and 2.0°C.

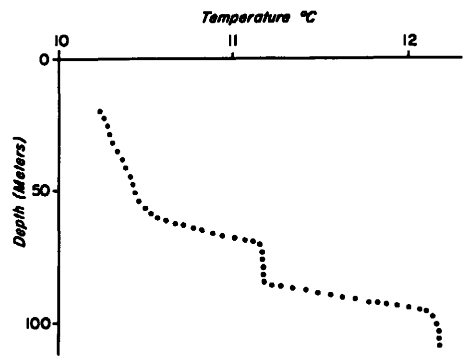

Fig. 1. Temperature-depth profile showing excessive ground water disturbance.

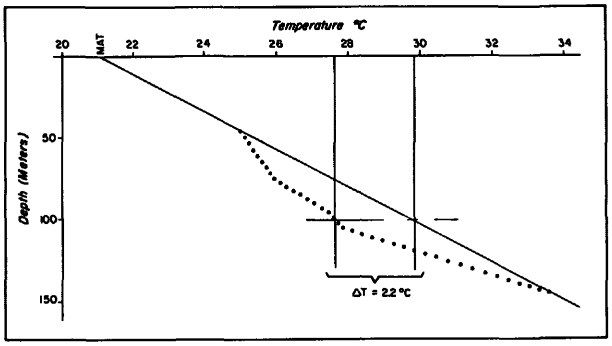

Fig. 2. Temperature-depth profile showing slight hydrologic disturbance due to ground water moving down the borehole. The temperature predicted by the straight line is 2.2°C greater than the measured temperature at 100 m.

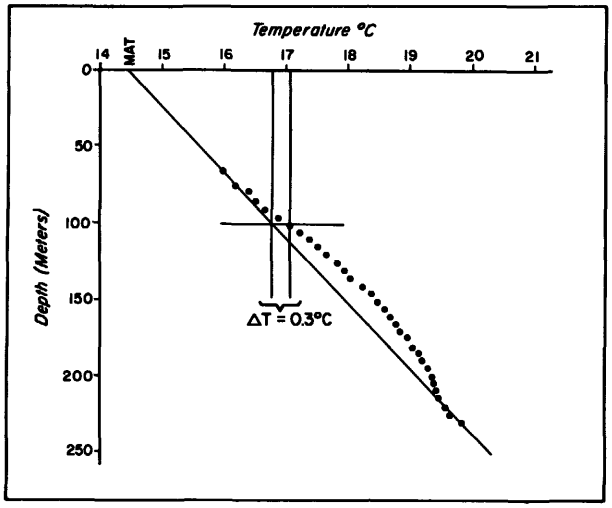

Fig. 3. Temperature-depth profile showing slight hydrologic disturbance due to ground water moving up the borehole. The temperature predicted by the straight line is 0.3°C less than the measured temperature at 100 m.

The second procedure was to select temperatures measured at 100-m depth. Use of this depth avoids seasonal temperature variations that may occur at shallower depths. In addition, selection of this depth maximized the number of wells that could be included in the data set because proportionately fewer wells are available with increasingly greater depths. The major drawback of this procedure involves loss of valuable information from deeper than 100 m. The trade off here is between presenting a standardized map based on a large number of sites and making a possibly invalid comparison between shallow and deep wells.

Third, the local mean annual temperature was subtracted from the 100-m temperatures in order to correct somewhat for hole elevation and latitude. Latitude within Arizona changes by 6 degrees; elevation changes by 2,000 m or more. Except in areas where near-surface heat transfer characteristics (e.g. albedo, thermal inertia, etc.) are anomalous, the mean annual temperature generally is 2 or 3 degrees lower than the less-well-known mean ground surface temperature, which also decreases with increasing elevation and increasing latitude. This correction produced a "number" that could be interpreted as a thermal gradient, but I prefer to avoid that terminology.

Finally, since rock thermal conductivity, which depends chiefly on mineral content and porosity, has a major effect upon thermal gradient and heat flow, the number thus far derived from temperature measurements in unconsolidated sedimentary rocks can not validly be compared with those derived from temperature measurements in crystalline rocks. A final correction was made to the numbers from sedimentary rocks (Ns) in order to normalize them to those from crystalline rocks (Nc). The correction was Nc = Ns x Ks/Kc, where Ks and Kc are average thermal conductivities for sedimentary and crystalline rocks, respectively. In Arizona, basin-fill sediments have an average conductivity about one half that of crystalline rocks (Sass, 1982, personal commun.), so that the value for Ks/Kc was 0.5. No distinction was made between consolidated and unconsolidated sedimentary rocks as the latter are usually quite porous in the upper 100 m. The few measurements made in volcanic rocks were corrected in the same manner as the sedimentary numbers. No correction was applied to Colorado Plateau measurements because average measured conductivities for these near-surface sedimentary formations are roughly equivalent to those of crystalline rocks (Bodell and Chapman, 1982; Sass and others, 1982).

RESULTS

The resulting map (Fig. 4) depicts residual temperatures across most of the state of Arizona. Obvious gaps in the data set occur in northwestern Arizona and in parts of east-central and northeastern Arizona. In other areas coverage varies from sparse to excellent.

Incorporating the procedures outlined above, this map provides a rough picture of the shallow conductive thermal regime of Arizona, modified to varying degrees at different locations by both regional and local hydrologic processes. Several prominent features on the map are worth pointing out.

1. Three major residual-temperature zones exhibiting a pronounced north-south trend cut across the major geologic and physiographic province boundaries (compare Figs. 4 and 5). The coolest zone is down the center of the state. Western Arizona is warmer than southeastern Arizona.

2. The thermal transition from cooler to warmer residual temperatures in southeastern Arizona approximates the boundary between the Mexican Highland and the Sonoran Desert subprovinces of the Basin and Range province.

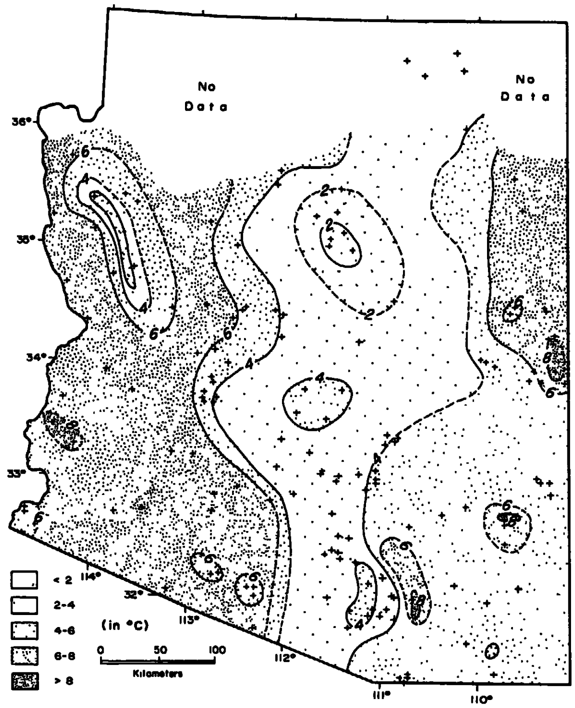

Fig. 4. Residual Temperature Map of Arizona. Crosses represent data points.

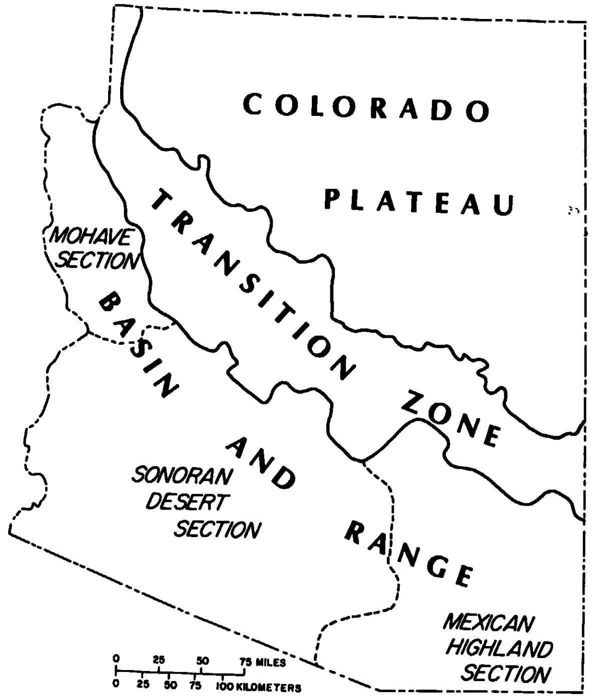

Fig. 5. Physiographic provinces of Arizona.

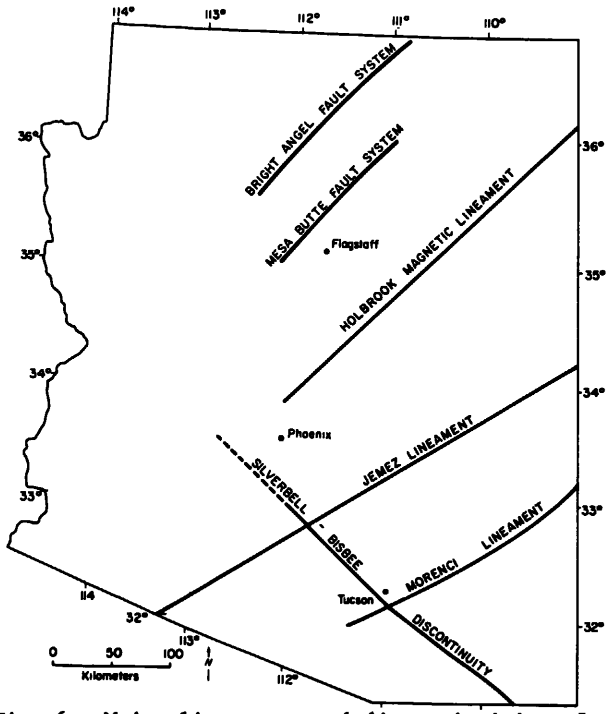

Fig. 6. Major lineaments and discontinuities of Arizona (from Chapin and others, 1978; Titley, 1976).

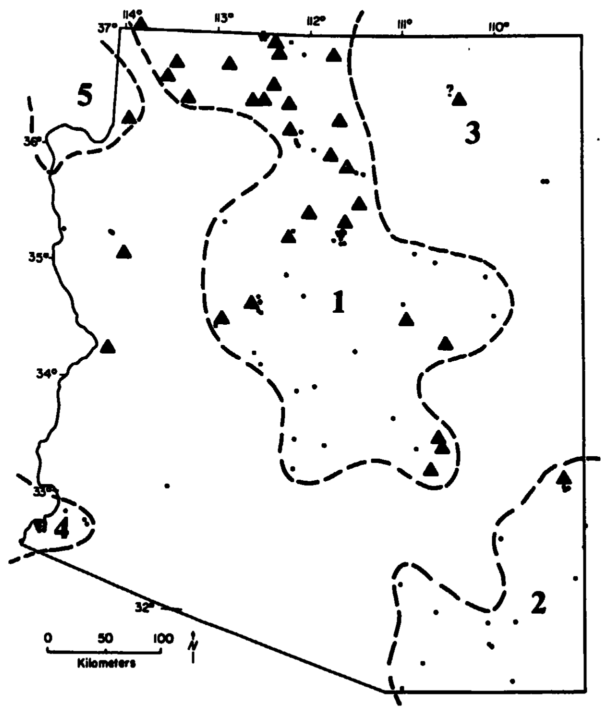

Fig. 7. Historical earthquake epicenters (1890-1980) and preliminary seismic source regions of Arizona (from DuBois and others, 1981).

3. Strong deflections to the southeast occur where the residual-temperature zones cross the Transition Zone.

4. Large negative anomalies exist slightly southeast of the San Francisco volcanic field and farther west in the Mohave subprovince.

Viewing the major lineaments and discontinuities crossing Arizona (Fig. 6) allows additional observations. Three small positive anomalies in southeastern Arizona fall along the Morenci lineament.

The positive anomaly in east-central Arizona falls on the Jemez lineament. Two major deflections in the generally north-south-trending residual temperature zones parallel segments of the northeast-trending Jemez lineament and an extension of the northwest-trending Silverbell-Bisbee discontinuity.

Historical epicenters (1830 to 1980) and preliminary seismic source regions in Arizona (Fig. 7) (DuBois and others, 1981) also correlate well with the Residual Temperature Map. Areas having cool residual temperatures roughly coincide with areas of active historical seismicity, and areas with warm residual temperatures approximate seismically quiet zones.

The Geothermal Gradient Map of the Conterminous United States (Fig. 8) (Kron and Heiken, 1980) shows positive gradient anomalies in approximately the same areas as they appear on the residual temperature map. Contouring of the gradients, however, suggests larger anomalies than may actually exist. Negative anomalies are smaller to absent on the gradient map, but stand out as major features on the residual temperature map.

INTERPRETATION

I have interpreted features on the Residual Temperature Map of Arizona as follows.

1. High heat flow and open vertical fracture permeability along the major lineaments and discontinuities probably has enabled local hydrothermal convection systems to become established in these areas. Smaller but still major faults probably cross these structures where the anomalies exist. The smaller anomalies chiefly in the southern part of the state are most likely a result of ground-water convection. Numerous other such anomalies must exist in Arizona, but sparse data in many areas preclude their detection.

2. It is likely that the negative anomalies represent zones of high permeability and groundwater recharge.

3. Correlation between the residual temperature map and the historical seismicity map probably reflect zones of warmer, less brittle crust where seismic activity is attenuated and zones of cooler, more brittle crust where seismicity is strong enough to be felt.

CONCLUSIONS

More confidence can be placed in a residual temperature map than in a gradient map because most of the problems inherent in using gradients have been removed. Use of temperatures at 100-m depth provides a relatively large data set. Although applying corrections to the data is time consuming, the resulting map is a good approximation of the shallow conductive thermal regime of this region.

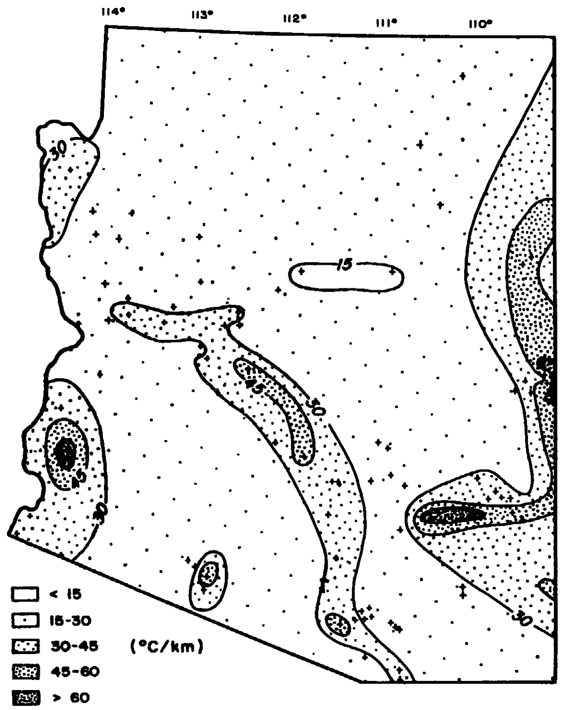

Fig. 8. Thermal gradients of Arizona, from the Geothermal Gradient Map of the Conterminous United States (Kron and Heiken, 1980). Crosses represent data points.

ACKNOWLEDGMENTS

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REFERENCES

Bodell, J.M. and Chapman, D.S., 1982, Heat flow in the north-central Colorado Plateau: Jour. of Geophys. Res., v. 87, p. 2869-2884.

Chapin, C.E., Chamberlin, R.M., Osburn, G.R., White, D.W., and Sanford, A.R., 1978, Exploration framework of the Socorro geothermal area, New Mexico, in Chapin, C.E. and Elston, W.E. (eds.), Field guids to selected cauldrons and mining districts of the Datil-Mogollon volcanic field, New Mexico: New Mexico Geological Society Special Publication No. 7, p. 115-129.

DuBois, S.M., Sbar, M.L., and Nowak, T.A., 1982, Historical seismicity in Arizona: GPO Sales Program, U. S. Nuclear Regulatory Commission, Washington, D.C., No. NUREG/CR-2577, RA, 199 p.

Goldstone, L.A. and Stone, C., 1982, Temperature-depth profiles, well location information, and tabulated temperatures for Arizona wells measured between May, 1979 and March, 1982: Arizona Bureau of Geology and Mineral Technology Open-File Report 82-7, 112 p.

Kron, A. and Heiken, G., 1980, Geothermal Gradient Map of the Conterminous United States: Los

Alamos Scientific Laboratory, LA-8476-MAP, scale 1:5,000,000.

Roy, R.F., Blackwell, D.D., and Birch, F., 1968a, Heat generation of plutonic rocks and continental heat-flow provinces: Earth and Planetary Science Letters, v. 5, p. 1-12.

Roy, R.F., Decker, E.R., Blackwell, D.D., and Birch, F., 1968b, Heat flow in the United States: Jour. of Geophys. Res., v. 73, p. 5207-5221.

Sass, J.H., Lachenbruch, A.H., Monroe, R.J., Greene, G.W., and Moses, T.H., 1971, Heat flow in the western United States: Jour. of Geophys. Res., v. 76, p. 6376-6413.

Sass, J.H., Stone, C., and Bills, D.J., 1982, Shallow subsurface temperatures and some estimates of heat flow from the Colorado Plateau of northeastern Arizona: U. S. Geological Survey Open-File Report 82-994, 112 p.

Shearer, C.R., 1979, A regional terrestrial heat-flow study in Arizona: Ph.D. dissertation, Socorro, New Mexico Institute of Mining and Technology, 184 p.

Titley, S.R., 1976, Evidence for a Mesozoic linear tectonic pattern in southeastern Arizona: Arizona Geological Society Digest, v. 10, p. 71-101.