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Approximation of Thermal Gradient in Southeastern New Mexico Using Bottom-Hole Temperatures from Electric Logs[1]

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Abstract Bottom-hole temperatures and depths were obtained from electric logs of wells in Chaves, Eddy, and Lea Counties, New Mexico. Thermal gradients obtained by linear regression ranged from 0.70°F/100 ft to 0.90°F/100 ft. Despite considerable "noise" in the data, these values compare favorably with earlier values reported in 1937 of 0.707°F/100 ft for the interval 1,500–4,000 ft and 1.006°F/100 ft for the interval 4,000–6,000 ft in a well in T20S, R29E, and with the average of 0.73°F/100 ft obtained from nine temperature logs of wells in the area. Linear regression of bottom-hole temperatures and depths in electric logs is a valid technique for estimating geothermal gradients.

Introduction

Information on the temperature at specific depths at specific locations in southeastern New Mexico is sparse; lack of data frustrates efforts to define isotherms. Information on the typical or average geothermal gradient is also sparse. Lang (1937), and Van Orstrand (1937) published the measurements made in the Getty-Dooley No. 7, Eddy County. These measurements were the first made specifically to determine the geothermal gradient in New Mexico. Herrin and Clark (1956) gave the gradient in 5 other wells in Eddy and Lea Counties. Moses (1961) drew contours through values of equal geothermal gradient in Lea and Eddy Counties.

Temperature logs are available for about 100 wells. Unfortunately, these logs not only lack the areal distribution needed for definitive thermal studies, but they were made primarily for the purpose of determining the top of a newly implaced column of cement. As a consequence, they do not necessarily record the natural temperature regime.

A potential source of "point" temperature data is the "botton-hole temperature" recorded on electric logs. This temperature (BHT) is read from a maximum thermometer contained in the body of the logging tool. Thus, it is not necessarily the temperature at the bottom of the hole nor is it necessarily the temperature of the formation. In general, the thermometer, although of excellent quality, is neither calibrated nor standard. Mud circulating in the bore as a hole is being drilled tends to raise the temperature at shallow depths and lower temperatures near the bottom. If the time between cessation of drilling and logging is short, the bottom-hole temperature may not have time to return to equilibrium. Therefore any individual measurement recorded on an electric log is susceptible to several sources of error. This note reports the results of an attempt to use bottom-hole measurements from electric logs to ascertain the subsurface temperature regime in southeastern New Mexico.

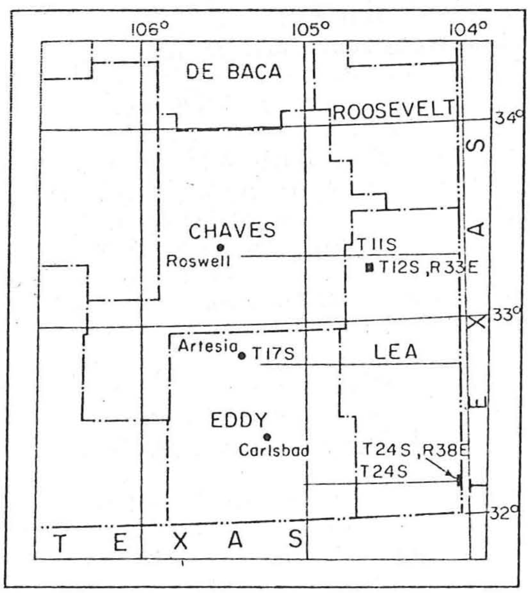

Fig. 1—Map of southeastern New Mexico showing data cross sections and townships.

Cross Section Approach

Two approaches were taken. The first searched out all the bottom-hole temperatures within 2 m of the plane of three cross sections (Fig. 1). Th

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approach was disappointing because the data tend to cluster in established oil and gas fields with gaps between and are available mainly for depths greater than 3,500 ft. For cross-section 11 S, the data simply are not adequate to draw isotherms. For cross-section 24 S, the interpreted isotherms seem to be smooth curves except in the vicinity of the Capitan reef, where they appear to be distorted by water flowing through the highly permeable limestone. Unfortunately, this interpretation is highly subjective, and other geologists using the same data easily could come to the conclusion that data plotted on the cross section are not susceptible to meaningful interpretation.

More data are available for cross-section 17 S than for either 11 S or 24 S. The isotherms based on these data are more or less parallel curves with crenulations. However, several closed isotherms suggest hot spots that cannot be verified from temperature logs, cannot be rationalized without specifying conditions that contravene those thought to exist, and are not due to the works of man.

Linear Regression

The second approach used the data from each cross section to determine the slope of the best

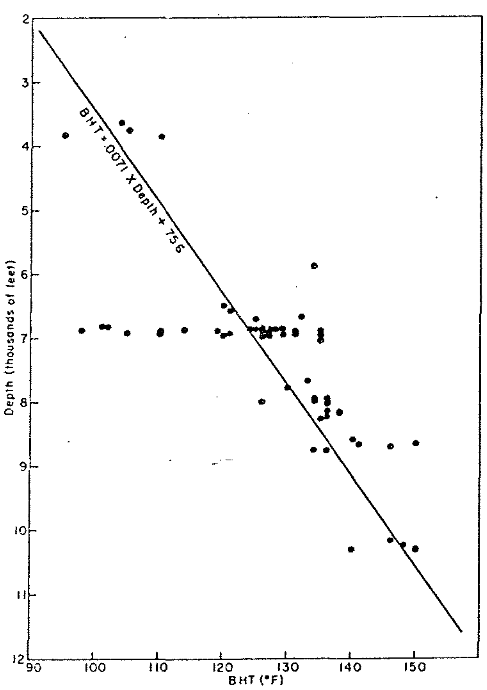

Fig. 2—Relation of bottom-hole temperature (BHT) to depth in T24S, R38E.

Table 1. Approximation of Geothermal Gradients in Southeastern New Mexico Using Electric Log Bottom-Hole Temperatures

Data Set	Gradient (°F/100 ft) Elev.	Depth	Number of Data Points	Correlation Coefficient Elev.	Depth
X-Sec. 24 S	.71	.74	115	.84	.86
X-Sec. 17 S	.70	.72	260	.84	.85
X-Sec. 11 S	.75	.73	35	.93	.94
T12S, R33E	.90	.90	63	.78	.79
T24S, R38E	.71	.71	73	.77	.77

straight line by linear regression, using a standard program. Two fits were made with each suite of data. The first considered only temperature versus depth. The second considered temperature versus the altitude of the bottom of the hole. The slope of either fitted line is an estimate of the geothermal gradient.

The results were amazingly consistent as Table 1 shows. The question then was raised: Would data for a particular township be amenable to this form of analysis? Two townships were selected—T24S, R38E, and T12S, R33E.

In T24S, R38E, 73 bottom-hole temperatures were reported, but they were zoned heavily (Fig. 2). The variability in each zone is fairly uniform, except around 7,000 ft where, for example, 18 bottom-hole temperatures were in the depth range 6,800-6,899 ft, and the temperature ranged from 90 to 135°F (arithmetic mean 120; median 125). The low temperatures probably were estimated rather than observed (an all too common practice). If indeed this is the true variability for this depth, a weighted regression rather than straightforward linear regression should be performed. However, this refitting would have a small effect on the curve. The second township had much better distribution of bottom-hole temperatures with depth. As Table 1 shows, the results for both townships were close to those obtained for the cross sections. The correlation coefficients for all regressions ranged from 0.77 to 0.94.

Lang's (1937) measurement of the thermal gradient in the Getty-Dooley well (T20S, R29E) shows that the gradient increased with depth. The gradient in the depth interval 250-1,500 ft was 0.496°F/100 ft; in the interval 1,500-4,000 ft it was 0.707°F/100 ft; and in the interval 4,000-6,000 ft it was 1.006°F/100 ft. The gradient for the interval 100-6,000 ft is 0.729°F/100 ft. Table

Table 2. Thermal Gradients in Selected Oil Tests in Southeastern New Mexico*
(Based on temperature logs)

County	Interval logged (ft) From	To	Gradient (°F/100 ft)
Chaves	1,300	2,250	0.6
	1,800	2,100	1.0
Eddy	100	1,745	0.9
	1,850	2,400	1.1
Lea	2,000	2,755	0.5
	1,000	1,800	0.6
	300	1,400	0.9
	9,000	11,000	0.4
Roosevelt	7,040	8,800	0.6
		Average	0.73

*After Summers, 1965, p. 3.

2 gives the geothermal gradients estimated by Summers (1965) for the area. The average is 0.73° F/100 ft. The Herrin and Clark measurements (1956, p. 1096) ranged from 0.437 to 0.534°F/100 ft, but these were for relatively shallow depths.

A technique commonly used to estimate the temperature (T) at depth (Pirson, 1963, p. 36) is to use the formula

$$T = \text{Mean annual air temperatures} + \text{depth} \times \text{gradient}.$$

A variation of this technique is that of Moses (1961), who estimated the geothermal gradient in southeastern New Mexico by substituting bottom-hole temperatures obtained during bottom-hole-pressure tests and subsurface sampling in the formula

$$T = 74 + \text{depth} \times \text{gradient}.$$

The number 74 was taken to be "the mean surface temperature." Moses apparently used data only from relatively shallow depths, because his map (p. 80) shows values ranging from 0.3 to 0.6°F/100 ft.

Linear regression of the data used here generates the constants A and B in the equation $T = Ax + B$, where T is temperature and x is either depth or altitude. In the regression temperature versus depth, B gives the temperature at the land surface (zero depth). By substituting the average land surface altitude for x and the coefficients obtained for regression of temperature versus depth, and solving for T, one obtains a second estimate of the land surface temperature. Table 3 gives these estimates. Average annual air temperatures in the region are in the range of 62-64°F. The estimated land surface temperatures in Table 3 are 68-78°F—5-15°F larger than those measured. Therefore, estimated temperature at depths, based on mean annual temperatures, will tend to be too low, whereas gradients based on bottom-hole temperatures and mean annual air temperatures will tend to be too large. Moses' use of 74°F as the mean annual temperature was a fortunate one, because it minimizes the error in his estimate. However, the use of a linear estimate of the geothermal gradient based on mean annual air temperature and individual bottom-hole-temperature measurements should be discouraged, or used only when no other basis for estimate is open.

Table 3. Comparison of Land Surface Temperature Estimated from Linear Regression of Bottom-Hole Temperature of Electric Logs with Approximate Average Annual Air Temperature

Data Set	Estimated Land Surface Temperature °F: From Elevation Regression	From Depth Regression	Approximate Average Annaul Air Temperature
X-Sec. 24 S	75.8	72.5	64
X-Sec. 17 S	74.0	68.6	63
X-Sec. 11 S	77.6	74.0	62
T12S, R33E	74.7	68.1	62
T24S, R38E	76.2	75.6	64

The agreement between the estimates from bottom-hole-temperature data presented here (0.70-0.90°F/100 ft) and those of Lang (1937) and of Summers (1965) is satisfactory for depth intervals of 1,500-10,000 ft. Whatever deficiencies may be inherent in the individual bottom-hole temperature measurements, they are collectively reliable, and the estimated gradients based on them are certainly as reliable as any linear estimation technique yet applied in the area.

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