ELECTRICAL EXPLORATION AND GEOTHERMAL
GRADIENT STUDIES NEAR COLUMBUS, NEW MEXICO

FINAL REPORT

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PART I
EXECUTIVE SUMMARY

Previous geologic studies in the southeastern Mimbres Basin have indicated the possibility that useable geothermal resources may exist near the city of Columbus, New Mexico, near the International Boundary with Mexico. The present study funded by the New Mexico Department of Energy and Minerals (contract EMD 68R-2204), was undertaken to evaluate the geothermal resource base in this area. Our conclusion is that no major geothermal reservoir exists within the study area. However, the geothermal gradient adjacent to the customs facilities on the American side of the border crossing is high ($50.5^{\circ}\text{C}/\text{km}$) even though the regional heat flow is only slightly above normal. Hence, temperatures in the range of $45\text{--}50^{\circ}\text{C}$ might be expected at a depth of 600 meters. These temperatures might be useful for some geothermal applications provided that suitable aquifers are present.

This final report consists of six parts as follows:

- I. Executive Summary
- II. Manuscript by Swanberg et al. (1981) published by the El Paso Geological Society in "Geology of the Border: Southern New Mexico-Northern Chihuahua," 96 p.
- III. Manuscript by Young et al. (Unpl), "Electrical Studies."
- IV. Temperature, heat flow, and lithology data for 17 shallow test holes (35 m)
- V. Temperature and lithology data for one deep test hole (300 m).
- VI. Electrical Resistivity Data.

We would like to thank V. Harder for assisting with the thermal conductivity measurements and J. Gilkey for assisting with the data reduction. Geoterrex Ltd. flew the airborne electrical survey. We would also like to thank the officials of Luna County and the personnel of the U.S. Customs Office in Columbus for their cooperation and support.

PART II

GEOPHYSICAL/GEOTHERMAL STUDIES IN THE SOUTHEASTERN
MIMBRES BASIN NEAR THE CITY OF COLUMBUS, SOUTHERN
RIO GRANDE RIFT, NEW MEXICO

by

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ABSTRACT

The city of Columbus, New Mexico, lies astride the Mexican border about 100 km (60 miles) west of El Paso, Texas. Geologically, the area lies in the southeastern part of the Mimbres Basin which, along with its extension in Mexico (the Los Muertos Basin) comprises the westernmost and southernmost of the deep sedimentary basins that constitute the Rio Grande Rift. During 1980, we conducted a series of geophysical studies aimed at evaluating the geothermal potential of the Columbus area. Reconnaissance gravity profiling confirms that the southeastern part of the Mimbres Basin is a fault-bounded graben located on the eastern flank of the broad alluvial filled valley that lies between the Tres Hermanas and West Potrillo Mountains. Surface and airborne geoelectric data reveal the presence of several resistivity lows which we attribute to increased groundwater salinity in this graben. Seventeen 35-meter heat flow test holes average 75 mW m^{-2} (1.8 HFU) with the higher values consistently located on the upthrown flanks of the graben, a feature which we attribute to thermal refraction. A single 296-meter temperature test hole located at the U.S.-Mexico customs facility south of Columbus has a bottom hole temperature of 33.4°C and a conductive, quasi-equilibrium temperature gradient of 51°C/km between 135 and 296 meters. The aeromagnetic data generally support the gravity data. None of the data collected to date has revealed the presence of a major geothermal prospect although the regional temperature gradient may be sufficiently high for some low temperature geothermal applications if appropriate users are available.

INTRODUCTION

The study area consists of approximately 2,000 km² (750 mi²) centered on the southeastern Mimbres Basin, New Mexico. The area extends east along the international boundary with Mexico from the city of Columbus, to the West Potrillo Mountains (Fig. 1). The geology of the area is summarized by Woodward et al. (1978) who show the basin to contain a thick sequence of synorogenic sedimentary deposits of Miocene to Holocene age. The basin is bounded on the east by a major Quaternary fault which also bounds the northern part of the Los Muertos Basin of Chihuahua, Mexico. Woodward et al. (1978) show the west margin of the basin to be an inferred fault which extends south from the east flank of the Florida Mountains into the study area. Gravity profiling confirms the existence of this fault in the Columbus area. The city of Columbus itself lies on the alluvium covering the upthrown block a few km west of the southeastern Mimbres Basin.

There are several geological data sets which imply that the southeastern Mimbres basin may be favorable for geothermal exploration. 1) The basin itself is part of the Rio Grande Rift, a north-south trending feature which is characterized by Quaternary tectonics and volcanics, deep sedimentary basins, high heat flow, numerous hot springs, and enhanced geothermal potential (Seager and Morgan, 1979). 2) Several of the groundwaters in the area have chemical characteristics which imply that they might have originated within the active geothermal system (Swanberg, 1978). 3) Finally, although hot springs are not observed in the southeastern Mimbres Basin, Swanberg et al. (1981) have reported hot spring activity on the Mexican side of the border near the southern end of the Los Muertos Basin. The above geological data

coupled with an increasing demand for geothermal energy associated with the development of the Columbus International Industrial Park, has prompted the present study.

Gravity and Magnetic Surveys

The initial geophysical data collected in the Columbus area were profiles of gravity and magnetic data. The gravity data were collected with a La Coste Romberg gravimeter and reduced the simple Bouguer anomalies by traditional techniques. The magnetic data were recorded with a proton precession magnetometer which reads directly in total magnetic field. These profiles were run along the roads shown in Figure 2. The purpose of these profiles was to determine the location of the major faults in the area in order to more precisely design the more detailed electrical and heat flow surveys. An interpretation of the gravity and magnetic data is shown in Figure 2. The gravity data confirms the presence of the fault which forms the west margin of the southeastern Mimbres Basin. The precise location of this fault, which is buried beneath the alluvium, had not been previously determined. The location of the east boundary fault is evident from surface geology as well as from the gravity data. The magnetic data reveal a very uniform magnetic field over the basin itself (i.e., variations generally less than 100 γ) but a very erratic field outside the basin with variations up to 800 γ occurring over a few km or less. This pattern is most easily explained by assuming that high susceptibility rocks (presumably basalt) are much nearer the surface outside the basin. Implicit in this interpretation is that shallow volcanics may be present underneath the alluvium in the immediate

vicinity of Columbus, a feature which has been verified by the drilling of the 296-meter heat flow test well.

Surface Resistivity Survey

The surface electrical resistivity study has consisted of 45 km (28 miles) of profiling using a Schlumberger configuration with an electrode spacing of both $AB/2 = 100$ and 800 meters. The profiling was conducted along the same roads as the gravity and magnetic surveys. This electric survey has delineated a zone of low apparent resistivity ($< 3 \Omega m$) located near the east margin of the southeastern Mimbres Basin (Fig. 2). There are several possible explanations for this resistivity anomaly including increased temperature and/or salinity of the groundwater, increased porosity, additional quantities of clay, or some combination of these and other factors. However, the lack of an obvious temperature gradient anomaly associated with the resistivity low (following sections) seems to preclude the possibility of a geothermal origin.

Induced Pulse Transient (INPUT) Airborne Electrical Survey

The INPUT survey is a less conventional type survey than the preceding surveys and therefore requires a more detailed explanation of its application and limitations. The basic system consists of a large loop of wire strung in a triangle along the aircraft wings and from the wing tips to the tail, and an induction coil towed behind the aircraft on a 500-foot cable. Discontinuous current pulses in the loop creates a magnetic field which induces eddy currents in the ground. The magnetic field from the eddy currents is detected by the induction coil during

the "off-time" of the discontinuous current pulse. Since the eddy currents are stronger for more conductive earth material, this method provides a method for airborne mapping of the ground conductivity.

The electromagnetic data is recorded in analogue fashion in six separate channels, each of which represents a different time lag since the cessation of the current pulse. The higher numbered channels (longer delay time) represent deeper penetration. For a normal flight line altitude of 120 meters, effective depth penetrations of about 120 meters are obtained. For the present survey, this penetration depth is approximately 2 to 3 times the depth to the water table.

A significant limitation of the INPUT technique is that the received signals are strongly dependent upon the altitude. Depending upon ground conductivity, the signals decrease according to the fourth to sixth power of altitude. Thus a slight variation in altitude can cause a significant error in the received signals and therefore, a significant error in the ground conductivity. To reduce this problem, channel ratios (Ch3/Ch6) have been used in the quantitative interpretations. Figure 3 shows the apparent resistivity along a profile extending east from the center of the southeastern Mimbres Basin to a point just east of the basin-bounding fault. Shown are resistivities as calculated by the Schlumberger profiling ($AB/2 = 100m$ and $800m$) and by the INPUT (Ch3/Ch6) technique. The excellent agreement between these independently calculated resistivities shows that reliable ground resistivities can be obtained by the INPUT technique. Also shown in Figure 3 is the channel 3 signal as measured in inches on the analog chart recording. The channel 3 data imply that highly resistive rocks are present in the western part of the profile. This erroneous

interpretation exemplifies the problem discussed above and emphasizes the need to interpret channel ratios rather than the signal amplitudes themselves.

The area covered by the INPUT survey is shown in Figure 1. Detailed coverage has been obtained over the area under investigation for geothermal evaluation with flight lines spaced one-half mile apart (Fig. 1). In addition, two lines were extended 40 km to the east of the detailed area in order to tie into the surface resistivity data of Jackson and Bisdorf (1975). Two lines were also extended 17 km to the west of the detailed area in order to complete the regional picture.

Figure 2 shows the areas of low resistivity as determined by the input (Ch3/Ch6) technique described above. The resistivity low near the east margin of the southeastern Mimbres Basin which had been depicted on the basis of surface resistivity is also obvious from the INPUT data. In addition, a second resistivity low (or two lows separated by a topographic feature known as Black Hill) is also apparent from the INPUT data. The significance of this anomaly cannot be determined due to the possibility of interference from power lines and other cultural activity near the city of Columbus.

Shallow Heat Flow Survey

Seventeen shallow (35 meters) heat flow test holes have been drilled in the study area. The locations of the holes and their heat respective heat flow values are given in Figure 2. The temperature gradients were obtained by making discrete temperature measurements ($\pm 0.01^{\circ}\text{C}$) at 5 meter intervals and applying the method of least squares to the most stable portion of the hole. Conductivity measurements were made with a standard divided bar apparatus using a cylindrical cell containing the rock

fragments (Sass et al., 1971). Porosity values of 40 percent have been applied to these shallow alluvial sediments.

The heat flow tests were positioned in such a way as to obtain data both inside and adjacent to the southeastern Mimbres Basin. Also, the holes were positioned so as to determine heat flow within and adjacent to the electrical resistivity anomalies described above. The average geothermal gradient is high ($52.5 \pm 17.1^\circ\text{C}/\text{km}$). However, the conductivity of these air-filled alluvial sediments is low, averaging only $1.4 \pm 0.11 \text{ W}/\text{m}^\circ\text{C}$. Therefore, the average heat flow over the study area is 75 mW m^{-2} (1.8 HFU). One obvious feature of the heat flow distribution is that the heat flow is higher on the upthrown sides of the two faults, an occurrence which we attribute to thermal refraction. Heat flow values in the basin typically fall in the range $55\text{--}70 \text{ mW m}^{-2}$ (1.3–1.7 HFU). These values are lower than normally found in the Rio Grande Rift and these low values may reflect thermal refraction, convective disturbances at depth, or the general difficulty in getting reliable heat flow values from such shallow holes. None of the heat flow holes located inside the resistivity anomalies show elevated heat flow. Therefore, we conclude that the resistivity anomalies are related to geological factors (i.e., increased groundwater salinity) rather than geothermal activity. The two highest heat flow values are 100 and 131 mW m^{-2} for holes 17 and 11, respectively. Since hole 17 is located at the Columbus International Industrial Park and therefore closest to potential users of geothermal energy, this site was selected for the 296-meter temperature test.

Deep Gradient Test

During late September and early October, 1980, a 296-meter temperature test well was drilled at location 17 (Figure 2) and encountered a maximum bottom hole temperature of 33.4°C. The hole generally penetrated alluvial strata of sand, clay, and gravel although at least two basalt flows were encountered at depths of 81 and 244 meters. Both basalts were underlain by highly permeable zones which resulted in lost circulation during drilling. The temperature data from this well is given in Tables 1 and 2. The quasi-equilibrium temperature gradient over the depth interval 135-296 m is $49.08 \pm 0.22^\circ\text{C}/\text{km}$ data from Table 1, 130-293 m is $50.5 \pm 0.3^\circ\text{C}/\text{km}$ data from Table 2, a value which is high, even for the Rio Grande Rift. If this gradient is maintained for another 300 meters, then temperatures in the range of 45-50°C should be encountered. Such temperatures would be sufficient for low temperature geothermal applications such as space heating provided that suitable aquifers are present.

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Figure 1. Index map showing study area, principal faults, and major geographic features.

Figure 2. Map of the Columbus area showing the major faults, heat flow values, electrical anomalies from the surface and airborne studies, and various geographic features.

Figure 3. Comparison of ground resistivity as determined by Schlumberger profiling ($AB/2 = 100$ and 800 meters), the Channel 3/Channel 6 ratio technique, and the Channel 3 amplitude method. The profile extends approximately between heat flow holes 11 and 7 (Figure 2).

Table 1. Test Hole #18, Columbus, NM 10/21/80.

Depth	Temp.	Depth	Temp.
m	°C	m	°C
5	22.40	150	26.18
10	21.13	155	26.44
15	21.27	160	26.72
20	21.32	165	26.99
25	21.78	170	27.25
30	22.02	175	27.53
35	22.35	180	27.78
40	22.76	185	28.06
45	23.21	190	28.32
50	23.63	195	28.57
55	23.80	200	28.84
60	23.99	205	29.07
65	24.07	210	29.28
70	24.15	215	29.53
75	24.23	220	29.74
80	24.73	225	29.96
85	24.43	230	30.20
90	24.27	235	30.47
95	25.26	240	30.69
100	24.52	245	30.99
105	24.66	250	31.24
110	24.74	255	31.47
115	24.75	260	31.67
120	24.88	265	31.88
125	25.05	270	32.10
130	25.26	275	32.32
135	25.49	280	32.58
140	25.70	285	32.85
145	25.93	290	33.09
		295	33.39
		296	33.40

Table 2

Test Hole No. 18

Columbus, New Mexico
Logged 17 March, 1981

Depth(m)	Temp. (°C)	Depth(m)	Temp. (°C)
5	19.79	155	26.45
10	20.32	160	26.73
15	20.37	165	27.01
20	20.77	170	27.29
25	21.16	175	27.57
30	21.62	180	27.85
35	22.05	185	28.14
40	22.51	190	28.41
45	22.88	195	28.68
50	23.36	200	28.93
55	23.70	205	29.19
60	23.77	210	29.42
65	23.86	215	29.64
70	23.93	220	29.85
75	23.99	225	30.08
80	24.07	230	30.35
85	24.06	235	30.61
90	24.11	240	30.89
95	24.26	245	31.15
100	24.30	250	31.38
105	24.38	255	31.60
110	24.50	260	31.80
115	24.65	265	32.02
120	24.74	270	32.23
125	24.96	275	32.47
130	25.19	280	32.71
135	25.38	285	32.97
140	25.67	290	33.25
145	25.91	293	33.43
150	26.18		

$$\frac{\Delta T}{\Delta z} = 50.5 \pm 0.3 \text{ } ^\circ\text{C/km}$$

$$T_o = 18.70 \pm 0.07^\circ\text{C}$$

for 130 to 293 m
34 pts.

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PART III

ELECTRICAL EXPLORATION AND GEOTHERMAL GRADIENT

STUDIES NEAR COLUMBUS, NEW MEXICO

ELECTRICAL STUDIES

by

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Large scale geologic features suggest that a geothermal resource may be found near Columbus, New Mexico. Columbus is located at the western edge of a filled basin at least 1400 meters deep in a region of high heat flow, greater than 3 HFU (Figures 1 and 2). The basin is bounded by faults that run approximately north-south. The general structure is confirmed by logs from wells drilled for oil and gas (Thompson, Tovar and Conley, 1978), by a reconnaissance gravity survey (Ramsberg, Cook and Smith, 1978) and by class field work done by New Mexico State University geophysics students (Chandler Swanberg, personal communication).

The area lies approximately 150 km south of Faywood Hot Springs, and is bracketed to the northeast and southwest by swarms of cinder cones, all of which suggest geothermal activity. One simple model for a possible geothermal resource near Columbus involves water circulating in the faults forming the basin boundaries, being heated by deep sources. The hot water would mix with other groundwater and move slowly southward.

New Mexico State University geophysicists conducted a coordinated exploration program to search for hot water. The exploration consisted of water sampling and geochemical calculations, resistivity, airborne electromagnetic (AEM), aeromagnetism and exploratory drilling. The resistivity, AEM and aeromagnetic surveys are described here.

The resistivity and AEM methods have the potential to directly locate hot rock or hot water. These substances conduct electricity better than their cold counterparts. However, one should not rely exclusively on these methods: there are other substances, for example, clays and salty water, which are also good conductors and are found in geothermal areas. Thus, it is necessary to conduct coordinated exploration using all geophysical tools available, including verification by temperature measurements in shallow drill holes.

Direct Current Resistivity

Reconnaissance direct current (d.c.) resistivity measurements consisted of profiling along roads. Three profile lines are shown as heavy lines on Figure 5 along with other data. The measured resistivities are plotted as depth sections on Figure 3. Apparent resistivities lower than 3 ohm-meters were encountered 12 to 15 miles east of Columbus. Another profile west of Columbus showed no low resistivities.

Resistivity soundings made over the anomalous zones showed depths of 40 to 60 meters to the top of conductive material (Figure 3). This is approximately the depth to the water table in the area. The minimum depth to the bottom of the conductor is more than 1000 meters. The models for the sounding data are also shown on the profiles of Figure 3. Plots of the sounding data and the sounding curves calculated for our best models are given in the appendix.

Airborne Electromagnetic and Magnetic Survey

The d.c. resistivity survey found low resistivities in the basin west of Columbus and roughly outlining the conductive region. Since a geothermal prospect may contain a very hot zone nearest the source of hot water, it was desirable to conduct a more detailed resistivity survey to hunt for it. Airborne electromagnetic measurements are a cost effective survey method. A recent demonstration test by the United States Geological Survey, over the Steamboat Springs, Colorado KGRA showed that the method is capable of delineating probable geothermal zones.

Operation of INPUT AEM

The Induced Pulse Transient (INPUT) airborne exploration system uses as its transmitted signal positive and negative magnetic pulses separated by dead time. The magnetic field is created by current pulses in a large loop of wire

strung in a triangle along the airplane wings and from wingtips to tail (see Figures 4 and 5).

The magnetic field pulses induce eddy currents in the earth. The currents are greater in more conductive ground. The magnetic field of the eddy current is detected by an induction coil towed behind the aircraft, on a 500 ft. cable. Thus, by mapping the strength of eddy currents, the conductivity of the ground may be determined. As illustrated in Figure 5, the induction coil voltages are recorded at six delay times, i.e. channels, during the dead time between the primary transmitted signal pulses.

Interpretation

Model studies and basic principles show that the later channels represent deeper penetration. A complication which hinders quantitative interpretation of INPUT data is the fact that the received signal varies drastically with altitude. Thus, slight altitude variations cause considerable variations in received signal strength. To reduce this problem, quantitative interpretation uses the ratios of one channel to another to determine apparent resistivity, rather than individual channel amplitudes.

In our survey, we mapped ground conductivity by matching ratios of channel 3 to 6 to a homogeneous earth model, (Hetu, 1980).

Results of Aerial Survey

The aerial survey covered the low resistivity zones found by ground resistivity. Flight line spacing of one mile and one-half mile were used, with the denser coverage over the central part of the survey. To verify the accuracy of the channel ratio resistivity calculations, resistivities from the d.c. resistivity profiles were plotted on the same axis with aerial data (Figures 6a - 6c). Considering the fact that two totally different methods were used to determine ground conductivity, the agreement is excellent.

Figure 7 shows apparent resistivity contours determined from AEM data. The data delineate the low resistivities zone found by d.c. resistivity, in the east center of the figure, and indicate two new zones, to the west, near Columbus. The aeromagnetic data from the survey are presented in Figure 8.

The magnetic data represent the magnetization of rocks. Volcanic rocks are generally strongly magnetized, and sediments are generally weak. Thus where the contours are dense, volcanic rocks are near the surface and where the contours are sparse, there is a thick layer of sedimentary rock. The magnetic data confirm our suspected geologic picture of a deep sedimentary basin in the east-central part of the survey area and flanked by new surface blocks which may be volcanic.

Based on the resistivity, aeromagnetic and AEM data we recommended drilling temperature gradient holes over the lowest resistivity areas, the shaded areas in Figure 7.

Our interpretation is that the low resistivity zone in the east-central portion of the survey area would have the greatest geothermal potential, due to the large reservoir volume formed by the deep basin. The low resistivities near the Mexican-U.S. border would have the second greatest potential, but less hot water found in the thinner layer of sedimentary rock. The low resistivity area immediately adjacent to Columbus is probably not of geothermal origin since if it were, elevated temperatures would show up in domestic water supplies.

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Figure 1. Survey area on tectonic map of southern Rio Grande rift, from Seeger and Morgan, 1979.

Figure 2. Heat flow map from Seager and Morgan, 1979.

Figure 3a. Apparent resistivity data. South profile, pseudo-depth section. Numbers are apparent resistivity in ohm-meters for profiling with $AB/2 = 100$ m (upper numbers) and $AB/2 = 800$ m (lower numbers). Columns labeled CL1 and CL2 represent resistivity depth sections determined from soundings. The horizontal lines in these sections represent the layer boundaries and the numbers represent the layer resistivities in ohm-m.

Figure 3b. Apparent resistivity data. North profile. Numbers are apparent resistivity in ohm-meters for profiling with $AB/2 = 100$ m (upper numbers) and $AB/2 = 800$ m (lower numbers). The horizontal lines in these sections represent the layer boundaries and the numbers represent the layer resistivities in ohm-m.

Figure 3c. Apparent resistivity data. East profile. Numbers are apparent resistivity in ohm-meters for profiling with $AB/2 = 100$ m (upper numbers) and $AB/2 = 800$ m (lower numbers). The horizontal lines in these sections represent the layer boundaries and the numbers represent the layer resistivities in ohm-m.

Figure 4. Equipment for airborne EM surveying using the Input system (Telford et al., 1976).

INPUT SIGNAL

Figure 5. Wave forms for airborne EM surveying using the Input system (Telford et al., 1976).

Figure 6a. Line 1 comparison of apparent resistivities from ground d.c. measurements represented by X's and circles, and airborne EM channel ratios represented by continuous lines.

Figure 6b. Line 2 comparison of apparent resistivities from ground d.c. measurements represented by X's and circles, and airborne EM channel ratios represented by continuous lines.

Figure 6c. Line 3 comparison of apparent resistivities from ground d.c. measurements represented by X's and circles, and airborne EM channel ratios represented by continuous lines.

Figure 7. Apparent resistivity map of the Columbus survey area from airborne EM survey. Resistivity soundings 1, 2, 3, and 4 are indicated by a heavy triangle.

Figure 8. Aeromagnetic map of the Columbus survey area. Contoured values are given in hundreds of gamma over 50,000 gamma. For example, the contour marked 5 is 50,000 gamma.

PART IV

Data from 17 Shallow Temperature Tests

Figure 1. Temperature-depth data.

Test Hole #1, Columbus, N.M.

Depth m	10/11/80	Temp. °C
5		21.28
10		20.08
15		20.65
20		21.02
25		21.29
30		21.52
33		21.62

Test Hole #2, Columbus, N.M.

Depth m	10/11/80	Temp. °C
5		20.52
10		19.79
15		20.26
20		20.59
25		20.88
30		21.15
31		21.19

Test Hole #3, Columbus, N.M.

Depth m	10/21/80	Temp. °C
5		21.41
10		20.44
15		20.83
20		21.06
25		21.26
30		21.44
30.3		21.44

Test Hole #4, Columbus, N.M.

Depth m	10/21/80	Temp. °C
5		21.31
10		20.33
15		20.85
20		21.11
25		21.30
30		21.50
30.2		21.50

Test Hole #5, Columbus, N.M.

Depth m	10/11/80	Temp. °C
5		21.41
10		20.19
15		20.63
20		20.91
25		21.09
30		21.30
32.5		21.37

Test Hole #6, Columbus, N.M.

Depth m	10/11/80	Temp. °C
5		21.24
10		20.16
15		20.52
20		20.72
25		20.85
27.5		20.92

Figure 1. (continued).

Test Hole #7, Columbus, N.M.

Depth m	10/11/80	Temp. °C
5		20.90
10		19.84
15		20.18
20		20.38
25		20.62
26.5		20.67

Test Hole #8, Columbus, N.M.

Depth m	10/3/80	Temp. °C
5		24.46
10		21.43
15		21.80
20		22.14
25		22.47
30		22.76
31.8		22.86

Test Hole #9, Columbus, N.M.

Depth m	10/3/80	Temp. °C
5		26.26
10		20.99
15		21.34
20		21.62
25		21.91
30		22.30
31.4		22.44

Test Hole #10, Columbus, N.M.

Depth m	10/21/80	Temp. °C
5		22.52
10		21.00
15		21.40
20		21.60
25		21.82
30		22.02
30.6		22.04

Test Hole #11, Columbus, N.M.

Depth m	10/2/80	Temp. °C
5		22.33
10		20.93
15		21.67
20		22.22
25		22.73
30		23.14
30.5		23.16

Test Hole #12, Columbus, N.M.

Depth m	10/6/80	Temp. °C
5		21.53
10		20.14
15		20.55
20		20.83
25		21.06
30		21.30
30.5		21.31

Figure 1. (continued).

Test Hole #13, Columbus, N.M.

Depth m	10/2/80	Temp. °C
5		21.37
10		20.18
15		20.72
20		20.95
25		21.14
30		21.34
31.5		21.38

Test Hole #14, Columbus, N.M.

Depth m	10/2/80	Temp. °C
5		21.04
10		20.25
15		20.64
20		20.82
25		21.00
30		21.21
34		21.36

Test Hole #15, Columbus, N.M.

Depth m	10/21/80	Temp. °C
5		21.41
10		20.78
15		21.23
20		21.52
25		21.81
30		22.04
32.5		22.14

Test Hole #16, Columbus, N.M.

Depth m	10/21/80	Temp. °C
5		21.05
10		20.15
15		20.44
20		20.75
25		20.97
28.8		21.16

Test Hole #17, Columbus, N.M.

Depth m	10/2/80	Temp. °C
5		21.32
10		19.80
15		20.16
20		20.65
25		21.01
30		21.46
31		21.52

Figure 2. Temperature logs.

Figure 2. (continued).

Figure 3. Lithologic logs of bore holes at Columbus.

1.	33.0 m	108 ft	Sand, sandy clay, clay
2.	31.0 m	101 ft	Sand, clay
3.	30.3 m	99 ft	Sand, sandy clay, clay
4.	30.2 m	99 ft	Sand, sandy clay, clay
5.	32.5 m	106 ft	Sand, sandy clays
6.	27.5 m	90 ft	Sand, streaks of clay
7.	26.5 m	87.5 ft	Sand, streaks of clay
8.	31.8 m	104 ft	Alluvium, sandy clays, clay
9.	31.4 m	103 ft	Alluvium, sandy clays, clay
10.	30.5 m	100 ft	Sand, sandy clay, clays
11.	30.5 m	100 ft	Sand, sandy clays, clays
12.	30.5 m	100 ft	Sand, sandy clays, clays
13.	31.5 m	103 ft	Sand, sandy clays, clays
14.	34.0 m	111 ft	Sand, sandy clays
15.	32.5 m	106 ft	Sand, sandy clays, clays
16.	28.8 m	94 ft	Sand, sandy clays
17.	31.0 m	101 ft	Sand, sandy clays, clays

All bore holes were drilled to a depth of 100 ft + 10 ft, but due to slumping and caving, some holes are not in the range. The meter depth is the actual amount of 1" PVC casing that was put downhole.

The PVC casing was capped at both ends and water-filled for the purpose of making temperature measurements.

Table 1. Columbus heat-flow data.

Borehole	Latitude	Longitude	Elevation (m)	Temperature Gradient (°C/km)	Thermal Conductivity (W/m-°C)	Heat Flow (mW/m ²)
CR-1	31° 51.5'	107° 28.1'	1215	53.47(1.87)	1.31(.73)	70(39)
CR-2	31° 51.5'	107° 23.2'	1212	57.96(1.71)	1.69(.44)	98(26)
CR-3	31° 50.3'	107° 29.0'	1215	39.73(0.44)	1.46(.34)	58(14)
CR-4	31° 50.2'	107° 27.1'	1212	42.10(0.44)	1.47(.38)	62(16)
CR-5	31° 49.3'	107° 26.0'	1209	41.82(2.25)	1.55(.24)	65(11)
CR-6	31° 48.6	107° 24.9'	1207	31.53(2.76)	1.33(.54)	42(17)
CR-7	31° 48.4'	107° 24.0'	1207	43.44(1.36)	1.47(.27)	64(12)
CR-8	31° 49.3'	107° 23.1'	1242	63.07(1.16)	1.44(.40)	91(25)
CR-9	31° 49.7'	107° 21.9'	1247	66.55(3.57)	1.44(.54)	95(36)
CR-10	31° 48.4'	107° 33.5'	1218	41.35(0.61)	1.42(.15)	59(6)
CR-11	31° 48.8'	107° 30.1'	1214	95.96(11.52)	1.36(.43)	131(44)
CR-12	31° 48.5'	107° 27.9'	1210	48.81(1.38)	1.41(.31)	69(15)
CR-13	31° 48.4'	107° 27.0'	1209	39.99(1.19)	1.44(.58)	57(23)
CR-14	31° 48.2	107° 26.0'	1207	38.11(0.66)	1.54(.58)	59(22)
CR-15	31° 47.0'	107° 27.0'	1207	52.29(2.21)	-----	-----
CR-16	31° 50.1'	107° 25.4'	1210	51.39(2.54)	1.38(.85)	71(44)
CR-17	31° 47.0'	107° 37.7'	1219	84.30(2.18)	1.19(.14)	100(12)
CR-18	31° 47.0'	107° 37.7'	1219	49.08(0.22)	1.03(.23)	51(11)

Thermal conductivity was corrected for porosity by the method of Sass et al. (1971). An assumed porosity of 40% was used.

Gradients calculated over depth range from 15 to 30 m for all wells but CR-18 gradient for CR-18 was calculated over an interval of 135 to 296 m.

Quantities in parentheses are error values.

Figure 4. Location map of deep-temperature test.

PART V

Data from One Deep Temperature Test

Test Hole #18, Columbus, N.M.

10/21/80

Table 1. Temperature-depth log (10/21/81)
disequilibrium.

Depth	Temp.	Depth	Temp.
m	°C	m	°C
5	22.40	150	26.18
10	21.13	155	26.44
15	21.27	160	26.72
20	21.32	165	26.99
25	21.78	170	27.25
30	22.02	175	27.53
35	22.35	180	27.78
40	22.76	185	28.06
45	23.21	190	28.32
50	23.63	195	28.57
55	23.80	200	28.84
60	23.99	205	29.07
65	24.07	210	29.28
70	24.15	215	29.53
75	24.23	220	29.74
80	24.73	225	29.96
85	24.43	230	30.20
90	24.27	235	30.47
95	25.26	240	30.69
100	24.52	245	30.99
105	24.66	250	31.24
110	24.74	255	31.47
115	24.75	260	31.67
120	24.88	265	31.88
125	25.05	270	32.10
130	25.26	275	32.32
135	25.49	280	32.58
140	25.70	285	32.85
145	25.93	290	33.09
		295	33.39
		296	33.40

Figure 1. Temperature log (10/21/80) disequilibrium.

Table 2. Temperature-depth log (3/17/81) equilibrium.

Test Hole No. 18

Columbus, New Mexico
Logged 17 March, 1981

Depth(m)	Temp. (°C)	Depth(m)	Temp. (°C)
5	19.79	155	26.45
10	20.32	160	26.73
15	20.37	165	27.01
20	20.77	170	27.29
25	21.16	175	27.57
30	21.62	180	27.85
35	22.05	185	28.14
40	22.51	190	28.41
45	22.88	195	28.68
50	23.36	200	28.93
55	23.70	205	29.19
60	23.77	210	29.42
65	23.86	215	29.64
70	23.93	220	29.85
75	23.99	225	30.08
80	24.07	230	30.35
85	24.06	235	30.61
90	24.11	240	30.89
95	24.26	245	31.15
100	24.30	250	31.38
105	24.38	255	31.60
110	24.50	260	31.80
115	24.65	265	32.02
120	24.74	270	32.23
125	24.96	275	32.47
130	25.19	280	32.71
135	25.38	285	32.97
140	25.67	290	33.25
145	25.91	293	33.43
150	26.18		

$$\frac{\Delta T}{\Delta z} = 50.5 \pm 0.3 \text{ } ^\circ\text{C/km}$$

$$T_o = 18.70 \pm 0.07^\circ\text{C}$$

for 130 to 293 m
34 pts.

Figure 2. Temperature log (3/17/81) equilibrium.

Depth in meters	Bits used	Rock Type	Date
0			
	1	sand	<u>9/29</u>
31.25			
	2	clay	<u>9/30</u>
62.50	3		
	4	Hard basaltic rock	10/1
93.75		zone of lost circulation	<u>10/2</u>
	5	clay, gravels	<u>10/3</u>
125			
	6	gravels	<u>10/4</u>
156.25			
187.50	7	gravels	
		zone of lost circulation	<u>10/6</u>
218.75			
250	8	hard basaltic rock	<u>10/7</u>
	9	very hard rock	<u>10/8</u>
		Permeability Zone (clays, gravels)	
281.25		lost circulation	
	10		<u>10/9</u>
312.50		course rock	<u>10/10</u>

Figure 3. Lithology.

Figure 4. Location map of deep temperature test.

PART VI

Electrical Resistivity Data*

SITE CL 1 3-LAYERS
R=5 120 6
T=0.8 27

Figure 1. Data and model sounding curve for Schlumberger resistivity sounding, site CL-1. Data are plotted as points, the best fitting calculated model curve is given as a continuous line. The model layer thicknesses are given in meters (m) and the resistivity is given in ohm-meters (ohm-m).

SITE CL 2 5-LAYERS
 R=9.5 100 8 3 100
 T=1.4 0.7 50 1E3

Figure 2. Data and model sounding curve for Schlumberger resistivity sounding, site CL-2. Data are plotted as points; the best fitting calculated model curve is given as a continuous line. The model layer thicknesses are given in meters (m) and the resistivity is given in ohm-meters (ohm-m).

SITE CL-3 4-LAYERS
 R=50 10 1.5 2.7
 T=2.5 60 100

Figure 3. Data and model sounding curve for Schlumber resistivity sounding, site CL-3. Data are plotted as points; the best fitting calculated model curve is given as a continuous line. The model layer thicknesses are given in meters (m) and the resistivity is given in ohm-meters (ohm-m).

SITE CL-4 3-LAYERS
 R=170 7 4.3
 T=6.5 20

Figure 4. Data and model sounding curve for Schlumberger resistivity sounding, site CL-4. Data are plotted as points; the best fitting calculated model curve is given as a continuous line. the model layer thicknesses are given in meters (m) and the resistivity is given in ohm-meters (ohm-m).