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Geothermal anomalies along the Rio Grande rift in New Mexico

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ABSTRACT

Heat-flow data suggest that there are regions along the Rio Grande rift where crustal temperatures are above those in neighboring areas. Magma bodies at 15 to 30 km, as predicted by several investigators, seem to provide reasonable sources of heat that could increase heat-flow values from 1.8 to about 2.5 HFU and somewhat higher. However, heat-flow values of 6.0 to 16.0 HFU occur at four locations along the Rio Grande rift; these values occur within geologic environments such as recent volcanic centers and the intersections of cauldron boundaries with large normal faults where upward heat transport by magmatic and/or ground-water movement is plausible. Test drillings of several kilometres are necessary to confirm the continuity with depth of these very high geothermal gradients and to relate them to their possible sources in the upper crust.

INTRODUCTION

The Rio Grande rift is a series of deeply filled en echelon grabens that trend south from Leadville, Colorado, past El Paso, Texas. The rift structure began to form about 24 to 29 m.y. ago along zones whose position was apparently influenced by late Paleozoic and Laramide uplifts (Chapin and Seager, 1975). Numerous studies suggest that the rift is a tectonically and volcanically active zone of deep-seated crustal weaknesses (Chapin and Seager, 1975; Cordell and Kottlowski, 1975; Cordell, 1976). Studies by Decker and Smithson (1975) and Reiter and others (1975) have shown that the Rio Grande rift is a high heat-flow region. From heat-production data, Edwards and others (1978) concluded that the high heat flow along the Rio Grande rift is not the result of anomalously high crustal radioactivity.

Table 1 presents basic subsurface temperature data from 17 new drill tests along the Rio Grande rift; from 11 of these drill tests, data are used to estimate the heat flow. Data are presented to three significant figures for calculation purposes; however, heat-flow values should be considered meaningful to only two significant figures. The experimental procedure for these heat-flow measurements and the evaluation criteria for the heat-flow estimates are given in Reiter and others (1975). Figure 1 shows heat-flow observation sites from several investigations of the Rio Grande rift in New Mexico.

GEOTHERMAL CHARACTERIZATION OF THE RIO GRANDE RIFT IN NEW MEXICO

Heat-flow data indicate a zone of high heat flow along the Rio Grande rift; this zone may be thought of as an envelope of heat-flow values greater than 2.5 HFU, although there are values less than 2.5 HFU within the envelope (Fig. 1). From the Colorado–New Mexico border south to about lat 35.5°N, the zone of high heat flow appears to coincide generally with the rift structure. From about lat 35.5°N to about lat 33.0°N, the zone appears to follow along the western part of the rift; south of lat 33.0°N, the zone seems to broaden. At four locations within the zone of high heat flow there are hot spots having heat flows in excess of 6.0 HFU (see Fig. 1).

It is likely that the geothermal environment within the zone of high heat flow along the Rio Grande rift is more dynamic than within areas bordering the rift structure. Heat-flow values within the high heat-flow zone are extremely variable, whereas values within areas bordering the zone are more consistent (Fig. 1). Large differences in heat flow over relatively small distances imply relatively shallow thermal sources—for example, in the Jemez Mountains and near Socorro.

Many of the critical characteristics of the high heat-flow zone are not known at present. It is possible that the high heat-flow zone is divided into segments (Sass and others, 1976), and in many places the width of the zone is uncertain. In the southern part of the rift structure the variability of the data, with many values less than 2.5 HFU, suggests that the zone is more complex than the ribbonlike trend to the north.

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Sites having high heat flow (>2.5 HFU) along the Rio Grande rift are often located in geologic environments of a structural and volcanic nature that suggests the presence of magmatic heat sources relatively close to the Earth's surface (Fig. 1). On the other hand, many measurements of less than 2.5 HFU, primarily in the southern part of the rift, are in similar geologic

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TABLE 1. DATA FROM NEW TEMPERATURE MEASUREMENT SITES IN NEW MEXICO

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Aden Hills	32° 09'	107° 03'	1325	150-230	46.6 ± 0.2	..	..	..	.	
Black Range 1	33° 17'	107° 43'	2098	180-230	43.8 ± 0.4	5	Core	5.37 ± 0.44	2.36 ± 0.[illegible]	B
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Monticello	33° 25'	107° 25'	1756	50-90	53.5 ± 3.6					
				90-135	44.8 ± 1.5	2	Core	8.11	3.64	B
Pecos 1	35° 45'	105° 39'	2463	80-101	14.1 ± 0.2					
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				130-170	24.3 ± 0.1	6	Core	8.74 ± 1.32	2.13 ± 0.34	B
Pecos 2	35° 45'	105° 39'	2470	30-60	46.9 ± 0.1					
				70-170	31.0 ± 0.2	7	Core	8.23 ± 1.47	2.56 ± 0.48	B
Pt. of Rocks 1	32° 48'	106° 52'	1356	170-230	53.3 ± 1.0	..	..	..	..	
				240-270	158. ± 4.					
				280-300	66.5 ± 0.5					
Pt. of Rocks 2	32° 48'	106° 54'	1334	180-200	29.9 ± 2.6	..	..	..	..	
				200-240	100. ± 5.					
				240-270	140. ± 1.					
				280-300	76.3 ± 5.2					
Organ N. 1	32° 27'	106° 36'	1530	80-310	29.5 ± 0.1	8	Core	10.1 ± 0.9	3.00 ± 0.28	
				310-840	36.7 ± 0.1	43	Core	8.81 ± 1.86	3.24 ± 0.68	B
Organ N. 2	32° 27'	106° 36'	1530	500-910	35.8 ± 0.1	25	Core	6.92 ± 0.65	2.48 ± 0.23	A
Orogrande S.	32° 25'	106° 07'	1378	100-600	34.5 ± 0.1	7	Core	6.36 ± 0.82	2.20 ± 0.28	A
San Diego Mt. 1	32° 37'	106° 58'	1303	30-60	190. ± 3.	8	Cuttings	7.20 ± 1.09	13.7 ± [illegible]	
				80-140	205. ± 1.	8	Cuttings	7.87 ± 0.82	16.1 ± [illegible]	B
San Diego Mt. 2	32° 37'	106° 58'	1353	41-61	209. ± 2.					
				61-140	218. ± 1.	6	Cuttings	6.99 ± 1.35	15.3 ± 3.0	B

environments. Therefore, it is generally necessary to consider convective heat transfer by ground-water movement as an additional and highly variable factor in the near-surface geothermal gradients at sites along the Rio Grande rift. Data at Monticello Canyon No. 1 (2.0 HFU) and Monticello Canyon No. 2 (4.7 HFU) (Reiter and others, 1975), only several hundred metres apart, indicate the potential for local abstraction of near-surface heat flow and exemplify the problems in interpreting near-surface heat flow in a structurally and hydrologically complex environment.

Heat-flow values greater than 6.0 HFU were measured within the high heat-flow zone (Fig. 1) of the Jemez Mountains (three sites; Reiter and others, 1976), Socorro Peak (Reiter and Smith, 1977), San Diego Mountain (two sites, this paper), and Mirage (Reiter and others, 1975). Heat flows of 5.3 and 4.7 HFU were measured at Dixon and Monticello Canyon No. 2 (Reiter and others, 1975). The San Diego Mountain and Socorro Peak sites are both on intersections of large normal faults with cauldron boundaries of Oligocene age (Seager, 1973; Chapin and Seager, 1975; Chapin and Chamberlin, 1976). The Jemez Mountains sites are within several kilometres of the Valles caldera, active in Pleistocene and Holocene time (Doell and others, 1968). The Mirage site is within several kilometres of a large normal fault, as are the sites at Dixon and Monticello Canyon No. 2. It should be noted, however, that heat-flow values less than 2.5 were estimated at Caballo (2.0 HFU, this paper) and at Big Red Canyon (1.3 HFU; Reiter and others, 1975) within geologic environments that are similar to those at San Diego Mountain and Socorro Peak.

Elevated geothermal gradients continue to a depth of several kilometres in the Jemez Mountains, as demonstrated by the commercial steam wells in the Valles caldera (Stone and Mizell, 1977). From the history of Quaternary eruptions (Doell and others, 1968) and the very high geothermal gradients, it is probable that the heat source in the Jemez Mountains is magmatic and is within the upper crust. However, the continuation with depth of the very high near-surface geothermal gradients at Socorro Peak, San Diego Mountain, and Mirage is not certain. Temperatures at these sites have not been measured at depth, and the cauldron structures at Socorro Peak and San Diego Mountain are much older than the Valles caldera (Seager, 1973; Chapin and Seager, 1975; Chapin and Chamberlin, 1976). Consequently, one must consider several alternative explanations for the very high near-surface geothermal gradients at Socorro Peak, San Diego Mountain, and Mirage. First, it is possible that elevated temperature gradients near the surface are caused by warm ground water moving upward along the fracture zones associated with these sites. Ground water could be warmed under the influence of (1) near-normal geothermal gradients in deeper levels of the fracture zones or (2) somewhat above-normal temperature gradients associated with magmatic intrusion into the lower crust. Alternatively, high near-surface temperature gradients may be caused primarily by magmatic intrusion into the upper crust, with or without associated vertical convective heat transfer by ater. The importance of vertical heat convection by water within geothermal areas has been discussed by y workers (for example, Helgeson, 1968; Renner and others, 75).

DISCUSSION

Several studies have related to the possibilities of magma bodies existing within the upper crust in the Western United States (Blackwell and Baag, 1973; Lachenbruch and others, 1976; Shuleski and others, 1977). If temperature gradients of about 200 °C/km (for example, San Diego Mountain) were to continue with depth, it would be reasonable to suppose that molten rock would be encountered within 5 to 6 km of the surface. The rapid lateral decrease in heat flow at Socorro and the Jemez Mountains supports the concept of relatively shallow thermal sources at these high heat-flow sites. A one-dimensional heat-conduction calculation shows that it is unlikely that magmatic bodies at depth could be directly responsible for very high near-surface temperature gradients. If an initial average temperature gradient in the crust of 30 °C/km and heat transfer only by conduction are assumed, a steady-state, continuous heat source such as magma at 15-km depth, which remains 100 to 500 °C hotter than the in situ rock, could only increase the geothermal gradient by a maximum of 6.7 to 33 °C/km (solidus curves in the presence of excess water in Wyllie, 1971; and Lambert and Wyllie, 1972). Therefore, if the background heat flow is 1.8 HFU, assuming a near-surface thermal conductivity of (6 mcal/(cm·s·°C)), then the observed heat flows greater than 6 HFU .

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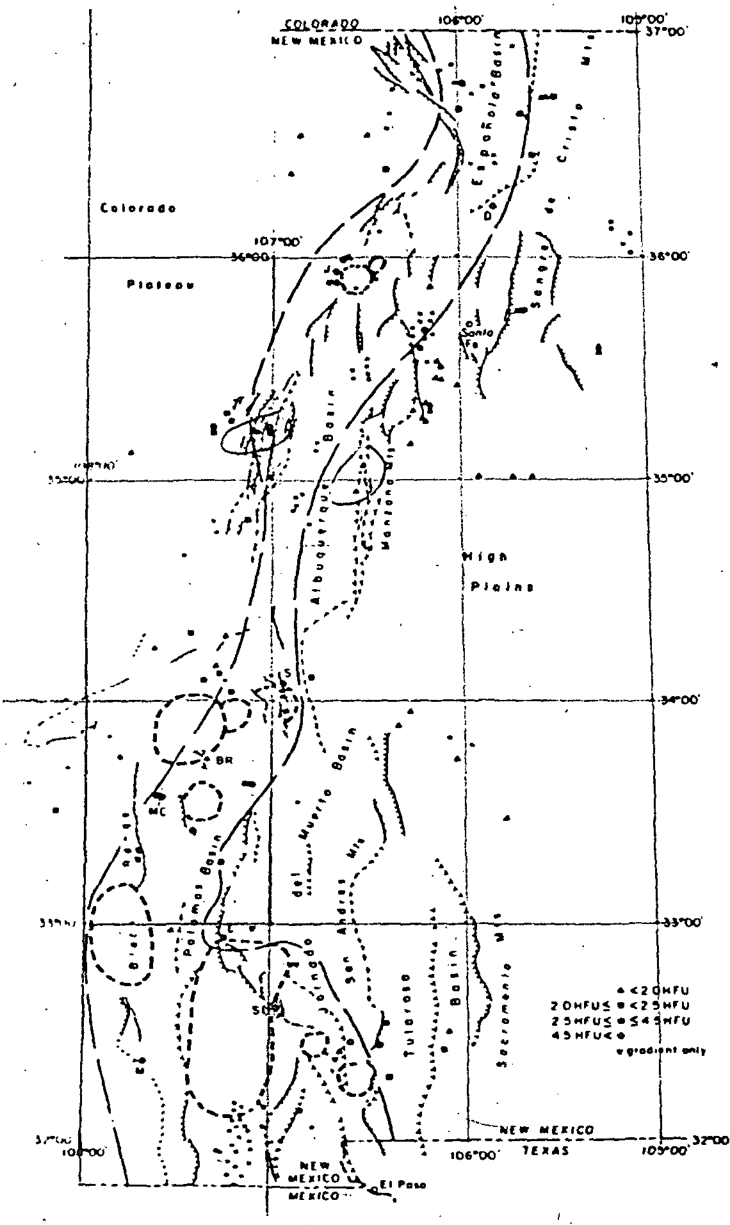

Figure 1. Heat-flow data and geologic features along the Rio Grande rift, New Mexico. Heat-flow sites from Reiter and others (1975), Edwards and others (1978), Reiter and others (1976), Reiter and Smith (1977), and this paper. Geologic features along the Rio Grande rift after Woodward and others (1975), Socorro Peak cauldron boundary by Chapin and Chamberlin (1976). From north to south, sites labeled are D, Dixon; J, Jemez Mountains; S, Socorro Peak; BR, Big Red Canyon; MC, Monticello Canyon 1 and Monticello Canyon 2; C, Caballo; SD, San Diego Mountain; and M, Mirage. Hachured lines indicate normal faults, hachures on downthrown side; solid line through points at Monticello Canyon indicates a high-angle fault; asterisks indicate volcanic centers; double broken lines encircle cauldron boundaries; heavy broken lines indicate the high heat-flow envelope.

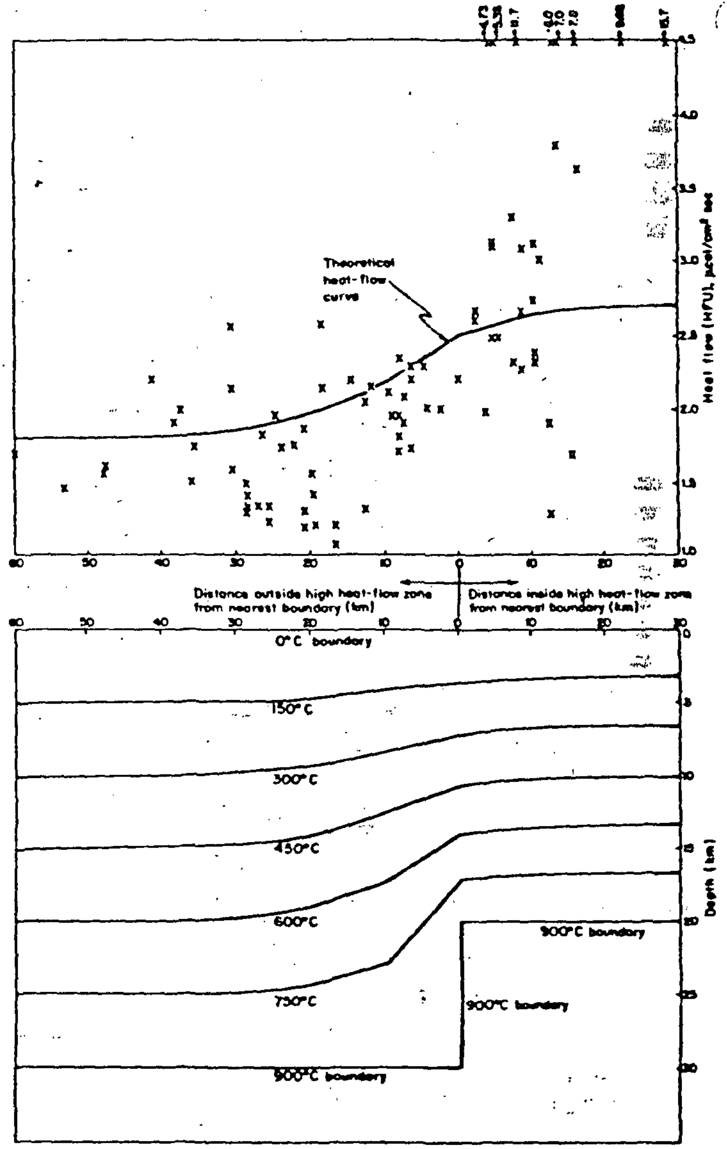

Figure 2. A steady-state finite-difference numerical model (below) of isotherms that would result from a 300 °C temperature increase (from 600 °C to 900 °C) at 20-km depth under the Rio Grande rift. An initial temperature gradient of 30 °C/km and a near-surface thermal conductivity of 6 mcal/cm·s·°C are assumed. A resulting theoretical heat-flow curve is shown above on a plot of measured data within and near the high heat-flow zone. (Dixon and San Diego Mountain sites are average values.)

that are due to direct conduction must result from thermal anomalies that are significantly shallower than 15 km. Nevertheless, it is probable that ground water transports heat vertically by convection at most sites characterized by high heat flow, and this convective thermal regime can make the interpretation of shallow thermal measurements ambiguous. Whether very high geothermal gradients at most of the high heat-flow sites are induced directly or secondarily by magmatic sources relatively close to the Earth's surface or primarily by nonmagmatic hydrological phenomena in deep fracture systems may require tests in boreholes several kilometres deep.

Several studies predict magma bodies within the crust under the Rio Grande rift at 15 to 30 km (Lipman, 1969; Sanford and others, 1973; Decker and Smithson, 1975). Within the heat-flow anomaly in the Rio Grande rift, about twice as many heat-flow values are above 2.5 HFU as are below. This may imply that our data are biased toward areas with high heat flow or, alternatively, that background crustal temperatures are indeed hotter along the Rio Grande rift than in neighboring areas. A straightforward calculation suggests that the heat-flow values of about 2.5 HFU may be due to magmatic bodies at 15 km or more, in contrast to sources for the local high heat-flow anomalies. If initial geothermal gradients are assumed to have been 30 °C/km and initial heat flows to have been 1.8 HFU, then an increase of about 12 °C/km in the geothermal gradient would be required to raise the regional heat flow to 2.5 HFU. Although there is considerable uncertainty in estimating the thermal regime of a deep magma body and its surroundings through time, as well as the temperature differential between the magma and host rock, it would appear reasonable to believe (using the calculation method of the preceding paragraph) that heat flows of about 2.5 HFU and somewhat greater could be induced by the introduction of magma sources of sufficient thermal capacity (volume) at 15 to 30 km. The projected half-width of the thermal anomaly along the Rio Grande rift at many locations (15 to 35 km) supports this conclusion (Reiter and others, 1975).

Figure 2 shows a steady-state model of isotherms in a thermal regime developed in the Rio Grande rift with an initial temperature gradient of 30 °C/km (heat flow of 1.8 HFU), which is subjected to a 300 °C temperature increase at a depth of 20 km. A theoretical heat-flow curve based on the described model is shown on a plot of heat-flow data measured along the rift. The average heat flow outside the high heat-flow zone as tentatively indicated in Figure 2 is 1.77 ± 0:38 HFU. The unadjusted average heat flow inside this zone is 4.20 ± 3.25 HFU. However, if we were to include only values between 2.25 and 3.50 HFU inside the high heat-flow zone, the average heat flow is 2.73 ± 0.35 HFU. Measurements within these limits are less scattered than the higher and lower heat-flow values, and it is reasonable to assume that these measurements are indicators of background heat flow of 2.7 HFU for many regions along the Rio Grande rift. Values outside of the high and low limits probably are caused by magmatic intrusion close to the surface and/or near-surface hydrothermal circulation. Deep ground-water circulation can result in a variety of temperature distributions at depth, but this aspect of the thermal regime in the Rio Grande rift has yet to be adequately explored.

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				130-170	24.3 ± 0.1	6	Core	8.74 ± 1.32	2.13 ± 0.34	B
Pecos 2	35° 45'	105° 39'	2470	30-60	46.9 ± 0.1					
				70-170	31.0 ± 0.2	7	Core	8.23 ± 1.47	2.56 ± 0.48	B
Pt. of Rocks 1	32° 48'	106° 52'	1356	170-230	53.3 ± 1.0	..	..	..	..	
				240-270	158. ± 4.					
				280-300	66.5 ± 0.5					
Pt. of Rocks 2	32° 48'	106° 54'	1334	180-200	29.9 ± 2.6	..	..	..	..	
				200-240	100. ± 5.					
				240-270	140. ± 1.					
				280-300	76.3 ± 5.2					
Organ N. 1	32° 27'	106° 36'	1530	80-310	29.5 ± 0.1	8	Core	10.1 ± 0.9	3.00 ± 0.28	
				310-840	36.7 ± 0.1	43	Core	8.81 ± 1.86	3.24 ± 0.68	B
Organ N. 2	32° 27'	106° 36'	1530	500-910	35.8 ± 0.1	25	Core	6.92 ± 0.65	2.48 ± 0.23	A
Orogrande S.	32° 25'	106° 07'	1378	100-600	34.5 ± 0.1	7	Core	6.36 ± 0.82	2.20 ± 0.28	A
San Diego Mt. 1	32° 37'	106° 58'	1303	30-60	190. ± 3.	8	Cuttings	7.20 ± 1.09	13.7 ± 2.3	
				80-140	205. ± 1.	8	Cuttings	7.87 ± 0.82	16.1 ± 1.8	B
San Diego Mt. 2	32° 37'	106° 58'	1353	41-61	209. ± 2.					
				61-140	218. ± 1.	6	Cuttings	6.99 ± 1.35	15.3 ± 3.0	B

environments. Therefore, it is generally necessary to consider convective heat transfer by ground-water movement as an additional and highly variable factor in the near-surface geothermal gradients at sites along the Rio Grande rift. Data at Monticello Canyon No. 1 (2.0 HFU) and Monticello Canyon No. 2 (4.7 HFU) (Reiter and others, 1975), only several hundred metres apart, indicate the potential for local abstraction of near-surface heat flow and exemplify the problems in interpreting near-surface heat flow in a structurally and hydrologically complex environment.

Heat-flow values greater than 6.0 HFU were measured within the high heat-flow zone (Fig. 1) of the Jemez Mountains (three sites; Reiter and others, 1976), Socorro Peak (Reiter and Smith, 1977), San Diego Mountain (two sites, this paper), and Mirage (Reiter and others, 1975). Heat flows of 5.3 and 4.7 HFU were measured at Dixon and Monticello Canyon No. 2 (Reiter and others, 1975). The San Diego Mountain and Socorro Peak sites are both on intersections of large normal faults with cauldron boundaries of Oligocene age (Seager, 1973; Chapin and Seager, 1975; Chapin and Chamberlin, 1976). The Jemez Mountains sites are within several kilometres of the Valles caldera, active in Pleistocene and Holocene time (Doell and others, 1968). The Mirage site is within several kilometres of a large normal fault, as are the sites at Dixon and Monticello Canyon No. 2. It should be noted, however, that heat-flow values less than 2.5 were estimated at Caballo (2.0 HFU, this paper) and at Big Red Canyon (1.3 HFU; Reiter and others, 1975) within geologic environments that are similar to those at San Diego Mountain and Socorro Peak.

Elevated geothermal gradients continue to a depth of several kilometres in the Jemez Mountains, as demonstrated by the commercial steam wells in the Valles caldera (Stone and Mizell, 1977). From the history of Quaternary eruptions (Doell and others, 1968) and the very high geothermal gradients, it is probable that the heat source in the Jemez Mountains is magmatic and is within the upper crust. However, the continuation with depth of the very high near-surface geothermal gradients at Socorro Peak, San Diego Mountain, and Mirage is not certain. Temperatures at these sites have not been measured at depth, and the cauldron structures at Socorro Peak and San Diego Mountain are much older than the Valles caldera (Seager, 1973; Chapin and Seager, 1975; Chapin and Chamberlin, 1976). Consequently, one must consider several alternative explanations for the very high near-surface geothermal gradients at Socorro Peak, San Diego Mountain, and Mirage. First, it is possible that elevated temperature gradients near the surface are caused by warm ground water moving upward along the fracture zones associated with these sites. Ground water could be warmed under the influence of (1) near-normal geothermal gradients in deeper levels of the fracture zones or (2) somewhat above-normal temperature gradients associated with magmatic intrusion into the lower crust. Alternatively, high near-surface temperature gradients may be caused primarily by magmatic intrusion into the upper crust, with or without associated vertical convective heat transfer by ground water. The importance of vertical heat convection by ground water within geothermal areas has been discussed by many workers (for example, Helgeson, 1968; Renner and others, 1975).

DISCUSSION

Several studies have related to the possibilities of magma bodies existing within the upper crust in the Western United States (Blackwell and Baag, 1973; Lachenbruch and others, 1976; Shuleski and others, 1977). If temperature gradients of about 200 °C/km (for example, San Diego Mountain) were to continue with depth, it would be reasonable to suppose that molten rock would be encountered within 5 to 6 km of the surface. The rapid lateral decrease in heat flow at Socorro and the Jemez Mountains supports the concept of relatively shallow thermal sources at these high heat-flow sites. A one-dimensional heat-conduction calculation shows that it is unlikely that magmatic bodies at depth could be directly responsible for very high near-surface temperature gradients. If an initial average temperature gradient in the crust of 30 °C/km and heat transfer only by conduction are assumed, a steady-state, continuous heat source such as magma at 15-km depth, which remains 100 to 500 °C hotter than the in situ rock, could only increase the geothermal gradient by a maximum of 6.7 to 33 °C/km (solidus curves in the presence of excess water in Wyllie, 1971; and Lambert and Wyllie, 1972). Therefore, if the background heat flow is 1.8 HFU, assuming a near-surface thermal conductivity of (6 mcal/(cm•s•°C)) then the observed heat flows greater than 6 HFU .

at "grad"

$= 6\times10^{-3}\,\frac{\text{cal}}{(\text{cm}\cdot\text{s}\cdot{}^\circ\text{C}}$

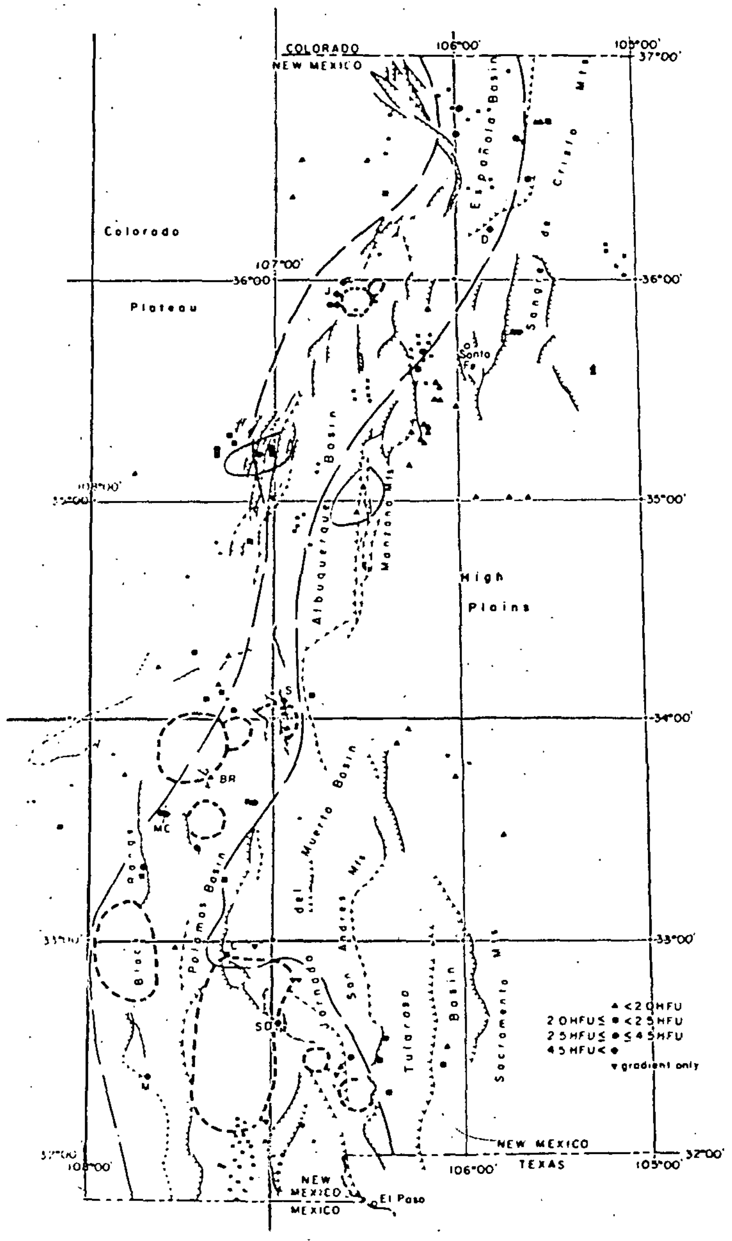

Figure 1. Heat-flow data and geologic features along the Rio Grande rift, New Mexico. Heat-flow sites from Reiter and others (1975), Edwards and others (1978), Reiter and others (1976), Reiter and Smith (1977), and this paper. Geologic features along the Rio Grande rift after Woodward and others (1975), Socorro Peak cauldron boundary by Chapin and Chamberlin (1976). From north to south, sites labeled are D, Dixon; J, Jemez Mountains; S, Socorro Peak; BR, Big Red Canyon; MC, Monticello Canyon 1 and Monticello Canyon 2; C, Caballo; SD, San Diego Mountain; and M, Mirage. Hachured lines indicate normal faults, hachures on downthrown side; solid line through points at Monticello Canyon indicates a high-angle fault; asterisks indicate volcanic centers; double broken lines encircle cauldron boundaries; heavy broken lines indicate the high heat-flow envelope.

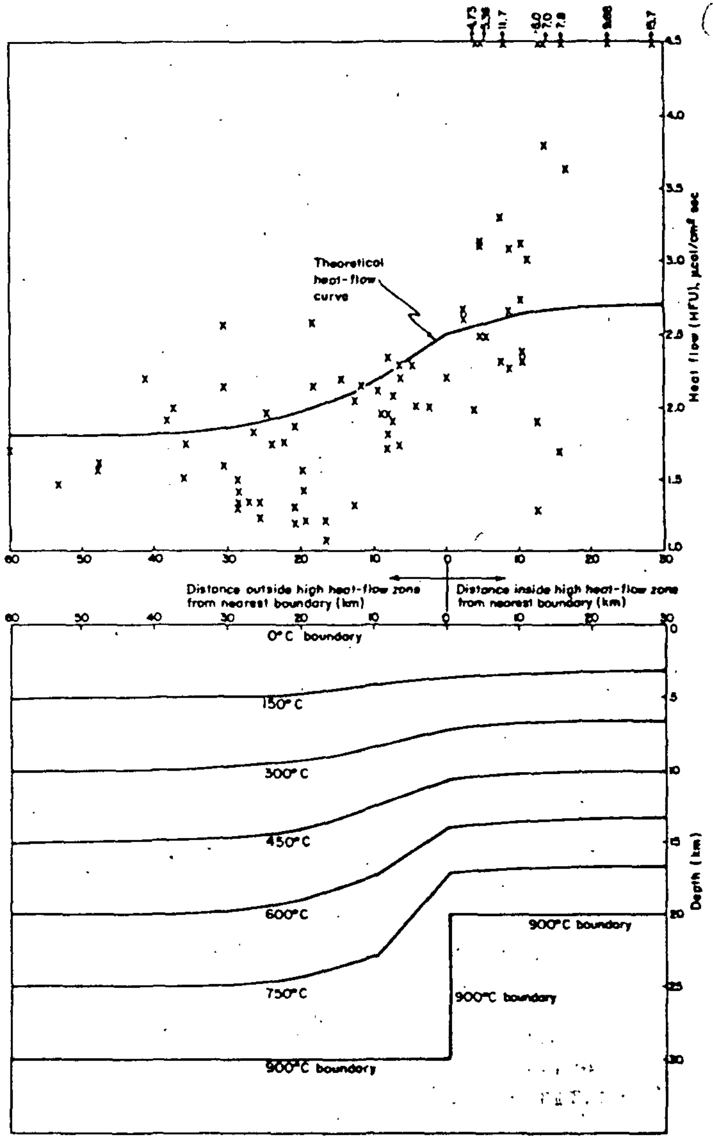

Figure 2. A steady-state finite-difference numerical model (below) of isotherms that would result from a 300 °C temperature increase (from 600 °C to 900 °C) at 20-km depth under the Rio Grande rift. An initial temperature gradient of 30 °C/km and a near-surface thermal conductivity of 6 mcal/cm·s·°C are assumed. A resulting theoretical heat-flow curve is shown above on a plot of measured data within and near the high heat-flow zone. (Dixon and San Diego Mountain sites are average values.)

that are due to direct conduction must result from thermal anomalies that are significantly shallower than 15 km. Nevertheless, it is probable that ground water transports heat vertically by convection at most sites characterized by high heat flow, and this convective thermal regime can make the interpretation of shallow thermal measurements ambiguous. Whether very high geothermal gradients at most of the high heat-flow sites are induced directly or secondarily by magmatic sources relatively close to the Earth's surface or primarily by nonmagmatic hydrological phenomena in deep fracture systems may require tests in boreholes several kilometres deep.

Several studies predict magma bodies within the crust under the Rio Grande rift at 15 to 30 km (Lipman, 1969; Sanford and others, 1973; Decker and Smithson, 1975). Within the heat-flow anomaly in the Rio Grande rift, about twice as many heat-flow values are above 2.5 HFU as are below. This may imply that our data are biased toward areas with high heat flow or, alternatively, that background crustal temperatures are indeed hotter along the Rio Grande rift than in neighboring areas. A straightforward calculation suggests that the heat-flow values of about 2.5 HFU may be due to magmatic bodies at 15 km or more, in contrast to sources for the local high heat-flow anomalies. If initial geothermal gradients are assumed to have been 30 °C/km and initial heat flows to have been 1.8 HFU, then an increase of about 12 °C/km in the geothermal gradient would be required to raise the regional heat flow to 2.5 HFU. Although there is considerable uncertainty in estimating the thermal regime of a deep magma body and its surroundings through time, as well as the temperature differential between the magma and host rock, it would appear reasonable to believe (using the calculation method of the preceding paragraph) that heat flows of about 2.5 HFU and somewhat greater could be induced by the introduction of magma sources of sufficient thermal capacity (volume) at 15 to 30 km. The projected half-width of the thermal anomaly along the Rio Grande rift at many locations (15 to 35 km) supports this conclusion (Reiter and others, 1975).

Figure 2 shows a steady-state model of isotherms in a thermal regime developed in the Rio Grande rift with an initial temperature gradient of 30 °C/km (heat flow of 1.8 HFU), which is subjected to a 300 °C temperature increase at a depth of 20 km. A theoretical heat-flow curve based on the described model is shown on a plot of heat-flow data measured along the rift. The average heat flow outside the high heat-flow zone as tentatively indicated in Figure 2 is 1.77 ± 0:38 HFU. The unadjusted average heat flow inside this zone is 4.20 ± 3.25 HFU. However, if we were to include only values between 2.25 and 3.50 HFU inside the high heat-flow zone, the average heat flow is 2.73 ± 0.35 HFU. Measurements within these limits are less scattered than the higher and lower heat-flow values, and it is reasonable to assume that these measurements are indicators of background heat flow of 2.7 HFU for many regions along the Rio Grande rift. Values outside of the high and low limits probably are caused by magmatic intrusion close to the surface and/or near-surface hydrothermal circulation. Deep ground-water circulation can result in a variety of temperature distributions at depth, but this aspect of the thermal regime in the Rio Grande rift has yet to be adequately explored.

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