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Terrestrial Heat Flow and Crustal Radioactivity in Northeastern New Mexico and Southeastern Colorado

by

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ABSTRACT

New heat flow data obtained in northeastern New Mexico and southeastern Colorado show three regional trends. 1) A broad heat flow anomaly associated with the Southern Rocky Mountains contrasts with a narrow heat flow anomaly between 35.5° N. lat. and 34° N. lat., apparently associated only with the Rio Grande rift. 2) The high heat flow anomaly apparently associated with the Southern Rocky Mountains extends 200-300 km onto the Great Plains of northeastern New Mexico and southeastern Colorado. 3) Areas of extensive volcanic activity do not necessarily have high heat flow. In addition, measurements of crustal radioactivity in the vicinity of the Rio Grande rift suggest that the radioactive heat generation contributes uniformly to the surface heat flow. This implies that the heat flow anomaly observed along the Rio Grande rift is caused by tectonic and volcanic sources and not by anomalously high crustal radioactivity.

INTRODUCTION

The purpose of this study was to refine the heat flow map in northeastern New Mexico and southeastern Colorado and to measure crustal radioactivity at drill sites in the vicinity of the Rio Grande rift in order to estimate the contribution of crustal radioactive heating to the surface heat flow. Sixty-five temperature logs were made in northeastern New Mexico and southeastern Colorado yielding fifty-three new unreduced heat flow values (Figure 1). Nine new reduced heat flows have been made along the Rio Grande rift and vicinity in New Mexico and southern Colorado.

PRESENTATION OF HEAT FLOW DATA

Table I summarizes previously unreported heat flow data at 53 sites in northern New Mexico and southern Colorado. The location of these and other published heat flow data is shown in Figure 2.

Heat flow is calculated by multiplying measured linear thermal gradients in drill tests by the corresponding average measured thermal conductivities. A best heat flow value for each site is normally chosen by averaging the heat flow throughout the drill hole. However, if the heat fluxes vary substantially we attempt to choose the heat flow that seems most reasonable in light of the thermal conductivity control, the linearity of the gradient, possible regional groundwater movement or vertical movement of water within the well bore. The heat flow measurements are evaluated in Table I as A, B, or C, using the criteria of Reiter and others (1975).

Figure 2 shows the major basins and uplifts in northern New Mexico and southern Colorado. The hatched areas show regions of extensive volcanic activity. Heat flow values vary considerably between various volcanic areas. High heat flow values were observed in the San Juan volcanic area (2.2-3.4 HFU) and in the Jemez volcanic field (> 3.0 HFU). Somewhat lower heat flow values were observed in the Mount Taylor volcanic area (1.5-2.0 HFU). Normal heat flow values were observed in the Raton, Clayton, and Capulin volcanic fields (1.3-1.5 HFU). Lipman and others (1973) summarize K-Ar ages of upper Cenozoic basaltic rocks in this region. The ages of volcanism range from 16 to 23 my in the San Juan Mountains, from 0.1 to >9 my in the Jemez volcanic field, from 0.1 to 3 my in the Mount Taylor volcanic field, and from 0.01 to 7 my in the Capulin and Clayton volcanic fields.

Heat flow varies from basin to basin within northern New Mexico and southern Colorado. In northwestern New Mexico and southwestern Colorado the San Juan and Blanding basins exhibit normal heat flows (1.3-1.5 HFU). In northeastern New Mexico and southeastern Colorado the Las Vegas and Raton Basins have higher heat flows ($\geq$2.0 HFU). In east central New Mexico the Tucumcari basin has a normal heat flow (1.4 HFU).

Figure 3 shows a heat flow contour map of northern New Mexico and southern Colorado. In northeastern New Mexico and southeastern Colorado this map is a revision of a previous heat flow map published by Reiter and others (1975). The contours are solid lines in areas where there is good control; that is, it appears unlikely that additional data will significantly change the character and location of the contours. Dashed contours indicate that additional data may change the location of the contours but probably not the character. Question marks are used where data coverage is sparse and considerable ambiguity exists in the location and character of contours.

The Great Plains has been considered an area of low to normal heat flow ($\leq$1.5 HFU); however, this characterization does not appear to be generally valid in northeastern New Mexico and southeastern Colorado where the heat fluxes vary from 1.3 to over 2.5 HFU. A broad heat flow anomaly in northern New Mexico and southern Colorado associated with the Southern Rocky Mountain complex contrasts with a narrow heat flow anomaly between Santa Fe (about 35.5° N. lat.) and Socorro (about 34.0° N. lat.), New Mexico, apparently associated only with the Rio Grande rift. Between 35.5° N. lat. and 38.5° N. lat. the change from heat flow values of 2.5 HFU, observed near the Rio Grande rift, to heat flow values of $\leq$1.5 HFU, observed on the

Great Plains, occurs over a distance of 200 to 300 km. However, between Santa Fe and Socorro, New Mexico, the change from heat flow values of $\geq$2.5 HFU to heat flow values of $\leq$1.5 HFU occurs over a distance of 20 to 30 km. Local anomalies in the Las Vegas basin, the Raton Basin, near Pueblo, Colorado, and near Questa, New Mexico, suggest that the heat flow pattern in the Southern Rocky Mountains is more complex than shown in Figure 3. More data will be necessary to determine the size and character of these anomalies.

PRESENTATION OF RADIOGENIC DATA

Reduced heat flow values were calculated according to the definition given by Roy and others (1972). The best heat flow value at each site is reduced by the amount AH where A is the radiogenic heat production at the site and H is 10 km. Roy and others (1972) and Decker and Smithson (1975) used H $\simeq$ 10 km to calculate reduced heat flows in southern New Mexico. Potassium, uranium, and thorium concentrations were measured for each site using samples from the drill hole and the heat production was calculated by the technique described by Swanberg (1972) and by Rybach (1971).

Figure 4 shows the locations of reduced heat flow sites in New Mexico and southern Colorado. The reduced heat flows and associated radioactivity data are presented in Table 2. Within the Southern Rocky Mountain region the reduced heat flows at Los Alamos (>3.2 HFU) and at Crested Butte (2.1 HFU) are higher than the intercept q* (1.3-1.4 HFU) predicted by Roy and others (1968) for the region. However the reduced heat flow values at Questa (0.52 and 0.74 HFU) are lower than the predicted intercept. East of the Rio Grande rift, between Santa Fe and Socorro, New Mexico, the reduced heat flow values at San Pedro (0.89 and 0.85 HFU) compare closely with the 0.8 ± 0.1 HFU intercept for the Great Plains as suggested by Roy and others (1968) and Decker and Smithson (1975). West of the Rio Grande in southern New Mexico, the reduced heat flow value at Animas Peak (1.1 HFU) is intermediate between Basin and Range and Great Plains values. A reduced heat flow of 1.4 HFU, a typical Basin and Range value, was measured in the southern region near Orogrande. This differs from the value of 2.0-2.6 HFU that Decker and Smithson (1975) measured about 15 km to the south.

Figure 5 shows a plot of the heat flow versus heat production for the Rio Grande rift and vicinity of New Mexico and southern Colorado. The solid line represents the linear heat flow - heat production relation for the Basin and Range (Roy and others, 1968). Of the 19 values plotted, only four, Lordsburg, Santa Rita, Orogrande North, and Animas Peak plot within ±20% of this linear relation. The vertical dashed line, representing a crustal radioactive heat production of 0.38 HFU, is the average heat generation of all sites measured in this study excluding Questa and Sierra Blanca, where the data plotted more than two standard deviations from the mean radioactive heat production. This implies that the radioactive heat generation in the Rio Grande rift vicinity is relatively constant, with about 0.38 HFU of the unreduced heat flow coming from radioactive decay in the upper crust.

DISCUSSION

The Southern Rocky Mountain complex in northern New Mexico and southern Colorado is characterized by a broad region of high heat flow with heat flows greater than 2.5 HFU along the Rio Grande rift and in the Las Vegas and Raton Basins. This broad high heat flow region narrows significantly between Santa Fe and Socorro, New Mexico, although more heat flow data would better determine the continuity of the high heat flow ribbon between Albuquerque and Socorro. This heat flow pattern suggests widely distributed and perhaps deeper thermal sources under the Southern Rocky Mountain complex of northern New Mexico and southern Colorado, as opposed to narrowly distributed, shallower thermal sources under the Rio Grande rift. Between 35.5° N. lat. and 38.5° N. lat. the transition from heat flows less than 1.5 HFU on the Great Plains occurs over a distance of 200 to 300 km. The same heat flow transition occurs over 15 to 35 km between Santa Fe and Socorro, New Mexico (for example along 34.5° N. lat.). The narrow width of the heat flow anomaly along the Rio Grande rift between Santa Fe and Socorro, 15 to 35 km, implies that the width of the thermal source at depth is probably no greater than 15 to 35 km. If one assumes that a continuous subsurface thermal source underneath the Rio Grande rift is solely responsible for the narrow ribbonlike heat flow pattern between Santa Fe and Socorro, then the associated half width of the observed heat flow anomaly suggests that the thermal source is no deeper than 15 to 35 km. This conclusion agrees with geochemical data presented by Lipman (1969) and with seismic data presented by Sanford and others (1973). The broad heat flow anomaly in the Southern Rocky Mountains implies more widely distributed sources probably deeper than those under the Rio Grande rift.

Gough (1974) shows that areas having high heat flow generally have high electrical conductivity in the mantle. Caner and others (1967) and Reitzel and others (1970) have shown that the electrical conductivity anomalies follow closely the boundaries of structural provinces with the electrical conductivity in the mantle increasing from the Great Plains to the Southern Rocky Mountains and then decreasing again under the Colorado Plateau. The new heat flow data presented in this manuscript show a broad heat flow anomaly associated with the Southern Rocky Mountains extending onto the Great Plains of northeastern New Mexico and southeastern Colorado (Figure 3). Caner and others (1967) discuss an electrical conductivity anomaly which appears coincident with this high heat flow anomaly. However, Porath and Gough (1971) postulate the existence of two distinct electrical conductivity anomalies superimposed in this area, one a mantle feature associated with the Southern Rocky Mountains and the other an upper crustal anomaly due to the conducting sediments of the deep Andarko Basin of southwest Oklahoma. Caner (1970) points out that such a reinterpretation of the original data is possible. The new heat flow data are consistent with the original interpretation of the geomagnetic data by Caner and others (1967) and are not consistent with the more recent interpretation of geomagnetic data by Porath and Gough (1971) and Caner (1970).

Porath and Gough (1971) show a model for a geomagnetic profile at 38° N. lat. The depth to the conducting layer is 350 km under the Great Plains, 150 km under the Southern Rocky Mountains and 350 km under the Colorado Plateau. Porath (1971) shows an alternative model to fit the same data. The depth to the conducting layer under the Great Plains is 160 km; however, the conducting layer under the Southern Rocky Mountains is modeled as a ridge and step structure with the shallowest depth to the conducting layer as 45 km. New heat flow data presented in this manuscript show high heat flow anomalies in the Las Vegas Basin, the Raton Basin, and near Pueblo Colorado (Figure 3). Present heat flow data indicate a small decrease in heat flow under the Southern Rocky Mountains near Questa. The complex thermal structure in this area suggests that a ridge and step electrical conductivity model for the mantle is reasonable. The high electrical conductivity under the Southern Rocky Mountains implies high mantle temperatures (Madden, 1970; Gough and Porath, 1970). The broad high heat flow anomaly associated with the Southern Rocky Mountains may reflect these high mantle temperatures.

With data presently available it is not possible to determine if the source of the high heat flow anomaly that extends onto the Great Plains is a continuation of the source of the high heat-flow anomaly associated with the Southern Rocky Mountains. It is possible that two separate high heat flow anomalies exist, one coincident with the Southern Rocky Mountains and the other associated with the Raton and Las Vegas Basins. The superposition of two anomalies with the possible masking effects of deep groundwater motion could produce the observed anomaly. Suppe and others (1975) have proposed a hot-spot trace across New Mexico from the White Mountain volcanic field of eastern Arizona to the Raton-Clayton volcanic field in the Great Plains of northeastern New Mexico with the hot-spot presently near Raton, New Mexico. This hot-spot could possibly be the source of the high heat flow anomaly in the Great Plains.

Heat flow data measured in volcanic areas (Figure 2) vary significantly from one area to another. The volcanics of the Raton-Clayton fields are derived from the mantle with essentially no crustal contamination (Jones and others, 1974), the heat flows measured in this area range from 1.2-1.5 HFU. The tholeiitic basalts within the Rio Grande rift in northern New Mexico and southern Colorado probably fractionated at a depth of 15-20 km (Lipman, 1969; Lipman and others, 1973). This area is characterized by heat flows greater than 2.5 HFU. The volcanic rocks in the San Juan volcanic area of southwestern Colorado erupted from a cluster of central vent volcanoes (Eardly, 1962; Lipman and others, 1973). The western and central portion of the San Juan volcanic area contain abundant cauldron subsidence structures (Luedke and Burbank, 1968; Steven and Epis, 1968). This area has high heat flows (2.2-3.4 HFU), but the values are not consistently as high as those within the northern Rio Grande rift. The Jemez volcanic area in north-central New Mexico is the result of multiple eruptions which have produced an immense cauldron structure. The heat flows on the western side of the Jemez volcanic area are greater than 3.0 HFU (Reiter and others, 1976b.) The Mount Taylor volcanic field in north-central New Mexico is the result of a large central vent volcano. The heat flows in the Mount Taylor area range from 1.5 to 2.0 HFU (Reiter and others, 1975).

The heat flow data within the basins of northern New Mexico and southern Colorado also show considerable variation between basins. The anomalously high heat flows in the Las Vegas and Raton Basins contrast with normal heat flows in other basins within the region, the San Juan, the Blanding and the Tucumcari Basins. The Las Vegas and Raton Basins have been extensively intruded by igneous rocks (Johnson and others, 1966;

Johnson, 1968). The Tucumcari Basin in the Great Plains of eastern New Mexico, and the San Juan and Blanding Basins within the Colorado Plateau, have had little igneous or volcanic activity (Eardley, 1962).

The results of the crustal radiogenic measurements in the Rio Grande rift vicinity (Decker and Smithson, 1975; this study) suggest that radioactive decay in the upper crust contributes about 0.38 HFU to the unreduced heat flow within the area (Figure 5). This implies that the heat flow anomalies observed in New Mexico and southern Colorado along the Rio Grande rift, (this study; Reiter and others, 1975; Decker and Smithson, 1975) are not caused by lateral variations in the concentrations of potassium, uranium and thorium within the crust. The Rio Grande rift high heat flow anomaly observed by Decker and Smithson (1975) in southern New Mexico and by Reiter and others (1975) throughout New Mexico and southern Colorado is probably a result of non-radioactive thermal sources underneath the Rio Grande depression.

The low reduced heat flow values at Questa, 0.52 HFU and 0.74 HFU, are below the 1.4 HFU intercept of the Southern Rocky Mountain-Basin and Range heat flow province. The reduced heat flow value of 0.59 HFU at Sierra Blanca is below the 0.8 HFU intercept for the Great Plains heat flow province. The heat generation measured at these sites is three times greater than the average for the Rio Grande rift vicinity. It is possible that the samples measured at these sites are not representative of the upper crust. The reduced heat flow values of 0.89 and 0.85 HFU at San Pedro suggest that this area is part of the Great Plains heat flow province. Reduced heat flow values of 2.1 HFU at Crested Butte and >3.2 HFU in the Jemez Mountains suggest the presence of additional nonradioactive, thermal sources within the crust and upper mantle at these sites. The reduced heat flow value of 1.1 HFU at Animas Peak is somewhat low for the Basin and Range.

The value of 1.4 HFU at Orogrande is appropriate for the Basin and Range. The uncertainty of all reduced heat flow measurements in the area is quite high,and caution should be exercised when considering the significance of a value at a single site.

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TABLE I SUMMARY OF HEAT FLOW DATA

LOCALITY	NORTH LAT	WEST LONG	ELEV METERS	DEPTH INTERVAL METERS	THERMAL GRADIENT DEG.C/KM	N	TYPE OF SAMPLE**	THERMAL CONDUCTIVITY MCAL/CM-SEC-DEG.C	HEAT FLOW HFU[a]	BEST HEAT FLOW ESTIMATE HFU[a]	QUALITY OF HEAT FLOW VALUE
ABBOT/EAST (NM)	36 16	104 06	1878	130-410	25.35±0.19	22	FRAGMENTS	6.04±0.19	1.53±0.06	1.53	A
ABBOT/NORTH (NM)	36 24	104 14	2012	230-470	27.56±0.10	61	FRAGMENTS	5.89±0.40	1.62±0.12	1.62	A
ALUM CREEK (C)	37 25	106 30	3201	60-160	30.89±0.27	8	FRAGMENTS	7.09±0.44	2.19±0.16	2.20	B
ARROYO TETILLA (NM)	35 40	106 11	2050	100-180	48.89±1.13	10	FRAGMENTS	5.32±0.49	2.60±0.31	2.60	C
BIG CROW CR (NM)	36 47	104 42	2439	90-325	36.19±0.30	12	FRAGMENTS	6.70±0.30	2.42±0.13	2.42	B
BLUEWATER(NM)	35 15	107 59	2195	20-110	18.90±0.49	7	FRAGMENTS	7.65±0.33	1.45±0.10	1.44	C
BUCKMAN #2 (NM)	35 53	106 09	1800	190-220	33.94±2.32	8	FRAGMENTS	5.11±0.09	1.73±0.15	1.73	C
CANON CITY EMBYMT (C)	38 13	105 01	2134	100-170#	36.22±1.02	3	FRAGMENTS	5.62±0.17	2.04±0.12	2.04	C
CARRIZO (NM)	34 48	107 08	1886	50-350	24.84±0.33	10	FRAGMENTS	5.77±0.31	1.43±0.10	1.96	A
				350-820	35.91±0.11	14	FRAGMENTS	5.46±0.15	1.96±0.06		
CEBOLLA (NM)	36 32	106 29	2317	20-190	31.28±0.34	8	FRAGMENTS	5.62±0.19	1.76±0.08	1.83	A
				300-340	39.20±0.46	7	FRAGMENTS	4.81±0.09	1.89±0.06		
CERRILLOS #1 (NM)	35 27	106 06	1866	70-150	24.06±0.20	13	FRAGMENTS	4.99±0.14	1.20±0.04	1.20	C
CERRILLOS #2 (NM)	35 27	106 06	1884	80-129	26.39±0.40	9	FRAGMENTS	4.98±0.19	1.31±0.07	1.31	C
CERRILLOS #3 (NM)	35 27	106 07	1829	80-184	24.86±0.15	13	FRAGMENTS	4.92±0.14	1.22±0.04	1.22	B
CHAPELL SPADE (NM)	35 16	103 51	1220	150-340	26.50±0.33	16	FRAGMENTS	5.25±0.19	1.39±0.07	1.40	A
				500-900	18.16±0.18	16	FRAGMENTS	7.61±0.23	1.39±0.06		
				940-1400	26.39±0.20	11	FRAGMENTS	5.40±0.19	1.43±0.06		
CHIMINEY CREEK (NM)	35 55	104 52	2439	120-260	64.38±1.06	8	FRAGMENTS	5.14±0.11	3.31±0.13	2.88	B
				370-480	38.46±0.95	42	FRAGMENTS	6.37±0.13	2.45±0.11		
COLMOR/WEST (NM)	36 13	104 41	1826	80-170	44.84±0.34	8	FRAGMENTS*	6.23±0.60	2.79±0.29	2.87	A
				220-300	53.02±0.79	5	FRAGMENTS*	5.56±0.11	2.95±0.10		
DIXON #2 (NM)	36 13	105 48	2270	40-160	33.74±0.66	7	CORE	14.69±0.33	4.95±0.21	5.47	C
GOLDEN #1 (NM)	35 16	106 12	2037	80-150	27.44±0.27	4	CORE	9.29±0.26	2.55±0.10	1.24	C
				150-250	18.83±0.20	5	CORE	6.56±0.40	1.24±0.09		
GRANEROS RD (C)	37 56	104 49	1857	30-110	19.81±0.68	6	FRAGMENTS*	10.46±0.22	2.07±0.12	2.07	C
JACKSON # 6 (C)	38 10	104 47	1524	60-180	45.93±0.40	5	FRAGMENTS*	4.99±0.07	2.29±0.05	2.41	B
				210-290	23.38±0.58	5	FRAGMENTS*	10.84±0.28	2.53±0.13		
LA JUNTA/NORTH (C)	38 01	103 32	1250	50-130	40.80±0.59	6	FRAGMENTS	5.46±0.17	2.23±0.10	2.23	C
LAS VEGAS #1 (NM)	35 35	105 15	1989	80-150#	17.78±0.48	4	FRAGMENTS	5.62±0.19	1.00±0.06	1.50	C
				150-198	27.25±0.52	3	FRAGMENTS	5.50±0.40	1.50±0.14		
LAS VEGAS #2 (NM)	35 34	105 15	1951	100-170	22.51±0.44	9	FRAGMENTS	6.45±0.68	1.45±0.18	1.45	B
LITTLE BEAR MTN (NM)	34 17	107 15	1902	60-210#	20.13±0.58	6	FRAGMENTS	7.04±0.28	1.42±0.10	1.72	C
				200-290	29.15±0.36	7	FRAGMENTS	5.90±0.12	1.72±0.06		
LITTLE CROW CR (NM)	36 49	104 41	2439	110-225	38.31±0.46	5	FRAGMENTS	5.56±0.57	2.13±0.25	2.13	B
MAES (NM)	36 09	104 42	1872	20-90	36.12±0.44	8	FRAGMENTS	6.32±0.62	2.23±0.25	2.35	C
				90-170	43.15±0.25	5	FRAGMENTS	5.66±0.08	2.44±0.05		
MT DORA (NM)	36 28	103 36	1788	190-290	20.74±0.88	8	FRAGMENTS	7.93±0.61	1.64±0.20	1.30	B
MUDDY CR/SE (C)	38 58	104 53	1924	60-100#	30.85±1.17	8	FRAGMENTS	5.25±0.15	1.62±0.11	1.93	C
				115-180	36.84±0.71	8	FRAGMENTS	5.25±0.15	1.93±0.09		
NOLAN/EAST (NM)	36 09	104 35	1921	80-140	43.37±0.29	8	FRAGMENTS*	6.23±0.60	2.70±0.28	2.75	C
				140-180	55.31±1.11	5	FRAGMENTS*	5.06±0.20	2.80±0.17		
NOLAN/NW (NM)	36 11	104 40	1861	80-170	43.17±0.17	8	FRAGMENTS*	6.23±0.60	2.69±0.27	2.98	C
				170-240	64.62±0.80	5	FRAGMENTS*	5.06±0.20	3.27±0.17		
ORTIZ MTN 2 (NM)	35 19	106 10	2399	140-720	18.18±0.11	26	CORE	7.32±0.29	1.33±0.06	1.33	A
ORTIZ MTN 3 (NM)	35 18	106 10	2218	130-280	16.03±0.13	7	CORE	7.82±0.77	1.25±0.13	1.33	B
				370-420	22.00±0.39	3	CORE	6.36±0.10	1.40±0.05		
POTATO CANYON (NM)	36 53	104 43	2409	40-160	38.08±0.73	8	FRAGMENTS	7.02±0.33	2.67±0.18	2.69	A
				160-280	50.58±0.92	5	FRAGMENTS	5.35±0.04	2.71±0.07		
PUEBLO/SOUTH (C)	38 11	104 44	1570	80-130	51.69±1.13	5	FRAGMENTS*	5.15±0.57	2.66±0.36	2.69	C
				130-200	25.31±1.10	5	FRAGMENTS*	10.71±0.23	2.71±0.18		
PUEBLO/WEST (C)	38 18	104 46	1524	80-190	51.77±0.70	5	FRAGMENTS*	5.15±0.57	2.67±0.34	2.85	C
				190-240	30.36±1.17	5	FRAGMENTS*	10.71±0.23	3.25±0.20		
QUESTA #2 (NM)	36 42	105 31	2933	310-450	18.52±0.17	2	CORE	9.25±1.08	1.71±0.22	1.74	A
				450-590	22.70±0.13	4	CORE	7.77±0.26	1.76±0.07		
				590-690	21.22±0.32	7	CORE	8.19±0.34	1.74±0.10		
QUESTA # 3 (NM)	36 42	105 32	2900	310-410	20.32±0.16	2	CORE	9.25±1.08	1.88±0.24	1.81	C
				430-510	23.32±0.30	4	CORE	7.77±0.26	1.81±0.09		
				510-590	21.21±0.41	7	CORE	8.19±0.34	1.74±0.11		
RED CREEK (C)	38 14	105 00	2134	50-150	22.14±0.41	4	FRAGMENTS	10.84±0.28	2.40±0.11	2.40	C
RIO CUCHARAS (C)	37 32	104 54	2104	100-240	31.91±0.38	7	FRAGMENTS*	6.09±0.13	1.94±0.07	1.97	B
				290-450	34.62±0.20	11	FRAGMENTS*	5.76±0.31	1.99±0.12		
SAN CRISTOBAL (NM)	36 38	105 39	2317	140-290	35.52±0.59	20	FRAGMENTS	8.79±0.15	3.12±0.11	3.12	A
SAN PEDRO 4 (NM)	35 15	106 11	2165	190-410	22.74±0.15	1	FRAGMENTS	6.26±1.56	1.42±0.37	1.42	A
SAUBLE (NM)	36 31	104 22	2010	120-330	30.69±0.25	14	FRAGMENTS	7.96±0.43	2.44±0.15	2.44	A
SHALE HILLS/NE (C)	37 46	103 37	1372	50-100	32.70±0.70	6	FRAGMENTS	4.79±0.13	1.57±0.08	1.90	C
				100-145	46.36±0.84	6	FRAGMENTS	4.79±0.13	2.22±0.10		
SIERRA DEL OJITO (C)	37 16	105 14	2363	250-350	64.20±0.35	8	FRAGMENTS	4.03±0.17	2.59±0.12	2.51	A
				350-470	58.30±0.37	7	FRAGMENTS	4.17±0.05	2.43±0.04		
SILOAM ROAD (C)	38 14	104 56	2134	105-135	38.74±0.59	5	FRAGMENTS*	5.15±0.57	2.00±0.25	2.00	C
SIMMS (NM)	36 08	104 43	1927	90-206	43.62±0.34	6	FRAGMENTS	6.13±0.12	2.67±0.07	2.71	B
SOCORRO/S (NM)	33 57	106 56	1555	40-100#	21.79±0.34	7	FRAGMENTS	5.03±0.40	1.10±0.11	1.73	C
				110-150	34.49±0.97	7	FRAGMENTS	5.03±0.40	1.73±0.19		
TETILLA PEAK (NM)	35 35	106 13	1889	70-140	39.57±0.46	10	FRAGMENTS	5.06±0.41	2.00±0.19	2.00	C
TRES MONTOSA (NM)	34 05	107 22	2098	90-200	34.56±0.51	3	FRAGMENTS	4.98±0.07	1.72±0.05	1.96	C
				200-240	44.79±0.53	2	FRAGMENTS	4.91±0.39	2.20±0.20		
TURQUOISE MTN 1 (NM)	35 30	106 06	1918	40-120	28.18±0.34	8	CORE	4.70±0.05	1.32±0.03	1.32	C
TURQUOISE MTN 2 (NM)	35 31	106 07	1916	60-110#	21.21±0.86	5	CORE	4.76±0.06	1.01±0.05	1.22	C
				110-160	23.68±0.21	6	CORE	5.15±0.29	1.22±0.08		
VAN BREMMER CR (NM)	36 48	104 57	2323	130-250	52.68±0.43	6	FRAGMENTS	4.14±0.23	2.13±0.14	2.04	A
				270-500	37.25±0.20	7	FRAGMENTS	5.11±0.15	1.90±0.07		
YATES (NM)	36 08	103 54	1720	90-430	25.29±0.30	24	FRAGMENTS	5.69±0.30	1.44±0.09	1.44	A

N IS NUMBER OF THERMAL CONDUCTIVITY SAMPLES

[a] 1 HFU = 1 UCAL/CM*CM-SEC

** CONDUCTIVITIES OF FRAGMENT SAMPLES HAVE BEEN CORRECTED FOR POROSITY

* OUTCROP SAMPLES

\# THIS DEPTH INTERVAL NOT USED IN DETERMINING BEST HEAT FLOW ESTIMATE

± INDICATES THE STANDARD DEVIATION

(C), SITE IN COLORADO; (NM), SITE IN NEW MEXICO

ELEVATIONS ARE ± 20 METERS

Table 2. Summary of Radioactivity and Reduced Heat Flow Data

Well Name	Rock Type	No. of Samples	Potassium (%)	Uranium (ppm)	Thorium (ppm)	Heat Generation (HGU)	Reduced Heat Flow (HFU)
Crested Butte+	Monzonite	5	4.10±.20	1.95± .15	5.41± .51	3.05	2.10
Questa/East+	Granite	3	0.78±.55	13.02±2.01	31.71± .57	12.85	0.52
Questa #2	Granite	5	1.49±.24	13.61±1.23	25.07±1.43	12.97	0.74
Los Alamos*	Granite	4	3.52±.17	0.92± .39	15.95±3.23	3.09	>3.20
San Pedro #3+	Monzonite	6	2.55±.18	2.51± .30	10.95± .80	3.98	0.89
San Pedro #4	Monzonite	4	3.33±.11	3.39± .07	12.02± .24	4.88	0.85
Sierra Blanca+	Monzonite	4	3.36±.63	9.97±3.24	28.65±6.78	11.76	0.59
Animas Peak+	Granite	5	3.96±.20	5.18± .33	14.50± .58	6.55	1.05
Orogrande+	Granodiorite	6	3.18±.31	1.96± .20	7.37± .25	3.18	1.43

+unreduced heat flows from Reiter and others (1975).

* " " " " " " " (1976b).

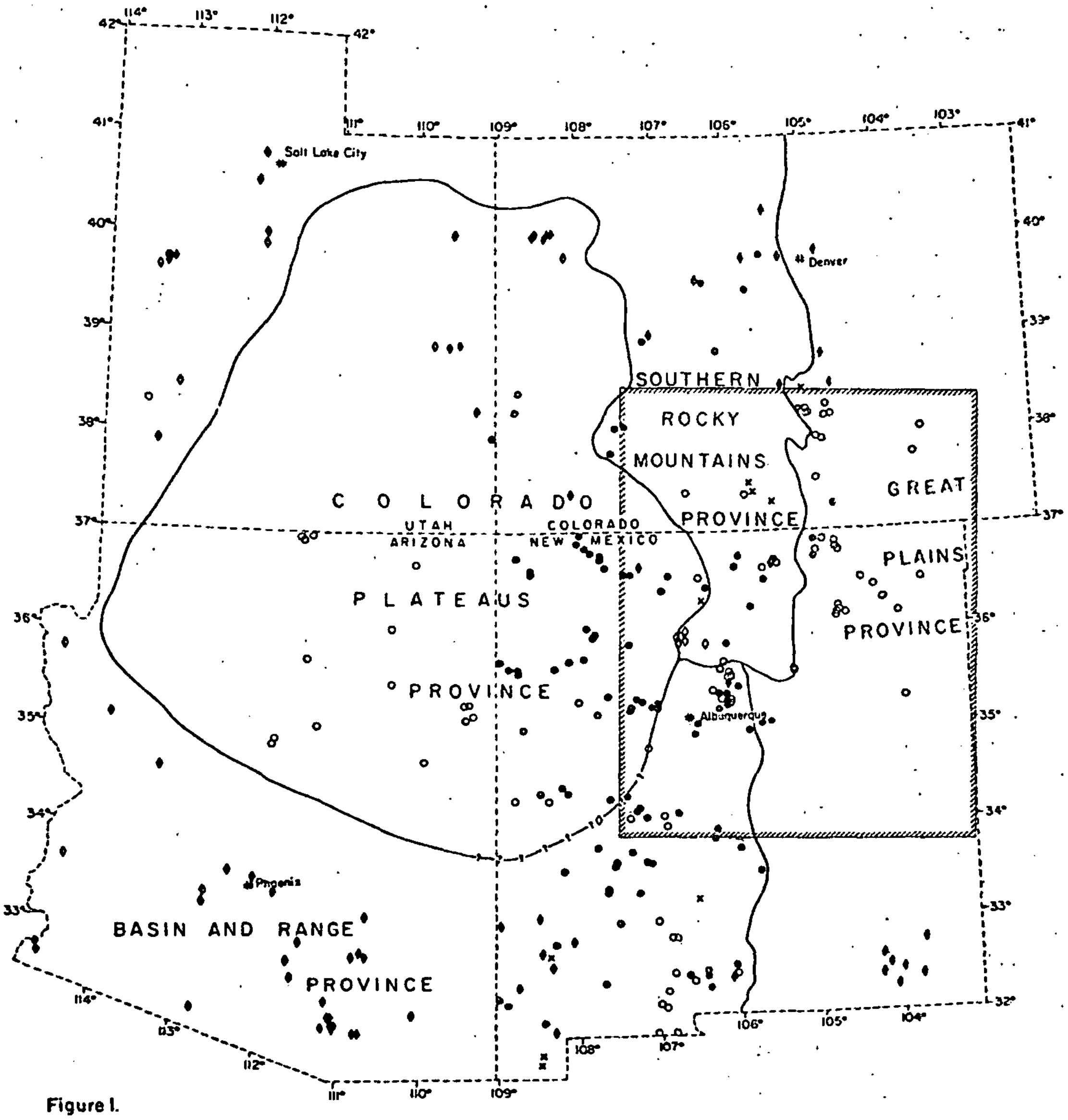
Figure 1. Heat flow sites in the Four Corners States. Solid diamonds indicate data from Birch (1947, 1950), Lovering (1948), Herrin and Clark (1956), Spicer (1964), Roy and others (1968), Warren and others (1969), Decker (1969), Sass and others (1971), Costain and Wright (1973). Open diamonds indicate data from M. Reiter and others (1976a, 1976b). Solid circles indicate data from Reiter and others (1975). Open circles in Arizona, Utah, western and southern New Mexico, indicate unpublished data of Reiter and others. Open circles in northeastern New Mexico and southeastern Colorado, within the hatched area, indicate data from this manuscript. Sites where data are disturbed such that no heat flow information is obtainable are indicated by X.

Figure 2. Heat flow sites in northern New Mexico and southern Colorado. Data in parenthesis from Reiter and others (1975) and Reiter and others (1976a, 1976b). Data in brackets from Decker (1969) and from Sass and others (1971). Other data presented in this manuscript.

Figure 3. Terrestrial heat flow contour map of northern New Mexico and southern Colorado. Contour interval, 0.5 HFU. Plus signs indicate control sites measured by New Mexico Institute of Mining and Technology; Xs indicate control sites measured by other investigators.

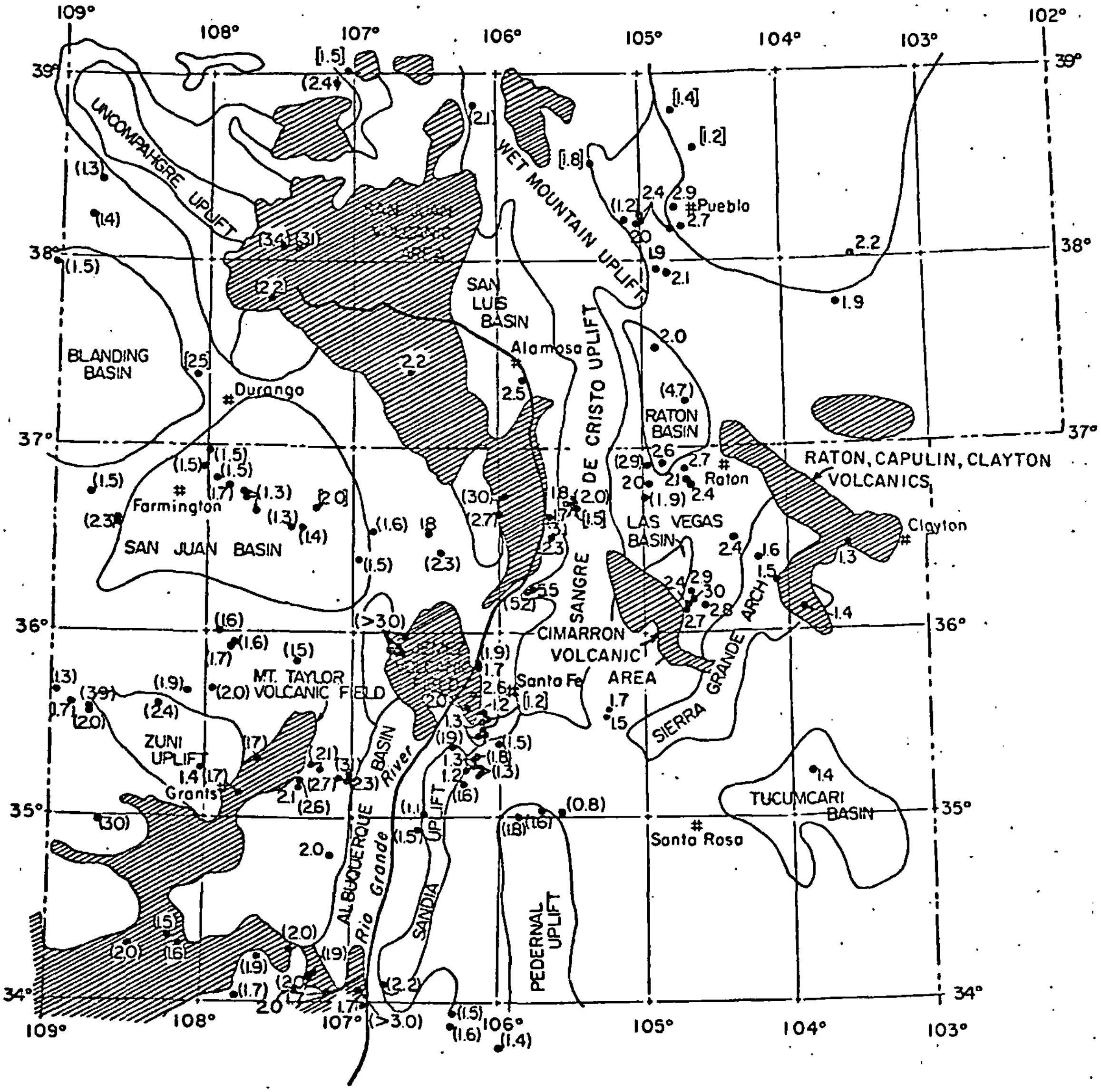
Figure 4. Reduced heat flow sites in New Mexico and southern Colorado. Reduced Heat flow data in parenthesis from Decker and Smithson (1975). Other reduced heat flow data presented in this manuscript.

Figure 5. Heat generation versus heat flow in New Mexico and southern Colorado. (+) reduced heat flow site from this manuscript; (x) reduced heat flow site from Decker and Smithson (1975)



Salt Lake City
Denver
Phoenix
Albuquerque
COLORADO PLATEAUS PROVINCE
SOUTHERN ROCKY MOUNTAINS PROVINCE
GREAT PLAINS PROVINCE
BASIN AND RANGE PROVINCE
UTAH
ARIZONA
COLORADO
NEW MEXICO
114°
113°
112°
111°
110°
109°
108°
107°
106°
105°
104°
103°
42°
41°
40°
39°
38°
37°
36°
35°
34°
33°
32°

Figure I.



109°
108°
107°
106°
105°
104°
103°
102°
39°
38°
37°
36°
35°
34°
UNCOMPAHGRE UPLIFT
SAN JUAN VOLCANIC AREA
WET MOUNTAIN UPLIFT
Pueblo
SAN LUIS BASIN
Alamosa
BLANDING BASIN
Durango
SANGRE DE CRISTO UPLIFT
RATON BASIN
Raton
RATON, CAPULIN, CLAYTON VOLCANICS
Clayton
Farmington
SAN JUAN BASIN
LAS VEGAS BASIN
CIMARRON VOLCANIC AREA
SIERRA GRANDE ARCH
MT. TAYLOR VOLCANIC FIELD
Santa Fe
ZUNI UPLIFT
Grants
ALBUQUERQUE BASIN
Rio Grande River
SANDIA UPLIFT
PEDERNAL UPLIFT
Santa Rosa
TUCUMCARI BASIN

FIGURE 2

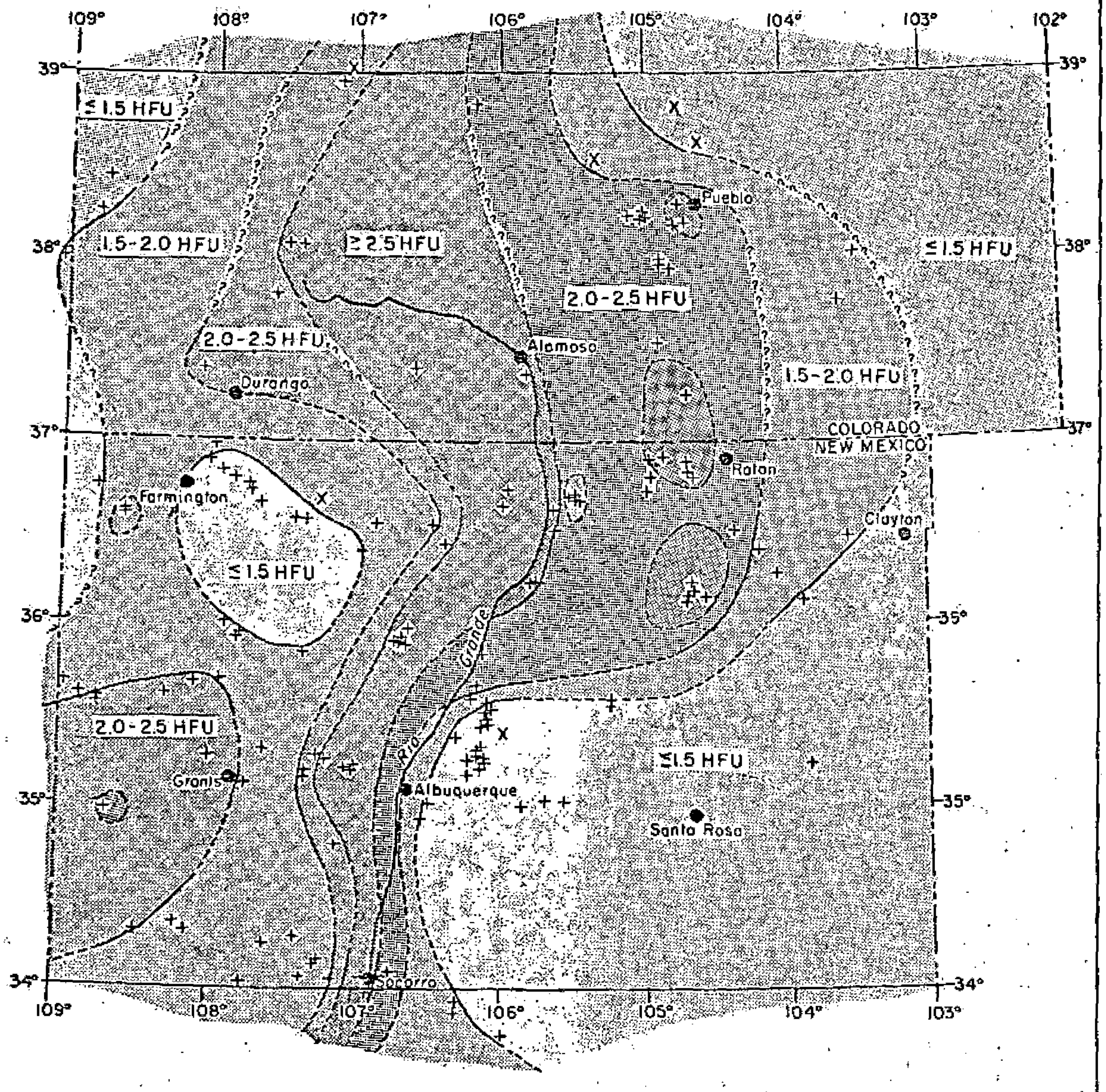

109°
108°
107°
106°
105°
104°
103°
102°
39°
38°
37°
36°
35°
34°
≤ 1.5 HFU
1.5-2.0 HFU
≥ 2.5 HFU
2.0-2.5 HFU
≤ 1.5 HFU
2.0-2.5 HFU
1.5-2.0 HFU
Pueblo
Alamosa
Durango
COLORADO
NEW MEXICO
Raton
Farmington
Clayton
≤ 1.5 HFU
Rio Grande
2.0-2.5 HFU
Grants
Albuquerque
≤ 1.5 HFU
Santa Rosa
Socorro

FIGURE 3

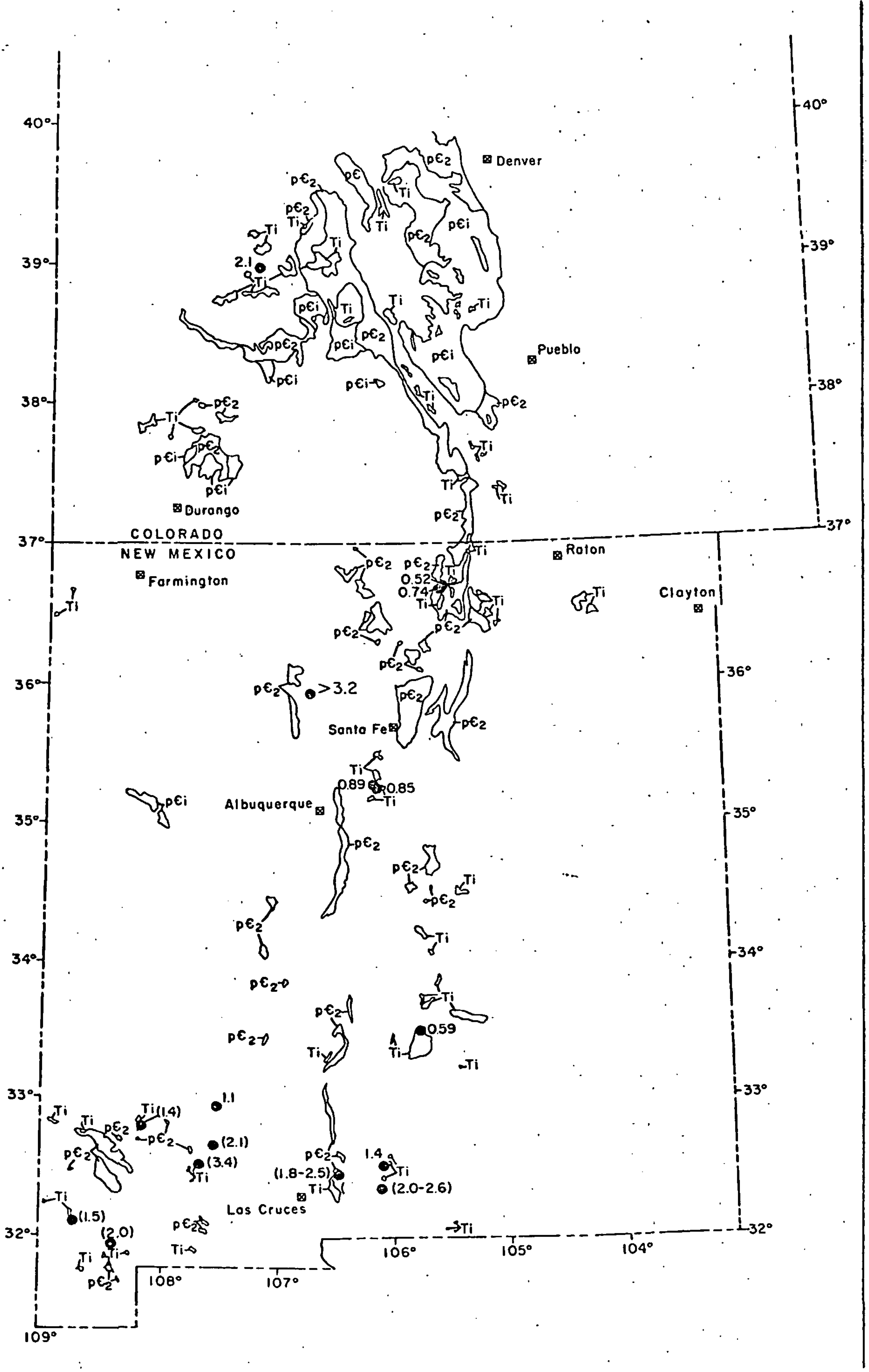
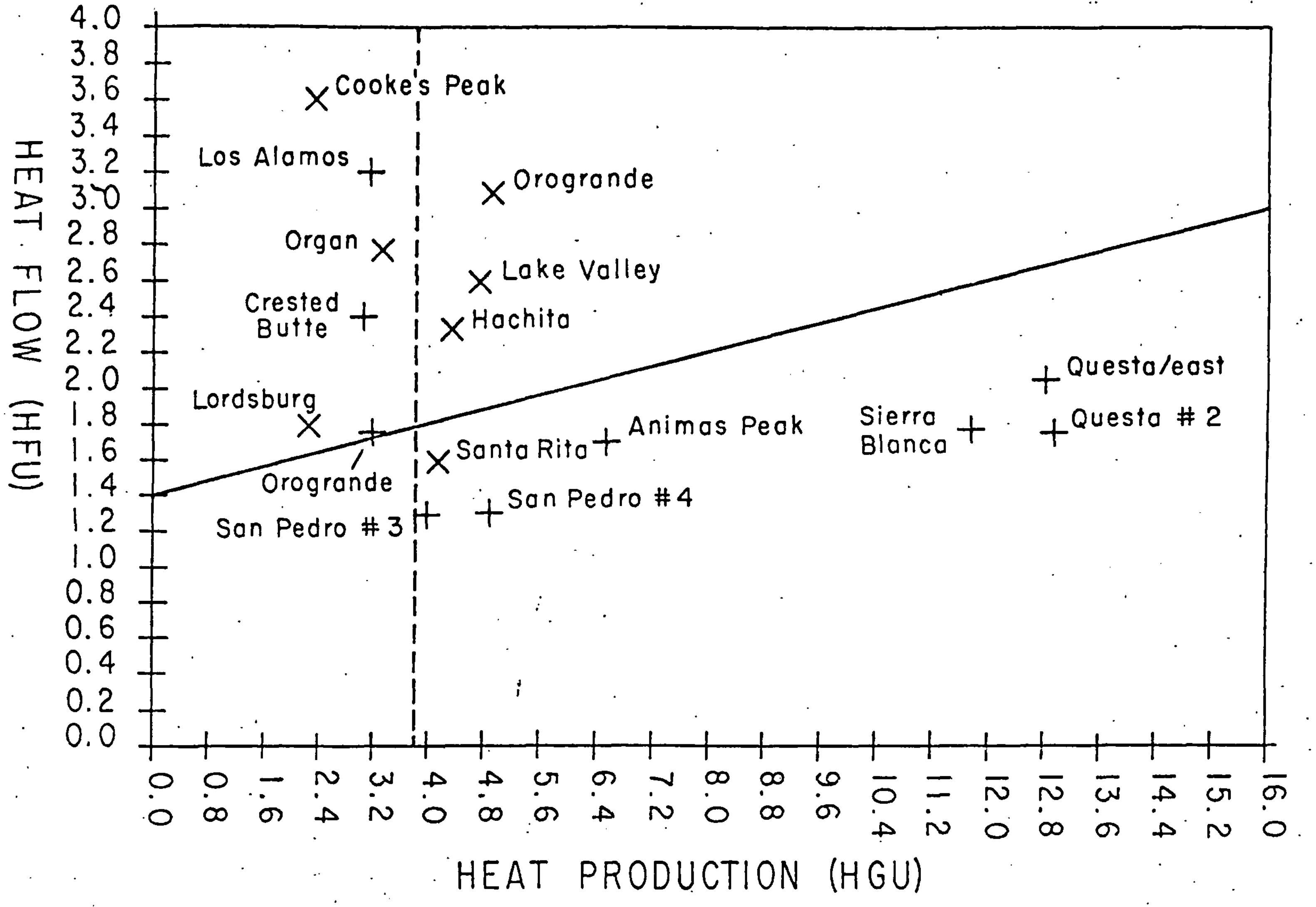

Denver
Pueblo
Durango
COLORADO
NEW MEXICO
Farmington
Raton
Clayton
Santa Fe
Albuquerque
Los Cruces
pЄ
pЄ₂
pЄi
Ti
2.1
>3.2
0.52
0.74
0.89
0.85
0.59
1.1
Ti(1.4)
(2.1)
(3.4)
(1.5)
(2.0)
1.4
(1.8-2.5)
(2.0-2.6)
40°
39°
38°
37°
36°
35°
34°
33°
32°
109°
108°
107°
106°
105°
104°

FIGURE 4



Cooke's Peak
Los Alamos
Orogrande
Organ
Lake Valley
Crested Butte
Hachita
Questa/east
Lordsburg
Sierra Blanca
Questa # 2
Animas Peak
Santa Rita
Orogrande
San Pedro #4
San Pedro # 3
HEAT FLOW (HFU)
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.8
1.6
2.4
3.2
4.0
4.8
5.6
6.4
7.2
8.0
8.8
9.6
10.4
11.2
12.0
12.8
13.6
14.4
15.2
16.0
HEAT PRODUCTION (HGU)

FIGURE 5