TABLE 2. Temperatures and thermal gradients, San Bernardino Valley

Name or No.	Location	Temp°C	Depth (m)	TG (°C/km)	Depth Interval (m)	Correl. Coeff.	MAT (°C)	T°C at 1 km	Source
Union Test	(D-23-30) 8bab	27 *	218	"~1°C/km"	-	-	-	-	Union
Malpai Ranch	10dac	32 +	218	85.0 M	31-182	0.9998	16.5	101.5	Union
7S82	18caa	22 *	182.9	27.3 E	-	-	-	-	1
3W82	33aab	22 *	79.3	63.1 E	-	-	-	-	1
--	36bab	29 *	-	-	-	-	-	-	3
Douglas State A-1	(D-23-29) 14bba	88 +	2143	27.0 E	314-2143	-	-	-	Phillips
--	(D-23-28) 15acc	27 *	-	-	-	-	-	-	4
14S82	(D-22-32) 6bcc	31 *	298.8	46.9 E	-	-	-	-	1
--	17cca	27 *	-	-	-	-	-	-	4
13W82	(D-22-30) 9cbb	23 *	234.8	25.6 E	-	-	-	-	1
--	13cbb	22 +	55	62.0 M	6.55	0.9947	18.21	80.2	2
AZ145	14ad	29 *	-	-	-	-	-	-	3
--	15add	30 *	-	-	-	-	-	-	4
14W82	(D-22-29) 2aba	27 *	274.4	36.4 E	-	-	-	-	1
--	(D-21-32) 15dcc	27 *	-	-	-	-	-	-	4
11S82	(D-21-31) 3bca	27 *	243.9	41.0 E	-	-	-	-	1
10S82	8dbd	26 *	243.9	36.9 E	-	-	-	-	1
8S82	26bbb	21 *	304.9	13.1 E	-	-	-	-	1
9S82	32bdd	20 *	304.9	9.8 E	-	-	-	-	1
--									
--	(D-21-30) 32acb	27 *	-	-	-	-	-	-	4
12W82	30bbd	20 *	91.5	32.8 E	-	-	-	-	1
11W82	(D-21-29) 13dcb	23 *	274.4	21.9 E	-	-	-	-	1

TABLE 2.

Data Sources:

1. Collected by Stone & Witcher for this report
2. Collected by Southland Royalty
3. Swanberg and others (1977)
4. U.S.G.S. Watstore Water Quality File

Symbols:

+	Measured bottom-hole temperature (^{o}C)
*	Reported or measured discharge temperature (^{o}C)
E	Gradient estimated from reported temp/depth data
M	Gradient calculated by least-squares fit from measured temp/depth data
M^1	Measured immediately (?) after drilling, 1971
M^2	Measured by Southland Royalty, 1979

WATER CHEMISTRY AND GEOTHERMOMETRY

CHEMISTRY. We collected 24 samples of ground water from San Bernardino Valley for chemical analysis to augment the published data (Tables 3 and 4). Two 250 ml bottles, one untreated and the other treated with 5 ml of 1:1 HCl (to preserve cations and SiO_2) were collected at each sampling location. B.C. Laboratories, Bakersfield, California analysed the samples. Their analytical results had cation and anion balances with less than 4 percent error, maximum. Most had less than 2 percent error. The analyses are appended.

Ground water in SBV has a bicarbonate composition that ranges from calcium bicarbonate through calcium, sodium, magnesium bicarbonate to sodium bicarbonate (figure 12). Total dissolved solids are no higher than 1,100 mg/l and generally range between 200 and 600 mg/l.

When comparing the milliequivalent ratio of chloride plus sulfate versus bicarbonate (CS/BI) to the location of the water sample, two distinct groupings of ground water are apparent (figure 13). Ground waters with CS/BI less than 10 percent are found mostly in wells that penetrate basalt.

Lithium and boron contents are generally higher in waters with higher CS/BI ratios in San Bernardino Valley. However, this relationship does not reflect geothermal conditions but rather it reflects lithology and possibly residence time of the ground water in the aquifer. In fact, low silica concentrations (less than 20 mg/l) are observed in the ground water with higher lithium and boron concentrations.

Magnesium contents in both CS/BI types of water, with one exception, range between 7.5 and 72 mg/l. The exception is a nonthermal water (23°C) with a 1.5 mg/l magnesium concentration. High magnesium contents are typical of low temperature water in contact with intermediate to basic igneous rocks or dolomitic sedimentary rocks.

Chloride concentrations are low (2.8 to 23 mg/l) in all samples of water in SBV. No correlation exists between chloride content and measured temperature or between chloride content and chemical geothermometers.

Sulfate contents are generally low (mostly less than 30 mg/l) and they also show no relation to measured temperature or to geothermometers.

GEOTHERMOMETERS. We examined geothermometers for about 43 samples (Tables 5 and 6, figures 14 and 15), a few of which may be duplicates. Maximum temperature predicted by the quartz geothermometer is 129°C. The mean silica temperature is 86°C for quartz and 55°C for chalcedony. The maximum temperature predicted by the Na-K-Ca geothermometer is 229°C. The mean Na-K-Ca temperature, excluding four abnormally high values is 65°C.

We calculated the ratio Mg/(Mg + Ca + K) in equivalent percent (R value of Fournier and Potter, 1978) for all water samples and found that it exceeds 50 for nearly 60 percent of the samples. The significance of the high R value was summarized by Fournier and Potter (1978): "Any water with an R value above 50 probably either equilibrated with rock at about the measured temperature (irrespective of much higher calculated Na-K-Ca temperature) or represents a non-equilibrium condition." Waters at the southern end of the valley have high magnesium contents and high R values. These conditions indicate that their high geothermometers are unreliable and that they are most probably nonthermal to low-temperature waters at best. In contrast, water samples from the northern end of the valley have R values less than 50 but relatively low Na-K-Ca temperatures, in the range of 21 to 72°C. These temperatures may or may not be reliable, as will be discussed next.

Geochemistry supports our interpretation that nontemperature-dependent chemical reactions control the chemistry of SBV ground water. Such chemical reactions include (1) breakdown of rock silicate minerals in contact with high CO_2 (greater than $10^{-3.5}$atmosphere) water, which releases silica and major cations to the ground water, and (2) carbonate precipitation, which decreases the calcium concentration in the ground water. An activity-activity diagram of calcium plus pH versus silica (calcium activity in moles per kg) (figure 16) indicates that kaolinite and montmorillonite are stable minerals in contact with SBV ground water, and feldspar is unstable. Thus, feldspar chemically breaks down and releases silica and major cations to the ground water. Because the chemical release of silica occurs at a faster rate than the rate at which it can attain temperature equilibrium with either quartz or chalcedony at the low temperatures measured in San Bernardino Valley, erroneously high silica temperatures are calculated.

Cations (principally Mg, Ca, Na, and K) are also released during the low-temperature breakdown of silicate minerals. Thus, as the high CO_2 water attacks feldspar, the water loses dissolved CO_2, pH increases, and the water becomes saturated with calcite. Any precipitation of this calcite will then decrease the Ca relative to Na and K, and will cause erroneously high Na-K-Ca temperatures. Thus, silica and Na-K-Ca temperatures calculated for SBV waters are unreliable.

Qualitative geothermometers are probably more reliable in predicting sub-surface temperatures in SBV. The high magnesium concentrations (Tables 3 and 4), however, are indicative of nonthermal water, as are the low Na/Ca and Cl/F ratios and the high Mg/Ca ratios (Tables 5 and 6).

Geothermometers in San Bernardino Valley generally are unreliable. While a few sampled waters have geochemical temperatures greater than 100°C, these values are artifacts of nontemperature-dependent processes operating at low temperatures. A low-temperature anomaly (to 65°C?) may exist in the area of San Bernardino Ranch due to forced convection, but additional exploration would be necessary to substantiate this suspicion.

TABLE 3. Water analyses, this study, San Bernardino Valley

Location	Temp°C	Na	K	Ca	Mg	SiO_2	SO_4	HCO_3	Cl	B	F	Li	TDS	pH
(D-24-32) 21aac	17	31	5	103	10	41	66	356	9.6	0.02	0.41	<0.01	417	8.5
(D-24-30) 23bab	30	63	4	20	12	33	11	262	6.4	0.04	0.5	0.04	233	7.7
16ccc	--	32	8	33	37	29	14	330	2.8	0.06	0.39	0.02	283	---
$11aad_1$	29	50	8	21	27	31	15	308	5.7	0.04	0.6	0.03	270	7.2
$11aad_3$	27	40	9	22	26	36	14	282	5.7	0.02	0.56	0.02	263	7.4
8daa	23	39	8	22	31	25	15	312	4.6	0.04	0.42	0.01	247	7.75
4aaa	--	31	11	15	28	21	11	251	7.8	0.01	0.43	<0.01	227	7.8
(D-24-29) 13ddd	28	245	26	131	34	58	125	1066	7.8	0.14	1.6	0.48	1043	7.2
11cab	22	31	3	100	36	41	95	437	5.0	0.04	0.6	0.04	493	7.9
9cbd	23	53	8	114	73	12	245	541	15.2	0.14	0.9	0.11	683	7.7
(D-23-31) 29dca	25	31	9	28	29	35	26	272	5.7	0.02	0.42	0.01	280	7.7
26abc	24	25	8	23	23	44	8	241	3.5	0.02	0.4	0.02	230	7.9
(D-23-30) 33aab	22	36	11	16	28	26	10	277	6.	0.02	0.42	<0.01	270	8.1
18caa	22	23	6	23	28	26	5	266	3.2	0.02	0.36	0.01	213	8.3
(D-23-29) 34aaa	26	45	6	32	29	45	12	333	10.3	0.04	0.4	0.02	280	7.9
33daa	24	57	2	53	15	45	28	340	8.9	0.06	0.64	0.07	350	7.8
(D-22-32) 6bcc	31	36	7	24	25	48	5	291	3.9	0.02	0.61	<0.01	250	7.7
(D-22-30) 9cbb	23	86	8	6	8	16	13	275	3.9	0.04	0.64	<0.01	290	7.6
(D-22-29) 2aba	27	85	11	64	47	16	22	629	7.4	0.10	0.86	0.34	600	6.8
(D-21-31) 32bdd	20	41	5	20	9	15	5	210	5.	0.02	1.3	0.04	187	7.8
26bbb	21	40	10	15	9	29	5	196	4.3	0.02	1.1	0.01	180	8.4
8dbd	26	20	7	43	8	47	6	215	5.3	0.02	1.2	<0.01	177	7.8
3bca	27	32	9	33	8	49	8	217	5.	0.02	1.7	0.02	217	7.8
(D-21-29) 13dcb	23	248	6	5	2	11	65	600	8.1	0.28	1.5	0.32	713	7.2

Constituents in parts per million

TABLE 4. Published water analyses, San Bernardino Valley

Location	Temp°C	Na	K	Ca	Mg	SiO_2	SO_4	HCO_3	Cl	B	F	pH	TDS	Source
(D-24-31) 10ccc	26	200	34	58	45	36	--	873	20	.19	2.5	--	--	1
10cc	25	200	38	10	46	87	64	588	21	.11	2.5	9.1	784	2
7ccd	24	48	7	38	27	35	--	359	7.3	.06	0.3	--	--	1
5acc	24	170	16	57	73	47	--	934	19	.14	0.1	--	--	1
3bab	29	190	32	50	45	30	--	838	19	.19	1.9	--	--	1
(D-24-30) 15dc	"cold"	42	11	19	25	38	14	271	8.5	.07	0.34	8.0	292	2
14cbd	29	69	5	17	12	33	--	272	6.9	.06	0.4	--	--	1
14b	30	60	4	21	16	39	14	236	8	.20	0.4	8.8	280	2
11bb	24	54	19	39	32	34	43	360	21	.23	0.51	7.8	404	2
(D-23-32) 6aad	22	31	4	98	12	48	--	220	23	.03	0.2	--	--	1
(D-23-31) 18cd	28	47	6	15	13	36	10	176	6.7	.38	0.38	8.8	268	2
4cab	28	41	9	15	17	35	--	232	5.7	.06	0.4	--	--	1
(D-23-30) 36bab	31	240	31	50	32	34	--	911	19	.20	2.7	--	--	1
36b	29	252	35	71	36	38	13	1108	20	.31	2.9	7.4	1088	2
(D-22-30) 14ad	29	35	8	16	14	72	7	204	5	--	0.48	7.8	244	2
(D-23-28) 15acc	27	--	--	63	34	--	--	368	14	.14	0.7	--	--	1
(D-22-32) 17cca	27	23	6	33	15	55	--	230	6.4	.03	0.3	--	--	1
(D-22-30) 15add	30	38	9	19	23	30	--	270	6.6	.04	0.3	--	--	1
(D-21-32) 15dcc	27	35	4	23	4	60	--	146	5	.04	1.1	--	--	1
(D-21-30) 32acb	27	20	3	41	12	30	--	175	10	.03	0.1	--	--	1

Constituents in parts per million

Sources:
1 = U.S.G.S. Watstore
2 = Swanberg and others (1977)

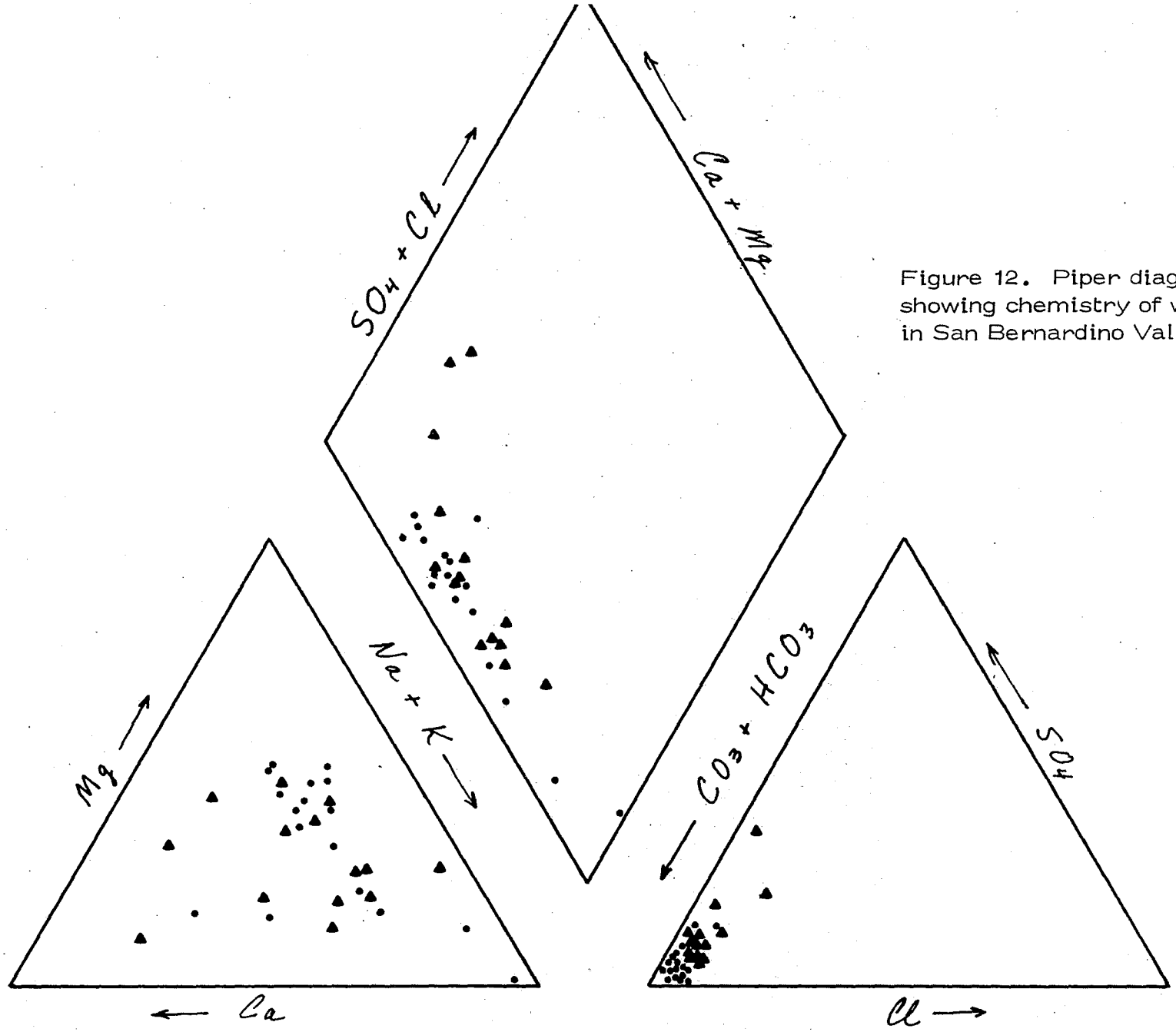

Figure 12. Piper diagram showing chemistry of water in San Bernardino Valley.

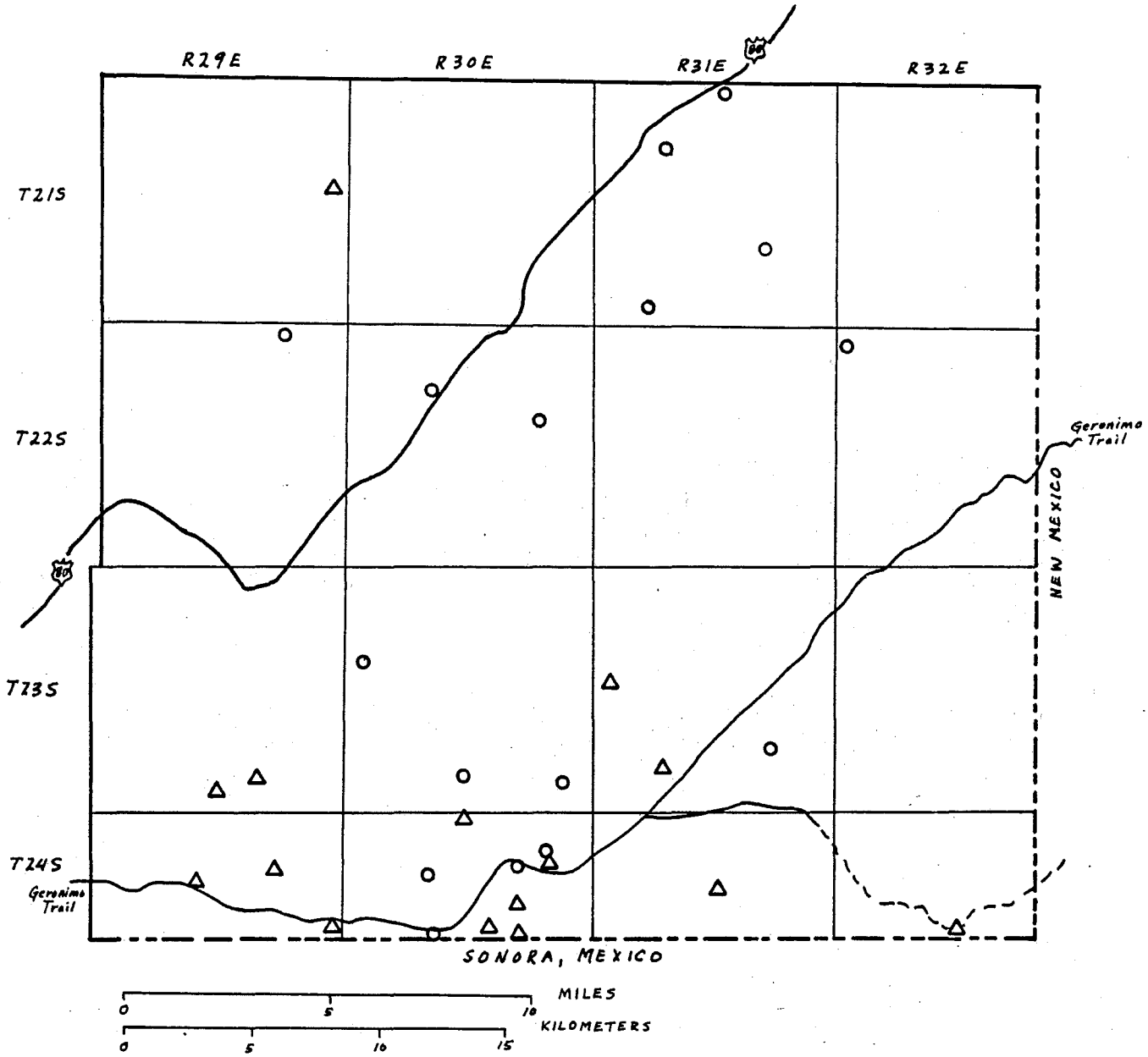

Figure 13. Map showing concentrations of sulfate plus chloride in San Bernardino Valley ground water. Open triangles have more than 10 percent total anions; open circles have less than 10 percent total anions.

TABLE 5. Geochemistry of San Bernardino Valley ground water, this study

Location	Temp°C	T_{SiO_2} (Q)	T_{SiO_2} (Ch)	$T_{Na-K-Ca}$	Mg/Ca (*)	Cl/F (*)	Na/Ca (*)	Mg (x) / Mg+Ca+K
(D-24-32) 21aac	17.0	93	62	35	1.5	12.5	0.26	12.9
(D-24-30) 23bab	30.0	83	52	61	1.0	6.9	2.8	47.3
16ccc	--	78	47	70	18.5	3.8	0.86	62.2
11aad$_1$	28.5	81	50	81	20.8	5.1	2.1	63.9
11aad$_3$	27.0	87	56	83	19.1	5.5	1.6	61.7
8daa	23.0	72	40	78	22.8	5.9	1.5	66.2
4aaa	--	65	33	97	31.3	9.7	1.9	69.1
(D-24-29) 13ddd	28.0	109	80	70 (•)	4.2	2.6	1.6	27.7
11cab	22.0	93	62	21	0.59	4.5	0.27	36.9
9cbd	23.0	45	13	48	10.5	9.0	0.41	50.3
(D-23-31) 29dca	25.0	86	55	74	17.0	7.3	0.98	59.4
26abc	24.0	96	66	72	16.5	4.7	0.97	58.3
(D-23-30) 33aab	22.0	74	42	95	3.0	7.7	2.0	68.1
18caa	22.0	74	42	65	19.7	4.8	0.87	63.9
(D-23-29) 34aaa	26.0	97	67	61	14.7	13.8	1.2	57.7
33daa	24.0	97	67	24	0.47	7.5	0.93	31.5
(D-22-32) 6bcc	31.0	100	70	71	17.2	3.4	1.3	59.9
(D-22-30) 9cbb	23.0	55	23	174 +	22.5	3.3	13.6	56.6
(D-22-29) 2aba	27.0	55	23	73	1.2	4.6	1.2	52.7
(D-21-31) 32bdd	20.0	53	21	69	7.2	2.1	1.8	38.7
26bbb	21.0	78	47	39 (•)	1.0	2.1	2.4	42.9
8dbd	26.0	99	69	53	2.9	2.4	0.41	21.0
3bca	27.0	101	71	72	0.40	1.6	0.84	26.0
(D-21-29) 13dcb	23.0	42	10	57 + (•)	5.5	2.9	48.0	24.9

(*) milliequivalents
(x) equivalent percent
\+ corrected to B = 1/3
(•) Mg correction applied

Q quartz geothermometer
Ch chalcedony geothermometer

TABLE 6. Geochemistry of San Bernardino Valley ground water, published data

Location	Temp°C	T_{SiO_2}(Q)	T_{SiO_2} (Ch)	$T_{Na-K-Ca}$	Mg/Ca (*)	Cl/F (*)	Na/Ca (*)	Mg (x) / Mg+Ca+K	Source
(D-24-32) 14bda	—	105	—	—	—	—	—	—	3
(D-24-31) 10ccc	25.5	87	56	204 +	1.28	4.29	3.00	49.6	1
10cc	25.5	129	102	229 +	7.74	4.50	17.78	72.1	2
7ccd	24.0	86	55	65	1.17	13.04	1.10	51.7	1
5acc	23.5	99	69	98	2.11	101.80	5.60	64.9	1
3bab	29.0	79	48	204 +	1.48	5.36	3.31	52.8	1
(D-24-30) 15dc	"cold"	89	59	94	2.22	13.40	1.97	62.9	2
14cbd	29.0	83	52	72	1.16	9.24	3.54	50.6	1
14b	29.5	90	59	62	1.23	10.71	2.49	53.6	2
11bb	24.0	85	54	100 +	1.35	22.06	1.21	51.8	2
(D-24-29) 18bcd	—	76	—	—	—	—	—	—	3
(D-23-32) 6aad	22.0	100	70	31	0.20	61.62	0.28	16.5	1
(D-23-31) 26abc	—	98	—	55	—	—	—	—	3
18cd	27.5	86	55	79	1.43	9.45	2.73	53.8	2
4cab	28.0	86	55	91	1.87	7.64	2.38	59.0	1
(D-23-30) 36bab	31.0	85	54	24 +(•)	1.05	3.77	4.18	44.5	1
36b	28.8	89	58	32 +(•)	0.84	3.70	3.09	40.0	2
14ad	29.0	119	91	84	1.44	5.58	1.88	53.7	2
(D-22-32) 17cca	26.5	106	77	54	0.75	11.43	0.61	40.8	1
(D-22-30) 15add	30.0	79	48	87	2.00	11.79	1.74	61.5	1
(D-21-32) 15dcc	27.0	111	81	58	0.29	2.44	1.33	20.3	1
(D-21-30) 32acb	26.5	79	48	31	0.48	53.58	0.43	31.8	1

Q quartz geothermometer
Ch chalcedony geothermometer
(*) milliequivalents
(x) equivalent percent
\+ corrected to B = 1/3
(•) Mg correction applied

Sources:
1 = U.S.G.S. Watstore
2 = Swanberg and others (1977)
3 = McMurdie (1979), unpublished report in T.G.I. files

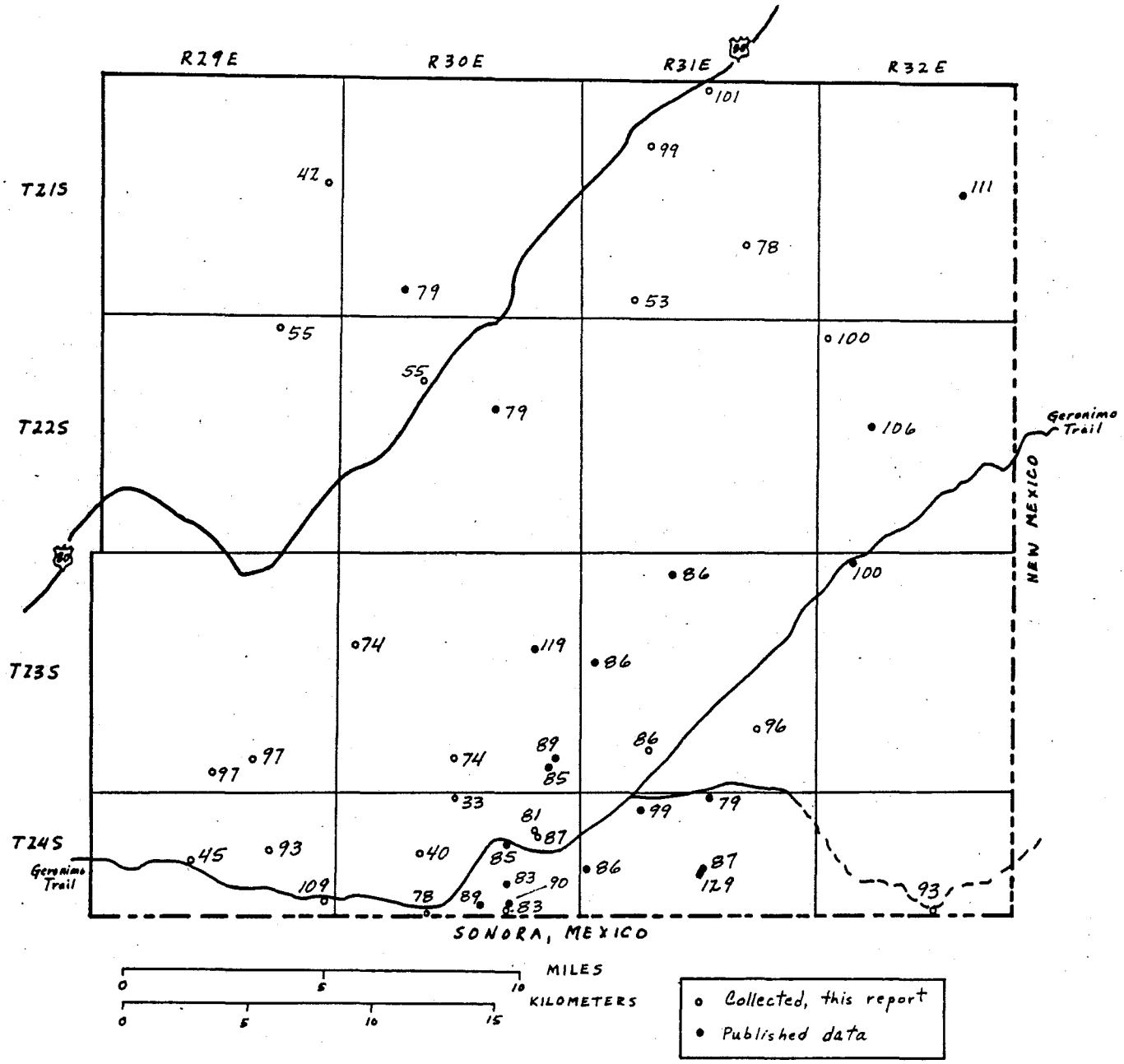

Figure 14. Silica geothermometers, San Bernardino Valley.

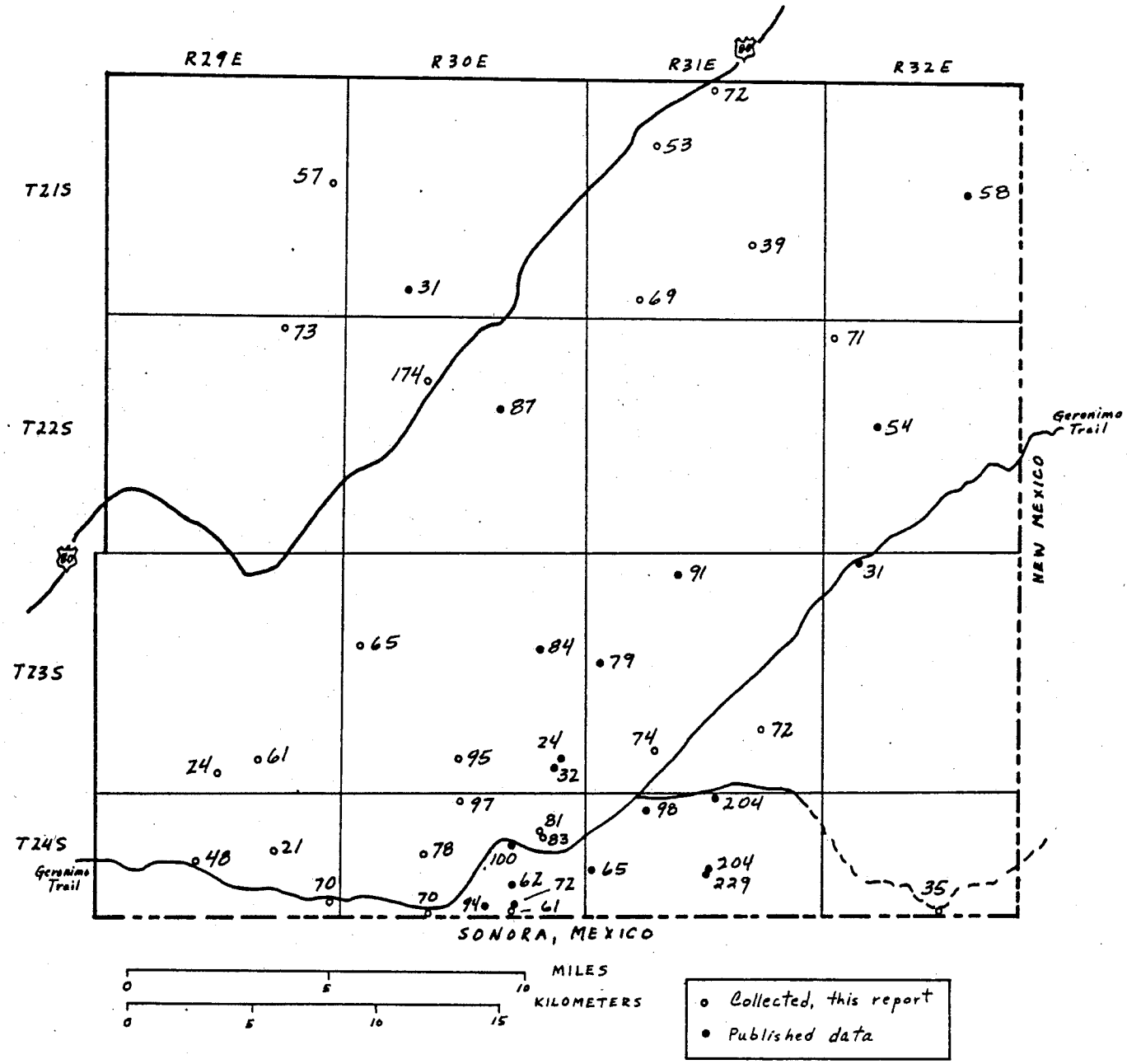

Figure 15. Na-K-Ca geothermometers, San Bernardino Valley.

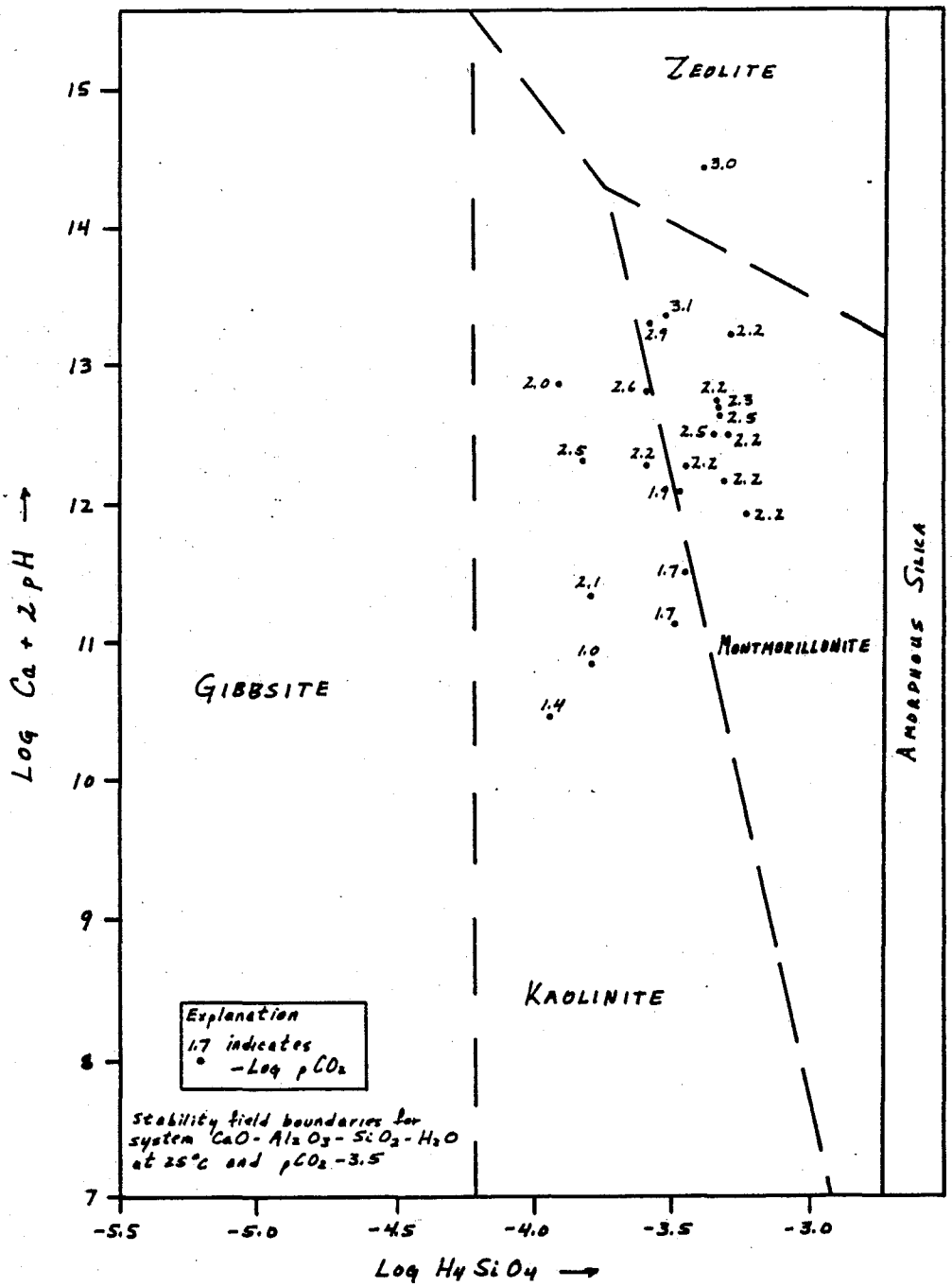

Figure 16. Activity-activity diagram of log calcium + 2pH versus log H4SiO4. See text for explanation.

HISTORICAL SEISMICITY

Southeastern Arizona has not experienced noticeable seismic activity between 1830 and 1980, according to a carefully documented report on historical earthquakes in Arizona (DuBois and others, 1982). However, six events having intensities of VI to XII occurred between 1887 and 1978 within and south of San Bernardino Valley, Sonora. The most significant and disasterous shock (M about 7.25 - 7.4) occurred in 1887 about 55 km south of the international border. Maximum dip-slip displacement was 3 to 4 m, down on the west. While ground rupture from the 1887 earthquake was about 80 km in length, the zone of seismicity was shown to be at least 115 km long and to abruptly terminate 13 km north of the fault scarp.

Three seismic networks along the 1887 scarp (summers, 1979 and 1980; 30 days of useable recordings) located 33 earthquakes over a 2,800 km^2 area. All events occurred within 15 km of the surface and had a magnitude between -1.3 and +2.0. Natali and Sbar (1982) suggested that the present microearthquake activity in SBV, Sonora has the appearance of an aftershock sequence and thus may explain the relatively high activity in northern Sonora compared to southeastern Arizona. A fourth seismic network operating in San Bernardino Valley, Arizona (summer, 1978) located a single microearthquake just north of the international border, about Lat. $109^{\circ}15'$ W. However, this network operated only two weeks, so such results are uncertain at best. SBV could be more active seismically than indicated by this one study.

TRANSMISSION LINES

Existing and projected EHV transmission lines and major power plants for Arizona, New Mexico, and southern California (1982-1992) are shown on Plate III, in pocket. Figure 17 shows the areas in and adjacent to San Bernardino Valley that have electrical service, and which of three companies owns the power lines.

Columbus Electric Co-op, Deming, New Mexico brings a 25 kV distribution line into Arizona at Rodeo, N.M. This line follows U.S. Hwy.80 southwest into T 21 S, R 31 E.

Sulpher Spring Valley Electrical Co-operative (SSVEC), Willcox, a member of Arizona Electric Power Co-op (AEPCO), buys power from the 520 mW-capacity AEPCO coal-and-gas-fired power plants at Cochise, about 90 km north northwest of Douglas, and distributes it to most of Cochise County. They own a 69 kV transmission line, the largest adjacent to SBV, which runs down Sulpher Spring Valley from Cochise to McNeal (see Plate III). SSVEC's largest distribution line into the study area is a single-phase 14.4 kV line into T 21 S, R 29 E.

Arizona Public Service (APS) is not a member of AEPCO. They generate electricity at Tucson and Phoenix and supply Douglas from these power plants. APS owns a 21 mW natural gas generator at Douglas as a back-up system but they seldom fire it up. APS owns the 69 kV transmission line from south of McNeal to Douglas. This line also runs east to within about 11 km of the Johnson Windmill prospect area. They also own transmission and distribution lines from Douglas to west of the San Pedro River, a distance of about 60 km. APS's largest line into the study area is a 7.2 kV distribution line into T 22 S, R 29 E.

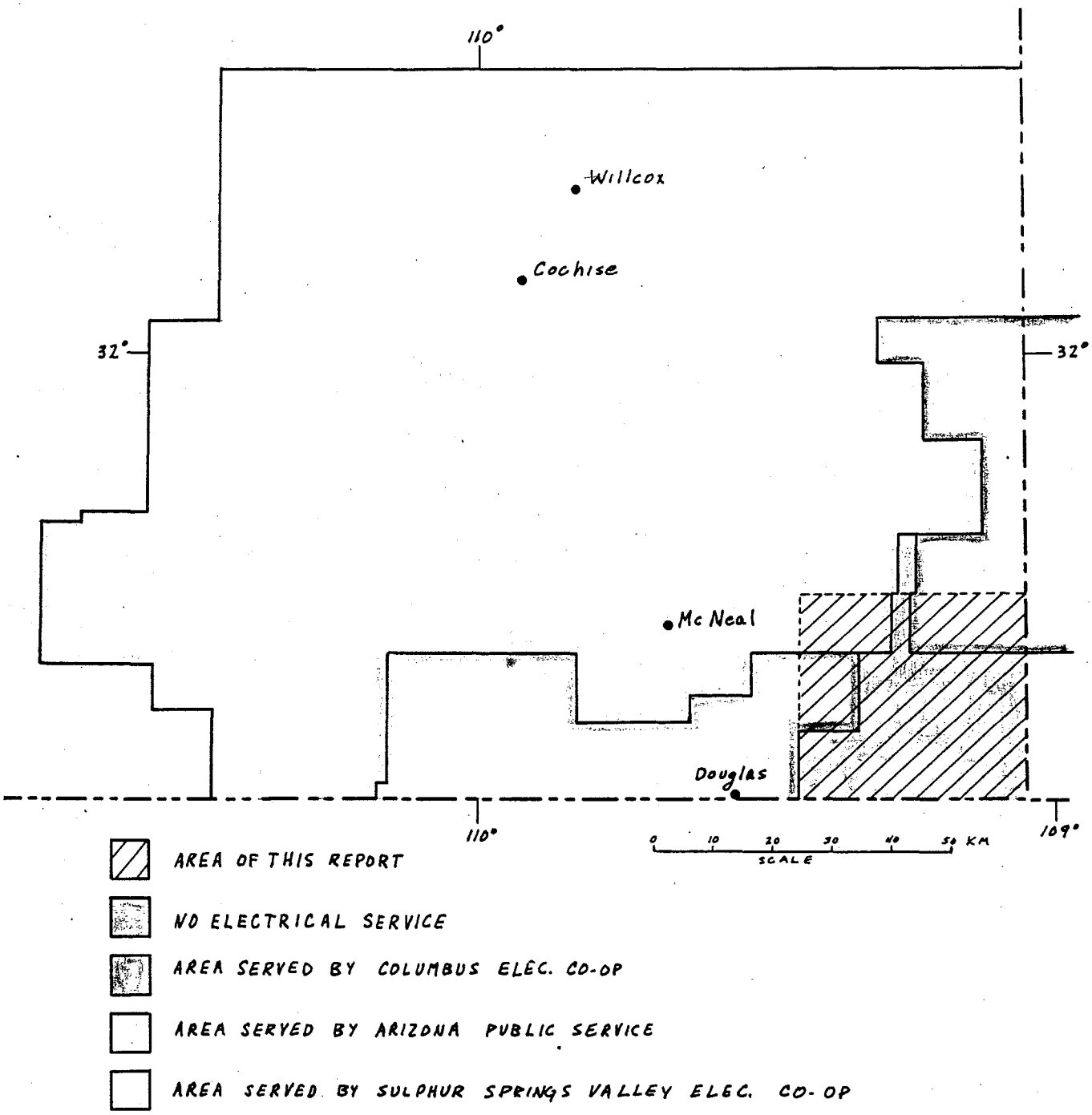

Figure 17. Map of areas served by electrical producers and distributors, southeastern Arizona.

San Bernardino Valley covers about 1,100 km^2. The only industry in the valley is cattle ranching, of which there are approximately 17 ranch headquarters in the study area. The "towns" of Bernardino, Chiricahua, and Apache, which are shown along Highway 80 on the state map, are not towns at all. They are sites of a closed school and an abandoned gas station. The town of Douglas is separated from San Bernardino Valley by the Perilla Mountains. Thus, potential uses for low-temperature geothermal energy are limited to such unlikely applications as space conditioning ranch headquarters or starting a totally new industry in the valley such as greenhousing, meat packing, or aquiculture.

OIL AND GAS POTENTIAL IN THE PEDREGOSA BASIN

San Bernardino Valley lies within the late Paleozoic Pedregosa basin, which compares favorably with the petroleum-rich Permian basin of West Texas and southeast New Mexico. On this basis, both Paleozoic and Mesozoic rocks of the Pedregosa basin could yield significant quantities of oil and gas. In SBV the best reservoir rocks would be the shelf dolomites and sandstones of the Devonian Martin Formation, the Pennsylvanian Horquilla Limestone, the Permian Epithaph Dolomite and Concha Dolomite, and the Lower Cretaceous Centura Formation and Mural Limestone. Source rocks would include the basin facies of the Pennsylvanian Horquilla Limestone, the Mississippian Paradise Formation, and the Devonian Percha Formation.

Mesozoic and Tertiary tectonic and igneous activity have had both positive and negative effects on possible petroleum accumulation in these older rocks. Tectonism may have created regional structural traps, but later extensional faulting of the Basin and Range disturbance probably disrupted such regional traps and allowed fresh meteoric water to flush hydrocarbons from the uplifted horst blocks. Kerogen and conodont studies indicate that thermal effects are destructive near intrusive complexes, but only a few thousand feet away temperatures are favorable to induce maturation of organic material to oil and most likely gas. However, regional ground-water flow recharging large hydrothermal systems near intrusions may have flushed petroleum from rocks distal to the intrusions. Thompson and others (1978) suggested that the potential for dry gas is better than for oil in the Pedregosa basin and that the best potential lies in the deep grabens. A small show of gas was encountered at 140 m depth (Epitaph-Colina ?) when plugging Thomson No. 2 State wildcat (D-24-31)2acd, on the east margin of SBV.

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