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A Geothermal Investigation of Spring and Well Waters of the Los Alamos Region, New Mexico

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A GEOTHERMAL INVESTIGATION OF SPRING AND WELL WATERS OF THE LOS ALAMOS REGION, NEW MEXICO

by

Fraser E. Goff and Suzanne Sayer

ABSTRACT

The chemical and isotopic characters of 20 springs and wells in the Los Alamos area were investigated for indications of geothermal potential. These waters were compared with known hot and mineral springs from adjacent Valles Caldera and San Ysidro. All waters in the Los Alamos area are composed of meteoric water. Isotopic data show that the two primary aquifers beneath the Los Alamos region have different recharge areas. Relatively high concentrations of lithium, arsenic, chlorine, boron, and fluorine in some of the Los Alamos wells suggest these waters may contain a small fraction of thermal/mineral water of deep origin. Thermal water probably rises up high-angle faults associated with a graben of the Rio Grande rift now buried by the Pajarito Plateau.

INTRODUCTION AND SIMPLIFIED GEOLOGY/GEOPHYSICS

Los Alamos Scientific Laboratory has been evaluating geothermal potential of the Pajarito Plateau through geology and geophysics. The object of these studies is to locate and characterize geothermal resources, both conventional hydrothermal and hot dry rock, for use in space heating of the Laboratory. This report summarizes the geochemistry of local ground waters and some hot springs from adjacent Valles Caldera and presents some thoughts on the hydrology beneath the Pajarito Plateau.

The Pajarito Plateau was formed from two copious ignimbrite sheets of Bandelier Tuff that erupted from Valles Caldera, a 1.1-Myr-old silicic volcano[1] (Fig. 1). Precaldera dacite domes and derivative sediments of the Tschicoma and Puye formations underlie Bandelier Tuff on the west, whereas basalts and interbedded pyroclastics of Cerros del Rio underlie the tuff on the east. These relations are best exposed in Los Alamos Canyon near the Rio Grande. All of these volcanic units overlie a thick sequence of basin-fill sediments of the Santa Fe formation within the Española Basin of the Rio Grande rift.[2] Many kilometers to the west and south, the Santa Fe formation and related Tertiary units overlie Mesozoic and Paleozoic layered sedimentary rocks.[1,3] Southwest of Valles Caldera in San Diego Canyon, the stratigraphy consists of Paleozoic red-beds and carbonates that overlie Precambrian basement.[4] The extent and thickness of Mesozoic and Paleozoic units beneath the Pajarito Plateau is unknown.

A detailed gravity survey by Budding[5] shows that a graben filled with low density (Tertiary) sediments underlies the Pajarito Plateau. The indicated depth to Precambrian basement is roughly 3 km, but the boundary between Tertiary and Mesozoic-Paleozoic rocks is uncertain. A time domain (geoelectric) survey of the Los Alamos area[6] suggests that a low resistivity layer of approximately 7 ohm-m occupies the graben at a depth of 2 to 3 km. These low resistivities could result from warm saline fluids in Paleozoic rocks at the bottom of the graben.

The Pajarito Plateau lies along the west margin of the Rio Grande rift where the regional heat flow is 2.7 HFU.[7] Details about how large potable aquifers in the buried graben affect the regional heat flow are unknown. However, moderate thermal gradients of 20-40°C/km in the Los Alamos area[8] suggest that these cooler aquifers suppress the upward flow of heat. Heat flow in adjacent Valles Caldera locally exceeds 10 HFU.[8]

GEOCHEMISTRY OF WATERS

No known hot or mineral springs discharge on the Pajarito Plateau, but abundant cold meteoric ground waters issue from surface rocks and flow in buried sands and gravels of the Santa Fe and Puye formations. The water quality of most of these waters has been investigated previously by Griggs and Hem[9] and by Purtymun and Cooper.[10] Thermal/mineral waters are relatively abundant in the Valles Caldera area along San Diego Canyon and were studied in

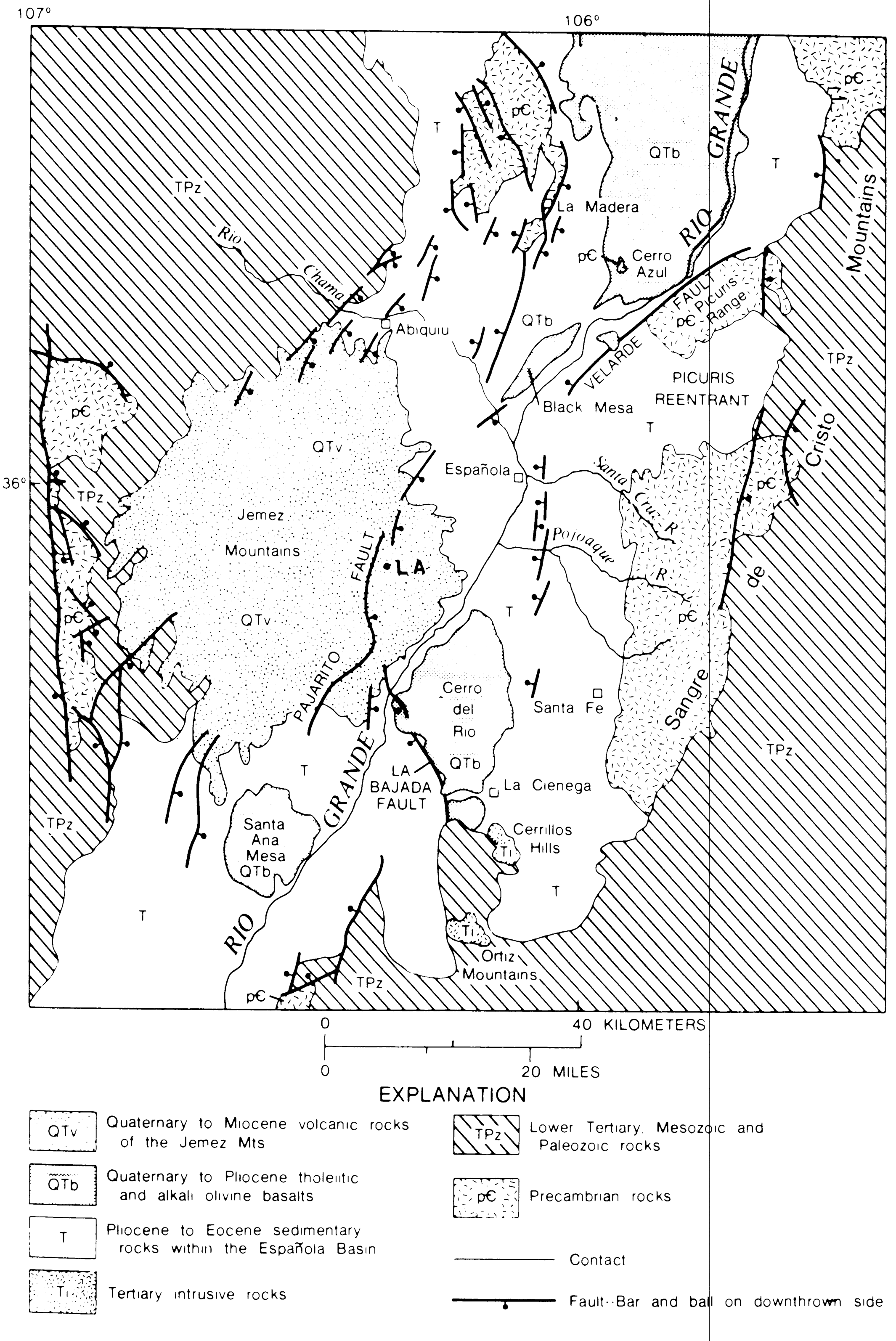

Fig. 1.
General geologic map of the Española Basin, Rio Grande rift, New Mexico (from Manley, 1979); LA = Los Alamos. The Pajarito Plateau lies east of the Pajarito fault in center of map.

recent years by Trainer[11] and Purtymun et al.[12] To aid in evaluating geothermal potential, 20 waters from the Los Alamos area and 6 thermal/mineral waters from Valles Caldera were analyzed for major element chemistry plus D and ^{18}O isotopes (Fig. 2). The majority of Los Alamos samples come from relatively deep water supply wells that possibly tap aquifers containing a small fraction of thermal water of deep origin. The data from these samples appear in Tables I and II.

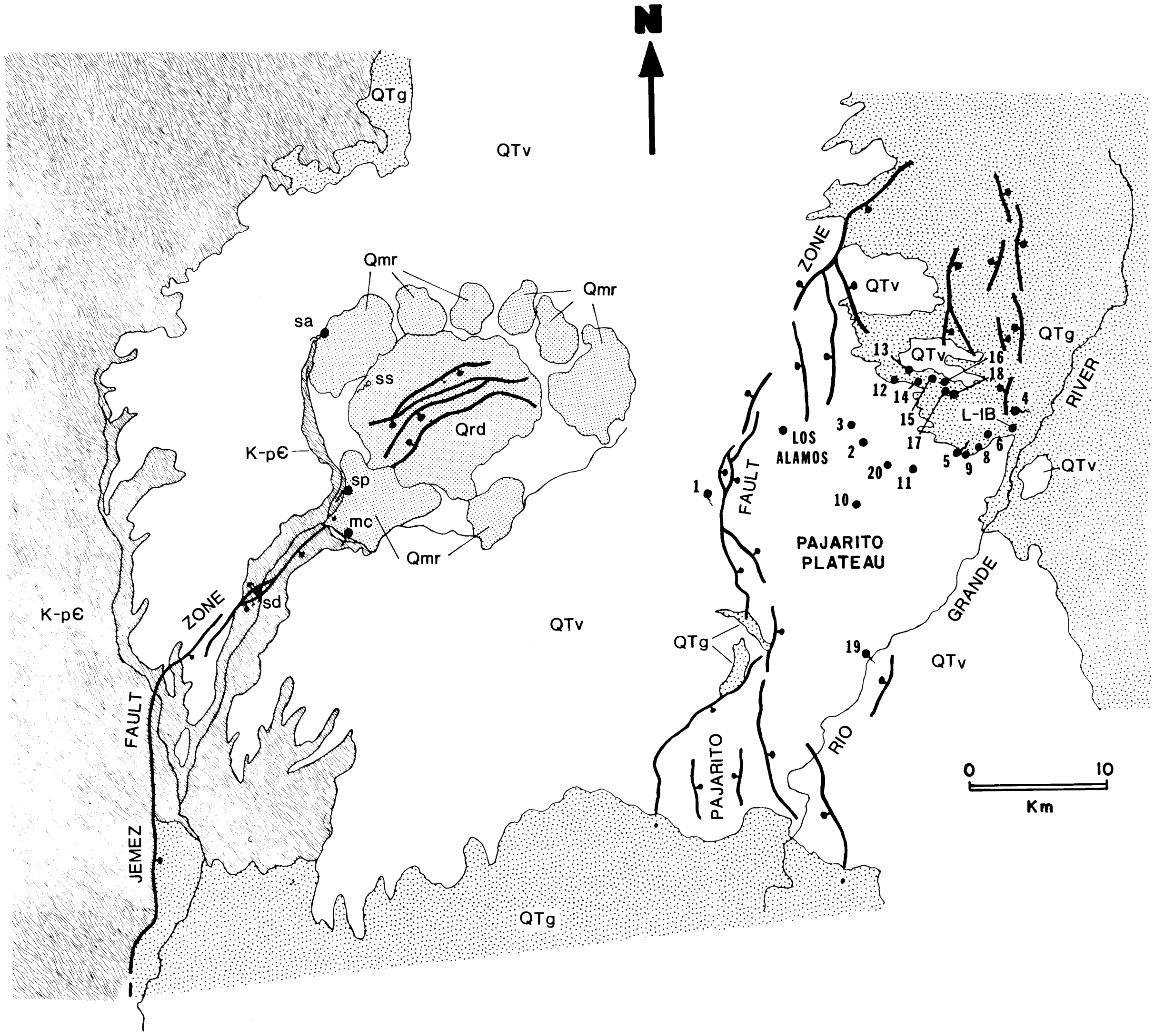

Fig. 2.
Schematic geologic map of the Los Alamos area showing major faults; numbers refer to LA water samples in Table I. SA = San Antonio Hot Spring, SP = Spence Hot Spring, MC = McCauley Hot Spring, SD = Soda Dam Spring, SS = Sulphur Spring, Qrd = Resurgent Dome of Valles Caldera, Qmr = Moat Rhyolites of Valles Caldera, QTv = Quaternary-Tertiary volcanic rocks, QTg = Quaternary-Tertiary Sediments, K-pЄ = Cretaceous-Precambrian bedrock.

TABLE I

CHEMISTRY AND FIELD CHARACTERISTICS OF 29 WATERS OF THE LOS ALAMOS AND VALLES CALDERA REGION, NEW MEXICO

No.[a]	Name	Measured Temp. (°C)	SiO_2	Fe	Mn	Ca	Mg	Na	K	Li	HCO_3	SO_4	Cl	F	B	Field pH	Flow Rate ℓ/min	Rock Type[b]	Depth of Well (m)
VA-1	Spence Hot Spg	45	66	<0.04	<0.02	5.5	1.9	50	1.3	0.66	144	16	8	0.55	0.15	6.7	60	Al & V	
VA-2	Little Spence Hot Spg	34	67	<0.04	<0.02	8.8	1.9	56	1.5	0.66	152	25	7	0.70	0.13	6.2	28	Al & V	
VA-3	McCauley Spg	31	56	<0.04	<0.02	8.5	4.9	18	0.8	0.24	86	7	6	0.85	0.24	6.2	140	V & P	
VA-4	San Antonio Hot Spg	42	79	<0.04	0.02	2.3	0.30	21	1.7	<0.02	56	7	2	0.80	<0.05	6.8	160	V	
VA-5	Grotto Spg	38	44	0.11	0.50	324	27	1000	174	13.2	834	41	1480	4.0	11.6	6.8	12	P	
VA-6	Soda Dam Spg	47	43	0.11	0.55	328	26	1010	174	13.2	886	37	1480	4.1	11.5	6.2	60	P	
LA-1	Gallery Spg	11	43	<0.04	<0.02	7.0	3.3	5.8	1.4	0.02	52	<5	<1	0.12	<0.05	5.6	160	V	
LA-2	T-3 well	13	15	0.53	0.11	14	5.0	11	1.9	0.03	102	5	4	0.26	<0.05	6.5	0-12	Al & Pu	800
LA-3	T-2 well	11	5	<0.04	<0.02	11	2.7	8.8	0.88	0.03	78	5	2	0.46	<0.05	5.7	0-8	Al & Pu	49
LA-4	Sacred Spg	14	34	<0.04	<0.02	22	0.45	20	2.5	0.04	114	7	2	0.46	<0.05	5.7	Seep	SF	55
LA-5	Basalt Spg	15	44	<0.04	<0.02	26	7.6	12	3.1	0.03	98	18	12	0.32	<0.05	5.8	4	V & Pu	
LA-6	L-6 well	27	33	<0.04	<0.02	2.8	0.15	72	0.8	0.04	170	6	4	2.2	<0.05	6.8	0-2160	SF	625
LA-7	L-1B well	30	36	<0.04	<0.02	6.5	0.30	138	2.0	0.11	326	32	15	2.3	0.45	7.2	0-2180	SF	694
LA-8	L-5 well	26.5	40	<0.04	<0.02	7.2	0.13	52	1.3	0.04	143	6	3	0.98	<0.05	6.5	0-1880	SF	623
LA-9	L-4 well	28	39	<0.04	<0.02	10	0.22	21	1.7	0.03	85	5	<1	0.33	0.38	6.5	0-1560	SF	622
LA-10	PM-2 well	23.5	83	<0.04	<0.02	8.8	3.0	9.6	1.7	0.02	65	<5	3	0.19	0.25	6.5	0-5520	SF	800
LA-11	PM-1 well	28	82	<0.04	<0.02	26	6.8	18	3.6	0.03	146	6	6	0.26	0.25	6.5	0-2320	SF	770
LA-12	G-6 well	30.5	55	<0.04	<0.02	15	2.3	15	2.0	<0.02	94	5	2	0.27	<0.05	6.5	0-1100	SF	617
LA-13	G-5 well	26.5	59	<0.04	<0.02	17	3.9	11	1.8	<0.02	93	5	2	0.25	0.12	6.5	0-2100	SF	614
LA-14	G-4 well	26	53	<0.04	<0.02	16	2.5	14	1.8	<0.02	92	5	2	0.27	0.12	6.5	0-1260	SF	616
LA-15	G-3 well	29	59	<0.04	<0.02	11	1.2	22	1.6	<0.02	93	5	2	0.45	<0.05	6.5	0-1620	SF	614
LA-16	G-2 well	30	77	<0.04	<0.02	11	0.61	33	2.5	0.02	122	5	4	1.0	0.12	6.5	0-1820	SF	617
LA-17	G-1A well	28	78	<0.04	<0.02	11	0.58	24	2.8	<0.02	100	5	1	0.55	<0.05	6.5	0-2060	SF	637
LA-18	G-1 well	26	84	<0.04	<0.02	13	0.68	22	3.1	<0.02	97	5	1	0.50	<0.05	6.5	0-1340	SF	646
LA-19	Spg, White Rock Can.	19	71	<0.04	<0.02	12	3.1	11	1.4	0.03	74	<5	<1	0.45	<0.05	6.5	6	V	
LA-20	PM-3 well	27.5	91	<0.04	<0.02	26	8.7	16	3.3	0.04	146	6	12	0.28	0.18	6.5	0-5600	SF	786
Mariner and others, 1977																			
	Unnamed Mineral Spg	11	18	<0.02	0.05	220	110	3800	140	6.3	2265	3700	2700	2.0	8.0	7.27	Seep	P	
	Unnamed Warm Spg	25	15	0.42	0.30	390	65	3000	91	5.2	1855	2600	2400	4.0	6.9	6.25	<20?	P	
	Unnamed Mineral Spg	15	20	0.14	0.57	300	68	2000	83	6.1	2005	1200	1900	3.4	11	6.33	<20?	P	

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[a] All analyses by John Husler, University of New Mexico. Unless otherwise noted, values reported in mg/ℓ.

[b] Al = alluvium; V = volcanic rocks; P = Paleozoic rocks; SF = Santa Fe formation; Pu = Puye formation.

TABLE II

DEUTERIUM, ^{18}O, LITHIUM, ARSENIC, CHLORIDE, FLUORIDE, AND BORON OF 23 WATERS OF THE LOS ALAMOS AND VALLES CALDERA REGION, NEW MEXICO

By L. Merlivat, Dept. De Recherche et Analyse, Saclay, France

				Per Mil		Milligrams per Liter				
No.	Name	Water Type[a]	Temp. °C	δD	$\delta^{18}O$	Li	As[b]	Cl	F	B
VA-1	Spence Hot Spg	tm	45.0	- 86.4	-12.35	0.66	0.072	8	0.55	0.15
VA-3	McCauley Spg	tm	31.0	- 88.4	-12.60	0.24		6	0.85	0.24
VA-4	San Antonio Hot Spg	tm	42.0	- 92.0	-12.65	<0.02		2	0.80	<0.05
VA-5	Grotto Spg	c	38.0	- 84.6	-10.65	13.20		1480	4.00	11.60
VA-6	Soda Dam Spg	c	47.0	- 84.9	-10.60	13.20	1.5	1480	4.10	11.50
LA-1	Gallery Spg	m	11.0	- 84.3	-12.20	<0.02		<1	0.12	<0.05
LA-2	T-3 well	m	13.0	- 73.8	-10.65	0.03		4	0.26	<0.05
LA-3	T-2 well	m	11.0	- 73.5	-10.60	0.03		2	0.46	<0.05
LA-4	Sacred Spg	m	14.0	- 81.8	-11.80	0.04		2	0.46	<0.05
LA-5	Basalt Spg	m	15.0	- 76.5	-10.85	0.03		12	0.32	<0.05
LA-6	L-6 well	m	27.0	- 94.7	-13.45	0.04	0.050-0.225	4	2.20	<0.05
LA-7	L-1B well	m	30.0	-103.0	-14.30	0.11	0.038-0.072	15	2.30	0.45
LA-10	PM-2 well	m	23.5	- 77.5	-11.40	0.02		3	0.19	0.25
LA-11	PM-1 well	m	28.0	- 74.1	-10.95	0.03		6	0.26	0.25
LA-12	G-6 well	m	30.5	- 76.0	-11.25	<0.02		2	0.27	<0.05
LA-14	G-4 well	m	26.0	- 76.3	-11.10	<0.02		2	0.27	0.12
LA-14	G-2 well	m	30.0	- 83.1	-11.95	0.02		4	1.00	0.12
LA-17	G-1A well	m	28.0	- 82.5	-11.80	<0.02		1	0.55	<0.05
LA-18	G-1 well	m	26.0	- 81.0	-11.65	<0.02		1	0.50	<0.05
LA-19	Spg, White Rock Can	m	19.0	- 76.8	-11.00	0.03		<1	0.45	<0.05
Mariner and others, 1977										
	Unnamed Mineral Spg	c	11.0	- 85.6	-10.01	6.30		2700	2.00	8.00
	Unnamed Warm Spg	c	25.0	- 90.1	-11.22	5.20	0.60	2400	4.00	6.90
	Unnamed Mineral Spg	c	15.0	- 86.5	-10.12	6.10		1900	3.40	11.00

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[a] tm = thermal meteoric
c = probable connate
m = surface meteoric

[b] Arsenic data from the following sources: Spence, Soda Dam, and Unnamed Mineral Springs from Trainer (1974); Wells L-1B and L-6 from Purtymun (1977); Arsenic levels in other wells of the Los Alamos well field are <0.030 mg/ℓ.

Methods and Procedures

Temperatures were recorded with mercury thermometers and field pH was determined using sensitive limited-range pH test papers (Colorfast Indicator Strips nos. 9581, 9582, and 9583). The pH values are considered reliable to ±0.25 pH units in the 6.5 to 7.0 pH range; values outside this range are considered reliable to ±0.15 pH unit. Laboratory values of pH are not considered reliable because most waters gain or lose CO_2 gas after sampling and before laboratory analysis. This alters the concentration of bicarbonate ions, which in turn changes the pH. Flow rates of springs were estimated visually; flow rates of wells were obtained from gauges on the wellhead.

Samples of water for chemical analysis were filtered using a large syringe attached to a filter holder containing 0.8 μ filter paper. The filtered water was squirted brimful into polyethylene bottles with Polyseal caps. Three types of samples were collected: (1) a 500-mℓ bottle of filtered unacidified water for anions, (2) a 250-mℓ bottle of filtered acidified water for cations, and (3) a 125-mℓ bottle of filtered diluted water for silica. Dilute hydrochloric acid was added dropwise to the acidified sample until the pH <2. The bottles used for silica analyses contained 90 mℓ of deionized water before 10 mℓ of sample were added. This dilution prevents polymerization of monomeric silica in more concentrated water samples before analysis.

Laboratory analyses were performed by the following methods: SiO_2, Fe, Mn, Ca, Mg, Na K, and Li by atomic absorption spectroscopy; HCO_3 by sulfuric acid titration, SO_4 by turbidimetric titration using $BaCl_2$; Cl by titration using $AgNO_3$; F by specific ion electrode, and B by colorimetric methods with carminic acid. Results appear in Table I in values of mg/ℓ.

Samples for D and ^{18}O analysis were collected by filling 125-mℓ glass bottles full of raw water and sealing with a Polyseal cap. Isotope variations were determined by standard methods and the data appear in Table II.

Hydrogeology

The hydrology of the Pajarito Plateau was determined by Purtymun and Johansen[13] (Fig. 3) from their studies of many deep water supply wells. Although the plateau dips gently eastward toward the Rio Grande, the underlying sediments of the Santa Fe formation dip westward toward Valles Caldera (Fig. 4). The main aquifer in the Los Alamos area dips very gently eastward at depths of 185 to 370 m beneath the surface of the plateau. The source of water lies undoubtedly in the Jemez Mountains. Because the Santa Fe sediments

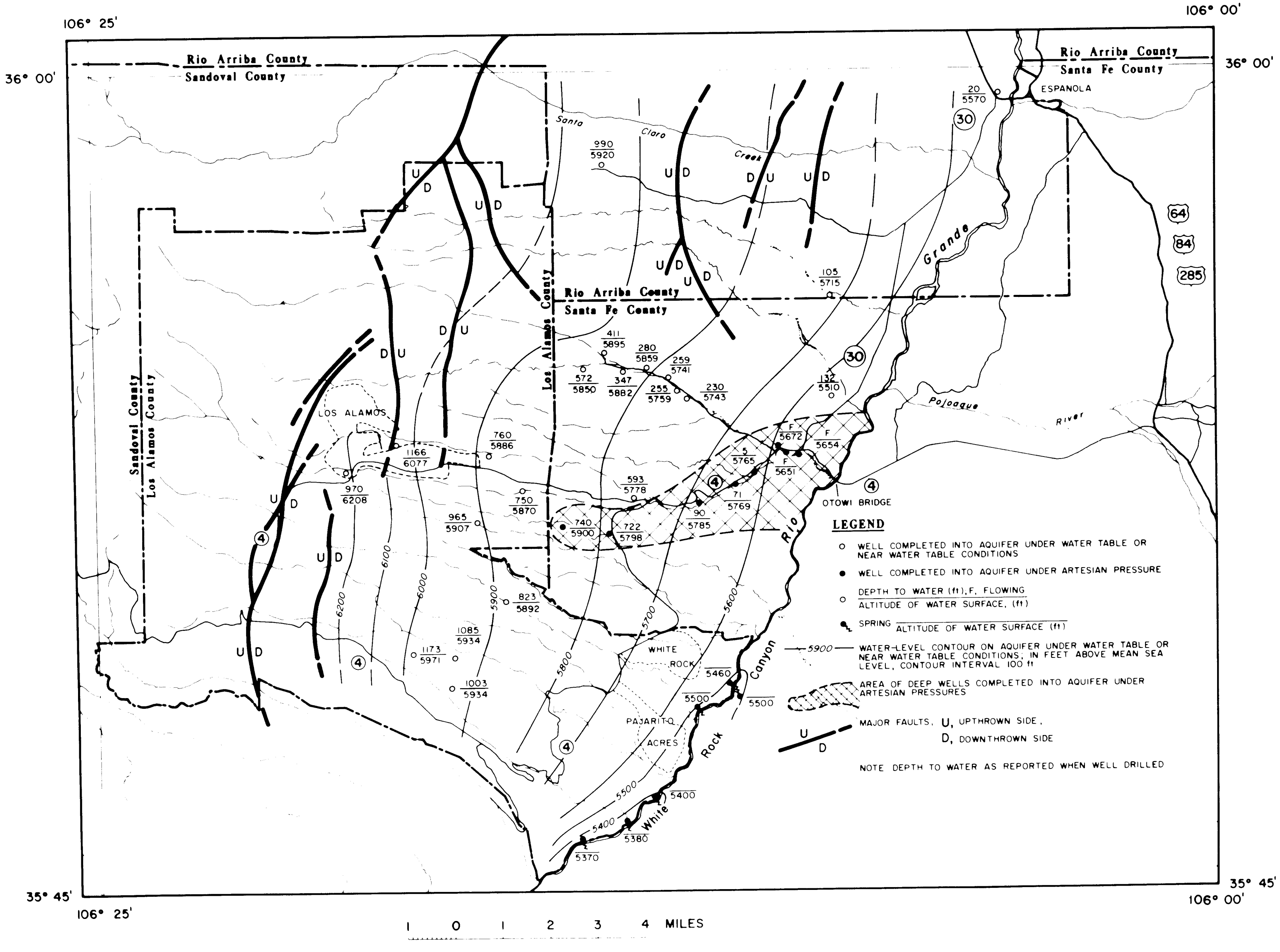

Fig. 3.
Hydrologic map of the Pajarito Plateau showing generalized contours of the main aquifer and location of confined (artesian) aquifer (from Purtymun and Johansen, 1974).

dip to the west, the main aquifer must cross lithologic boundaries (that is, bedding planes) as the water migrates to the east. Wells of the Los Alamos well field are completed into a confined aquifer and yield water under artesian pressure. This confined aquifer probably has its source to the east as suggested by the isotope data described below. The depths of the wells and the rocks that yield water are summarized in Table I. The rock types from which the springs emerge are also listed in Table I.

Geochemistry

The chemical composition of the various waters are displayed in Fig. 5. The 20 Los Alamos samples range from calcium and magnesium to sodium bicarbonate water. The dilute hot springs chemically resemble the Los Alamos waters. Spence and San Antonio Hot Springs are comprised of sodium bicarbonate water whereas McCauley Spring, a warm spring, contains relatively higher calcium and magnesium. In contrast, Soda Dam and Grotto Springs, which are hot mineral springs, contain appreciable chloride and thus are chemically distinct from the other waters of this study.

Isotopes. The D and ^{18}O isotope compositions of the waters are shown in Fig. 6 and Table II. All 20 Los Alamos samples plot along the Craig Meteoric Line as do the dilute hot springs, indicating that they are all composed of meteoric water.

However, Soda Dam, Grotto Springs, plus three mineralized springs near San Ysidro are significantly richer in ^{18}O than meteoric waters. Because of their relatively high chloride content and origin in marine sediments, the mineral waters may be composed partly of connate water, a derivative of ancient sea water. Connate waters are enriched in ^{18}O relative to meteoric water.[14]

Deep geothermal fluids are also enriched in ^{18}O by virtue of isotope exchange of water with very hot rock.[15] The waters of Soda Dam and Grotto Springs may contain a fraction of deep geothermally heated water because of their close proximity to Valles Caldera, but the San Ysidro mineral springs, which lie many kilometers to the south and west, probably do not.

Although well waters L-1B and L-6 are composed of meteoric water, they are relatively lighter in both D and ^{18}O than other meteoric waters, suggesting a source of water to the east (farther from the ocean). The hydrologic data of Purtymun and Johansen[13] (Fig. 3) indicate that waters of the Los Alamos well field originate from a confined aquifer in westward dipping Santa Fe formation sediments. The artesian water in this confined aquifer probably

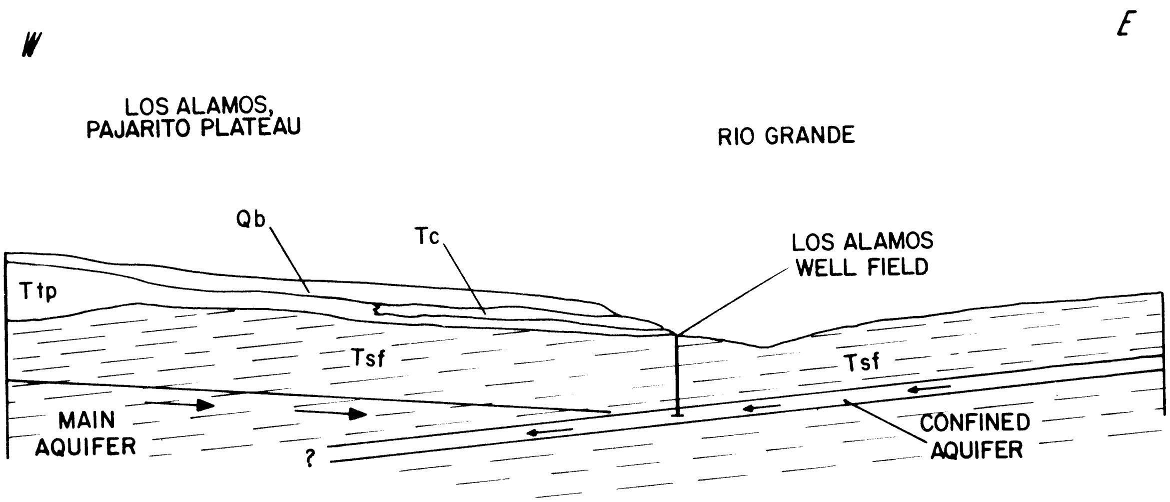

Fig. 4.
Schematic cross section of Pajarito Plateau showing simplified model of main and confined aquifers. Qb = Bandelier Tuff, Tc = Cerros del Rio Basalt, Ttp = Tschicoma and Puye formations, Tsf = Santa Fe formation. Surfaces of main aquifer crosses bedding (dashed lines) of Santa Fe formation.

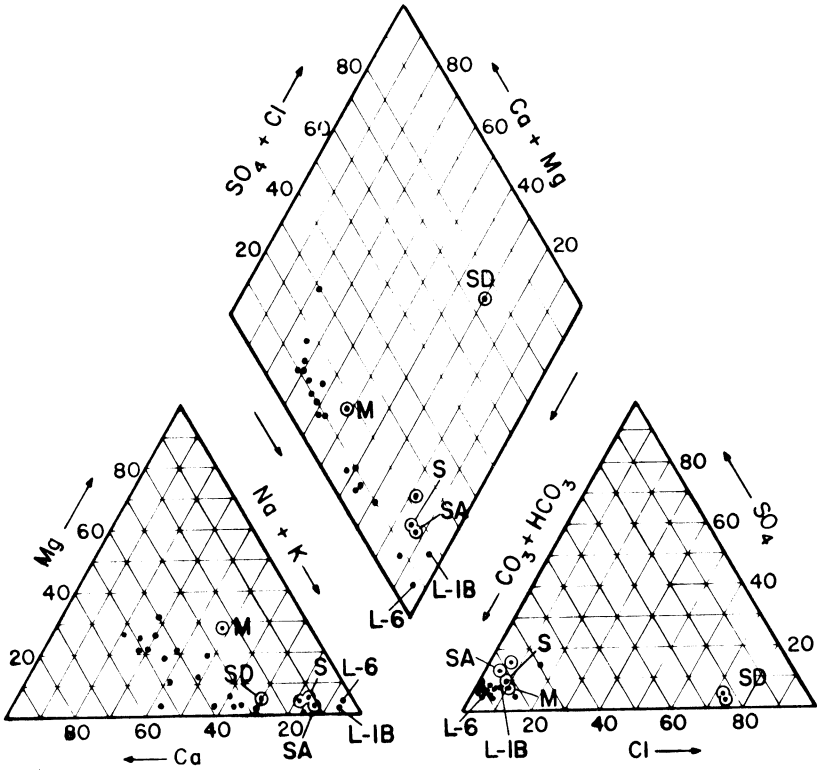

Fig. 5.
Piper diagram showing the chemical composition in equivalents of 26 thermal and nonthermal waters in the Los Alamos-Valles Caldera region, New Mexico; ⊙ = thermal waters, ● = nonthermal waters, SA = San Antonio Hot Spring, M = McCauley Spring, S = Spence Hot Spring, SD = Soda Dam Spring, L-1B and L-6 = wells from Los Alamos well field.

comes from the east as suggested by the isotope data. Also, the isotopes suggest that well L-6 is a mixture of the main aquifer beneath Los Alamos and the confined aquifer.

Silica. The silica data (Fig. 7) show that the thermal meteoric and mineral springs have two different trends. Both show increasing silica with increasing temperature, but the mineralized waters contain substantially less silica. This may be due to the different bedrock types associated with these waters. The mineral springs originate in part from Paleozoic limestones, whereas the thermal meteoric waters issue from silica-rich Quaternary rhyolites. Cold meteoric well waters of the Los Alamos area fall into groups in Fig. 7, probably because of variations of their local source aquifers. Note, however, that silica concentration is independent of temperature for the deep wells even though all waters originate in sands and gravels of the Santa Fe formation. The relatively shallow T-2 and T-3 wells contain the least silica, perhaps caused by the combined effects of cooler temperature and shorter residence time of water in the rocks. Unlabeled points represent data for Los Alamos springs; those discharging from volcanic rocks contain more silica than Sacred Spring, which issues from Santa Fe gravels.

Chloride. A plot of chloride vs measured temperature appears in Fig. 8. The mineral springs contain 3 orders of magnitude more chloride than other waters of this study, but interestingly, the mineral waters display decreasing chloride with increasing temperature.

Thermal meteoric waters and meteoric waters of the Los Alamos area contain equivalent amounts of chloride. Only one group of well waters from the silica plot forms a group on the chloride plot (G-3 to G-6 wells). Well L-1B contains more chloride than all other meteoric waters of this study.

Trace Elements. Thermal waters are commonly enriched in lithium, arsenic, chloride, fluoride, and boron relative to cold meteoric waters; in particular, high ratios of lithium/chloride and boron/chloride often suggest a deep thermal origin of the waters.[16]

The lithium and boron data (Figs. 9 and 10) show that the mineral and thermal meteoric waters contain more lithium and boron than most cold meteoric waters of the Los Alamos area. The thermal meteoric waters have higher lithium/chloride and boron/chloride ratios than the mineral springs. Water supply well L-1B contains above-background concentrations of both boron and lithium; in fact, it contains more boron than any of the thermal meteoric waters, which

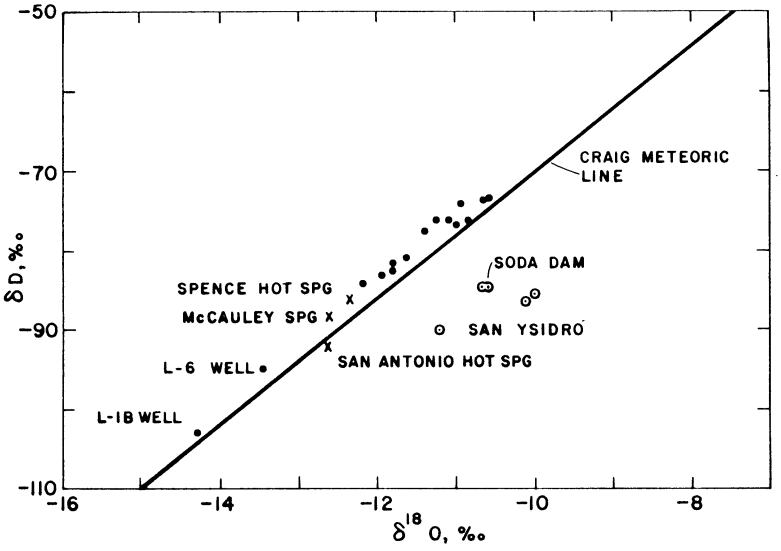

Fig. 6.
Plot of δD vs $\delta^{18}O$ for 23 thermal and nonthermal waters of the Los Alamos-Valles Caldera region, New Mexico; ⊙ = thermal/mineral waters, X = thermal meteoric waters, • = cold meteoric waters; data for San Ysidro mineral springs from Mariner et al. (1977).

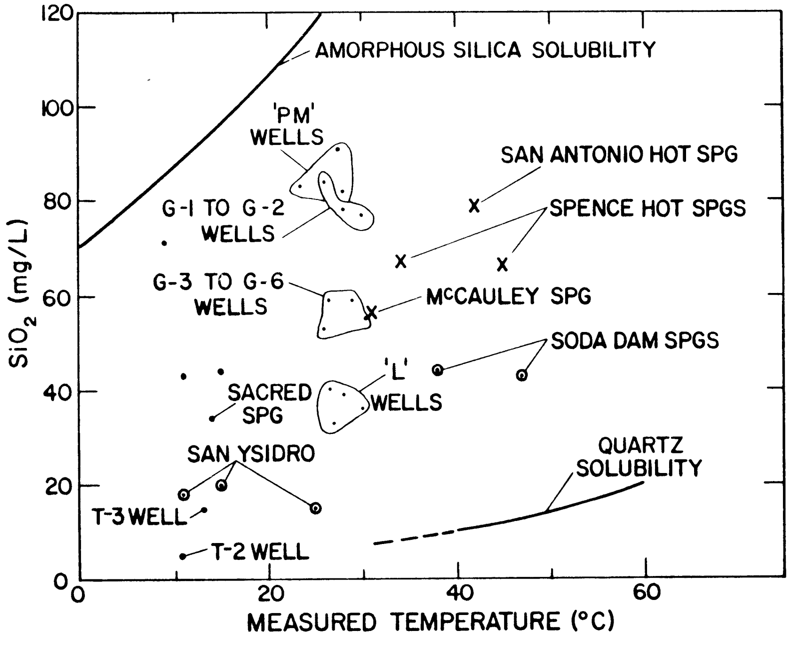

Fig. 7.
Plot of SiO_2 vs measured temperature for thermal and nonthermal waters of the Los Alamos-Valles Caldera region, New Mexico; data and symbols same as Fig. 6.

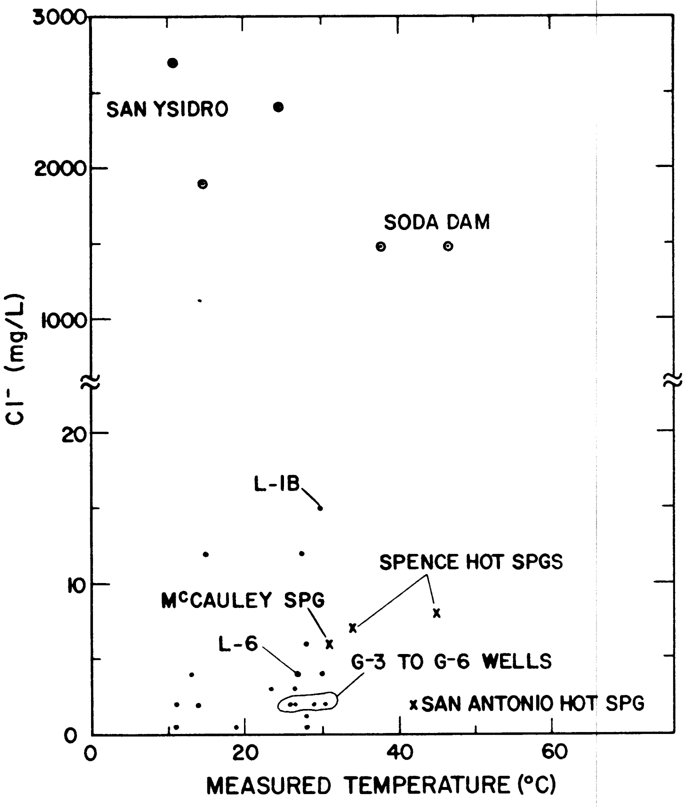

Fig. 8.
Plot of chloride vs measured temperature for thermal and nonthermal waters of the Los Alamos-Valles Caldera Region, New Mexico; data and symbols same as Fig. 6

suggests that it may contain a small fraction of thermal/mineral water of deep origin.

Water supply well L-1B is also anomalously high in both fluoride and arsenic compared with other cold meteoric of the Los Alamos area (Figs. 11 and 12). This again suggests that a small component of water of deep origin has mixed with the aquifer tapped by L-1B.

Chemical Geothermometry

Subsurface aquifer temperatures of hot water geothermal systems can be estimated using the concentrations of temperature-dependent species such as silica and sodium, potassium, and calcium.[17,18] Several assumptions must be satisfied, however, before the direct application of the geothermometers has any meaning. These include water-rock equilibrium at depth, negligible reequilibration as the water rises toward the surface, and no mixing of deep hot

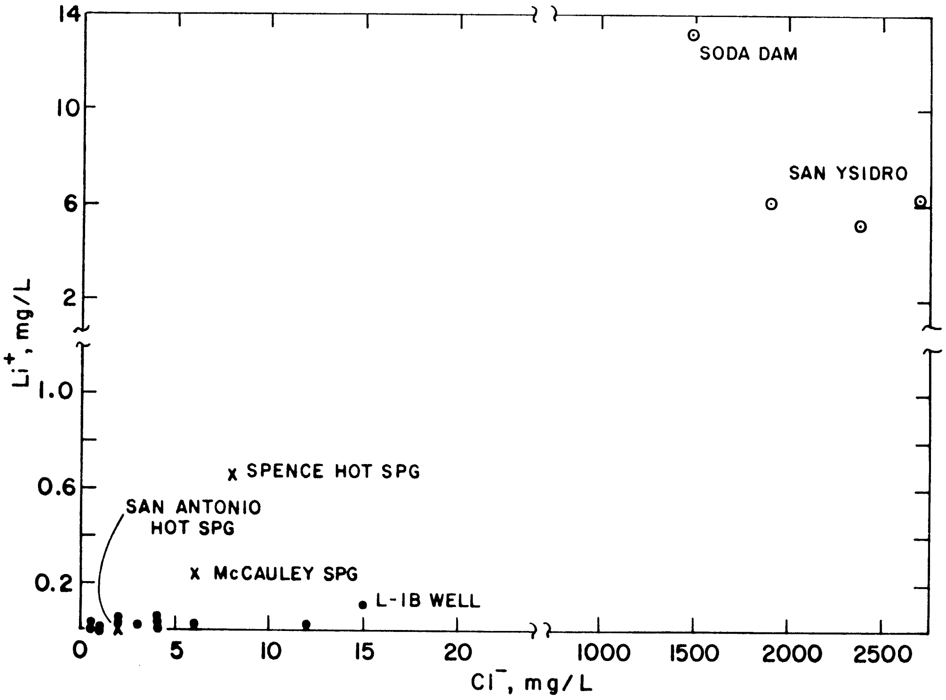

Fig. 9.
Plot of lithium vs chloride for thermal and nonthermal waters in the Los Alamos-Valles Caldera region; data and symbols same as Fig. 6.

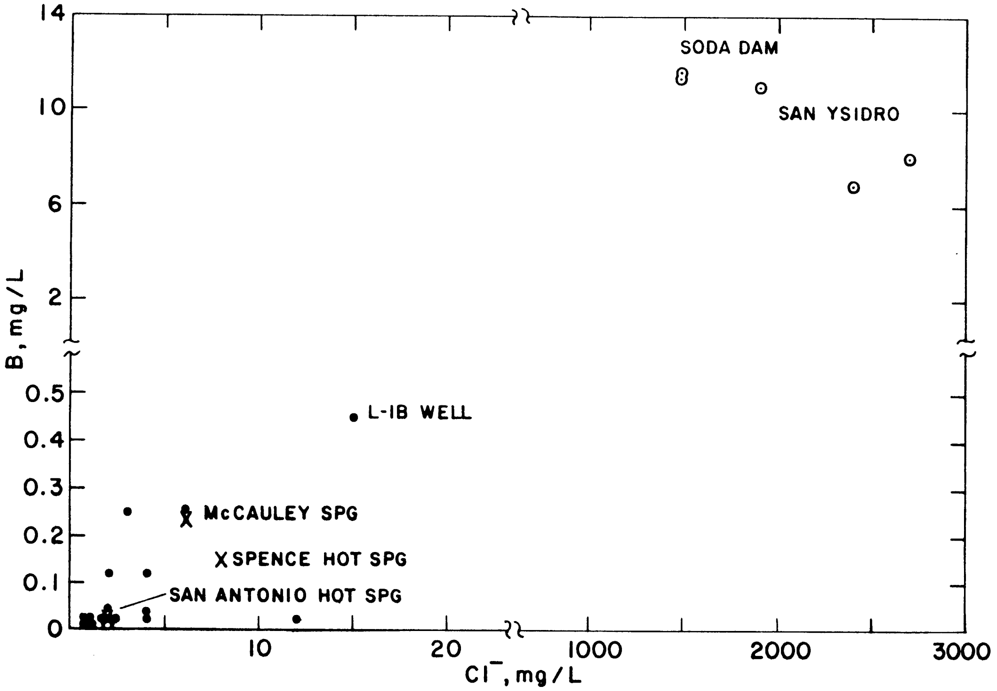

Fig. 10.
Plot of boron vs chloride for thermal and nonthermal waters in the Los Alamos-Valles Caldera region; data and symbols same as Fig. 6.

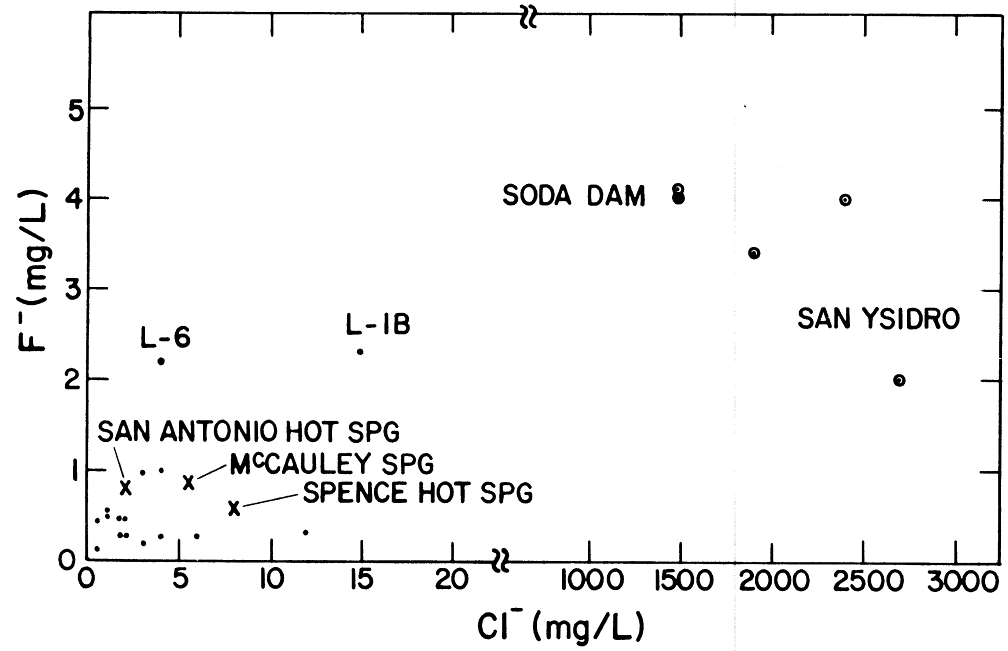

Fig. 11.
Plot of fluoride vs chloride for thermal and nonthermal waters in the Los Alamos-Valles Caldera region; data and symbols same as Fig. 6.

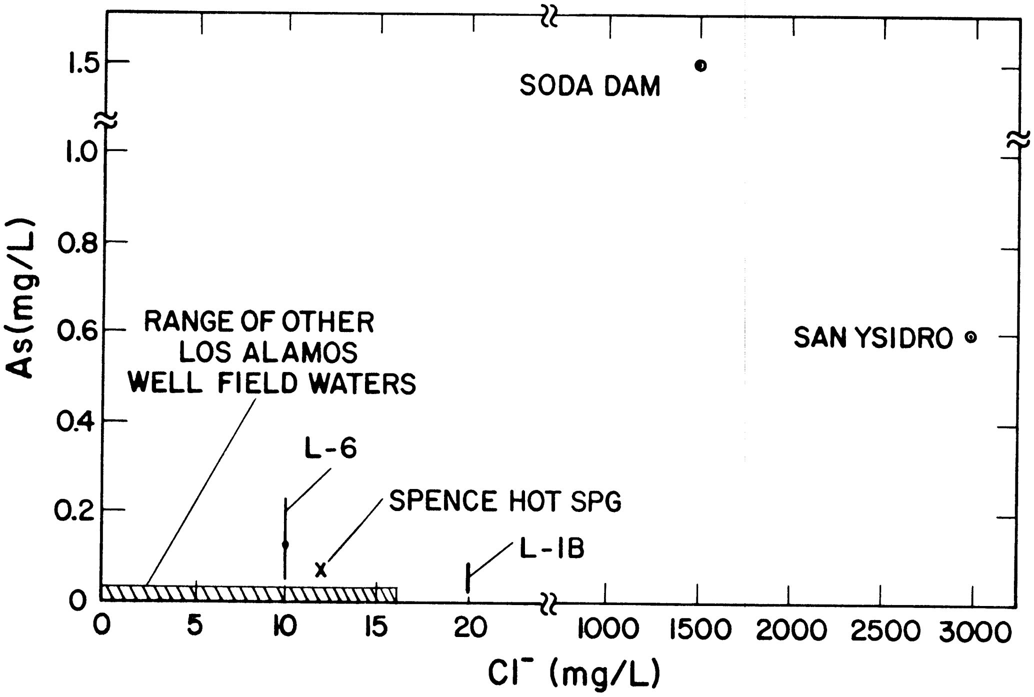

Fig. 12.
Plot of arsenic vs chloride for thermal and nonthermal waters in the Los Alamos-Valles Caldera region; arsenic data from Trainer (1974) and Purtymun (1977); symbols same as Fig. 6.

and cold surface waters. Because of such restraints, the application of the geothermometers to real systems may be very difficult.

The Na-K-Ca geothermometer of Fournier and Truesdell[18] contains a factor, β, that is dependent on whether or not the water equilibrated above 100°C ($\beta = 1/3$) or below 100°C ($\beta = 4/3$). Their equation was derived by considering reactions that involve feldspars, thus the geothermometer is most reliable for igneous and metamorphic terrains where ample feldspar is available for reaction. The $\beta = 1/3$ case is not considered reliable if the $\beta = 4/3$ temperature is less than 100°C, the log $(Ca^{1/2}/Na)$ in equivalents is positive, or if the water contains high concentrations of magnesium. A magnesium correction procedure for this geothermometer has been published recently,[19] which is applicable if the Na-K-Ca temperature is >70°C and the factor $R = Mg/(Mg+Ca+K) \times 100$ in equivalents <50.

Table III lists the temperature estimates of the thermal/mineral waters plus water supply wells L-1B and L-6. All waters are undersaturated with respect to amorphous silica and oversaturated with respect to quartz, except possibly the T-2 well (Fig. 7). Possibly the waters are in equilibrium with some intermediate silica phase such as chalcedony or cristobalite. The Na-K-Ca temperature estimates are probably more reliable because, in the case of meteoric waters, they are generally within ±25°C of the measured temperatures.[20]

EVALUATIONS OF GEOTHERMAL POTENTIAL

The evaluations that follow serve as a comparison between the known Valles thermal/mineral springs and spring and well waters of the Los Alamos area. Because of the limited data, they should be considered tentative.

Thermal meteoric waters--Spence, San Antonio, and McCauley Springs--are composed solely of meteoric water, are relatively dilute and contain only modest concentrations of lithium and boron. The Na-K-Ca $\beta = 4/3$ temperatures are all <100°C and, except for San Antonio, within 25°C of the measured spring temperature. These data indicate that the thermal meteoric waters are merely heated surface ground water in equilibrium at the measured spring temperature. Contrary to Trainer,[21] these springs are probably not in equilibrium with quartz because the quartz temperature estimates appear to be too high.

The hot mineral springs at Soda Dam contain substantial quantities of boron, lithium, fluoride, and arsenic; the ratios of boron/chloride and lithium/chloride are quite high. Estimation of a deep reservoir temperature

TABLE III

CHEMICAL GEOTHERMOMETRY OF THERMAL AND NONTHERMAL WATERS OF THE LOS ALAMOS AND VALLES CALDERA REGION

					Na-K-Ca		
No.	Name	Measured Temp. (°C)	Quartz	Amorphous SiO_2	$\beta = 4/3$	$\beta = 1/3$	Mg Corrected
VA-1	Spence Hot Spg	45	112	- 2.3	55		
VA-3	McCauley Spg	31	105	- 9.3	27		
VA-4	San Antonio Hot Spg	42	124	5.8	71		71
VA-5	Soda Dam Spg	47	95	-20.0	178	220	160
LA-1	Gallery Spg	11			34		
LA-2	T-3 well	13			34		
LA-3	T-2 well	11			18		
LA-4	Sacred Spg	14			39		
LA-5	Basalt Spg	15			37		
LA-6	L-6 well	27	83	-49.0	59		
LA-7	L-1B well	30	86	-26.0	75		75
LA-10	PM-2 well	23.5			38		
LA-11	PM-1 well	28			45		
LA-12	G-6 well	30.5			38		
LA-14	G-4 well	26			33		
LA-16	G-2 well	30			56		
LA-17	G-1A well	28			56		
LA-18	G-1 well	26			55		
LA-19	Spg, White Rock Canyon	19			30		
Mariner and others, 1977							
	Unnamed Mineral Spg	11	58	-49.0	206	162	37
	Unnamed Warm Spg	25	55	-54.0	158	144	84
	Unnamed Mineral Spg	15	60	-46.0	155	155	70

from the Na-K-Ca (Mg corrected) geothermometer is 160°C, considerably greater than the discharge temperature of 48°C. These data suggest that the waters of Soda Dam are derivatives of some moderate- to high-temperature geothermal system. Trainer[11] has indicated that they may be derived from the 260°C geothermal system within Valles Caldera.

In contrast, the mineral waters near San Ysidro have lower boron/chloride and lithium/chloride ratios and yield Na-K-Ca (Mg corrected) temperatures of <85°C. Mariner et al.[22] feel these fluids are probably not derived from a high-temperature geothermal system. We suggest that the waters at San Ysidro issue from a unique geothermal system in that area.

The Los Alamos springs and wells are composed of meteoric water, are relatively low in dissolved solids, and indicate no geothermal potential except for wells L-1B and L-6. In general, these last two waters contain anomalous quantities of lithium, boron, fluoride, and arsenic. In addition, L-1B and L-6 give anomalously high Na-K-Ca $\beta = 4/3$ geotemperature estimates that indicate they may be mixed waters containing a small fraction of deep thermal/-mineral water. The composition and temperature of this hypothetical deep fluid cannot be guessed with the present data. However, the electrical resistivity data indicate that such a deep fluid exists.[6]

Because the waters of L-6, and particularly L-1B, have a different source aquifer and isotopic signature than waters of the other deep wells, it is easy to assume that the anomalies in chemical composition of L-1B and L-6 merely result from the unique composition of the confined aquifer. However, two facts argue against this simple explanation. (1) Well L-6, although it appears to be a mixture of waters from the Main and Confined Aquifers, has more arsenic than any of the other wells. This suggests a separate source for the arsenic. (2) The Na-K-Ca geothermometry suggests that wells L-1B and L-6 are picking up a small component of deeper, hotter water.

We speculate that this fluid leaks upwards along the set of north-trending normal faults[1] that cut the east side of the Pajarito Plateau near the Los Alamos well field. We suspect that this fluid is dispersed locally into the deep confined aquifer of the Tesuque Member of the Santa Fe formation. The Los Alamos well field lies at the south end of a belt of normal faults that cut sediments of both the Puye and Santa Fe formations and these faults may be surface expressions of a much deeper fault system. The large volume of the diluting Santa Fe aquifers masks the composition of the less voluminous deep fluid. Possibly, the deep fluid is mineralized water that originates in deeply buried Paleozoic sediments at the base of the graben. If such a Paleozoic section exists, it is at a maximum depth of roughly 3075 m beneath the top of the Pajarito Plateau according to the gravity data of Budding.[5] This means the fluid rises a maximum height of about 2000 m before mixing. A similar idea was offered by Purtymun[23] to explain the occurrence of the arsenic, fluoride-rich component entering wells L-1B and L-6 of the Los Alamos well field. The model presented here is very simplistic. In reality there may be several stages of mixing within intermediate level aquifers before the deep fluid ever enters the L-1B well bore.

CONCLUSIONS

The Los Alamos area contains no springs or deep aquifers composed solely of thermal water of deep origin. Isotope data indicate all waters of the Los Alamos area are of meteoric origin. The two aquifers supplying most of the potable water for Los Alamos have different recharge areas. Chemical data and arguments based on geothermometry suggest that a small fraction of thermal/-mineral water of deep origin is mixing with waters of the Los Alamos well field. We feel this deep water probably rises along high-angle faults on the eastern side of the Pajarito Plateau. Available electrical resistivity data[6] indicate that such a deep fluid probably exists.

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