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The Bishop Ash Bed, a Pleistocene Marker Bed in the Western United States [1]

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Biotite-bearing chalky-white rhyolitic ash, here called the Bishop ash bed, occurs in middle Pleistocene alluvial and lacustrine deposits at eight localities scattered from California to Nebraska and is correlated with the basal air-fall lapilli of the Bishop Tuff, an ash flow of eastern California, radiometrically dated about 0.7 million years. Correlation of the Bishop ash bed with the air-fall lapilli is made on the basis of similar petrography and on chemistry as determined by electron microprobe, atomic absorption, and emission spectrographic analyses. At five localities the Bishop ash bed lies stratigraphically below a Pearlette-like ash. As more occurrences of the Bishop ash bed are found, it should become an increasingly important dated stratigraphic marker relating middle Pleistocene deposits and events across several geomorphic provinces.

Another biotite-bearing chalky-white ash, here called the ash of Green Mountain Reservoir, occurs at three other localities and is distinguishable from the Bishop ash bed by small differences in chemical composition of the glass. The ash of Green Mountain Reservoir is younger than the Bishop ash bed, as shown by the fact that at one locality it lies stratigraphically above the aforementioned bed of Pearlette-like ash.

INTRODUCTION

The extensive beds of light-colored rhyolitic ash interlayered in upper Cenozoic alluvial and lacustrine deposits in the Western United States must have originated from volcanic eruptions of extraordinary intensity. The series of eruptions from a particular center that produced the ashes also produced rhyolitic ash-flow sheets whose volumes commonly exceed several tens of cubic miles. During middle Pleistocene time three rhyolitic volcanic centers generated multiple rhyolitic ash-flow sheets, and the eruptions culminated in caldera-forming collapses. These centers (Fig. 1) are the Yellowstone National Park area in Wyoming and Idaho (Christiansen and others, 1969), the Jemez Mountains area in northern New Mexico (Smith and Bailey, 1968), and the Long Valley area north of Bishop in eastern California (Gilbert, 1938; Sheridan, 1968; Smith and Bailey, 1968, p. 629). The ash derived from each center is clearly distinguishable from ash of the other centers by petrographic and chemical properties, but ashes erupted from the same center but at significantly different times may differ only slightly, and some may not be distinguished from each other by present methods.

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The Bishop Tuff of eastern California (Gilbert, 1938; Bateman, 1965; Sheridan, 1965, 1968) was erupted as ash flows about 0.7 million years (m.y.) ago (Dalrymple and others, 1965) from an area which then collapsed to form the Long Valley caldera (Smith and Bailey, 1968, p. 629) at the eastern base of the Sierra Nevada in Mono County, California. Coarse air-fall pumice emplaced early in the eruptive episode locally occurs beneath and beyond the boundaries of the Bishop ash-flow deposit. Among the middle Pleistocene ash samples in our collection we found samples from 11 localities scattered from California to Nebraska (Fig. 1) whose petrographic characters match those of the coarse air-fall pumice at the base of the Bishop Tuff. The ash of these samples contains phenocrystic biotite and is chalky white, in contrast to other middle Pleistocene ashes which contain no biotite and are silver gray. The chalky-white ash at eight of these localities, furthermore, matches in detail the chemical composition of the glass of the known Bishop air-fall pumice lapilli below the ash flows. Ash of the three remaining localities has a chemical composition similar in some respects to that of the Bishop air fall but differs in certain important details, notably the amounts of iron and some minor elements. On the basis of stratigraphic evidence, the chalky-white ashes seem to represent two ash falls, one being equivalent of the 0.7-m.y.-old Bishop Tuff and referred to here as the Bishop ash bed, and the other being slightly younger and referred to here as the ash of Green Mountain Reservior, for its occurrence at locality 13 (Fig. 1).

The silver-gray ashes mentioned above are from a group that has been called "Pearlette-like" (Wilcox, 1965) to denote Pleistocene ash having the general petrographic characters listed by Swineford and Frye (1946) for the well-known "Pearlette ash" of Kansas, but without the implication that all occurrences represent a coeval ash fall.

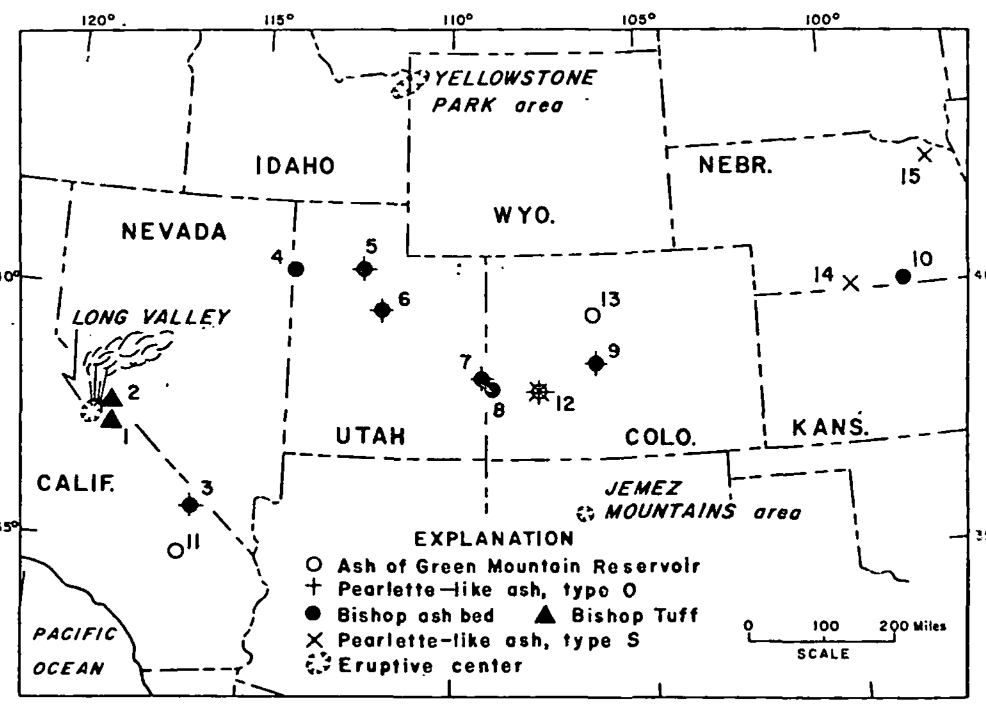

FIG. 1. Map showing sample localities of Bishop Tuff, Bishop ash bed, ash of Green Mountain Reservoir, and Pearlette-like ashes of this report.

In this report we will designate one ash fall of this group as Pearlette-like ash, type O, from its occurrence on Onion Creek, Grand County, Utah (locality 7, Fig. 1), and designate another as Pearlette-like ash, type S, from its occurrence at the type locality of the Sappa Formation, Harlan County, Nebraska (locality 14).

At localities 3, 5, 6, 7, and 9 (Figs. 1 and 2 and Appendix) the Bishop ash bed lies stratigraphically below the Pearlette-like ash, type O, which we believe, on the basis of detailed petrographic and chemical study, to be one ash fall.

At locality 12 in the Cerro Summit area, Colorado, the ash of Green Mountain Reservoir occurs stratigraphically above the Pearlette-like ash, type O (Fig. 2). By this evidence the ash of Green Mountain Reservoir seems to be younger than the Bishop ash bed. Of special interest is the fact that at locality 12 the Pearlette-like ash, type S, is separated from the Pearlette-like ash, type O, by 30 feet of sediments containing a soil zone. The ash-type S differs only slightly from the type O (see "Petrography" and "Chemistry" sections), and as yet this is the only locality where two Pearlette-like ash beds have been found superposed in the same stratigraphic succession.

One or another of us has visited and collected the ash at 9 of the 15 localities shown in Fig. 1, and we take responsibility for the correlations shown. The stratigraphic sections of fig. 2 are generalized to emphasize the stratigraphic relations of the ash beds;

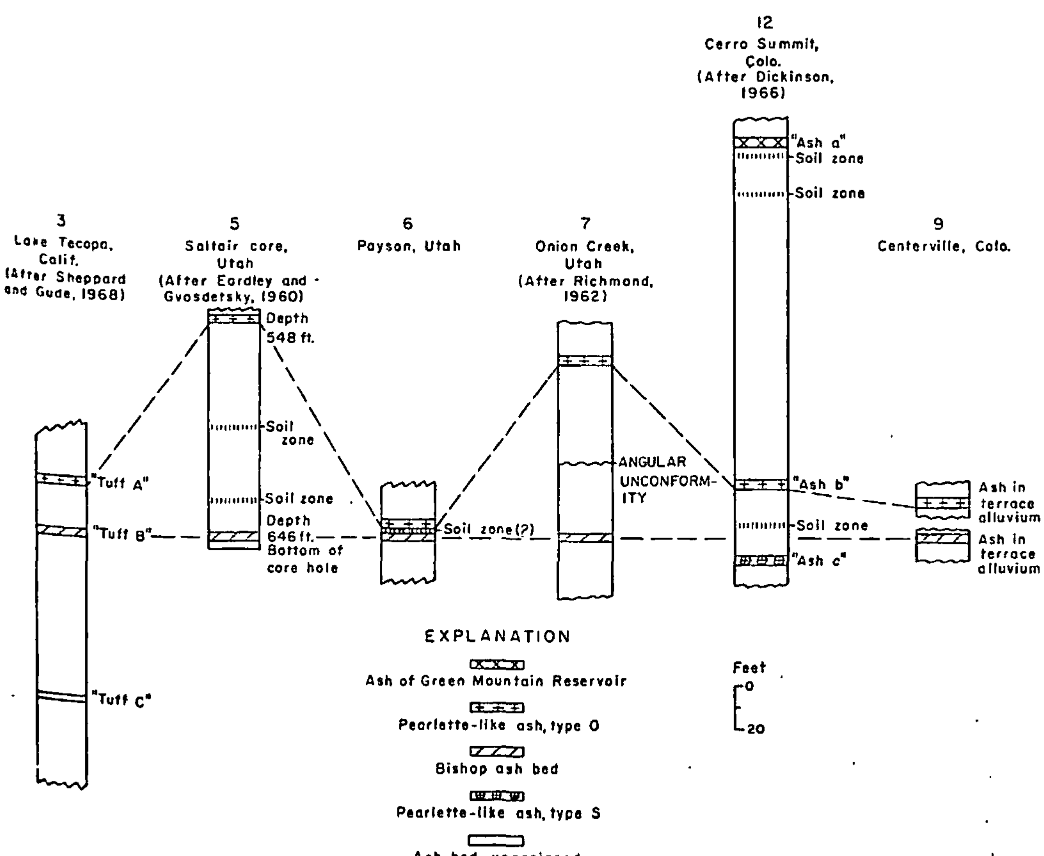

FIG. 2. Generalized stratigraphic sections showing relations of ash beds of Fig. 1. Ash-bed thicknesses are generalized.

FIG. 3. Shards in immersion oil, refractive index 1.540, plane polarized light. Shards from Bishop ash bed (A) (locality 9) and from ash of Green Mountain Reservoir (B) (locality 13) are pumiceous and are easily distinguished from bubble-wall and bubble-junction shards of the Pearlette-like ashes (C) (Pearlette-like ash, type O, locality 7).

other details of the stratigraphic sections are given in the cited reports.

PETROGRAPHY

The Bishop ash bed and the ash of Green Mountain Reservoir differ from most other Pleistocene ashes by their chalky-white color, minutely pumiceous shards (Fig. 3), and the presence of phenocrystic biotite. Shard refractive indices average about 1.495–6 and have a range from 1.492 to 1.499. We have found no other Pleistocene ashes from the Western United States having these characteristics, and we are able to distinguish between these two only by their chemical composition (see below).

The phenocryst content of the Bishop ash bed at some localities of Fig. 1 is masked by abundant admixed detrital minerals. Phenocrysts concentrated from the least contaminated Bishop ash bed include dominant biotite, lesser amounts of hornblende(?), quartz, sodic plagioclase, and sanidine of low 2V, and sparse zircon, apatite, allanite, sphene, ilmenite, and magnetite. This assemblage is similar to that of samples of Bishop air-fall lapilli examined by us and is compatible with the assemblage in thin sections of the Bishop welded ash flow described by Gilbert (1938). Additional minerals in samples of the ash flow were identified by Sheridan (1965), but it is not clear whether they are vapor-phase or xenocrystic minerals.

Phenocrysts concentrated from the Pearlette-like ash beds include quartz, oligoclase, sanidine of moderate $2V_x$ (30°–50°), ferroaugite, and green-brown hornblende, with scattered chevkinite, allanite, zircon (pink and/or colorless), apatite, magnetite, and ilmenite. Fayalite occurs in a few samples and may have been lost from others through alteration after deposition. The only petrographic difference found as yet between the type O Pearlette-like ash and type S ash is in the refractive indices of the hornblendes. Table 1 lists the petrographic features of the ashes.

CHEMISTRY

Electron microprobe, atomic absorption, and quantitative spectrographic analyses of glass shards separated from samples of the ash beds and of air-fall lapilli of known Bishop Tuff are listed in Table 2 along with standard chemical analyses used for calibration of the electron microprobe.

The electron microprobe, first used for ash correlation by Smith and Westgate (1969), seems to be remarkably well suited for determining major-element content of ash beds to distinguish between ashes from different sources. The electron microprobe can chemically analyze individual glass shards in a sample without the elaborate and time-consuming cleaning and separation required for most other types of chemical analyses. Only a few shards need to be analyzed to explore the range of composition of one sample from shard to shard or to compare several samples.

The amounts of seven elements—Si, Al, Fe, Ti, Ca, Na, and K—were determined with the ARL-EMX model electron microprobe using procedures outlined in the Appendix. Splits of most of the samples were analyzed by atomic absorption spectroscopy to provide a rapid and accurate cross-check on the microprobe results for Fe, Ca, Na, and K, as well as separate determinations of Rb, Sr, Mg, and Zn. Of these elements, amounts of Fe, Zn, Ca, Rb, and Sr seem useful for distinction between many rhyolitic ashes. Results by the two methods show excellent agreement.

Glass of the Bishop ashes (Table 2) is rhyolitic and contains about 75–76 wt. % SiO_2, recast water-free. The Al_2O_3 content of the glasses does not seem abnormally high for average rhyolites, but the glasses as erupted were probably peraluminous, that is, the molecular proportion of Al_2O_3 exceeded that of $K_2O + Na_2O + CaO$. Mineralogically, this excess Al_2O_3 is reflected in the presence of biotite in the ash. Direct calculation to determine if the glass phase as erupted was peraluminous may not be meaningful, however, because of alkali exchange accompanying hydration (Aramaki and Lipman, 1965).

The Bishop glasses are distinguished from glasses of the ash of Green Mountain Reservoir on the basis of total Fe and CaO content (Table 2). The Bishop glasses, from localities 1–10 (Fig. 1), contain about 0.2% more iron (calculated as FeO), about 0.1–

TABLE 1

SUMMARY OF PETROGRAPHIC CHARACTERISTICS OF ASH BEDS OF THIS REPORT

	Bishop ash bed and ash of Green Mountain Reservoir	Pearlette-like ash	
		Type O	Type S
Color	Chalky white	Silver gray	
Predominant shard shape	Pumiceous	Bubble wall and bubble junction	
Refractive index of glass	Range 1.492–1.499; average 1.495–6	Range 1.498–1.500; average 1.499	
Diagnostic phenocrysts	Biotite	Ferroaugite	
		Hornblende (N_x = 1.688–1.694)	Hornblende (N_x = 1.678–1.682)

0.2% less CaO, and slightly less Al_2O_3 than the glasses of the ash of Green Mountain Reservoir (Localities 12 and 13); the Bishop glasses also contain less Rb than glasses of localities 12 and 13. The differences in composition are small, but repeated microprobe determinations demonstrate that they are consistent, and atomic absorption and quantitative spectrographic analyses confirm the chemical differences (Tables 2 and 3). In common with many ashes we have studied, the K_2O and Na_2O content of the glasses varies somewhat from sample to sample, probably due to alkali exchange accompanying hydration. We have tentatively correlated the ash at locality 11 (Table 2) with the ash of Green Mountain Reservoir on the basis of its similar major-element chemical composition, but some differences in trace-element composition between the two ashes were found by instrumental neutron activation analyses (G. A. Borchardt, written communication, 1969).

Several analyses of glasses of representative type O Pearlette-like ash and type S ash beds are given in Table 2. The Pearlette-like ashes contain more Fe and Zn and generally have higher ratios of K_2O to Na_2O than the glasses of the Bishop ash bed and the ash of Green Mountain Reservoir. Chemically, the type O and type S ashes are

TABLE

ELECTRON MICROPROBE AND ATOMIC ABSORPTION ANALYS[...]S FROM PLEISTOCENE AS[...]

Oxides are in wt.%; values in italics are from standard rock analysis used for electron microprobe calibration; numbers in parenth[...]e standard deviation fro[...] G. A. Desborough; atomic absorption analyses by V. Merritt; standard rock analyses by D. F. Powers; H_2O determinations of [...]les by Vertie Smith.

Locality No. (Fig. 1)			SiO_2	Al_2O_3	[...]tal Fe [...] FeO	MgO	Ca[...]
Bishop Tuff							
1	Bishop air-fall lapilli, Bishop, Inyo County, Calif.	Electron microprobe:	71.9(±1.0)	12.5(±.[...]	±.10)	—	.52(±
		Atomic absorption spec.:	—	—		.05	.43
2	Bishop air-fall lapilli, Benton, Mono County, Calif.	Electron microprobe:	72.6(±1.8)	12.4(±.[...]	±.08)	—	.50(±
		Atomic absorption spec.:	—	—		.04	.41
Bishop ash bed							
3	Lake beds, Lake Tecopa, Inyo County, Calif.	Electron microprobe:	72.8(±.4)	12.4(±.[...]	±.06)	—	*.47*[b]
		Atomic absorption spec.:	—	—		.04	.41
4	Lake beds, Wendover, Toole County, Utah	Electron microprobe:	72.9(±.4)	12.2(±[...]	±.08)	—	.52(±.
		Atomic absorption spec.:	—	—		—	—
5b	Lake deposits, 646-ft depth, Saltair core, Saltair, Salt Lake County, Utah	Electron microprobe[c]	*73.58*	*11.79*		.17	.74
		Atomic absorption spec.:	—	—		.09	.50
6	Alluvial deposits, Payson Canyon, Utah County, Utah	Electron microprobe:	73.4(±.6)	12.3(±.[...]	±.06)	—	.64(±.
		Atomic absorption spec.:	—	—		.06	.43
7b	Harpole Mesa Formation, Onion Creek, Grand County, Utah	Electron microprobe:	73.2(±.4)	11.5(±.[...]	±.08)	—	.42(±.[...]
		Atomic absorption spec.:	—	—		.04	.42
8	Alluvial deposits, Paradox Valley, Montrose County, Colo.	Electron microprobe:	72.7(±.9)	11.8(±.[...]	±.09)	—	.52(±.[...]
9	Alluvial deposits, Centerville Cemetery, Chaffee County, Colo.	Electron microprobe:	73.0(±1.4)	12.1(±[...]	±.08)	—	.36(±.[...]
		Atomic absorption spec.:	—	—		.06	.46
10	Alluvial deposits, Nuckolls County, Nebr.	Electron microprobe:	73.1(±.8)	12.1(±.[...]	±.08)	—	.47(±.[...]
		Atomic absorption spec.:	—	—		.08	.46
Ash of Green Mountain Reservoir							
11	Lake deposits, Manix Lake, San Bernardino County, Calif.	Electron microprobe:	73.6(±.7)	12.9(±.[...]	±.07)	—	.64(±.0
12	Alluvial deposits, Cerro Summit quadrangle, Montrose County, Colo.	Electron microprobe:	71.5(±.7)	13.2(±[...]	±.08)	—	.64(±.0[...]
		Atomic absorption spec.:	—	—		.07	.62
13	Alluvial deposits, Green Mountain Reservoir, Summit County, Colo.	Electron microprobe:	71.5(±1.1)	13.3(±[...]	±.06)	—	.69(±.0[...]
		Atomic absorption spec.:	—	—		.08	.67
Pearlette-like ash, type S							
14	Type locality of Sappa Formation, Harlan County, Nebr.	Electron microprobe:	72.1(±.2)	11.7(±[...]	±.07)	—	.77(±.05
		Atomic absorption spec.:	—	—		.02	.49
15	Below till, Cedar County, Nebr.	Electron microprobe:[d]	*72.76*	*11.76*		.06	*.72*
Pearlette-like ash, type O							
5a	Lake deposits, 548-ft depth, Saltair core, Saltair, Salt Lake County, Utah	Electron microprobe:[e]	*72.63*	*11.71*		.17	*.67*
7a	Harpole Mesa Formation, Onion Creek, Grand County, Utah	Electron microprobe:[f]	72.2(±.2)	11.9(±[...]	±.07)	—	.52(±.05)
		Atomic absorption spec.:	—	—		.06	.50

[a] Total of electron probe values plus MgO and Rb_2O from atomic absorption spectrographic analyses plus H_2O.
[b] This value for CaO from USGS Laboratory No. 101150 (Sheppard and Gude, 1968, p. 13, Table 3, col. 3) was used in calib[...] of presence of carbonate in [...]
[c] USGS Laboratory No. E1820 (Richmond, 1962, p. 35, col. 6) used for calibration. (CaO not used because of presence of carbo[...]d material.)
[d] USGS Laboratory No. G2895 used for calibration.
[e] USGS Laboratory No. E1886 (Richmond, 1962, p. 35, col. 1) used for calibration.
[f] Compare these values with USGS Laboratory No. D1764 (Richmond, 1962, p. 35, col. 5).

distinguished fr[...] consistent differ[...] [...]ent.

Spectrographic [...] glasses of most [...] bed and the ash [...] voir, and the re[...] Of the 25 elemen[...] elements that sh[...] between the Bish[...] Green Mountain [...] analyses of the [...] Reservoir are nee[...] tions can be made, [...] to indicate that s[...] glass fractions can [...]

distinguished from each other by small but consistent differences in the total iron content.

Spectrographic analyses were made of glasses of most samples of the Bishop ash bed and the ash of Green Mountain Reservoir, and the results are listed in Table 3. Of the 25 elements searched for, only those elements that show conspicuous differences between the Bishop ash bed and the ash of Green Mountain Reservoir are listed. More analyses of the ash of Green Mountain Reservoir are needed before firm generalizations can be made, but the results so far seem to indicate that spectrographic analyses of glass fractions can be used to distinguish it from the Bishop. Although spectrographic analyses of Pearlette-like ashes are not included in Table 3, Bishop and Pearlette-like ashes can be separated with ease by spectrographic analyses (compare, for instance, Richmond, 1962, p. 35, columns 5 and 6).

It is worth noting that the general petrographic-chemical characteristics of the Bishop ash bed and the ash of Green Mountain Reservoir are similar to those of the many beds of chalky-white rhyolitic ash in Oligocene and lower Miocene rocks in that they contain phenocrystic biotite and that their glasses, probably metaluminous to peraluminous before hydration, are low in iron (generally less than 1% total, calculated

TABLE

...ON ANALYSES ... GLASS FROM PLEISTOCENE ASHES FROM THE WESTERN UNITED STATES

...rs in parenth... one standard deviation from the mean value from the microprobe determinations. Electron micropobe analyses by G. A. Izett and ...inations of ... ...les by Vertie Smith.

Al_2O_3	Total Fe as FeO	MgO	CaO	Na_2O	K_2O	TiO_2	Zn (ppm)	Rb_2O	SrO	H_2O+	H_2O-	Total[a]
12.5(±	65(±.10)	—	.52(±.02)	3.8(±.2)	4.8(±.2)	.06(±.03)	—	—	—	4.15	.28	98.8
—	67	.05	.43	3.00	4.95	—	40	.017	.0018			
12.4(±	65(±.08)	—	.50(±.01)	3.1(±.2)	4.2(±.2)	.07(±.03)	—	—	—	4.08	.22	98.0
—	64	.04	.41	3.45	4.59	—	30	.017	.0014			
12.4(±	68(±.06)	—	.47[b]	3.5(±.4)	4.6(±.4)	.07(±.03)	—	—	—	3.84	.14	98.6
—	63	.04	.41	3.30	5.05	—	30	.019	.0009			
12.2(±	66(±.08)	—	.52(±.01)	3.5(±.3)	4.4(±.2)	.08(±.03)	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—			
11.79	66	.17	.74	*3.37*	*4.52*	*.07*	—	—	—	4.2	.24	99.3
—	67	.09	.50	3.45	4.60	—	30	.017	.0022			
12.3(±	68(±.06)	—	.64(±.01)	3.4(±.3)	4.3(±.2)	.08(±.03)	—	—	—	3.62	.22	98.7
—	65	.06	.43	3.25	4.75	—	30	.017	.0012			
11.5(±	63(±.08)	—	.42(±.02)	3.1(±.2)	4.3(±.2)	.07(±.05)	—	—	—	4.28	.03	97.6
—	64	.04	.42	3.28	4.86	—	30	.017	.0014			
11.8(±	74(±.09)	—	.52(±.01)	3.2(±.4)	4.7(±.4)	.08(±.04)	—	—	—	—	—	—
12.1(±	65(±.08)	—	.36(±.02)	4.0(±.3)	4.6(±.3)	.08(±.03)	—	—	—	4.12	.08	99.1
—	67	.06	.46	3.20	4.80	—	30	.016	.0021			
12.1(±	73(±.08)	—	.47(±.01)	3.6(±.4)	4.8(±.4)	.08(±.05)	—	—	—	3.90	.18	99.1
—	70	.08	.46	2.73	4.59	—	30	.015	.0021			
12.9(±	.48(±.07)	—	.64(±.02)	4.4(±.4)	4.1(±.5)	.05(±.03)	—	—	—	—	—	—
13.2(±	.43(±.08)	—	.64(±.02)	3.5(±.3)	4.0(±.2)	.03(±.03)	—	—	—	4.54	.14	98.1
	.44	.07	.62	3.48	4.45	—	30	.032	.0021			
13.3(±	.46(±.06)	—	.69(±.02)	4.3(±.4)	4.1(±.1)	.07(±.05)	—	—	—	4.52	.09	99.1
—	.46	.08	.67	3.50	4.13	—	50	.031	.0024			
11.7(±	1.20(±.07)	—	.77(±.05)	2.6(±.3)	6.6(±.5)	.12(±.04)	—	—	—	3.64	.25	99.1
—	1.15	.02	.49	2.44	6.11	—	70	.024	<.001			
11.76	*1.25*	.06	*.72*	*2.77*	*5.64*	*.10*	—	—	—	4.01	.16	—
11.71	*1.40*	.17	*.67*	*3.00*	*5.44*	*.12*	—	—	—	3.80	.19	—
11.9(±	1.42(±.07)	—	.52(±.05)	3.0(±.4)	5.2(±.3)	.10(±.03)	—	—	—			
—	1.33	.06	.50	3.10	5.28	—	90	.021	<.001			

...n calibration ... because of presence of carbonate in 5b.
...carbonate ... analyzed material.)

TABLE 3

Quantitative Spectrographic Analyses for Selected Elements in Glasses of Bishop Tuff, Bishop Ash Bed, and Ash of Green Mountain Reservoir

Results are reported in ppm to two significant figures and have an overall accuracy of ±15%, except that they are less accurate near limits of detection, where only one digit is intended. N = not detected at values shown; L = detected but below value shown. Analyses by Harriet G. Neiman.

Locality No. (Fig. 1)		Laboratory No.	B	Be	Ga	Mn	Mo	Nb	Pb	Sc	Y	Yb
Bishop Tuff												
1	Bishop lapilli, Bishop, Inyo County, Calif.	D137852	56	6	17	260	10	19	46	6	34	4
2	Bishop lapilli, Benton, Mono County, Calif.	D137853	52	6	16	280	8	22	40	5	38	4
Bishop ash bed												
3	Pleistocene lake beds, Lake Tecopa, Inyo County, Calif.	D137851	57	9	18	290	10	23	44	7	38	5
5	Pleistocene lake beds, Saltair core, Saltair, Salt Lake County, Utah	D137856	50	5	15	260	9	19	41	5	32	3
6	Pleistocene deposits, Payson Canyon, Utah County, Utah	D137854	52	5	16	280	8	19	39	5	32	4
7	Lower ash in Harpole Mesa Formation, Onion Creek, Grand County, Utah	D137855	L50	6	15	290	8	24	42	5	38	4
9	Pleistocene deposits, Centerville Cemetery, Chaffee County, Colo.	D137858	L50	4	14	260	7	16	36	4	29	3
10	Pleistocene deposits, Nuckolls County, Nebr.	D137860	L50	4	14	220	9	14	35	4	26	3
Ash of Green Mountain Reservoir												
12	Pleistocene deposits, Cerro Summit quadrangle, Montrose County, Colo.	D137857	N50	10	26	900	N5	54	84	12	82	9
13	Pleistocene deposits, Green Mountain Reservoir, Summit County, Colo.	D137859	N50	10	26	900	N5	54	86	16	86	9

Colorado; to A. J. Eardley for splits of ash from cores of Lake Bonneville sediments of the Great Salt Lake basin, Utah; and to R. J. Janda for samples from the pumice bed at Friant and for ash from the Corcoran Clay Member of the Tulare Formation. Acknowledgment is made of the help of David Ramaley, who carefully made mineral separations used in some of the analyses. Thanks are due to colleagues R. L. Christiansen R. G. Dickinson, G. R. Scott, R. E. Van Alstine and R. G. Van Horn for field guidance and for discussion of problems associated with late Cenozoic volcanism and stratigraphy in the Western United States.

APPENDIX

For the electron microprobe analyses, ultrasonically cleaned glass fractions of the ash samples (sized at 0.050–0.200 mm) were mounted in ⅛-inch-diameter holes in 1-inch-diameter aluminum discs. The mounts were polished with 6, 3, and 1 μ diamond paste on cotton laps followed by mechanical buffing with 0.05 μ Al_2O_3. Electron microprobe instrument conditions were as follows: (1) Take-off angle = 51.5°, (2) emission current = 2×10^{-4} A, (3) operating voltage = 15 kV, (4) sample current = 7×10^{-8} A on quartz, equivalent to a beam current of 3.2×10^{-8} A, (5) fixed count of beam current with a counting period for each point analysis of about 15 seconds. Under these operating conditions, each sample was analyzed for the following elements, three at a time: Si, Al, Ti, Fe, Ca, Na, and K. Iron was determined on two different runs. Consistent results were obtained by analysis of 2–5 points on each of 10 shards, not necessarily the same shards for the successive sets of three elements. Mg and Mn are in too low amounts in these samples to be detected reliably. Pulse-height analyzers were used on all channels except for Ti and Fe. Quartz was used to determine background counts at each of the spectral peaks for all the above elements except Si.

Counts were calibrated in terms of percentage of constituent using samples of homogenous volcanic ash that had been carefully analyzed by standard wet chemical analysis, as indicated in Table 2. This eliminates in large part the need for corrections for absorption, fluorescence, and atomic number. Significant errors in alkali determinations due to volatilization were minimized by the use of the fixed count of beam current for runs on both standard and unknown materials. The effect of instrument drift due to variations in sample current was essentially eliminated by using a fixed count of beam current and counting the standards prior to and after the samples.

LOCALITIES

1. Bishop Tuff: air-fall pumice lumps, pit of Insulating Aggregates Co., 6 miles north of Bishop, Inyo County, Calif., in NW ¼ sec. 4, T. 6 S., R. 33 E. Collector, R. E. Wilcox. Sample No. 64W96. Same locality as that sampled by Dalrymple, Cox, and Doell (1965); isotope age sample No. 4G001.
2. Bishop Tuff: air-fall lapilli at Benton, Mono County, Calif., from pit in SE ¼ NE ¼ sec. 10, T. 2 S., R. 31 E. Collector R. E. Wilcox. Sample No. 64W109.
3. Bishop ash bed: white biotitic ash from a 6.5-foot-thick bed in Pleistocene lake deposits at Lake Tecopa, Inyo County, Calif., called tuff B by Sheppard and Gude (1968, p. 9, and Table 3, col. 3). About 20 feet stratigraphically below a Pearlette-like ash, type O (tuff A of Sheppard and Gude, 1968, Table 3, column 1). Collectors, R. A. Sheppard and A. J. Gude 3d. Sample No. 68W156.
4. Bishop ash bed: white biotitic ash bed at 324-foot depth in core from well drilled in Pleistocene Lake Bonneville deposits about 7 miles east of Wendover, Tooele County, Utah. Collector, A. J. Eardley. Sample No. N-46

5a. Pearlette-like ash, type O: silver-gray ash from 548-foot depth in core from well drilled in Pleistocene Lake Bonneville deposits in SE ¼ sec. 24, T. 1 N., R. 3 W., near Saltair Resort, Salt Lake County, Utah, assigned to the Pearlette by Powers (in Eardley and Gvosdetsky, 1960, p. 1330; see also Eardley, 1967). Analysis in Richmond (1962, p. 3, column 5). Collector, A. J. Eardley. Core No. 179. Sample No. 57P129.

5b. Bishop ash bed: white biotitic ash bed as FeO). In contrast, the ashes of the Pearlette are chemically and petrographically similar to those of the abundant gray-toned ashes common in upper Miocene and Pliocene rocks in that they do not contain biotite and their subaluminous to peralkaline glasses contain 1–3% iron calculated as FeO (Izett, 1969).

DISCUSSION AND CONCLUSIONS

The Bishop ash bed is a time-stratigraphic marker dated at about 0.7 million K-Ar years in the middle Pleistocene deposits of the Western United States. We expect that this ash bed will be found at many more localities than those described here and that it will prove useful in deciphering the Quaternary stratigraphy and history over widely separated geomorphic provinces.

Preliminary petrographic and microprobe results on ash from two additional occurrences in California not shown in Fig. 1 and Table 2 correspond to those of the Bishop ash bed. The occurrences are (1) ash and lapilli from the pumice bed at Friant to which a K-Ar age of 0.6 m.y. has been ascribed (Janda, 1965), and (2) an ash bed in the Corcoran Clay Member of the Tulare Formation (Frink and Kues, 1954; R. J. Janda, written communication, 1970).

The ash of Green Mountain Reservoir is younger than the Bishop ash bed, from which it can be distinguished by minor chemical differences. The source of the ash of Green Mountain Reservoir is unknown, but because of the resemblance in petrographic and gross chemical character to the Bishop ash bed, it seems worthwhile to examine the possibility that the ash of Green Mountain Reservoir might be later ejecta from the Bishop magma. East of the Sierra Nevada drainage divide, Sheridan (1968) noted that the Bishop Tuff in lower Owens Gorge consists of two ash flows, the younger emplaced at an undetermined time after the first. West of the Sierra Nevada drainage divide in the Devils Postpile quadrangle, remnants of two ash-flow units, together called the tuff of Reds Meadow, were noted by Huber and Rinehart (1967), who tentatively correlated them with the Bishop Tuff. A K-Ar age of 0.66 m.y. was determined on sanidine from pumice in the lower of the two ash-flow units.

The stratigraphic association of the Pearlette-like ashes with the Bishop ash bed and the ash of Green Mountain Reservoir (Fig. 2) draws attention to the general Pearlette problem, with its important bearing on the delineation of the Pleistocene history of the Western United States. On the basis of its stratigraphic association with the Bishop ash bed, the type O Pearlette-like ash is considered to be younger than 700,000 years. Furthermore, on the basis of preliminary evidence from other work beyond the scope of this paper, it seems that the type S Pearlette-like ash is significantly older than 700,000 years. Although much work remains, we are convinced that the Pearlette-like ashes, including what has been called the "Pearlette ash" in the central Great Plains, represent at least two ash falls during the Pleistocene. The petrographic and chemical characteristics of the Pearlette-like ashes have strong family resemblances to Pleistocene air-fall rhyolitic ash from eruptive centers in the Yellowstone National Park area of Wyoming and Idaho, and we suspect that these eruptive centers are the sources of the Pearlette-like ashes. The Pearlette-like ashes differ significantly in mineralogic and chemical composition from Pleistocene air-fall rhyolitic ash of the Jemez Mountain eruptive centers in New Mexico, previously suggested as a "Pearlette ash" source (Swineford, 1949).

ACKNOWLEDGMENTS

We are grateful to R. A. Sheppard and A. J. Gude, 3d for providing samples of ash beds from Lake Tecopa, California; to R. G. Dickinson for samples from the Cerro Summit, Green Mountain Reservoir, and Centerville, Colorado areas; to F. W. Cater for a sample from near Paradox, Colorado; to A. J. Eardley for splits of ash from cores of Lake Bonneville sediments of the Great Salt Lake basin, Utah; and to R. J. Janda for samples from the pumice bed at Friant and for ash from the Corcoran Clay Member of the Tulare Formation. Acknowledgment is made of the help of David Ramaley, who carefully made mineral separations used in some of the analyses. Thanks are due to colleagues R. L. Christiansen R. G. Dickinson, G. R. Scott, R. E. Van Alstine and R. G. Van Horn for field guidance and for discussion of problems associated with late Cenozoic volcanism and stratigraphy in the Western United States.

APPENDIX

For the electron microprobe analyses, ultrasonically cleaned glass fractions of the ash samples (sized at 0.050–0.200 mm) were mounted in ⅛-inch-diameter holes in 1-inch-diameter aluminum discs. The mounts were polished with 6, 3, and 1 μ diamond paste on cotton laps followed by mechanical buffing with 0.05 μ Al_2O_3. Electron microprobe instrument conditions were as follows: (1) Take-off angle = 51.5°, (2) emission current = 2×10^{-4} A, (3) operating voltage = 15 kV, (4) sample current = 7×10^{-9} A on quartz, equivalent to a beam current of 3.2×10^{-8} A, (5) fixed count of beam current with a counting period for each point analysis of about 15 seconds. Under these operating conditions, each sample was analyzed for the following elements, three at a time: Si, Al, Ti, Fe, Ca, Na, and K. Iron was determined on two different runs. Consistent results were obtained by analysis of 2–5 points on each of 10 shards, not necessarily the same shards for the successive sets of three elements. Mg and Mn are in too low amounts in these samples to be detected reliably. Pulse-height analyzers were used on all channels except for Ti and Fe. Quartz was used to determine background counts at each of the spectral peaks for all the above elements except Si.

Counts were calibrated in terms of percentage of constituent using samples of homogenous volcanic ash that had been carefully analyzed by standard wet chemical analysis, as indicated in Table 2. This eliminates in large part the need for corrections for absorption, fluorescence, and atomic number. Significant errors in alkali determinations due to volatilization were minimized by the use of the fixed count of beam current for runs on both standard and unknown materials. The effect of instrument drift due to variations in sample current was essentially eliminated by using a fixed count of beam current and counting the standards prior to and after the samples.

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1. Bishop Tuff: air-fall pumice lumps, pit of Insulating Aggregates Co., 6 miles north of Bishop, Inyo County, Calif., in NW ¼ sec. 4, T. 6 S., R. 33 E. Collector, R. E. Wilcox. Sample No. 64W96. Same locality as that sampled by Dalrymple, Cox, and Doell (1965); isotope age sample No. 4G001.
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5b. Bishop ash bed: white biotitic ash bed at

646-foot depth in core from same drill hole as locality 5a. Analysis in Richmond (1962, pp. 34–35; column 6). Collector, A. J. Eardley. Core No. 212. Sample No. 57P133.

6. Bishop ash bed: white biotitic ash from basal 6 inches of an 8-foot-thick ash bed in Pleistocene deposits in a tributary to Payson Canyon about 4 miles south of Payson, Utah, in SW ¼ NW ¼ sec. 35, T. 9 S., R. 2 E., Santaquin Peak quadrangle, Utah County, Utah. This bed is separated from an overlying Pearlette-like type-O ash bed by 1–2 feet of red-brown clay silt. Collectors, R. E. Wilcox and R. G. Van Horn. Sample No. 67W161.

7a. Pearlette-like ash, type O: silver-gray ash from a 3-foot-thick bed in the middle member of the Harpole Mesa Formation (Pleistocene) in SE ¼ NE ¼ sec. 26, T. 24 S., R. 24 E., headwaters of Onion Creek, La Sal Mountains, Grand County, Utah. This bed, assigned to the Pearlette by Powers (Richmond, 1962, p. 34; analysis, p. 35, column 1), lies about 80 feet above Bishop ash bed locality 7b of this report. Collector, G. M. Richmond. Sample No. 50-61A.

7b. Bishop ash bed: white biotitic ash from a 3-foot-thick bed in the lower member of the Harpole Mesa Formation (Pleistocene), same locality as 7a (Richmond, 1962, p. 34) Collector, R. E. Wilcox. Sample No. 65W5.

8. Bishop ash bed: white biotitic ash from a 2- to 3-inch-thick bed in Pleistocene deposits in SE ¼ NW ¼ sec. 26, T. 48 N., R. 19 W., Montrose County, Colo., about 3 miles northeast of Paradox Store. Collector, F. W. Cater. Sample No. 65W1.

9. Bishop ash bed: white biotitic ash from a 1-foot-thick dirty ash bed near the top of a Pleistocene terrace deposit about 200–300 feet above the Arkansas River, Chaffee County, Colo., in SW ¼ SW ¼ sec. 9, T. 51 N., R. 78 W., along U.S. Highway 285 at Centerville Cemetery. A Pearlette-like ash type O, occurs in the next youngest terrace deposit. Collectors, R. E. Wilcox and R. E. Van Alstine. Sample No. 65W131.

10. Bishop ash bed: white biotitic ash from a 2-foot-thick bed in NE¼ SE¼ sec. 26, T. 3 N., R. 8 W., Nuckolls County, Nebr. (Miller *et al.*, 1964, unit 3, meas. sec. 7, p. 79). Collector, R. E. Wilcox, Sample No. 66W8.

11. Ash of Green Mountain Reservoir (?). white biotitic ash from a 1- to 6-inch-thick bed in Pleistocene lake beds in Manix Lake in SW¼ sec. 10, T. 10 N., R. 4 E., Newberry quadrangle, San Bernardino County, Calif. Collector, R. A. Shepard. Sample No. 68W153.

12. Ash of Green Mountain Reservoir: white biotitic ash from a 0- to 8-inch-thick bed in Pleistocene deposits in NW¼ SE¼ sec. 24, T. 49 N., R. 8 W., Cerro Summit quadrangle Montrose County, Colo. ("ash a" of Dickinson, 1966, p. 71). Ash bed is about 150 feet stratigraphically above Pearlette-like ash, type O ("ash b" of Dickinson, 1966, in turn 30 feet above Pearlette-like ash, type S). Collector, R. G. Dickinson. Sample No. 910-41.

13. Ash of Green Mountain Reservoir: white biotitic ash from a 1-inch-thick bed in Pleistocene deposits about 200–300 feet above the former level of the Blue River; exposed in roadcut along State Highway 9 near Green Mountain Reservoir in SE ¼ sec. 18, T. 2 S., R. 79 W., Mount Powell quadrangle, Summit County, Colo. Collector, R. G. Dickinson. Sample No. 65W81.

14. Pearlette-like ash, type S: silver-gray ash from an 8-foot-thick bed at the type locality of the Sappa Formation (Pleistocene) in SW ¼ NW ¼ sec. 12, T. 2 N., R. 20 W., Harlan County, Nebr. (Miller and others, 1964, p. 80). Collector, R. E. Wilcox. Sample No. 66W4.

15. Pearlette-like, ash, type S: silver-gray ash from a 2-foot-thick bed below till in roadcut 3 miles west of Coleridge, Nebr., in NE ¼ NE ¼ sec. 11, T. 29 N., R. 1 E., Cedar County, Nebr. Stop 7, "Guidebook of the 1959 Field Conference on Pliocene-Pleistocene Stratigraphy and Correlation in the High Plains of Kansas and Nebraska" (unpublished). Collector, G. R. Scott. Sample No. "Nebr. 7."

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AREA
USwest
Gthm
Promise

THE MOST PROMISING GEOTHERMAL FIELDS IN THE WESTERN UNITED STATES (EXCLUDING THE GEYSERS GEOTHERMAL FIELD)

BY
DAVID N. ANDERSON
EXECUTIVE DIRECTOR
GEOTHERMAL RESOURCES COUNCIL

Presented at the
Geothermal Resources Council
Special Short Course No. 9
San Francisco, California
April 8-9, 1980

TABLE OF CONTENTS

ABSTRACT

This paper contains a brief summary of each of the most promising geothermal fields in the Western United States. The summaries contain data on size, ownership, discoveries, number of wells, involved utilities and operators, estimated power production potential, reservoirs, load centers, geology, geothermal phenomena and other important information concerning recent and on-going activities.

DISCUSSION OF TERMS

Numerous terms have been used on the summary sheets in this report that may not have meaning to a casual acquaintance of geothermal energy. Therefore, a list of the less obvious terms, with a brief explanation of each, follows:

1. KGRA - Known Geothermal Resource Area. This term was originated by the U.S. Geological Survey.

2. AREA - Area is used to define that part of the state in which a specific field is located.

3. SIZE AND LAND OWNERSHIP - Figures are always in acres.

4. DISCOVERY AND TOTAL WELL DATA - Year, refers to year of the discovery; Operator, to who made the discovery; and Deep Wells to the number of wells drilled into the reservoir. Note: Some of the wells in the count may have been abandoned or converted to injection service.

5. UTILITY AND POWER POTENTIAL - Involved Utility, refers to that company which is involved directly in the development of power generation facilities or as otherwise noted, Estimated MWe, means the amount of electrical power in MW's that could be produced for a 30 year period. A MW is equal to 1,000 kilowatts (KW). Note: All power estimates are from U.S.G.S. Circular 790.

6. PRINCIPAL OPERATORS - Names of the most active operators in the field. In some cases not all of the operators in a field have been listed. Wells refers to the number of wells drilled or controlled by the operator that penetrate the reservoir (some of the wells may have been abandoned or converted to injection). Tests refers to the kinds of tests made.

7. FIRST POWER PLANT - Type considered refers to the type of plant design e.g. double flash, single flash, binary, etc. Size refers to the size of the plant in MW's. Status means where the plant development presently sits in time. Scheduled on Line means the date when the plant is expected to start producing power.

8. RESERVOIR DATA - Type refers to what kind of reservoir is present - dry steam (vapor) or hot water (all of the reservoirs covered in this report are hot water types). Temp. refers to the reservoir temperature in degrees Fahrenheit. Depth refers to the distance from the surface to the top of the reservoir. Salinity depicts the amount of dissolved chemicals in parts per million. Max. Flow Rate is the maximum rate of

fluid that a well produced during a flow test. Flows from geothermal wells are usually measured in thousand pounds per hour.

9. RESERVOIR TEMPERATURE - All areas in this report have reservoir temperatures in excess of 300°F (149°C or nominal 150°C) except Raft River, Idaho which has a reservoir temperature of 295°F. Although the Raft River reservoir temperature is below 300°F (the generally agreed threshold for economic power production is 375°F) it has been included because of the construction of two research power plants; a 60 KW and a 5 MW unit.

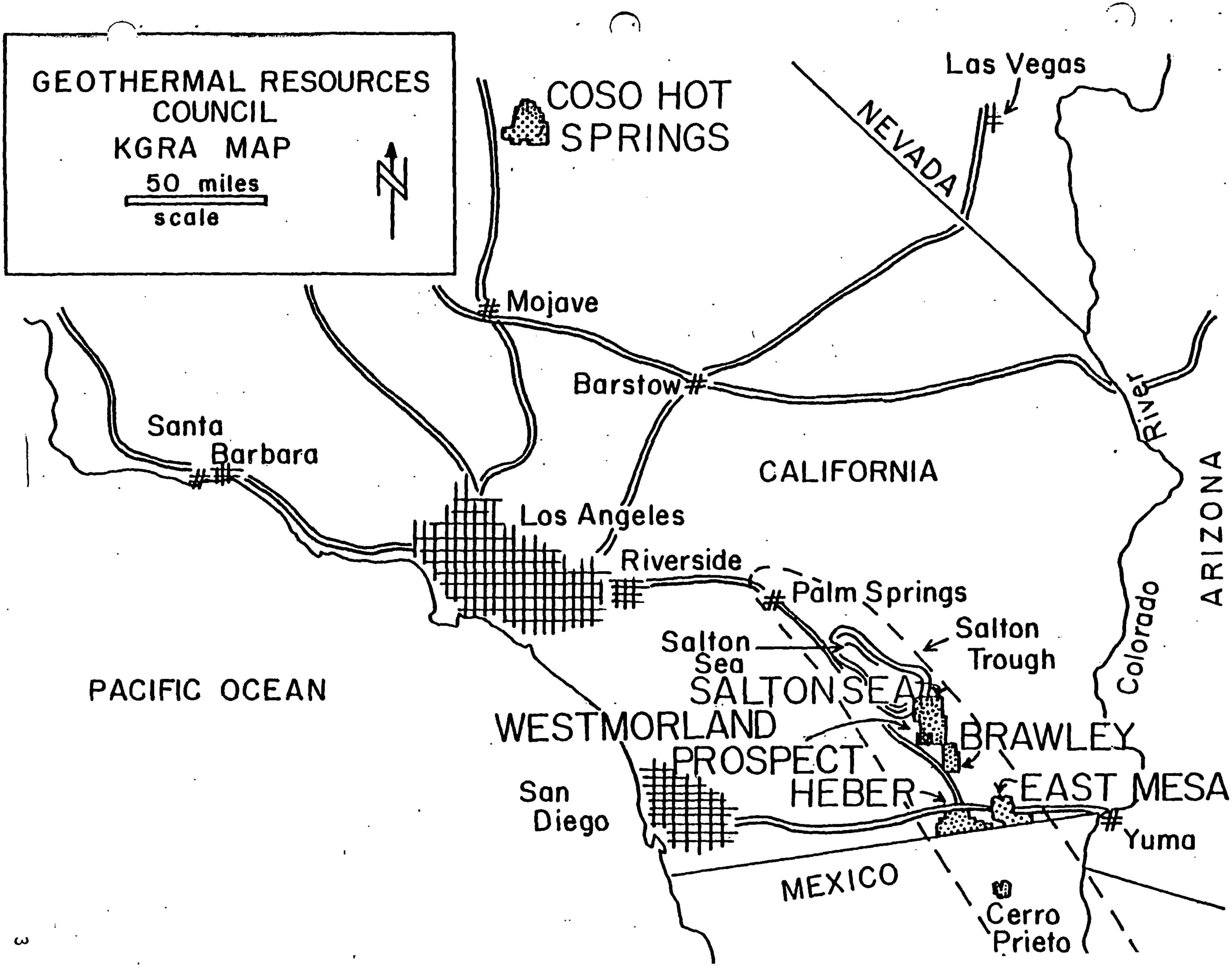
10. LOAD CENTERS - This listing shows the population and the power line distance from the field to the closest city or metropolitan area.

11. GEOLOGY AND GEOTHERMAL PHENOMENA - These terms are self explanatory.

It should be noted that The Geysers geothermal field has been omitted from the following summaries because it is now under production and its details have been widely published. However, this dry steam field is now producing 663 gross MW's of electricity and an additional 600 MW's are now being planned or are under construction.

PRODUCTION RECAP

The total estimated electrical potential of the 13 fields covered in the summaries is 12,684 MWe for 30 years. The estimates are taken from U.S. Geological Survey Circular 790 (1978). It should also be recognized that the fields covered are only a small percentage of the more than 57 Known Geothermal Resource Areas (KGRA's) that have convection systems with temperatures greater than 300°F (150°C) which have been identified by the U.S. Geological Survey.


GEOTHERMAL RESOURCES COUNCIL KGRA MAP
50 miles
scale
N
COSO HOT SPRINGS
Las Vegas
NEVADA
Mojave
Barstow
Santa Barbara
CALIFORNIA
River
ARIZONA
Los Angeles
Riverside
Palm Springs
Colorado
Salton Sea
Salton Trough
PACIFIC OCEAN
SALTON SEA
WESTMORLAND
BRAWLEY
PROSPECT
San Diego
HEBER
EAST MESA
Yuma
MEXICO
Cerro Prieto

KGRA SALTON SEA | AREA IMPERIAL VALLEY | STATE CALIFORNIA

KGRA

SIZE: 95,824 acres

LAND OWNERSHIP:

Federal: 18,644 acres
State and Private: 77,180 acres

DISCOVERY AND TOTAL WELL DATA

YEAR: 1958

OPERATOR: Kent Imperial Corp.

DEEP WELLS: 30

INVOLVED UTILITY: Southern California Edison and San Diego Gas & Electric Co.

ESTIMATED POWER POTENTIAL: 3,400 MW

PRINCIPAL OPERATORS

NAME: Magma Power Co.

WELLS: 11

TESTS: Production and injection

NAME: Union Oil Co.

WELLS: 6

TESTS: Production and injection

FIRST POWER PLANT	SCE	Magma/SDG&E
TYPE CONSIDERED:	Flash	Double Flash
SIZE (NOMINAL):	10 MW	49 MW
STATUS:	Under design	Preliminary design
SCHEDULED ON LINE:	1982	--

RESERVOIR DATA

TYPE: Hot water

TEMPERATURE: 640°F+

SALINITY: 250,000-330,000 ppm

DEPTH (TOP OF RES.): 3,000 ft

MAXIMUM FLOW RATE: 500,000 lbs/hr

LOAD CENTERS

CITY: Los Angeles area

POPULATION: 9 million

DISTANCE: 185 miles

CITY: San Diego area

POPULATION: 1.5 million

DISTANCE: 130 miles

GEOLOGY AND GEOTHERMAL PHENOMENA

Tertiary and quaternary marine sands and shales, non marine fluvial and lacustrine sediments and interbedded evaporites; field is traversed by five rhyolite volcanoes trending NE-SW; numerous mud pots and mud volcanoes; minor CO_2 surface vents; major faults strike at high angle to trend of volcanic cones. Area underlain by an active spreading center (the east Pacific rise).

REMARKS

Presence of field known prior to 1925; CO_2 produced from shallow wells during the 1940's; major drilling effort (12 wells) in the early 1960's, which was accompanied by an attempt to reclaim potash from the produced brine; drilling activity renewed in early 1970's; SDG&E and ERDA funded and constructed a 10 MW equivalent (no turbine generator) pilot flash binary power plant in 1975 which is not included under first power plants; high salinity (20 to 30%) will hamper full development due to corrosion and scaling problems. Techniques are being developed to lessen the corrosion problems by a three party association: Union Oil Co., Mono Power Co. (a subsidiary of Southern California Edison), and Southern Pacific Land Company. In addition, Magma Power Co. is also active in corrosion and scaling research.

KGRA WESTMORLAND PROSPECT (Salton Sea) AREA IMPERIAL VALLEY STATE CALIFORN

KGRA

SIZE: approx. 20,000 acres

LAND OWNERSHIP:
- Federal: 0
- State: 0
- Private: 20,000 acres

DISCOVERY AND TOTAL WELL DATA

YEAR: 1976

OPERATOR: Republic Geothermal, Inc.

DEEP WELLS: 6

INVOLVED UTILITY:

Imperial Irrigation District service area

ESTIMATED POWER POTENTIAL:

1710 MW

PRINCIPAL OPERATORS

NAME: Westmorland Geothermal Associates (Republic Geothermal, Inc. and MAPCO)

WELLS: 6

TESTS: Production and injection

FIRST POWER PLANT

TYPE CONSIDERED: Double Flash

SIZE (NOMINAL): 50 MW

STATUS: Under design

SCHEDULED ON LINE: 1983

RESERVOIR DATA

TYPE: Hot water

TEMPERATURE: 500°F

SALINITY: 20,000-70,000

DEPTH (TOP OF RES.): 4,000 ft

MAXIMUM FLOW RATE: 580,000 lbs/hr

LOAD CENTERS

CITY: Los Angeles area

POPULATION: 9 million

DISTANCE: 185 miles

CITY: San Diego area

POPULATION: 1.5 million

DISTANCE: 130 miles

GEOLOGY AND GEOTHERMAL PHENOMENA

Tertiary and quaternary marine sands and shales and lacustrine lake bed and deltaic sediments; no surface volcanic expression or geothermal indicators; vertical strike slip faulting controls distinct fault block salinities; distinct gravity and thermal anomalies. Area underlain by an active spreading center (the east Pacific rise).

REMARKS

Area is jointly leased and operated by Westmorland Geothermal Associates (Republic Geothermal, Inc. and MAPCO); a federal loan guarantee for reservoir evaluation and development drilling was obtained in 1979 and work on two additional wells is under way; area lies to the SW of the Salton Sea anomaly.

KGRA BRAWLEY AREA IMPERIAL VALLEY STATE CALIFORNI[A]

KGRA

SIZE: 28,885 ACRES

LAND OWNERSHIP:
- Federal: 0
- State: 0
- Private: 28,885 acres

DISCOVERY AND TOTAL WELL DATA

YEAR: 1975

OPERATOR: Union Oil Co.

DEEP WELLS: 10

INVOLVED UTILITY: Southern California Edison

ESTIMATED POWER POTENTIAL: 640 MW

PRINCIPAL OPERATORS

NAME: Union Oil Co.

WELLS: 8

TESTS: Production and injection

NAME: Chevron Resources Co.

WELLS: 2

TESTS: Short term production

FIRST POWER PLANT SCE

TYPE CONSIDERED: Single Flash

SIZE (NOMINAL): 10 MW

STATUS: Under construction

SCHEDULED ON LINE: 1980

RESERVOIR DATA

TYPE: Hot water *TEMPERATURE:* 500°F *SALINITY:* 100,000 ppm

DEPTH (TOP OF RES.): 3,000 ft *MAXIMUM FLOW RATE:* 70,000 lbs/hr

LOAD CENTERS

CITY: Los Angeles area

POPULATION: 9 million

DISTANCE: 200 miles

CITY: San Diego area

POPULATION: 1.5 million

DISTANCE: 115 miles

GEOLOGY AND GEOTHERMAL PHENOMENA

Tertiary and quaternary marine sands and shales and non marine fluvial and lacustrine sediments; no surface volcanic expression or geothermal indicators; field in close proximity to active Brawley fault. Area is underlain by an active spreading center (the east Pacific rise).

REMARKS

Field was identified by University of California at Riverside field studies in late 1960's and early 1970's; high salinity due to close proximity to lowest portions of northern landward extension of Salton Trough (evaporite sink); high salinity will cause problems in the design, construction and operation of power plants; the Union 10 MW power plant is approximately 85% complete.

KGRA HEBER | AREA IMPERIAL VALLEY | STATE CALIFORNIA

KGRA

SIZE: 58,568 acres

LAND OWNERSHIP:
Federal: 0
Private: 58,568 acres

DISCOVERY AND TOTAL WELL DATA

YEAR: 1972

OPERATOR: Magma Power Company

DEEP WELLS: 17

INVOLVED UTILITY: Southern California Edison and San Diego Gas & Electric Co.

ESTIMATED POWER POTENTIAL: 650 MW

PRINCIPAL OPERATORS

NAME: Chevron Oil Company

WELLS: 8

TESTS: Extensive production and injection

NAME: Union Oil Company

WELLS: 7

TESTS: Short term, production

FIRST POWER PLANT	SCE	SDG&E (see remarks)
TYPE CONSIDERED:	Double Flash	Flash Binary
SIZE (NOMINAL):	50 MW	65 MW
STATUS:	In final design	Design complete
SCHEDULED ON LINE:	Late 1982	1984

RESERVOIR DATA

TYPE: Hot water *TEMPERATURE:* 350-375°F *SALINITY:* 14,000 ppm

DEPTH (TOP OF RES.): 3,200 ft *MAXIMUM FLOW RATE:* 440,000 lbs/hr

LOAD CENTERS

CITY: Los Angeles area

POPULATION: 9 million

DISTANCE: 225 miles

CITY: San Diego area

POPULATION: 1.5 million

DISTANCE: 100 miles

GEOLOGY AND GEOTHERMAL PHENOMENA

Tertiary and quaternary marine sands and shales and non marine fluvial and lacustrine sediments, minor volcanic sills; no surface volcanic expression or geothermal indicators. Area is underlain by an active spreading center (the east Pacific rise).

REMARKS

In 1977-78 the field was considered by U.S. Department of Energy as a possible site for a 50 MW binary power plant (the plant was subsequently awarded to Union Oil Co. at their Baca location in northern New Mexico). In December of 1979 Chevron Resources Company (the major operator) signed a contract with Southern California Edison, who will construct a 50 MW power plant. The completion date is late 1982. San Diego Gas & Electric is contemplating the co-sponsoring of a 50 MW binary type demonstration power plant with the U.S. Department of Energy.

KGRA EAST MESA AREA IMPERIAL VALLEY STATE CALIFORNI

KGRA

SIZE: 38,365 ACRES

LAND OWNERSHIP:

Federal: 32,725
Federal leased: 11,770 acres
State and Private: 4,840 acres

DISCOVERY AND TOTAL WELL DATA

YEAR: 1972

OPERATOR: U.S. Bureau of Reclamation

DEEP WELLS: 18

INVOLVED UTILITY: San Diego Gas and Electric Co.

ESTIMATED POWER POTENTIAL: 360 MW

PRINCIPAL OPERATORS

NAME: Republic Geothermal, Inc.

WELLS: 8

TESTS: Production and injection

NAME: Imperial Magma

WELLS: 5

TESTS: Production and injection

FIRST POWER PLANT

	Republic	Magma
TYPE CONSIDERED:	Double Flash	Binary
SIZE (NOMINAL):	48 MW (net)	10 MW
STATUS:	Plant designed	Construction completed
SCHEDULED ON LINE:	Late 1982	Spring 1980

RESERVOIR DATA

TYPE: Hot water *TEMPERATURE:* 400°F *SALINITY:* 2,500 ppm

DEPTH (TOP OF RES.): 2,450 ft *MAXIMUM FLOW RATE:* 740,000 lbs/hr

LOAD CENTERS

CITY: Los Angeles àrea

POPULATION: 9 million

DISTANCE: 245 miles

CITY: San Diego area

POPULATION: 1.5 million

DISTANCE: 120 miles

GEOLOGY AND GEOTHERMAL PHENOMENA

Tertiary and quaternary marine sands and shales and non marine fluvial and lacustrine sediments; no surface volcanic expression or geothermal indicators; area is slightly westward sloping, sandy mesa with a minimum elevation a few feet above the valley floor; major faults trend NW-SE. Area is underlain by an active spreading center (the east Pacific rise)

REMARKS

In the early 1970's the U.S. Bureau of Reclamation drilled and tested 5 wells and constructed and tested multi-stage flash and vertical tube desalination units; a facility (operated by U.S. DOE) at the site is available for the testing of various prototype energy conversion machines; loan guarantee granted to Republic Geothermal, Inc. for reservoir development; a shallow, slightly brackish aquifer is present over most of the mesa. Magma's 10 MW binary power plant will be the first binary type plant in the United States and the first hot water plant in the United States.

KGRA COSO HOT SPRINGS AREA MOJAVE STATE CALIFORN

KGRA

SIZE: 51,760 acres

LAND OWNERSHIP:

Federal: 43,330 acres
(BLM: 16,690 acres)
(Navy: 26,640 acres)
State and private: 8,430 acres

DEVELOPMENT

Numerous shallow temperature wells have been drilled and a deep reservoir test was completed by U.S. Department of Energy in December 1977.

INVOLVED UTILITY: Mono Power Co. (a subsidiary of Southern California Edison)

ESTIMATED POWER POTENTIAL: 650 MW

PRINCIPAL OPERATORS (see remarks)

NAME:

WELLS:

TESTS:

NAME:

WELLS:

TESTS:

FIRST POWER PLANT

TYPE CONSIDERED: Decision pending confirmation of a reservoir

SIZE (NOMINAL):

STATUS:

SCHEDULED ON LINE:

RESERVOIR DATA

TYPE: Hot water *TEMPERATURE:* 390°F+ *SALINITY:* 6,000 ppm

DEPTH (TOP OF RES.): 2,000 ft *MAXIMUM FLOW RATE:* well was not tested

LOAD CENTERS (see remarks)

CITY: Los Angeles area

POPULATION: 9 million

DISTANCE: 160 miles

CITY: Bakersfield area

POPULATION: 86,000

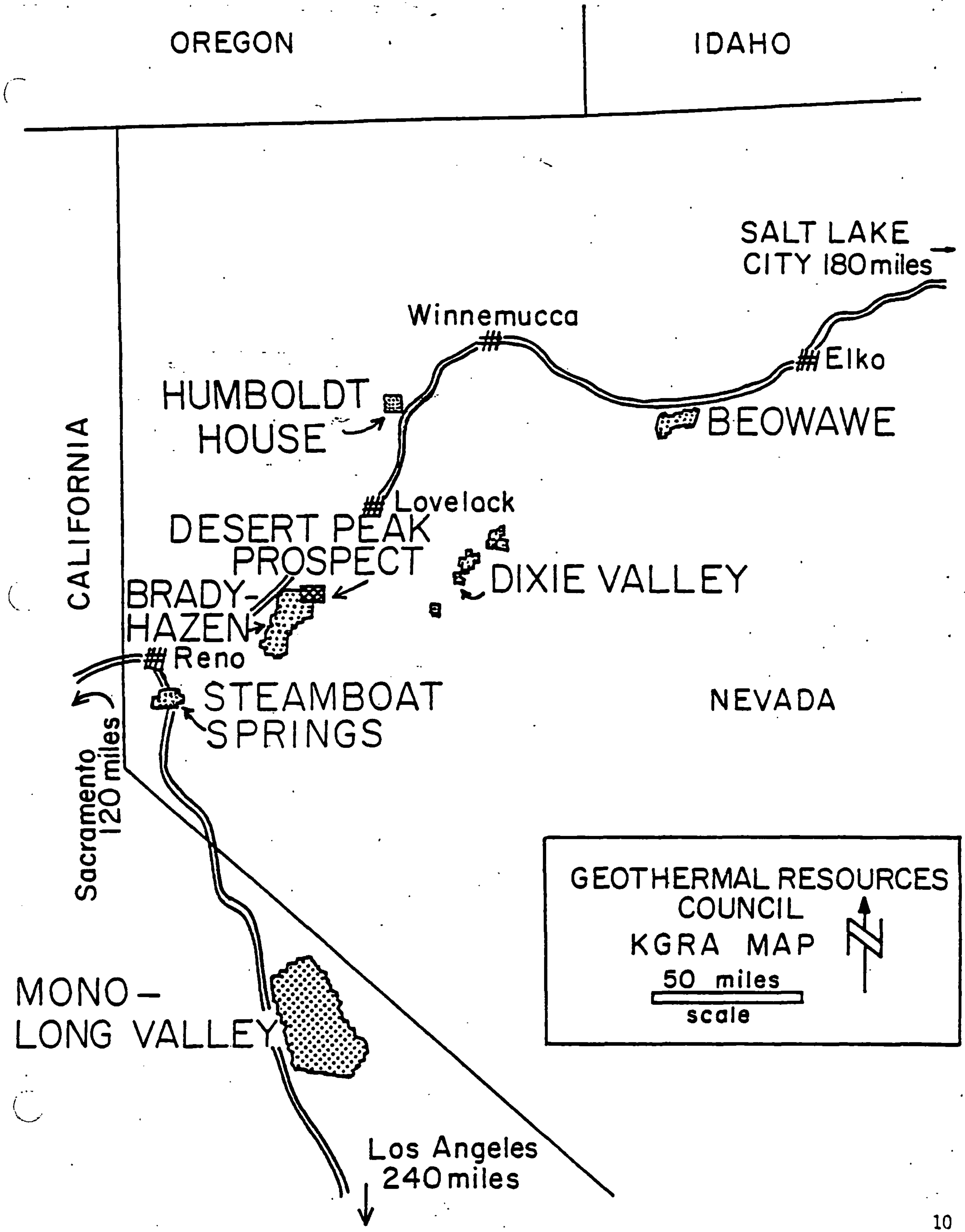
DISTANCE: 60 miles

GEOLOGY AND GEOTHERMAL PHENOMENA

Granitic, metasedimentary and metavolcanic rocks extruded and overlaid by rhyolites and andesites in the form of cinder cones, pierlitic domes and flows. Volcanic flows and air falls are interbedded with lacustrine and fanglomerate deposits. Structurally the area appears to have been under tension throughout the late Cenozoic which caused a fault pattern to develop that served as volcanic conduits. Fumaroles and hot springs are common in some parts of the KGRA.

REMARKS

Major portion of KGRA land is controlled by the federal government and is partially overlain by instrumented bombing ranges operated by the U.S. Navy. This aspect, in the past, has caused a general reluctance by the Navy to lease or allow the land to be opened for leasing by the U.S. Bureau of Land Management. Recently the Navy has developed a program to contract directly for the development of several square miles of land owned in fee and to allow the U.S. BLM to commence leasing procedures on other lands. In late 1979 the U.S. Navy and California Energy Company (CEC) signed a contract to develop the Navy fee land. The contract calls for CEC to ultimately develop 75 MW's of electrical power. The power produced on the Navy fee


OREGON
IDAHO
SALT LAKE
CITY 180 miles
Winnemucca
Elko
HUMBOLDT
HOUSE
BEOWAWE
CALIFORNIA
Lovelock
DESERT PEAK
PROSPECT
DIXIE VALLEY
BRADY-
HAZEN
Reno
STEAMBOAT
SPRINGS
NEVADA
Sacramento
120 miles
GEOTHERMAL RESOURCES
COUNCIL
KGRA MAP
50 miles
scale
MONO-
LONG VALLEY
Los Angeles
240 miles

KGRA STEAMBOAT SPRINGS AREA WESTERN NEVADA STATE NEVADA

KGRA

SIZE: 8,914 acres

LAND OWNERSHIP:

Federal: 4,457 acres
Private: 4,457 acres

DISCOVERY AND TOTAL WELL DATA

YEAR: Unknown

OPERATOR: Unknown

DEEP WELLS: 1

INVOLVED UTILITY: Sierra Pacific Power Co. service area

ESTIMATED POWER POTENTIAL: 350 MW

PRINCIPAL OPERATORS

NAME: Phillips Petroleum Co.

WELLS: 1 deep, 20+ temp. grad. and four 800-2,000 ft observation wells

TESTS: None

NAME: Gulf Mineral Resources Co. (Gulf has extensive land interests in the area.)

WELLS: None

TESTS: None

FIRST POWER PLANT (see remarks)

TYPE CONSIDERED:

SIZE (NOMINAL):

STATUS:

SCHEDULED ON LINE:

RESERVOIR DATA

TYPE: Hot water *TEMPERATURE:* 400°F+ *SALINITY:* 3,000 ppm

DEPTH (TOP OF RES.): 2,000 ft+ *MAXIMUM FLOW RATE:* --

LOAD CENTERS

CITY: Reno

POPULATION: 150,000

DISTANCE: 12 miles

CITY:

POPULATION:

DISTANCE:

GEOLOGY AND GEOTHERMAL PHENOMENA

Sierra Nevada granitic rocks, highly fractured; fractures related to the eastern Sierra frontal fault system; hot springs and siliceous sinter terraces common.

REMARKS

Phillips Petroleum Co. drilled a deep test in mid 1979 and the test results looked promising. A follow-up exploration program which includes three 2,000 ft. temperature test holes is in progress.

A utility group consisting of Sierra Pacific Power Co. (the lead agency), Sacramento Municipal Utility District, Pacific Power and Light, Portland General Electric and the Eugene Water and Electric Board is considering the co-funding of a 50 MW plant at Desert Peak, Beowawe or Dixie Valley provided that a suitable reservoir can be developed and an agreement can be reached with the operator(s). In addition, the group is considering a 10 MW pilot plant at any one of five sites (the three mentioned above plus Steamboat Springs and Humboldt House).

KGRA DESERT PEAK PROSPECT (Brady-Hazen) AREA RENO STATE NEVADA

KGRA

SIZE: 98,508 acres

LAND OWNERSHIP:
Federal: 59,358 acres
Federal leased: 26,049 acres
State and private: 39,150 acres

DISCOVERY AND TOTAL WELL DATA

YEAR: 1976

OPERATOR: Phillips Petroleum Co.

DEEP WELLS: 4

INVOLVED UTILITY: Sierra Pacific Power Co. service area

ESTIMATED POWER POTENTIAL: 750 MW

PRINCIPAL OPERATORS

NAME: Phillips Petroleum Co.

WELLS: 4

TESTS: Production

NAME:

WELLS:

TESTS:

FIRST POWER PLANT (see remarks)

TYPE CONSIDERED:

SIZE (NOMINAL):

STATUS:

SCHEDULED ON LINE: unavailable

RESERVOIR DATA

TYPE: Hot water

TEMPERATURE: 400°F+

SALINITY: 6,000-8,000 ppm

DEPTH (TOP OF RES.): 2,000+ ft

MAXIMUM FLOW RATE: Test program under way

LOAD CENTERS

CITY: Reno

POPULATION: 150,000

DISTANCE: 55 miles

CITY:

POPULATION:

DISTANCE:

GEOLOGY AND GEOTHERMAL PHENOMENA

Faulted tertiary volcanics (basalts, rhyolites) overlying a metamorphosed basement complex; hot springs, sinter and travertine deposits.

REMARKS

Desert Peak area lies just north of the Brady-Hazen KGRA and will eventually be included. Preliminary meetings have taken place between the operator, utility and an engineering firm concerning the design and construction of a power plant. Additional exploration and development work is under way.

A utility group consisting of Sierra Pacific Power Co. (the lead agency), Sacramento Municipal Utility District, Pacific Power and Light, Portland General Electric and the Eugene Water and Electric Board is considering the co-funding of a 50 MW plant at Desert Peak, Beowawe or Dixie Valley provided that a suitable reservoir can be developed and an agreement can be reached with the operator(s). In addition the group is considering a 10 MW pilot plant at any one of five sites (the three mentioned above plus Steamboat Springs and Humboldt House).

KGRA DIXIE VALLEY AREA CENTRAL NEVADA STATE NEVADA

KGRA

SIZE: 38,989 approx. acres

LAND OWNERSHIP:

Federal: 38,989 approx. acres

DISCOVERY AND TOTAL WELL DATA

YEAR: 1978

OPERATOR: Sunoco Energy Devel. Co. (Sunedco)

DEEP WELLS: 4

INVOLVED UTILITY: Sierra Pacific Power Co. service area

ESTIMATED POWER POTENTIAL: --

PRINCIPAL OPERATORS

NAME: Sunedco

WELLS: 4

TESTS: Production

NAME: Natomas/Thermal Power Co. / Southland Royalty

WELLS: 2

TESTS: Preliminary testing

FIRST POWER PLANT (see remarks)

TYPE CONSIDERED:

SIZE (NOMINAL):

STATUS:

SCHEDULED ON LINE:

RESERVOIR DATA

TYPE: --

TEMPERATURE: --

SALINITY: --

DEPTH (TOP OF RES.): --

MAXIMUM FLOW RATE: --

LOAD CENTERS

CITY: Reno

POPULATION: 150,000

DISTANCE: 110 miles

CITY:

POPULATION:

DISTANCE:

GEOLOGY AND GEOTHERMAL PHENOMENA

Jurassic metasedimentary rocks overlain by tertiary sediments, which are overlain by volcanic deposits including basalt and andesitic rocks, rhyolitic flows and ash deposits, and younger alluvial fans. Early structural history consists of complexed folding and thrust faulting. Active structure consists of normal faults bounding a north-northeast trending graben with horst blocks. Numerous hot springs present.

REMARKS

In November 1978, Sunedco completed and production tested the first deep well in the area. Results from the test have been encouraging and have caused the drilling of two additional wells. In addition, a two company association (Natomas/Thermal Power Co. and Southland Royalty) have drilled two additional wells. Although the area was discovered over two years ago, none of the involved operators have made a formal press release concerning the potential.

A utility group consisting of Sierra Pacific Power Co. (the lead agency), Sacramento Municipal Utility District, Pacific Power and Light, Portland General Electric and the Eugene Water and Electric Board is considering the co-funding of a 50 MW plant at Desert Peak, Beowawe or Dixie Valley provided that a suitable reservoir can be developed and an agreement can be reached with the operator(s). In addition, the group is considering a 10 MW pilot plant at any one of five sites (the three men-

FIELD HUMBOLDT HOUSE AREA BATTLE MOUNTAIN STATE NEVADA

FIELD

SIZE: Unknown

LAND OWNERSHIP:

DISCOVERY AND TOTAL WELL DATA

YEAR: 1978

OPERATOR: Phillips Petroleum Co.

DEEP WELLS: 3

INVOLVED UTILITY: Sierra Pacific Power Co. service area.

ESTIMATED POWER POTENTIAL: 47 MW

PRINCIPAL OPERATORS

NAME: Phillips Petroleum Co.

WELLS: 2

TESTS: Production tests only

NAME: Union Oil Co.

WELLS: 1

TESTS: Preliminary

FIRST POWER PLANT (see remarks)

TYPE CONSIDERED:

SIZE (NOMINAL):

STATUS:

SCHEDULED ON LINE:

RESERVOIR DATA

TYPE: Hot water *TEMPERATURE:* 360°F+ *SALINITY:* 6,000 ppm

DEPTH (TOP OF RES.): 1,800 ft *MAXIMUM FLOW RATE:* Unavailable

LOAD CENTERS

CITY: Reno

POPULATION: 150,000

DISTANCE: 120 miles

CITY:

POPULATION:

DISTANCE:

GEOLOGY AND GEOTHERMAL PHENOMENA

Mesozoic metamorphosed volcanic and sedimentary rocks overlain by tertiary lake beds in the valleys; large hydrothermally altered areas, old tuffa mounds and other hot springs deposits; structure is high angle faults bounding basins and mountain ranges.

REMARKS

Phillips Petroleum Co. feels that they have only penetrated a shallow auxiliary reservoir and that the main reservoir exists at depth and will contain water at temperatures of approximately 430°F. The Humboldt House area is not an official KGRA, however, it is near the Rye Patch KGRA.

A utility group consisting of Sierra Pacific Power Co. (the lead agency), Sacramento Municipal Utility District, Pacific Power and Light, Portland General Electric and the Eugene Water and Electric Board is considering the co-funding of a 50 MW plant at Desert Peak, Beowawe or Dixie Valley provided that a suitable reservoir can be developed and an agreement can be reached with the operator(s). In addition, the group is considering a 10 MW pilot plant at any one of five sites (the three mentioned above plus Steamboat Springs and Humboldt House).

KGRA BEOWAWE AREA BATTLE MOUNTAIN STATE NEVADA

KGRA

SIZE: 33,225 acres

LAND OWNERSHIP:

Federal: approx. 16,000 acres
State and private: approx. 1,600 acres

DISCOVERY AND TOTAL WELL DATA

YEAR: 1959

OPERATOR: Magma Power Co.

DEEP WELLS: 8

INVOLVED UTILITY: Sierra Pacific Power Co. service area

ESTIMATED POWER POTENTIAL: 127 MW

PRINCIPAL OPERATORS

NAME: Chevron Oil Co.

WELLS: 4

TESTS: Limited production

NAME: Getty Oil Co.

WELLS: none

TESTS: none

FIRST POWER PLANT (see remarks)

TYPE CONSIDERED:

SIZE (NOMINAL):

STATUS:

SCHEDULED ON LINE:

RESERVOIR DATA

TYPE: Hot water

TEMPERATURE: 412°F

SALINITY: 1,400 ppm

DEPTH (TOP OF RES.): 700 ft

MAXIMUM FLOW RATE: 1,500,000 lbs/hr ±

LOAD CENTERS

CITY: Reno

POPULATION: 150,000

DISTANCE: 220 miles

CITY: Elko

POPULATION: 10,000

DISTANCE: 40 miles

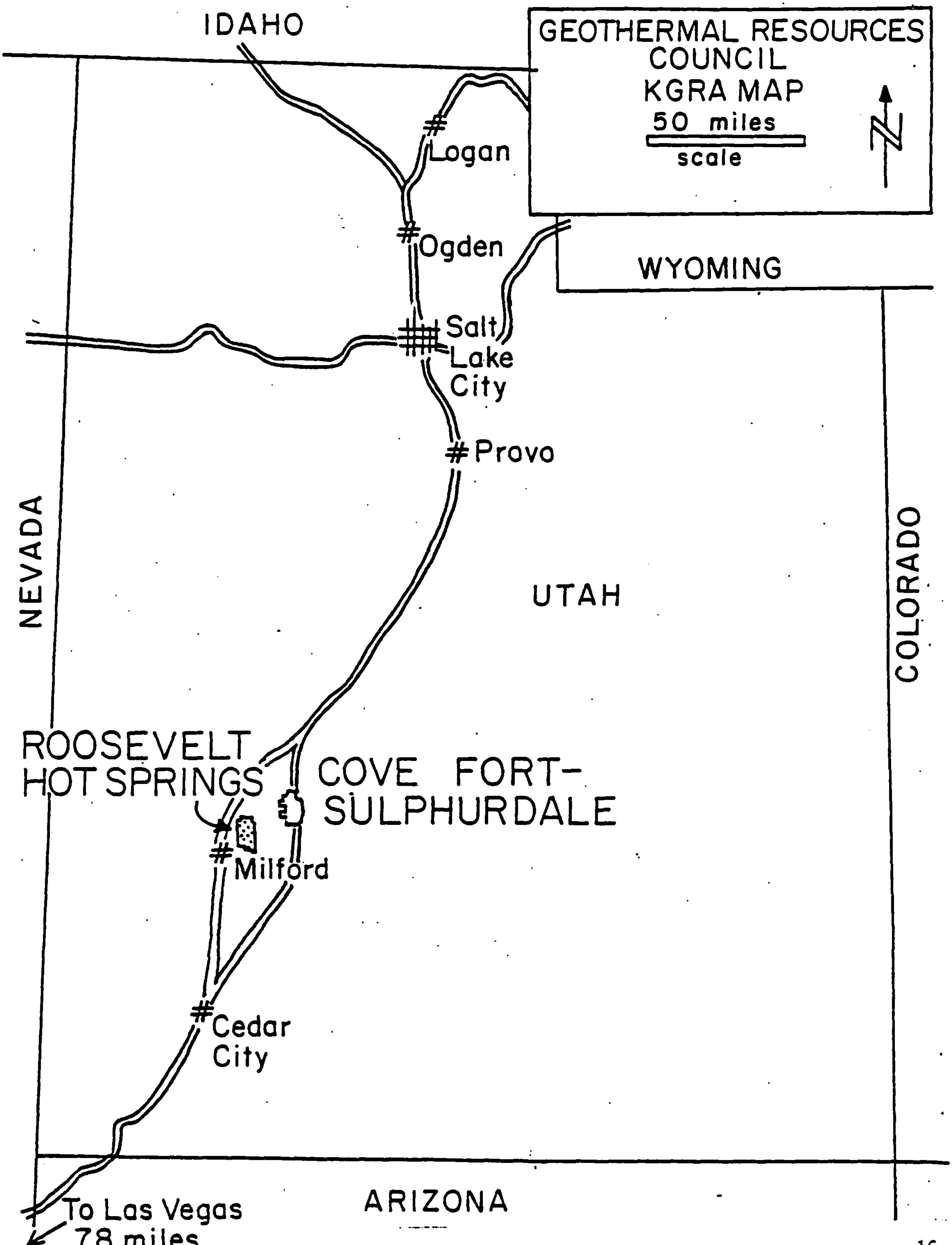
GEOLOGY AND GEOTHERMAL PHENOMENA

Paleozoic sediments overlaid by tertiary volcanics, principally basaltic flows; area centered along a major normal, NE-SW trending fault; numerous hot springs, geysers, fumaroles and sinter deposits.

REMARKS

Chevron Oil Co. has an extensive exploration program under way which includes the drilling of several wells. Getty Oil Co. has started a temperature gradient well program. The field area has been unitized (Chevron and Getty Oil Cos.)

A utility group consisting of Sierra Pacific Power Co. (the lead agency), Sacramento Municipal Utility District, Pacific Power and Light, Portland General Electric and the Eugene Water and Electric Board is considering the co-funding of a 50 MW plant at Desert Peak, Beowawe or Dixie Valley provided that a suitable reservoir can be developed and an agreement can be reached with the operator(s). In addition, the group is considering a 10 MW pilot plant at any one of five sites (the three mentioned above plus Steamboat Springs and Humboldt House).


GEOTHERMAL RESOURCES COUNCIL
KGRA MAP
50 miles
scale
IDAHO
Logan
Ogden
WYOMING
Salt Lake City
Provo
NEVADA
UTAH
COLORADO
ROOSEVELT HOT SPRINGS
COVE FORT-SULPHURDALE
Milford
Cedar City
To Las Vegas 78 miles
ARIZONA

KGRA ROOSEVELT HOT SPRINGS AREA MILFORD STATE UTAH

KGRA

SIZE: 29,791 acres

LAND OWNERSHIP:

Federal leased: 24,592 acres
State and private: 5,199 acres

DISCOVERY AND TOTAL WELL DATA

YEAR: 1975

OPERATOR: Phillips Petroleum Co.

DEEP WELLS: 9

INVOLVED UTILITY: Utah Power and Light service area

ESTIMATED POWER POTENTIAL: 970 MW

PRINCIPAL OPERATORS

NAME: Phillips Petroleum Co.

WELLS: 7

TESTS: Extensive production and injection

NAME: Thermal Power Co.

WELLS: 2

TESTS: Production

FIRST POWER PLANT

TYPE CONSIDERED: Several power plant proposals are now being considered

SIZE (NOMINAL):

STATUS:

SCHEDULED ON LINE:

RESERVOIR DATA

TYPE: Hot water *TEMPERATURE:* 500°F *SALINITY:* 7,800 ppm

DEPTH (TOP OF RES.): 2,700 ft *MAXIMUM FLOW RATE:* 1,000,000 lbs/hr

LOAD CENTERS

CITY: Salt Lake City area

POPULATION: 820,000

DISTANCE: 200 miles

CITY: Las Vegas, Nevada

POPULATION: 160,000

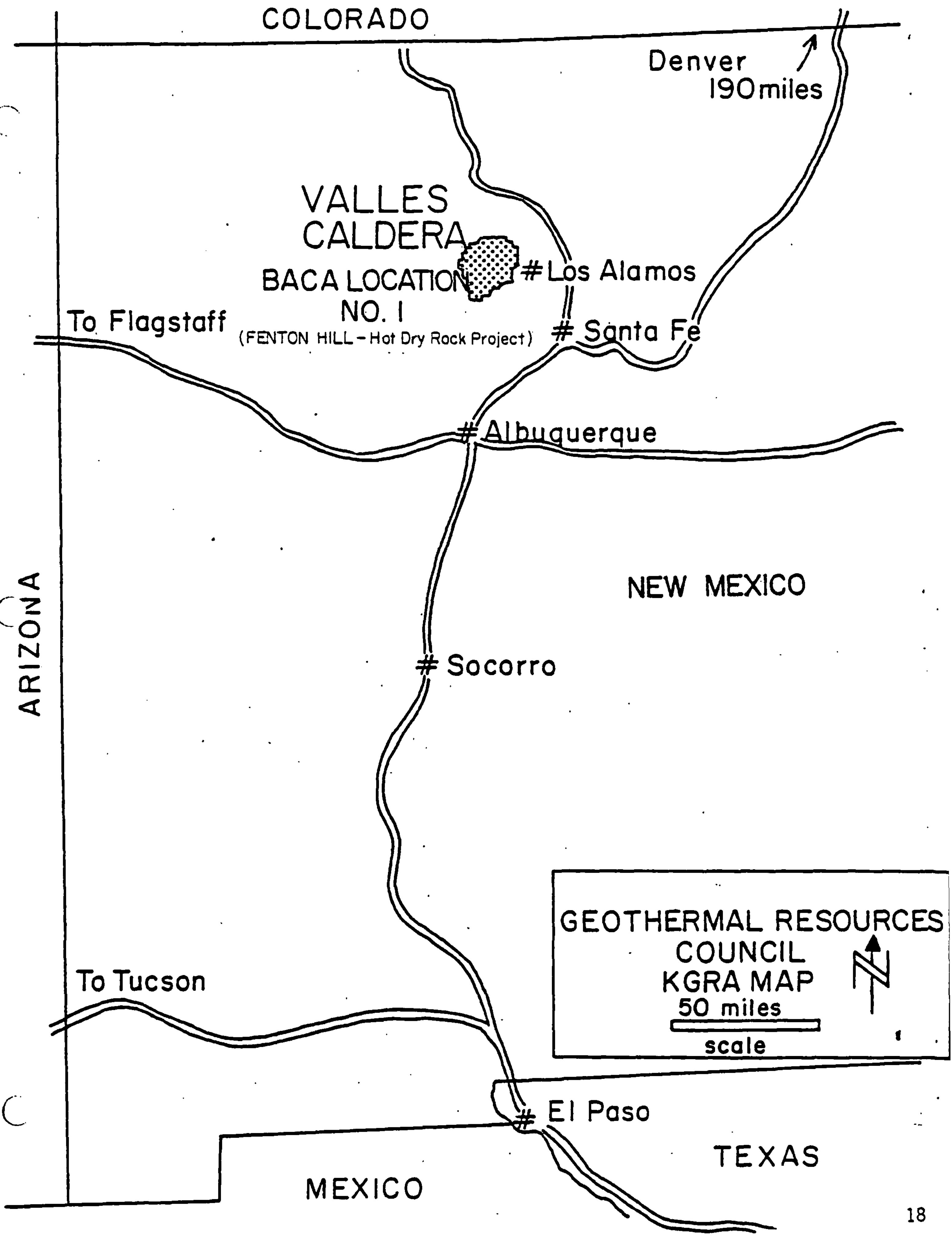
DISTANCE: 240 miles

GEOLOGY AND GEOTHERMAL PHENOMENA

Precambrian (?) metamorphics overlaid by unconsolidated tertiary and quaternary sediments; quaternary volcanics are present on the surface three miles east of the field; sinter deposits in KGRA area.

REMARKS

Large percentage of KGRA has been unitized; cooling water may be difficult to obtain.


COLORADO
Denver
190 miles
VALLES
CALDERA
BACA LOCATION
NO. 1
(FENTON HILL - Hot Dry Rock Project)
Los Alamos
To Flagstaff
Santa Fe
Albuquerque
ARIZONA
NEW MEXICO
Socorro
GEOTHERMAL RESOURCES
COUNCIL
KGRA MAP
50 miles
scale
To Tucson
El Paso
TEXAS
MEXICO

KGRA BACA LOCATION NO. 1 AREA -- STATE NEW MEXI
(Valles Caldera)

KGRA

SIZE: 168,761 acres

LAND OWNERSHIP:

Federal: 30,000+ acres
Federal leased: 18,000 acres
State and private: 120,700+ acres

DISCOVERY AND TOTAL WELL DATA

YEAR: 1970

OPERATOR: Pat Dunigan

DEEP WELLS: 14

INVOLVED UTILITY: New Mexico Public Service Co.

ESTIMATED POWER POTENTIAL: 2,700 MW

PRINCIPAL OPERATORS

NAME: Union Geothermal Co. of New Mexico (a subsidiary of Union Oil Co.)

WELLS: 14

TESTS: Extensive production and injection

FIRST POWER PLANT

TYPE CONSIDERED: Double Flash

SIZE (NOMINAL): 50 MW

STATUS: Preliminary design under way by Bechtel National Corp.

SCHEDULED ON LINE: 1982

RESERVOIR DATA

TYPE: Hot water *TEMPERATURE:* 530°F *SALINITY:* 6,000 ppm

DEPTH (TOP OF RES.): 3,200 ft *MAXIMUM FLOW RATE:* 50,000 lbs/hr

LOAD CENTERS

CITY: Santa Fe, New Mexico
POPULATION: 50,000
DISTANCE: 65 miles

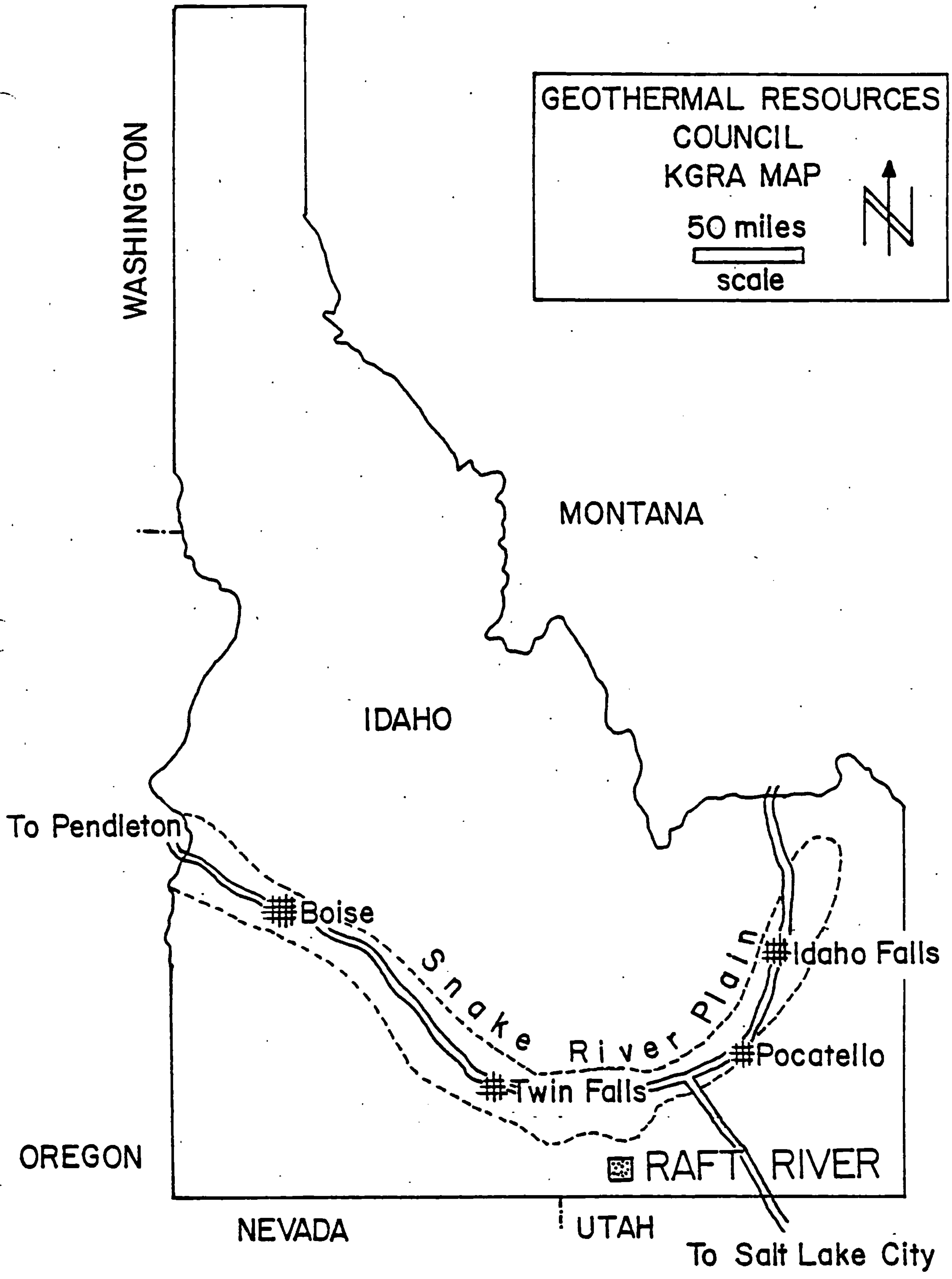
CITY: Albuquerque, New Mexico
POPULATION: 409,000
DISTANCE: 70 miles

GEOLOGY AND GEOTHERMAL PHENOMENA

Predominantly quaternary volcanics consisting of rhyolitic ash flows (tuff); subsequent caldera collapse followed by localized volcanic activity; hot springs and travertine deposits.

REMARKS

Union Geothermal Company of New Mexico and New Mexico Public Service Co. have entered into an agreement with the U.S. Department of Energy to construct and operate a 50 MW demonstration plant at the Baca location no. 1; the power plant is now being designed by the Bechtel Corporation; field development drilling will start in mid-1979. Operations are being delayed by environmental problems concerning Native Americans.


GEOTHERMAL RESOURCES COUNCIL
KGRA MAP
50 miles
scale
WASHINGTON
MONTANA
IDAHO
To Pendleton
Boise
Snake River Plain
Idaho Falls
Pocatello
Twin Falls
OREGON
RAFT RIVER
NEVADA
UTAH
To Salt Lake City

KGRA RAFT RIVER AREA SOUTHERN IDAHO STATE IDAHO

KGRA

SIZE: 22,529 acres

LAND OWNERSHIP:

Federal: 17,430 acres (No federal land has been leased under the Geothermal Act of 1970. A 5,000 acre federal land withdrawal is pending)

State and private: 5,099 acres

DISCOVERY AND TOTAL WELL DATA

YEAR: 1974

OPERATOR: EG&G Idaho, Inc.

DEEP WELLS: 7

INVOLVED UTILITY: Raft River Geothermal Cooperative

ESTIMATED POWER POTENTIAL: Unavailable

PRINCIPAL OPERATOR

NAME: U.S. Department of Interior through EG&G Idaho, Inc.

WELLS: 7

TESTS: Extensive production and injection tests

FIRST POWER PLANT (The power plants will probably be operated by a utility group)

TYPE CONSIDERED:	Binary	Binary
SIZE (NOMINAL):	60 KW	5 MW
STATUS:	Constructed	Under construction
SCHEDULED ON LINE:	Compl. 1977	1980

RESERVOIR DATA

TYPE: Hot water *TEMPERATURE:* 295°F *SALINITY:* 2,000-5,000 ppm

DEPTH (TOP OF RES.): 4,000-5,000 ft *MAXIMUM FLOW RATE:* 1,500 gpm

LOAD CENTERS

The power produced would probably be used within the Raft River Geothermal Cooperative service area for agricultural purposes.

GEOLOGY AND GEOTHERMAL PHENOMENA

The reservoir is basically fractured granitic rock overlain by the tuffaceous sediments of the Salt Lake formation which is also fractured at depth. The main reservoir at depth is leaking into a shallow reservoir that was discovered in the 1930's.

REMARKS

Area has been developed by EG&G Idaho, Inc. under the sponsorship of U.S. Department of Energy as a research site. Experiments have been conducted on aquaculture, agriculture, alcohol, potato waste, multiple direction drilling, injection, reservoir stimulation and power generation. The power generation facilities are research in nature and employ the binary cycle system. Note that the binary system is used because the reservoir temperature is below 390°F.

Selected References

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The American Association of Petroleum Geologists Bulletin
V. 58, No. 8 (August 1974), P. 1581-1585, 1 Fig., 3 Tables

Developments in Four Corners–Intermountain Area in 1973[1]

N. D. THOMAIDIS[2]
Salt Lake City, Utah 84111

Abstract Total drilling in the Four Corners–Intermountain area during 1973 was up from 1972. Development drilling increased significantly, and success rates were higher than in 1972. Exploratory drilling decreased, and success rates were lower than in 1972.

The increased prices for crude oil and natural gas paid to producers should result in increased exploration and development throughout the area during 1974. However, rig and casing shortages could slow the anticipated increase in drilling activity.

Introduction

This report summarizes exploratory and development activities in Utah, Nevada, Arizona, southwestern Colorado, and western New Mexico (Fig. 1). Table 1 is a tabulation of this activity. Drilling operations in the Four Corners–Intermountain area increased during 1973. Development work increased by 283 wells. The success rate for development work increased from 84.0% in 1972 to 90.9% in 1973. Exploratory work decreased by 18 wells. Successful exploratory wells decreased from 25.2% in 1972 to 21.6% in 1973. The San Juan basin led the area in total drilling followed by the Uinta and Paradox basins.

Exploratory Drilling and Significant Discoveries

As during the past 4 years, the most significant oil exploration in the Four Corners–Intermountain area during 1973 was in the western Uinta basin of Utah. Four discoveries were completed during 1973 (Table 2; Fig. 1). The productive Tertiary trend, which includes the area from the Bluebell field 40 mi southwest through the Altamont and Cedar Rim fields, was extended southeast as a result of these discoveries. At year-end 173 producing wells on 640-acre spacing had been completed along the trend. A significant deep well was drilled east of the Bluebell field in an attempt to extend the Tertiary productive trend northeast (Table 3; Fig. 1). Shows of oil were present, but a completion attempt was unsuccessful. This exploratory failure probably delineates the northeastern extent of the productive trend. Exploratory drilling in the southeastern Uinta basin resulted in 11 gas discoveries in Cretaceous and Jurassic rocks.

Exploration of the Paleozoic rocks in the Paradox basin of southeastern Utah, southwestern Colorado, and northeastern Arizona resulted in 4 gas discoveries and 1 oil discovery.

Seven gas discoveries and 2 oil discoveries were completed in Cretaceous rocks and 1 gas discovery was completed in Paleozoic rocks in the San Juan basin of northwestern New Mexico and southwestern Colorado.

Development Drilling

The San Juan basin of northwest New Mexico led the area in development drilling at a significantly faster pace than in 1972. The increased price for natural gas paid to producers makes closer spacing of gas wells economic and has resulted in a significant increase in development drilling. This increased pace of development drilling should continue for the next 2 years. Successful development for Paleozoic oil at the Tocito field was carried out during 1973 and will continue during 1974.

The significant increase in development drilling in Utah was along the Bluebell-Altamont-Cedar Rim trend in the western Uinta basin. Development drilling along this trend will continue although at a considerably slower pace. At the present time, 2 gas plants are in the area, a 20-MMCFGPD plant operated by Gary Operating Co. at Bluebell and a 40-MMCFGPD plant operated by Shell Oil Co. at Altamont. A third 20-MMCFGPD plant is to be built by Gary Operating Co. in the Bluebell area. Two twin 10-in. crude-oil pipelines are in the area. One of these has been converted to a heated line and transports crude from the Bluebell-Altamont area directly into Salt Lake City. A feasibility study is under way to construct a new pipeline which will carry crude oil from the Altamont-Bluebell area northeast to major

[1] Manuscript received and accepted, March 19, 1974.

[2] Division Geologist, Mountain Fuel Supply Company.

Appreciation is expressed to the CSD for statistical data; John Lopez, Mountain Fuel, for drafting services; and Candace van der Meyden, Mountain Fuel, for typing.

east-west pipelines in Wyoming. The increased crude-oil price will result in additional development drilling during 1974 at the Aneth field in the Paradox basin.

Exploration Trends

At year-end 77 wells were awaiting completion, were being drilled, or were announced locations along the Tertiary trend in the western Uinta basin of Utah. The productive area has not been fully delineated and additional exploratory wells will be drilled. The discoveries in the southeastern Uinta basin will result in additional exploratory drilling for Dakota and Morrison objectives.

Continued leasing and geophysical activity in central and western Utah and Nevada could result in increased exploratory drilling in these areas.

A strong interest in the Paradox basin of southeastern Utah and southwestern Colorado is indicated by continued leasing and geophysical activity. Exploratory drilling in the Paradox basin is expected to increase during 1974.

Exploration of the Cretaceous rocks in the San Juan basin of northwest New Mexico is expected to continue at the 1973 pace. Successful development of apparently significant oil and gas reserves in the Paleozoic rocks at Tocito field should result in additional exploration of Paleozoic objectives.

Exploratory drilling in Arizona is expected to remain at the 1973 level.

The forecast for 1974 is for increased drilling in both exploratory and development categories in the Four Corners–Intermountain area. However, rig and casing shortages could slow the anticipated increase in drilling activity.

Geothermal Activity

Large-scale leasing for geothermal resources occurred in western Utah and Nevada during 1973. At year-end geothermal exploratory wells were being planned for the Brigham City area of Box Elder County, Utah, and the Whirlwind Valley area of Lander County, Nevada. Testing of geothermal wells in the Jemez Caldera geothermal area of Sandoval County, New Mexico, and the Phoenix area of Maricopa County, Arizona, reportedly is under way.

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TABLE 1. COMPLETION SUMMARY, FOUR CORNERS-INTERMOUNTAIN AREA, 1973

	OIL	GAS	DRY	TOTAL	% SUCCESS
Exploratory Tests					
Arizona	1	1	3	5	40.0
SW Colorado	0	2	11	13	15.4
W. New Mexico	2	7	42	51	17.6
Nevada	0	0	0	0	0
Utah	4	13	53	70	24.3
Total	7	23	109	139	21.6
Development Wells					
Arizona	0	0	4	4	0
SW Colorado	4	5	3	12	75.0
W. New Mexico	55	365	34	454	92.5
Nevada	0	0	0	0	0
Utah	100	12	13	125	89.6
Total	159	382	54	595	90.9
Grand Total	166	405	163	734	77.8

TABLE 2. DISCOVERIES IN FOUR CORNERS-INTERMOUNTAIN AREA IN 1973

MAP NO.	COUNTY, LOC.	OPERATOR, WELL NO. & LEASE	COMP. DATE M-Y	TOTAL DEPTH (FT)	DEEPEST FORMATION OR ZONE TESTED	PROD. DEPTH (FT)	PROD. FORM. OR ZONE	I. P.	FIELD OR POOL NAME	EXPL. CLASS.	REMARKS
1.	Duchesne 4-2S-1W	Chevron Oil No. 9-4-B1 Ute Tribal	7/73	13,600	Wasatch	13,497	Wasatch	1632 BOPD	Bluebell	O/E	
2.	Duchesne 1-2S-3W	Shell Oil No. 1-1-B3 Shell Et Al-Jenkins	6/73	14,714	Wasatch	14,639	Wasatch	782 BOPD	Altamont	O/E	
3.	Duchesne 7-3S-4W	Gulf Oil No. 1 Blue Bench-Ute	8/72	12,660	Wasatch	12,269	Green River & Wasatch	470 BOPD	Altamont	O/E	
4.	Duchesne 20-3S-[illegible]W	Texaco Inc. No. 1 Texaco-Gulf	4/73	10,330	Wasatch	9,890	Wasatch	985 BOPD	Altamont	O/E	
5.	Grand 8-16S-25E	Pease Willard No. 1 Anderson-Fed.	8/73	7,090	Cedar Mtn.	7,020	Cedar Mtn.	3155 MCFGPD	San Arroyo	O/E	
6.	Grand 12-16S-24E	Pease Willard No. 2 Anderson-Fed.	7/73	6,242	Cedar Mtn.	6,235	Cedar Mtn.	4000 MCFGPD	San Arroyo	O/E	
7.	Grand 10-20S-23E	Moore Johnny No. 3 U.S. Smelting-Fed.	1/73	2,135	Morrison	2,104	Morrison	3950 MCFGPD	Cisco	O/E	
8.	Grand 16-21S-23E	Adak Energy No. 1 State	10/72	1,600	Entrada	760	Dakota	478 MCFGPD	Cisco	O/E	
9.	Grand 3-21S-23E	Vukasovich Drlg. No. 4 Fed.	4/73	1,405	Morrison	1,290	Morrison	1630 MCFGPD	Cisco	O/E	
10.	Grand 10-21S-23E	Vukasovich Drlg. No. 5 Fed.	4/73	1,375	Morrison	1,365	Morrison	1400 MCFGPD	Cisco	O/E	
11.	Grand 4-21S-23E	Vukasovich Drlg. No. 6 Fed.	4/73	1,303	Morrison	1,229	Morrison	1700 MCFGPD	Cisco	O/E	
12.	Grand 5-21S-23E	Vukasovich Drlg. No. 7 Fed.	4/73	1,294	Morrison	1,264	Morrison	500 MCFGPD	Cisco	O/E	
13.	Grand 17-21S-23E	Adak Energy No. 4 Fed.	1/73	1,150	Morrison	1,150	Mancos, Dak., Buckhorn, Morrison	335 MCFGPD	Cisco	O/E	Open hole Comp. 735-1150
14.	Grand 7-21S-23E	Adak Energy No. 5 Fed.	2/73	1,337	Morrison	1,200	Dakota	35 MCFGPD	Cisco	O/E	
15.	Grand 10-21S-23E	Vukasovich Drlg. No. 10 Fed.	5/73	1,452	Morrison	1,452	Morrison	996 MCFGPD	Cisco	O/E	Open hole Comp. 1430-1452
16.	San Juan 26-33S-25E	Mtn. Fuel Supply No. 1 Piute Knoll	2/73	6,031	Desert Crk.	5,772	Ismay	1260 MCFGPD	Piute Knoll	NFW	
17.	San Juan 34-43S-23E	Merrion & Bayless No. 34-1 White Belley Wash	1/73	2,526	Organ Rock	2,476	Organ Rock	944 MCFGPD	White Belley Wash	NFW	
18.	Apache 9-40N-29E	American Fuels No. 1 Navajo	6/73	5,865	Miss.	4,822	Ismay	11 BOPD	Black Rock	O/E	
19.	Apache 15-40N-29E	Universal Resources No. 1-15 Navajo	4/73	5,775	Miss.	5,775	Hermosa, Desert Crk., Akah, Barker Crk	1390 MCFGPD	Black Rock	O/E	
20.	Dolores 7-38N-19W	Cherokee & Pittsburg No. 1 Cross Canyon Unit	5/73	6,200	Desert Crk.	5,914	Ismay	2250 MCFGPD	Cross Canyon	NFW	

TABLE 2. (Continued)

21.	La Plata 6-33N-11W	Track M.F. Et Al No. 1 Long-Harris	10/72	1,357	Point Lookout	924	Menefee	S.I. Gas Well	Red Mesa	O/E	
22.	San Juan 25-32N-14W	Amoco Prod. No. 1 Mtn. Ute Gas Comm. F	4/73	9,207	Miss.	9,110	Hermosa Paradox	5226 MCFGPD	Ute Dome	O/E	
23.	San Juan 35-28N-15W	Dugan Prod. No. 5 Pet. Inc.	12/72	591	Pic. Cliffs	591	Fruitland Pic. Cliffs	657 MCFGPD	Unnamed	O/E	Slotted Casing 549-591
24.	San Juan 25-28N-15W	Dugan Prod. No. 7 Pet. Inc.	12/72	760	Pic. Cliffs	760	Pic. Cliffs	194 MCFGPD	Unnamed	O/E	Open hole Comp. 739-760
25.	San Juan 26-28N-15W	Dugan Prod. No. 3 Pet. Inc.	6/72	572	Pic. Cliffs	572	Pic. Cliffs	125 MCFGPD	Unnamed	O/E	
26.	San Juan 36-28N-15W	Dugan Prod. No. 6 Pet. Inc.	12/72	667	Pic. Cliffs	667	Fruitland Pic. Cliffs	614 MCFGPD	Unnamed	O/E	Slotted 620-667
27.	Rio Arriba 33-32N-5W	Schalk J. E. No. 2 Lone Star Ind.-Schalk-62	8/73	7,717	Gallup	7,686	Gallup	10,000 MCFGPD	Basin	SPT	
28.	San Juan 35-27N-12W	McHugh J.P. No. 5 Nassum	5/73	1,560	Pic. Cliffs	1,538	Pic. Cliffs	584 MCFGPD	Unnamed	SPT	
29.	Sandoval 26-21N-3W	Guadalupe Expl. No. 1 Taylor Ranch-Gov't.	4/73	6,315	Morrison	5,504	Gallup	54 BOPD	Unnamed	NFW	
30.	McKinley 29-16N-6W	Northern Minerals No. 8 Santa Fe Pacific RR	10/73	754	Hospah	754	Hospah	9 BOPD	Unnamed	NFW.	Open hole 736-754

TABLE 3. IMPORTANT EXPLORATORY FAILURES IN FOUR CORNERS-INTERMOUNTAIN AREA IN 1973

MAP NO.	COUNTY LOC.	OPERATOR, WELL NO. AND LEASE	COMP. DATE M-Y	TOTAL DEPTH	DEEPEST FORMATION TESTED	EXPL. CLASS.
31	Uintah 28-1N-1E	Sun Oil No. 1 Topoof	2/73	16,000	Wasatch	NFW

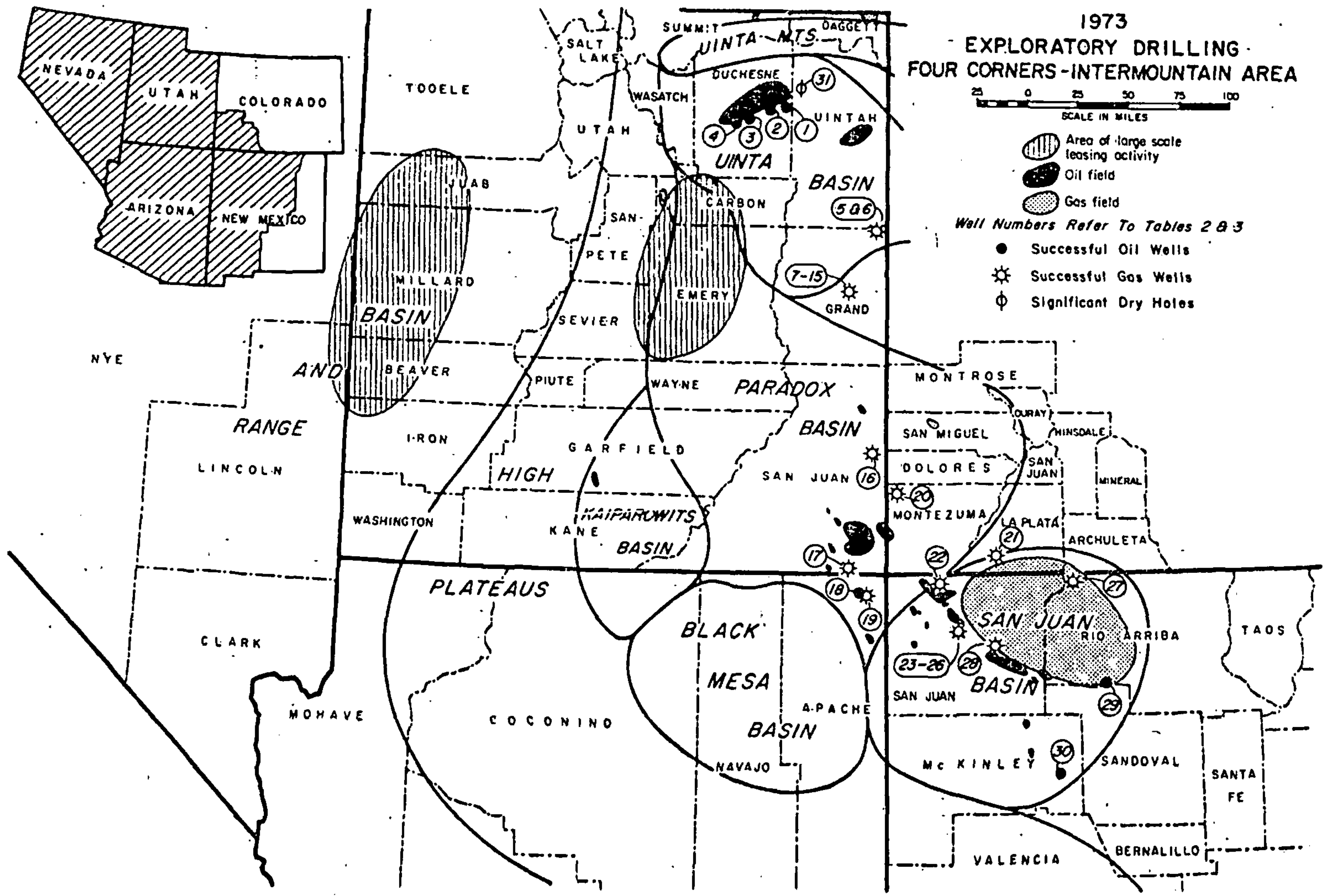

Fig. 1—Exploratory drilling in Four Corners-Intermountain area in 1973.

AREA
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drilling
1974

The American Association of Petroleum Geologists Bulletin
V. 58, No. 8 (August 1974), P. 1536-1546, 9 Figs., 6 Tables

Developments in West Coast Area in 1973[1]

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Abstract Exploratory activity in Washington declined. One exploratory well in Oregon was drilled during the year. Exploratory drilling in California increased moderately over 1972. Most of the increase was in wells drilled primarily to find gas. The number of wells drilled in California was less than in any year since 1942. New oil and gas discoveries reversed the trend of the past several years and showed a significant increase in the volume of reserves discovered. There were 5 significant oil discoveries, but no new oil-field discoveries, and 9 significant gas discoveries made in California. Exploration activity was high in the Sacramento Valley and in the Outer Basins area south of the Santa Barbara Channel Islands. A campaign of deep drilling was initiated in California which will continue in 1974.

Geothermal exploration continued in northern California. One geothermal test was drilled in south-central Oregon. The Geysers became the world's largest producer of geothermal power. Testing continued in the Imperial Valley to determine if highly saline and lower temperature reservoir fluids can become a commercial source of power.

Introduction

West Coast exploration and development activity for 1973 are summarized in this report, which covers the states of Washington, Oregon, and California. Data from exploratory and development drilling were compiled by the West Coast CSD Committee and listed by the American Petroleum Institute Division of Statistics and Economics. Oil and condensate production information was provided by the Committee of California Oil Producers. Dry gas production and geothermal statistics were furnished by the State of California Division of Oil and Gas. Data on geophysical activity were obtained from the Exxon scouting report through the courtesy of the Society of Exploration Geophysicists and may be some 20% lower than those which will be reported by the SEG. Oil and gas reserve estimates were provided by the API and the American Gas Association.

Washington

During 1973, 4 unsuccessful exploratory wells were drilled in the state. A fifth well reported as drilling in 1972, Ozark Development Co., Ozark State 1 in Lewis County, reached TD 2,875 ft and was abandoned. Two wells in Clallum County near the town of Forks were drilled by Eastern Petroleum Co. The wells Soleduck 1 and Sniffer-Forks 1 reached TDs of 1,680 and 3,095 ft, respectively. Development Associates M. A. Baker 1–30 in Grays Harbor County was abandoned at 4,200 ft. A shallow well, Concept Resources Concept-Orting 2 in Pierce County, announced as a 1,700-ft test, drilled to 680 ft and was suspended. None of these wells was reported by CSD. No geophysical activity was reported in the state during 1973. Odessa Natural Gas Co. and Washington Water Power acquired leases at Grays Harbor County lease sales. Most of the 1973 exploratory activity in the state was directed toward finding gas.

Oregon

Permits to drill a well in Malheur County finally were granted Standard Oil Co. of California. The Blue Mountain Unit 1 was abandoned at TD 8,414 ft. No information on this well has been released. No other exploratory oil and gas wells were drilled in Oregon during 1973.

No geophysical activity was reported in 1973. Lease activities slowed somewhat as compared to 1972, but Mobil Oil Co. was reported leasing in Lane and Douglas Counties.

California

Exploratory drilling increased moderately in 1973. A total of 220 exploratory wells of all classes was drilled during the year as compared to 185 wells in 1972. About the same number of new-field wildcats were drilled, 89 versus 86. Exploratory drilling statistics are listed in Table 1. An offshore well, drilled by Standard Oil Co. of California, was not listed by CSD nor is it included in the drilling statistics.

Two core holes were drilled by American Petrofina in the Los Angeles basin. Vernon Core Hole 1 reached a TD of 14,938 ft and Vernon Core Hole 2 drilled to 3,948 ft. A third core hole, not reported by CSD, was

[1] Manuscript received and accepted, April 1, 1974.

[2] Standard Oil of California Western Operation Inc.

drilled by Standard Oil Co. of California in the San Fernando Valley; the core hole, Mission Properties 1, was abandoned after several redrills.

Between 1972 and 1973 there was little change in the number of exploratory wells drilled primarily to find oil. Exploratory wells drilled primarily to find gas increased from 81 in 1972 to 117 in 1973. Most of this increase was in new-pool wildcats which doubled in number from 26 to 52.

The 1973 success ratio of all classes of exploratory wells increased by 1.5%, from 14.0% in 1972 to 15.5% in 1973. There were no successful new-field wildcats drilled primarily to find oil in 1973. Successful new-pool wildcats drilled primarily for gas increased from 3 in 1972 to 8 in 1973. This increase plus increases in the number of successful deeper pool tests and extensions caused the success ratio of all classes of exploratory wells to increase.

In 1973 the percentage of exploratory wells drilled by major oil companies decreased from 31.7% in 1972 to 25.5%. Majors drilled about the same percentage of gas wells, but wells drilled to find oil decreased from 37.0% to 11.4%. Table 2 lists the distribution and success of exploratory drilling in California by major companies and others for 1973.

Discoveries

A total of 34 wells is listed as discoveries by CSD. Of this total 5 oil wells and 9 gas wells are considered significant. An extension, not listed by CSD or included in the drilling statistics, was made by Standard Oil Co. of California at P-0215 No. 1 in the Santa Barbara Channel. Significant oil and gas discoveries are listed in Tables 3 and 4 and are indicated by number on the California maps (Figs. 2, 3).

The most significant onshore oil discovery was Standard Oil Co. of California's 333-7R in Kern County (No. 5). This well discovered a new pool in the Miocene Asphalto sandstone. The pool, designated Tule Elk, is a stratigraphic trap formed by the sandstone pinching out against the plunging nose of the West Elk anticline. It is separated from the previously known production in the Elk Hills Naval Petroleum Reserve by wet sandstone or by nondeposition of the reservoir sandstone. Approximately 90% of the pool lies outside the Elk Hills Naval Petroleum Reserve. The discovery well had an initial production of 6,940 b/d oil and 1,410 MCFGD gas. Oil gravity was 23.3° API. The new pool was developed rapidly reaching a producing rate of 18,000 b/d at year-end.

In the Sacramento Valley Shell Oil Co. made 2 new-field discoveries. At Putah Sink, Shell 1 Shoshone Cowell (no. 9) was tested at 10,000 MCFGD from Cretaceous sandstones. The second discovery was the 1-25 Silva-Betts designated the Sacramento Airport field (No. 14). Production is from Paleocene sandstones. Shell also made 2 new-pool discoveries in Paleocene sandstones at the 1 Natomas I.O.C. (No. 10) and 1 I.O.C. (No. 11) in the Conway Ranch field.

Standard Oil Co. of California in the Santa Barbara Channel extended a Union Oil Co. discovery. This well, Standard P-0215 No. 1 (No. 15), tested commercial rates of oil before it was suspended. The remaining oil and gas discoveries in California appear to be of small size and are not listed.

Exploratory Methods

Three core holes were drilled in Los Angeles County, 1 in the San Fernando Valley (No. 16) and 2 in the Los Angeles basin (No. 17).

Onshore geophysical activity increased from 50 crew-months in 1972 to 77 crew-months in 1973. Much of this work was done in the Sacramento Valley where "Bright-Spot" analysis has led to the discovery of several new gas fields.

Offshore geophysical activity increased from 3.2 crew-months in 1972 to 13 crew-months in 1973. Most of this work was done in the Outer Basins area south of the Santa Barbara Channel Islands. One crew-month of gravity and magnetics was reported from this area. In addition, there were 10 crew-months of bottom sampling in the Outer Basins area. This work was done in response to the Bureau of Land Management call for nominations in the area. Geophysical work was continuing in the area early in 1974.

Mobil Oil Co. initiated a core-hole drilling program on Santa Rosa Island (No. 18). Four core holes were completed and a fifth was drilling at year-end. No information on the results of these core holes has been released.

A campaign of deep drilling was undertaken in 1973. The depth record in California was extended 158 ft by the Great Basins–Tenneco 31X-10, in Sec. 10, T27S, R22E, Kern County (No. 19), which reached a TD of 21,640 ft. Encouraging shows of oil and gas were found while testing, but the well was plagued by mechanical problems and, after an extensive testing program, was abandoned. Two deep wells were drilled in Kern County. Mobil Tupman USL 1–10, Sec. 10, T28S, R23E (No. 20), drilled to 20,753 ft and began a testing program which was continuing at year-end. The well was abandoned early in 1974. As with the Great Basins well, mechanical problems prevented making a diagnostic test. Texaco San Emidio 1, Sec. 14, T11N, R22W (No. 21), was the second deep test. While drilling at 20,704 ft the bit stuck and was left in the hole. Attempts to sidetrack were unsuccessful. The well subsequently was plugged back and a testing program was initiated. In January 1974 the well was designated a new-field discovery, the Yowlume oil field.

In Ventura County, Shell drilled a deep test on the Ventura Avenue anticline. The well Shell Taylor D.T. 653, Sec. 21, T3N, R23N (No. 22), was drilled to 21,500 ft TD. Preparations were being made to test the well at year-end.

A new depth record was set in the Sacramento Valley by the Great Basins Cache Creek 1, Sec. 8, T9N, R1E, Yolo County (No. 23), which was abandoned at TD 18,275 ft. The deep drilling campaign still leaves unanswered the question of whether or not California sandstone reservoirs will produce commercial volumes of oil from depths greater than 12,000 ft.

Developments

For the first time since 1959 the number of oil wells completed in California dipped below 1,000. Total number of wells drilled was less than in any year since 1942 when drilling was restricted by wartime shortages. Drilling statistics are listed in Table 5.

This drop in drilling was caused by several factors. First, the new-field and new-pool discoveries made on shore during the past 4 years have been few and quite small. Second, the drilling moratorium on state tidelands prevented development drilling on state leases. Another factor was the delay caused by the requirement for an environmental impact statement before development drilling on Santa Barbara Channel OCS leases could be permitted. As a result, indicated discoveries with the potential of more than a billion bbl of oil remain undeveloped.

A draft environmental impact statement for development drilling on Santa Barbara Channel outer continental shelf leases has been prepared by the USGS. Public hearings on the EIS were held late in 1973. It is expected that a final statement will be filed early in 1974. Then Exxon, as operator of the Santa Ynez unit, will be issued a permit to install a development platform. Antidrilling forces no doubt will test this approval in the courts.

In the Los Angeles basin, Occidental Petroleum was granted a permit to drill 2 core holes at Pacific Palisades in the city of Los Angeles. These core holes were intended to evaluate a significant discovery made several years ago. Occidental had erected a rig on location and was preparing to commence operations when the company was enjoined from drilling by the California Supreme Court. Basis for this injunction was a suit by No Oil Inc. seeking to force the city of Los Angeles to file an environmental impact statement before issuing Occidental a permit to drill. Occidental, in a brief prepared for submission to the District Court of Appeals, estimated that the city of Los Angeles is denied the use of 15,000 b/d of low-sulfur crude oil and 27,000 MCFGD of natural gas.

Additions to Reserves

In 1973, 269.1 million bbl of new-oil reserves were added in California. New discoveries accounted for 35.8 million bbl. Extensions and revisions comprised 234.3 million bbl. Production during 1973 was 335.7 million bbl. As a result, California year-end reserves are estimated to be 3,488 million bbl., a net reduction of 66 million bbl.

Industry was more successful in exploring for dry gas (nonassociated) than for oil. During the year 359.9 Bcf of dry gas were added to reserves in California. New discoveries accounted for 54.3 Bcf. Extensions and revisions comprised 305.6 Bcf. Dry-gas production was 275 Bcf during the year. Reserves of dry gas were estimated to be 2,380 Bcf at year-end, an increase of 90.1 Bcf.

Trends

The reductions in exploratory drilling and production in California are shown on Figures 4 and 5. A reversal in reserves discovered per new-field and new-pool wildcat was made in 1973. Unfortunately the 2 significant oil discoveries made during the year were not producing in March 1974. The Tule Elk pool was shut in by court order on February 14, 1974. Production will remain shut in until the dispute between the Secretary of the Navy and Standard Oil Co. of California over drainage of the Elk Hills Naval Petroleum Reserve has been settled in the courts. An indicated extension in the Santa Barbara Channel, made by Standard Oil Co. of California, will require further evaluation before the decision to file a development plan for the Santa Clara unit can be made. It is hoped that Standard will not be plagued with the same delays experienced by Exxon at the Santa Ynez unit.

An exploratory tool finding increased use in California is deeper drilling in and adjacent to known oil fields. A deep drilling campaign was started in 1973 and is expected to continue in 1974.

Industry has been leasing actively in the Sacramento Valley. This leasing, coupled with the increased geophysical activity in the area, should cause a number of exploratory wells to be drilled in the area during 1974.

Increased prices for crude oil and natural gas have given the oil industry adequate incentive to explore in the West Coast. Environmental conflicts between the oil industry and a few rabid antioil groups still impede efforts to explore for and develop new oil and gas production. Until the oil industry is given the opportunity to develop new discoveries which already have been made in the California tidelands, the West Coast will become even more dependent on imported crude oil and natural gas.

Geothermal

In the Geysers area of Lake and Sonoma Counties, California (Fig. 1, GP1), 30 steam wells were completed for production. This area became the world's largest producer of geothermal power in December 1973. Generating capacity in the area now is rated at 396,000 KW from 10 generating units. Five additional units are planned. When these are completed, generating capacity at the Geysers will reach 908,000 KW.

A joint venture has been formed by San Diego Gas and Electric, Magma Power, and Standard Oil Co. of California. The group is building a pilot plant to test a 1972 geothermal discovery near Heber (GP2). This plant will use energy developed by a heat exchanger. If this test is successful the way will be open for the development of geothermal power in areas where reservoir fluids exhibit high salinity and/or low temperatures.

Gulf Oil Co., active in prospecting in northern California and southern Oregon during 1973, drilled 2 wells in Lassen County and 2 wells in Modoc County, California (GP3). The Oregon well was in Lake County (GP4) near the town of Lakeview. Phillips drilled and abandoned a shallow geothermal test in Plumas County (GP5). Magma drilled 3 geothermal tests in the Imperial Valley (GP2) and 1 in Modoc County (GP3).

Table 1. Summary of Exploratory Well Completions by All Operators in California in 1973
(Reported by CSD of AAPG)

	Number of Wells Completed			Exploratory Footage			Avg. Exploratory Footage	
	All Wells	Success. Wells	% Success	Total for All Wells	Success. Footage	% Success	All Wells	Success. Ft/ Success. Well
New-Field Wildcats								
Drilled primarily to find oil	45	0	-	258,080	0	-	5,735	-
Drilled primarily to find gas	44	2	4.5	267,704	12,574	4.7	6,084	6,287
Total	89	2	2.2	525,784	12,574	2.4	5,908	6,287
New-Pool Wildcats								
Drilled primarily to find oil	18	3	16.7	110,728	23,240	21.0	6,151	7,747
Drilled primarily to find gas	52	8	15.4	240,398	46,908	19.5	4,623	5,864
Total	70	11	15.7	351,126	70,148	20.0	5,016	6,377
Deeper Pool Tests								
Drilled primarily to find oil	11	2	18.2	94,764	14,360	15.2	8,615	7,180
Drilled primarily to find gas	5	1	20.0	30,531	5,488	18.0	6,106	5,488
Total	16	3	18.8	125,295	19,848	15.8	7,831	6,616
Shallower Pool Tests								
Drilled primarily to find oil	0	0	-	0	0			
Drilled primarily to find gas	1	1	100.0	944	944	100.0	944	944
Total	1	1	100.0	944	944	100.0	944	944
Extensions								
Drilled primarily to find oil	29	12	41.4	161,704	71,195	44.0	5,576	5,933
Drilled primarily to find gas	15	5	33.3	89,222	34,673	38.9	5,948	6,935
Total	44	17	38.6	250,926	105,868	42.2	5,703	6,228
All Exploratory Wells								
Drilled primarily to find oil	103	17	16.5	625,276	108,795	17.4	6,071	6,400
Drilled primarily to find gas	117	17	14.5	628,799	100,587	16.0	5,374	5,917
Total	220	34	15.5	1,254,075	209,382	16.7	5,700	6,158

* Redrills counted as separate wells.

Table 2. Distribution and Success of Exploratory Drilling in California
by Major Companies and Others, 1973

	% of Wells Drilled		% of Expl. Footage		Success		NFW
	All Classes	NFW	All Classes	NFW	% Wells All Classes	% Footage All Classes	Av. Total Ft/Well
All Exploratory Wells							5,908
Majors	25.5	19.1	28.7	50.9	30.4	28.2	6,013
Others	74.5	80.9	71.3	49.1	10.4	12.0	5,883
Wells Drilled Primarily to Find Oil							6,071
Majors	11.4	17.8	15.8	24.0	32.0	28.4	7,742
Others	35.5	82.2	34.0	76.0	11.5	12.3	5,301
Wells Drilled Primarily to Find Gas							5,374
Majors	14.1	20.5	12.9	15.0	29.0	28.0	4,476
Others	39.0	79.5	37.3	85.0	9.3	11.8	6,498

TABLE 3. Significant California Oil Discoveries For 1973 Reported By CSD Of AAPG

Map No.	Operator Well Name	County Location	Comp. Date	Total Depth (Feet)	Prod. Depth (Feet)	IP B/D	IP API GR°	Age of Prod. Fm.	Name of Field or (Pool)	Class
1	Lawrence Baker, Jr. 1-Baker-Ferndale	Ventura Sec. 16, T4N, R21W	2-7-73	7,264	4,932	24	26.0	Miocene	Sisar-Silverthread (East)	Ext. New Area
2	Tenneco 58 Tenn-CBR-Tiger-Paloma	Kern Sec. 3, T32S, R26E	2-22-73	12,062	11,547	268	45.0	Miocene	Paloma (L Stevens)	DPD
3	Montara Pet. Co. 73 Cotty	Kern Sec. 17, T27S, R21E	5-24-73	6,005	5,405	40	35.7	Miocene	Lost Hills (Cahn)	NPD Ext.
4	Overland Pet. Co. 4 Cox-Tesoro	Kern Sec. 21, T29S, R21E	6-7-73	7,220	6,146	110	31.0	Miocene	Cymric (Phacoides)	NPD Ext.
5	Standard of Calif. 333 7-R	Kern Sec. 7, T30S, R23E	9-14-73	10,015	8,985	6,940	23.3	Miocene	Elk Hills (Asphalto)	NPD

TABLE 4. California Gas Discoveries For 1973 Reported By CSD Of AAPG

Map No.	Operator Well Name	County Location	Comp. Date	Total Depth (Feet)	Prod. Depth (Feet)	IP MCFGD	Age of Prod. Fm	Name of Field or (Pool)	Class
6	Union of Calif. 4 Sonol Securities	San Joaquin Sec. 10, T1S, R5E	1-26-73	9,999	9,885	5,500	Cretaceous	Union Island (Winters)	DPD
7	Atlantic-Sumpf-Williams 1 Andco	Yolo Sec. 12, T8N, R2E	3-21-73	5,658	5,410	3,000	Cretaceous	Tod hunters Lk. (Starkey)	Ext.
8	Montara Pet. Co. 1 Greene	Merced Sec. 36, T9S, R13E	5-5-73	8,182	2,377	1,827	Miocene	Cowchilla (Zilch)	Ext.
9	Shell Oil Co. 1 Shoshone-Cowell	Yolo Sec. 34, T8N, R3E	6-11-73	6,975	6,500	10,000	Cretaceous	Putah Sink	NFD
10	Shell Oil Co. 1 Natomas I.O.C.	Yolo Sec. 9, T9N, R3E	6-14-73	4,700	3,080	5,310	Paleocene	Conway Ranch	NPD
11	Shell Oil Co. 1 I.O.C.	Yolo Sec. 15, T9N, R3E	7-3-73	4,504	3,123	6,250	Paleocene	Conway Ranch	NPD Ext.
12	Standard Oil Calif. 4 Van Sickle Gas Unit	Solano Sec. 32, T3N, R1E	9-5-73	8,175 4,466 Rd	3,225	1,700	Miocene	Van Sickle Is.	NPD
13	Atlantic Oil Co. 2 Winchester Lk.	Yolo Sec. 17, T7N, R4E	9-20-73	5,599	3,315	2,000	Paleocene	Winchester Lk.	NFD
14	Shell Oil Co. 1-25 Silva-Bette	Sacramento Sec. 25, T10N, R3E	11-30-73	3,062*	2,470	3,000	Paleocene	Sacramento Airport	NFD

Table 5. Completion Summary in California, 1973

	Oil	Gas	Dry	Total	% Success
Exploratory Wells	17	17	186	220	15.5
Development Wells*	867	44	95	1,006	90.6
Total	884	61	281	1,266	77.1

* Excludes 114 Service Wells

Table 6. Production in California 1972-1973

	1972	1973	Cum. to 12/31/73
Oil (bbl)	346,800,000	335,700,000	16,400,000,000
Condensate (bbl)	331,500	315,500	41,320,800
Total liquids (bbl)	347,131,500	336,015,500	16,441,320,800
Dry Gas (MCF)*	274,346,000	275,000,000	6,956,654,000

* Includes state tidelands.

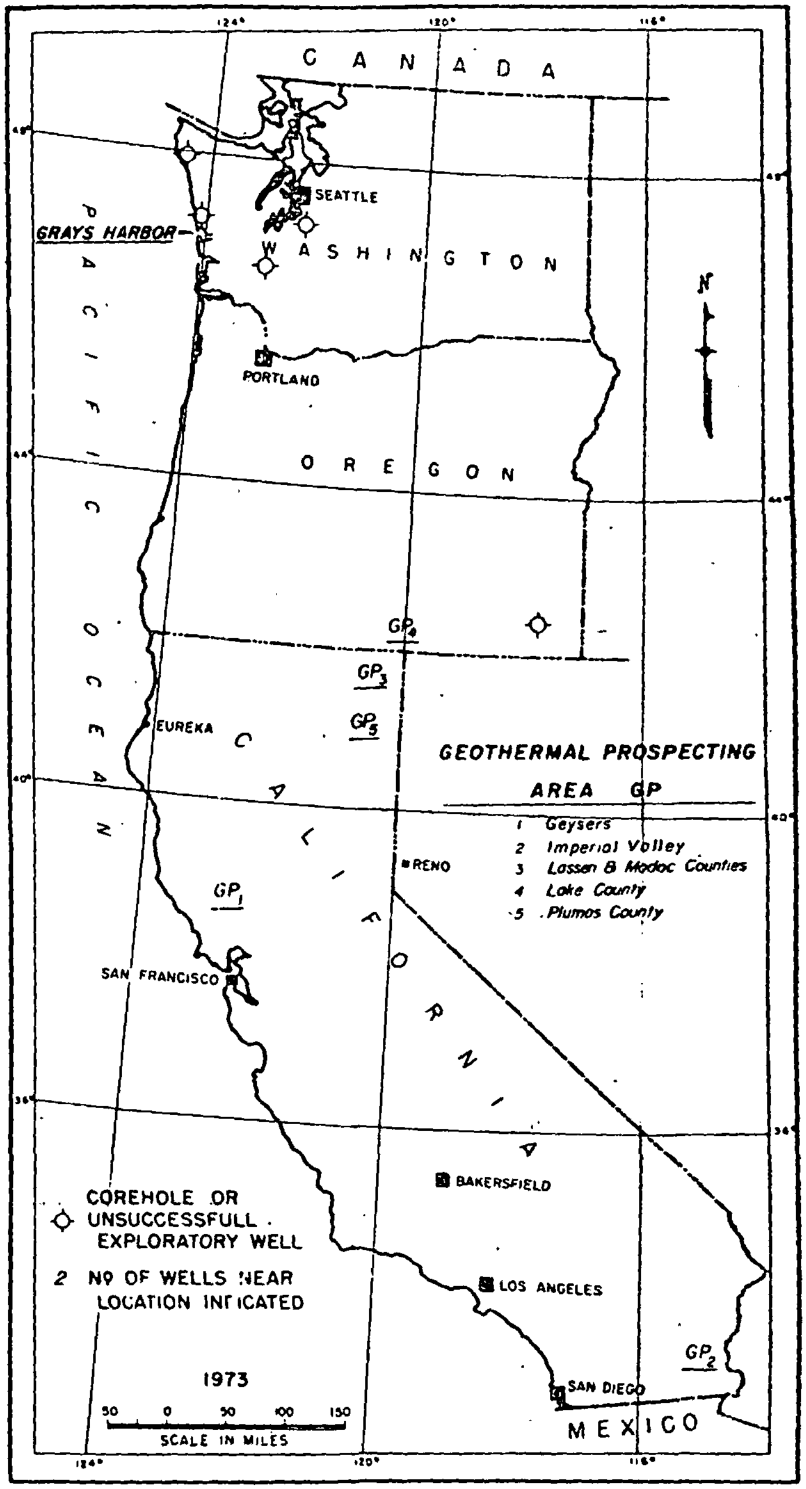

CANADA
WASHINGTON
OREGON
CALIFORNIA
PACIFIC OCEAN
MEXICO
SEATTLE
GRAYS HARBOR
PORTLAND
EUREKA
RENO
SAN FRANCISCO
BAKERSFIELD
LOS ANGELES
SAN DIEGO
N
GP1
GP2
GP3
GP4
GP5
GEOTHERMAL PROSPECTING AREA GP
1 Geysers
2 Imperial Valley
3 Lassen & Modoc Counties
4 Lake County
5 Plumos County
COREHOLE OR UNSUCCESSFULL EXPLORATORY WELL
2 NO OF WELLS NEAR LOCATION INDICATED
1973
50 0 50 100 150
SCALE IN MILES
124°
120°
116°
48°
44°
40°
36°

Fig. 1

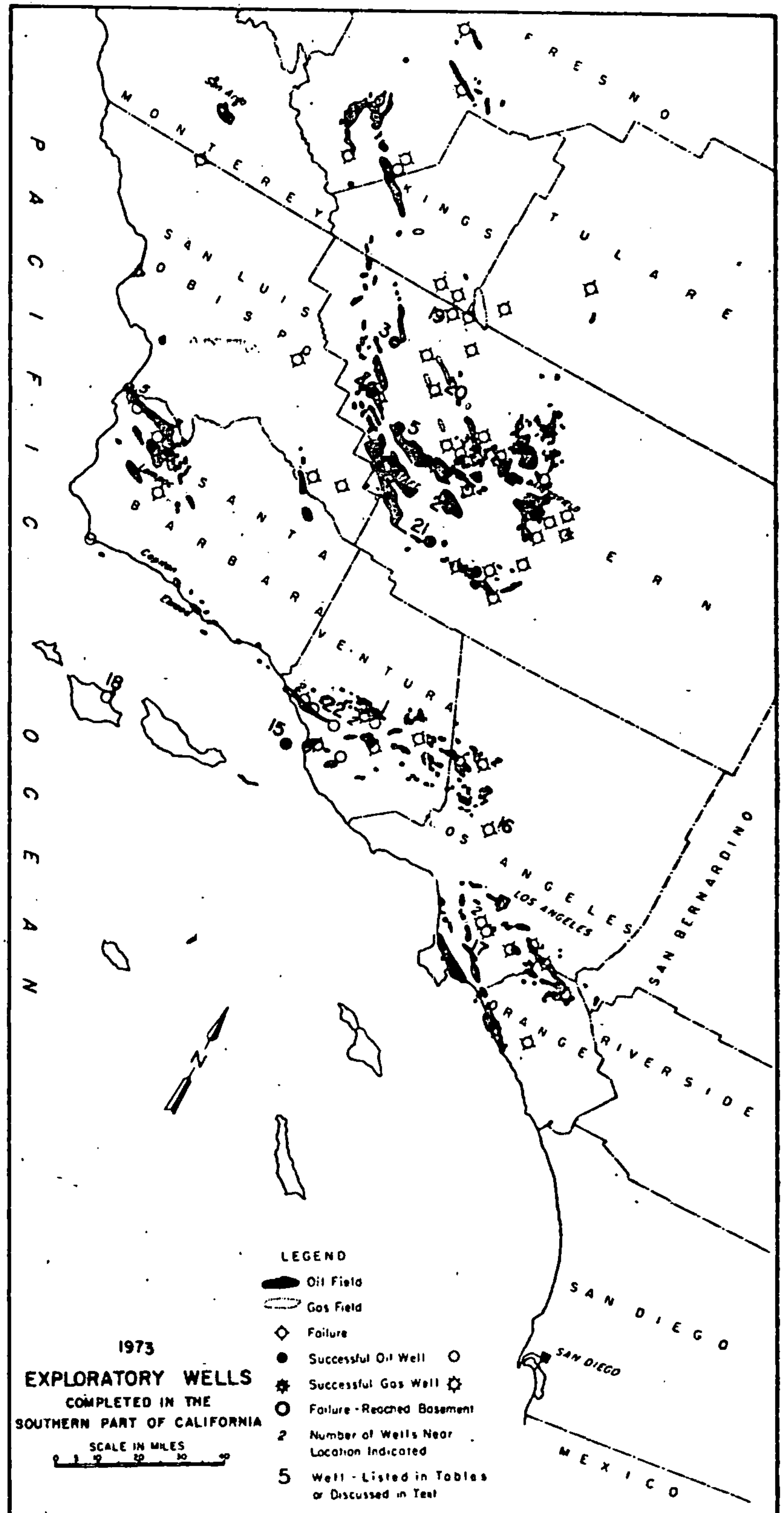
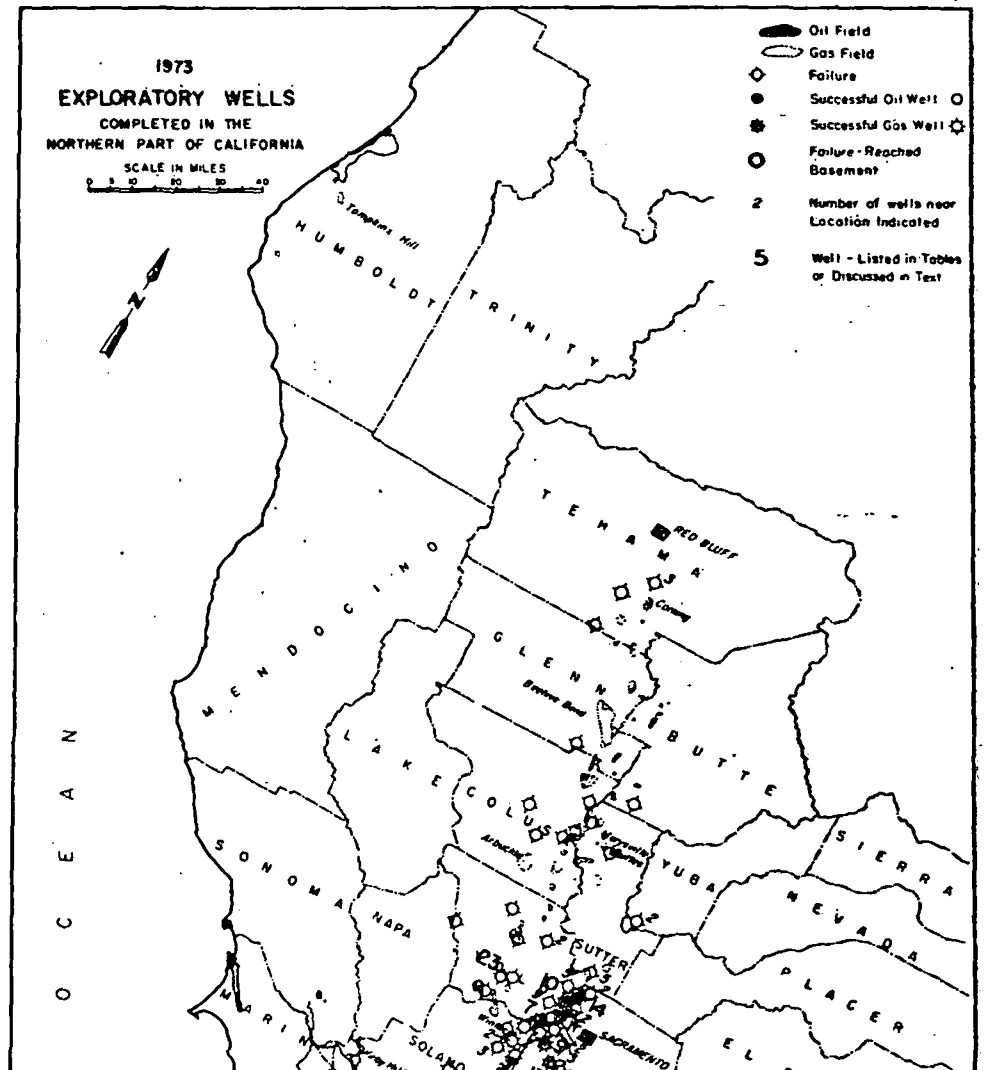

1973
EXPLORATORY WELLS
COMPLETED IN THE
SOUTHERN PART OF CALIFORNIA
SCALE IN MILES
LEGEND
Oil Field
Gas Field
Failure
Successful Oil Well
Successful Gas Well
Failure - Reached Basement
Number of Wells Near Location Indicated
Well - Listed in Tables or Discussed in Text
PACIFIC OCEAN
MONTEREY
FRESNO
KINGS
TULARE
SAN LUIS OBISPO
SANTA BARBARA
KERN
VENTURA
LOS ANGELES
SAN BERNARDINO
ORANGE
RIVERSIDE
SAN DIEGO
MEXICO
N

FIG. 2


1973
EXPLORATORY WELLS
COMPLETED IN THE
NORTHERN PART OF CALIFORNIA
SCALE IN MILES
Oil Field
Gas Field
Failure
Successful Oil Well
Successful Gas Well
Failure - Reached Basement
Number of wells near Location Indicated
Well - Listed in Tables or Discussed in Text
PACIFIC OCEAN
HUMBOLDT
TRINITY
TEHAMA
RED BLUFF
GLENN
BUTTE
MENDOCINO
LAKE
COLUSA
YUBA
SIERRA
NEVADA
SONOMA
NAPA
SUTTER
PLACER
MARIN
SOLANO
SACRAMENTO
EL DORADO
SAN FRANCISCO
CONTRA COSTA
AMADOR
CALAVERAS
ALPINE
SAN MATEO
ALAMEDA
SAN JOAQUIN
TUOLUMNE
SANTA CLARA
STANISLAUS
SANTA CRUZ
MARIPOSA
MERCED
MADERA
MONTEREY
SAN BENITO
FRESNO
FIG 3

CALIFORNIA
ADDITIONS TO OIL RESERVES VS. PRODUCTION
1958 TO 1973 INCLUSIVE

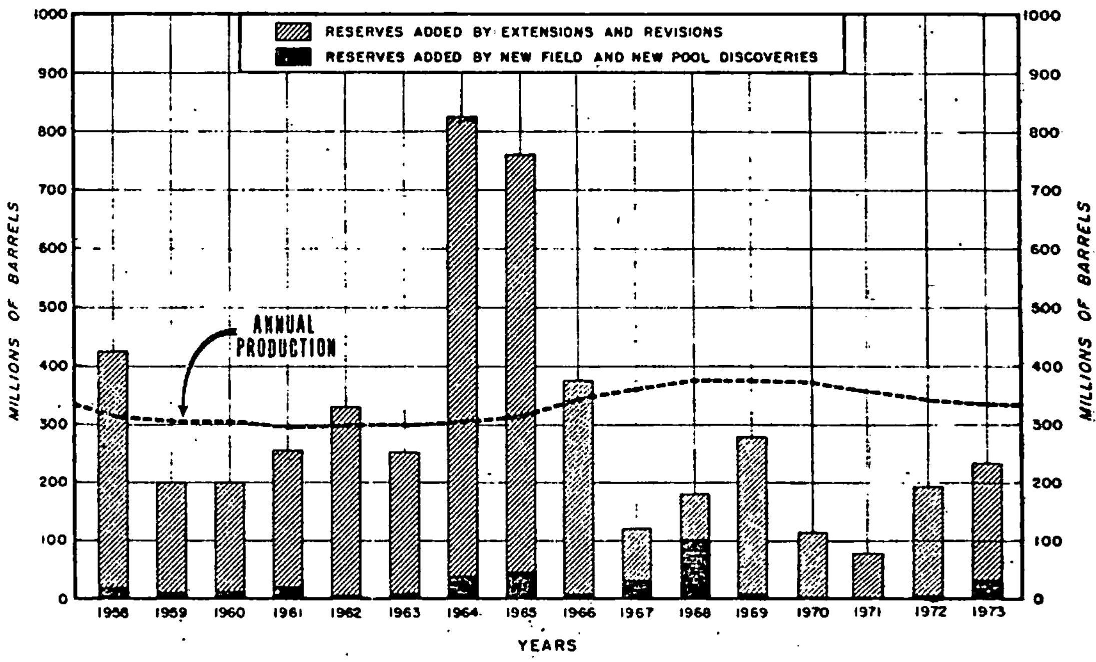


FIG. 4

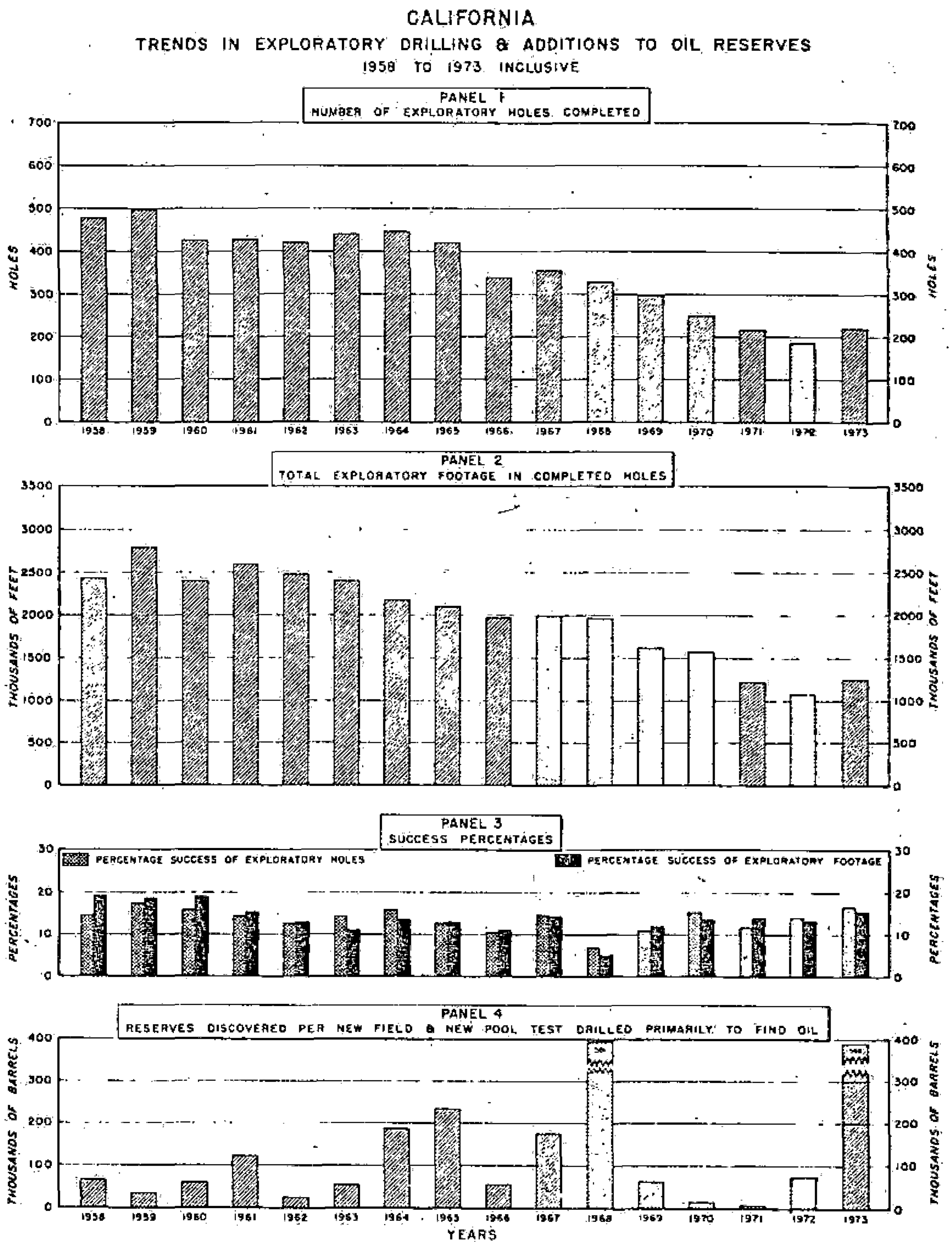

CALIFORNIA
TRENDS IN EXPLORATORY DRILLING & ADDITIONS TO OIL RESERVES
1958 TO 1973 INCLUSIVE
PANEL 1
NUMBER OF EXPLORATORY HOLES COMPLETED
HOLES
PANEL 2
TOTAL EXPLORATORY FOOTAGE IN COMPLETED HOLES
THOUSANDS OF FEET
PANEL 3
SUCCESS PERCENTAGES
PERCENTAGE SUCCESS OF EXPLORATORY HOLES
PERCENTAGE SUCCESS OF EXPLORATORY FOOTAGE
PERCENTAGES
PANEL 4
RESERVES DISCOVERED PER NEW FIELD & NEW POOL TEST DRILLED PRIMARILY TO FIND OIL
THOUSANDS OF BARRELS
YEARS

FIG 5

Exploration and Development of Geothermal Resources in the United States, 1968–1975

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ABSTRACT

From 1968 to 1975, exploration for geothermal resources in the Western United States increased rapidly. The pace accelerated in late 1973 due to the rise in the price of energy. Energy demand and a favorable economic climate should sustain geothermal development in the future.

Federal and state lands are now becoming available, and efforts are being made to speed the leasing programs.

Extensive exploration and development are ongoing at The Geyser's and there have been significant discoveries made in the Imperial Valley, California, and at the Valles Caldera, New Mexico. Exploration is continuing at Beowawe and Brady's Hot Springs, Nevada, and Surprise Valley, California. In addition, exploration has been increased in portions of Utah, Idaho, Oregon, and Arizona. Discoveries have been sparse, but should improve as land becomes available and exploration is expanded.

Exploration and utilization technology is advancing, but a greater effort is required to meet the demand.

Environmental, legal, and institutional problems are still delaying exploration and development; however, increased coordination of federal, state, and local government regulatory programs has been proposed and if undertaken could speed development.

The federal government is heavily financing research and development, including exploration and utilization technology and solutions to environmental, legal, and institutional problems.

INTRODUCTION

Exploration of geothermal systems in the United States increased steadily through the late 1960s and the first half of the '70s. Stimulus came from continued successful development of geothermal electricity at The Geysers, California, from legislation enabling the leasing of public land for geothermal exploration, and from increases in costs of traditional forms of energy.

Significant discoveries were made in the Valles Caldera of New Mexico (Figure 1). Wells of potential importance were drilled in three widely separated areas of the Imperial Valley of California (Heber, East Mesa, North Brawley), at Roosevelt, Utah, and in the Carson Desert of western Nevada. Drilling continued in varying degrees in previously explored areas of Surprise Valley, California; Beowawe, Nevada; and near Niland in Imperial Valley. However, several areas previously thought attractive, such as Steamboat Springs, Nevada, and Long Valley, California, were not drilled further. Part of the reason for this may be the continued unavailability of public land in these regions. Wildcat wells were drilled with little or no success at numerous locations in Oregon (La Grande, Lakeview), Idaho (Mountain Home), California (Honey Lake, Sierra Valley, Mono Lake, Kelly Hot Springs), Utah (Brigham City), Arizona (Casa Grande, Chandler), and Nevada (Tipton). Deep exploratory holes were drilled at varying distances from the proven productive area at The Geysers. Certain of these resulted in extension of the known steam field to the north, east, and south. Others were not productive. Finally, public funds were used to finance drilling for research purposes at Marysville, Montana, Raft River, Idaho, Kilauea, Hawaii (not shown on map), and west of the Valles Caldera of New Mexico.

Beginning in the middle 1960s, several states have passed laws to allow the leasing of state land for geothermal exploration. Leases of state land in California were granted as early as 1968. This has been followed by sale of geothermal leases by Oregon, Idaho, and New Mexico. The Geothermal Steam Act of 1970 established the legal framework for leasing of geothermal resources on federally administered public lands. Procedures for the actual leasing of public land required approximately three years to formulate, and the first applications were accepted in January 1974. Since that time, leases of approximately 100 000 acres of public land have been sold on a competitive basis in four states (California, Oregon, Nevada, Utah), and noncompetitive leases have been granted on about twice that acreage in Utah and Nevada. This has a potentially vast importance in furthering exploration, as nearly two-thirds of the total land in the western United States is publicly owned. For example, the important prospect at Roosevelt, Utah, is on federal acreage.

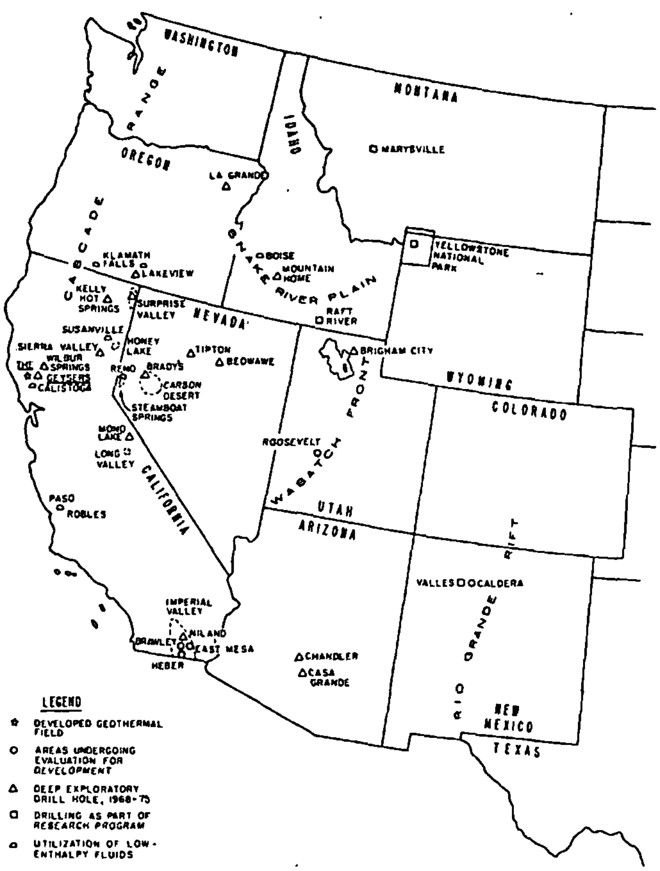


Figure 1. Geothermal exploration and development in the western United States, 1968–1974.

The Department of the Interior has a stated goal of awarding 1 000 000 acres in geothermal leases by the end of 1975. This represents approximately 10 percent of the total acreage covered in applications for lease.

LEGAL AND ENVIRONMENTAL PROBLEMS

As problems have decreased concerning the availability of land in the past 18 months, problems have arisen concerning the compatibility of geothermal exploration and development with the legal requirements of environmental protection. These problems have erupted into conflicts over the issuance of specific leases of public land or permits to drill, especially in the state of California, with its stringent environmental act (California Environmental Quality Act).

Environmental safeguards are stipulated in leases of public land. Further, certain classes of public land (national parks and monuments, for example) are closed to geothermal exploration, and there is wide discretion to deny leases for land in national forests and other areas of designated use.

Concurrently, there have continued to be problems (often involving court action) over the nature of the geothermal resource, its relationship to water resources, and its ownership in cases where ownership of surface rights is severed from ownership of mineral rights. Several states, following the implicit definition in the Geothermal Steam Act of 1970, have declared geothermal resources to be *sui generis*, a separate category of resource subject to legislation and regulation specific to it. This has not stopped legal and administrative efforts in several states to make geothermal exploration and development subject to regulation under water rights law. Most recently, several states have considered legislation to give ownership of geothermal resources to the state.

FINANCING

Financing for geothermal exploration, research, and development has become more plentiful in the past few years, from both private and public sources. This has been accompanied by improved access to markets as electric utilities, government agencies, and major industrial users of energy have expressed greater willingness to develop and consume geothermal energy.

The federal budget for geothermal research, development, and regulation has grown to about $50 million at this writing. This has funded research by the U.S. Geological Survey, and by numerous research laboratories, universities, and private companies. This has included assessment of the quantity and nature of the geothermal resource, testing of exploration methodology, development of instrumentation and technology for utilization, and attempts to resolve various legal, institutional, and environmental problems. Not all of these research projects have born fruit.

Because there is no adequate assessment of the extent of geothermal resources in the United States, companies have tended to lease extensive acreage prior to carrying out detailed exploration. Because of the difficulties in assembling large blocks of acreage (legal and title problems, federal holdings, land withdrawals), leasing has been competitive and increasingly expensive. Data of exploration largely are proprietory. Even the specifics of which surveys are used under which field conditions tend to be kept confidential.

EXPLORATION PROCEDURES

There has been increased use of geoelectric surveys (dc-resistivity, electromagnetic soundings, magnetotelluric surveys), as well as temperature-gradient drilling, hydochemical surveys, and passive seismic surveys in the past decade, and lessened reliance upon aerial infrared surveys or aeromagnetic and gravity surveys. Increasing attention has been given to the geologic delineation of geothermal provinces on the basis of regional structures, plate tectonic theory, and extrapolation outward along previously identified features. Drilling of temperature-gradient holes has become the most widely used exploration tool in The Geysers area.

The Geysers, California

Although there is far less drilling of deep exploratory holes without prior geological, geophysical, and hydrochemical exploration than in previous decades, several companies continue to drill deep holes solely on the basis of land control. As the availability of obvious targets has lessened, so has the success rates of these random holes.

Drilling has progressed to greater depths, in response to the increased value of steam, improved methods of exploration, and a decrease in obvious, shallow targets. Average well depth at The Geysers is 2 300 m. Wildcat drillings elsewhere have gone to as great a depth as 3 300 m. Few significant holes are drilled to less than 1 200 m.

Generation capacity at The Geysers presently is about 500 mW. Four additional plant sites have been chosen, for the generation of an additional 400 mW. These may come on line in 1978. Nearly 200 deep holes have been drilled at The Geysers. Its area of proven productivity is greater than 40 km^2, and exploration is continuing at its present margins. Estimates of total sustainable yield run to 2 000 mW or more.

Geologically, the source of heat is related to late Quaternary volcanism and shallow intrusion in an area north and east of The Geysers. The region of extrusion and intrusion may exceed 600 km^2 in area, and an area in excess of 1 500 km^2 may be abnormally hot at depth. The reservoir is fractured, brittle, Mesozoic Franciscan graywacke of great thickness and lateral extent and is vapor dominated. Blowdown from the power plant cooling towers is reinjected into the reservoir, both on environmental grounds and to maintain mass and pressure within the reservoir. Reinjection comprises about 20 percent of production.

Hot water reservoirs of lower enthalpy have been encountered by drilling at distances of 20 to 40 km to the north (Clear Lake, not shown on map), northeast (Wilbur Springs) and southeast (Calistoga) in areas underlain by Franciscan graywacke, Tertiary volcanic rocks, and Mesozoic mafic and ultramafic rocks. Conditions at depth across the intervening distances are unknown.

Local opposition to geothermal development, based on the desire to preserve rural values, has slowed exploration through widespread use of regulatory and appellate hearings.

Jemez Mountains, New Mexico

The Jemez Mountains of northwestern New Mexico have as their principal feature a Quaternary caldera over 100 km^2. Within the Valles Caldera, 15 holes have been drilled to an average depth of almost 2000 m near the southwestern caldera margin. Extensive field tests of reservoir capacity and performance are scheduled for the summer of 1975, and the operator is negotiating with a local electric utility for the construction of a power plant. The reservoir contains hot water at temperatures that exceed 250°C. Its extent is unknown. To the west of the caldera, holes have been drilled for research purposes into Precambrian crystalline rock of the Nacimiento uplift. Attempts are being made to fracture the hot, essentially impermeable amphibolite and gneiss. This is the so-called hot, dry rock experiment. Other companies have taken leases in the vicinity and geophysical exploration is active.

Imperial Valley, California

Exploratory holes have been drilled at four locations across an 80-km distance in the Imperial Valley. Reservoirs contain hot waters of varying salinities. Highest temperatures (over 300°C) and enthalpies (250 cal/gm) are found in the area of greatest salinity (over 250 000 ppm TDS) at Niland. Exploratory drilling and research into treatment of the high salinity brine have continued at Niland, without satisfactory resolution of problems of corrosion, scaling, and waste disposal. On the East Mesa, the U.S. Bureau of Reclamation is attempting desalination of water using the thermal energy of low salinity (15 000 ppm) geothermal brines. At Brawley, three holes have been drilled into a low salinity reservoir; six holes have been drilled at Heber. In each of these, evaluation of reservoir conditions is continuing. Temperatures at 2000 m probably do not greatly exceed 200°C at any of these areas. Fractured, cemented sands of Pliocene age form the reservoir. Crystalline basement probably is deeper than 5 km in each of these areas, and it may be possible to locate a deeper, higher enthalpy reservoir in one or more of these areas. However, permeability is known to decrease rapidly with depth. Heat source probably is related to conductive and convective transfer of heat from a very shallow mantle (less than 20 km in places).

Other Areas

Recent news items have dealt with exploratory drilling near Roosevelt, Utah, where four relatively shallow holes have been drilled in an area of opalitized and steaming ground, and are undergoing evaluation. Roosevelt is one of several prospects along the Wasatch front of Utah, an area characterized by Tertiary intrusions and mineralization, and by development of deep, sedimentary basins in late Tertiary and Quaternary time.

Another area of active exploration is the Carson Desert of Nevada, where four companies have drilled five holes in the past 18 months. A major sale of federal leases is planned there for June 1975. Temperatures are known from past exploration at Brady's Hot Springs to exceed 200°C. Permeability is questionable. The Carson Desert is an extensive region of downwarp or downdrop, within which pre-Tertiary basement may be depressed 2000 to 3000 m in places. Late Tertiary or Quaternary intrusions are suspected as the source of heat, although total crust is thin (30 to 35 km) across the Basin and Range province, and heat transfer mechanisms may be similar to those of the Imperial Valley. Drilling depths have reached 2300 m.

Research by the U.S. Geological Survey is continuing in Yellowstone National Park. Although exploratory drilling barely exceeded 300 m in depth, field temperatures of 250°C or higher are projected on chemical and thermodynamic bases, and a molten body of batholithic dimensions is suspected at relatively shallow depth. Private companies now are beginning exploration of areas of Quaternary volcanism to the west and southwest in the Snake River plain of Idaho.

Increased costs of heating fuels have refocused attention on utilization of low enthalpy waters for space heating, agricultural use, and industrial processing. Research and development activity is underway in several localities in widely differing geologic terrains (Paso Robles, California—thermal fish farming; Susanville, California, Boise, Idaho, and Klamath Falls, Oregon—municipal heating; Lakeview, Oregon, and Calistoga, California—greenhouse heating; and Reno-Steamboat Springs, Nevada—municipal and commercial heating). In general, drilling depth does not exceed 600 m and is often less than 100 m, and high capacity, low salinity, hot water aquifers are sought.

Research into utilization of low enthalpy aquifers has led to drilling of a 1500-m-deep hole at Raft River, Idaho, where 150°C conditions were encountered.

Widespread drilling for hydrocarbons on the Gulf Coast of Texas and Louisiana (not shown on map) has allowed improved definition of the low salinity, geopressured, hot water aquifers found at depths greater than 3500 m. Methane dissolved in the hot water provides both an additional recoverable energy resource and an expanding gas drive to lift these fluids to the surface. Heat source is thermal gradient plus exothermic diagenetic changes in Tertiary sediment. The reservoir is faulted, wedge-shaped sands deposited in the high-energy environment. Temperatures to 270°C at 400 m are reported. The geopressured system is believed to be extensive. Exploratory drilling is thought to be imminent.

Oil and gas exploration have continued to identify high temperature aquifers elsewhere.

Continued exploration is forecast within the Carson Desert of Nevada, along the Wasatch front of Utah, in the Rio Grande rift of New Mexico and Colorado, within the Snake River Plain of Idaho and Oregon, and along the Oregon Cascade Range of Quaternary volcanoes, in addition to development drilling in the Imperial Valley, the Valles Caldera, and the vicinity of The Geysers.

Hunt for Oil, Gas Quickens All Across U.S.

In oceans, mountains and desert, drillers are looking for—and finding—new fuel supplies. Cost: 50 billion dollars in 1980 alone.

EVANSTON, Wyo.

What's happening around this little town nestled in the Rocky Mountain foothills along the Wyoming-Utah border is viewed by many experts as proof that the U.S. is a long way from running out of natural gas and oil.

Drillers are making strike after strike in one of the hottest series of oil-and-gas discoveries in years. It's all part of a fresh drive, literally stretching from coast to coast, to find domestic fuel supplies and cut the country's reliance on foreign producers.

Evanston's population has jumped from 4,890 to almost 7,000 in two years. About one fourth of the newcomers live in tents, campers or motels. Public services are strained to the limit, causing widespread resentment of oil-field workers who have flocked to the area. A sign in a downtown restaurant: "We will not serve oil-field trash."

Billions targeted. Like it or not, Evanston is caught up in a boom that is spreading across the nation as oil companies plow more and more of their record profits into a multibillion-dollar search for new energy supplies.

The petroleum industry plans to spend more than 50 billion dollars on exploration and production inside the U.S. this year, 26 percent more than the 40 billion spent in 1979. The spurt is so sharp that drilling rigs are in short supply, experienced workers are in heavy demand and the costs of oil leases are soaring.

In early September, 3,069 drilling rigs were working in the U.S., 34.7 percent more than a year ago. Oil companies expect to complete some 60,000 wells this year, breaking a record of 58,160 set in 1956.

The driving forces behind the boom are sharply higher prices for newly discovered oil and gas, plus new seismic techniques that help geologists find oil in formations deeper and more complex than ever before.

Drilling activity around Evanston is a prime example of how new technology is being used. The city sits atop an energy-rich formation called the Rocky Mountain Overthrust Belt, which stretches from southern Canada to northern Mexico and is 100 miles wide at its broadest point.

The Overthrust Belt was created more than 100 million years ago when the Pacific and North American tectonic plates separated, then later reversed and collided. The shifting pushed older, harder rock over the top of younger, softer formations where oil and gas usually are found.

Geologists estimate that the upheaval trapped up to 14 billion barrels of oil and 52 trillion cubic feet of gas that can be recovered from the formation with existing technology. By comparison, the U.S. uses about 6.9 billion barrels of oil and about 20 trillion cubic feet of gas each year.

Even with new methods, exploring the Overthrust is risky. More than 500 dry holes were drilled in the formation before American Quasar, a small independent firm, discovered a major oil field four years ago about 40 miles east of Salt Lake City. Since then, 175 wildcat wells—exploratory probes drilled in unproved areas—have led to discovery of 16 more oil-and-gas fields.

The Overthrust terrain is considered the most difficult onshore-drilling environment in the U.S., outside of Alaska. Much of the mountainous region is roadless. Drilling rigs often must be airlifted in by helicopter. Winter temperatures sometimes plunge below zero and 30-foot snowdrifts are common.

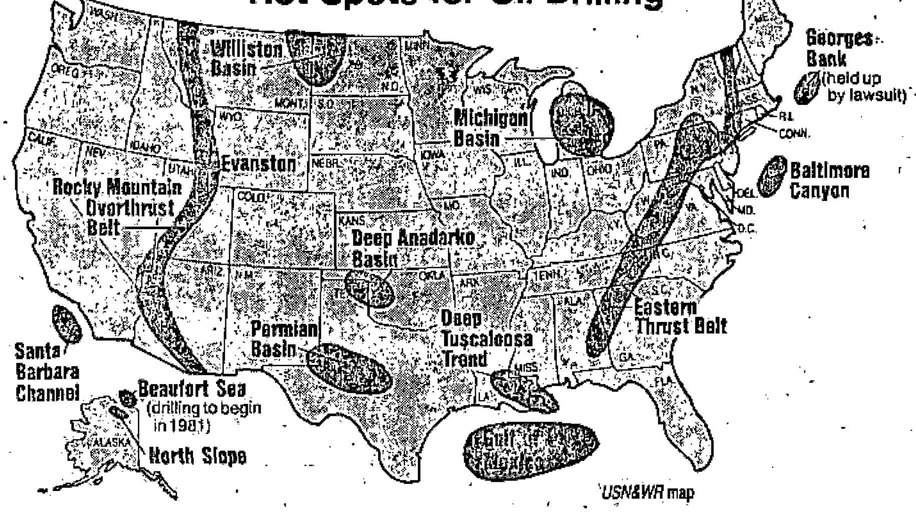
As many as 100 drill bits, costing $2,000 each, are needed to drill up to 18,000 feet through hard rock shielding oil and gas deposits. The cost of drilling a well in this region ranges from 2 million to 8 million dollars. Chevron U.S.A., Inc., a subsidiary of Standard Oil Company of California, recently completed a 15,000-foot gas well that cost 10 million.

The Overthrust Belt is only one part of the U.S. under heavy exploration. Texas, Oklahoma and offshore Louisiana still rank as the top drilling targets in the country. Along the Louisiana coast, oil companies recently tapped a formation called the Deep Tuscaloosa Trend, which is yielding major natural-gas discoveries below 15,000 feet.

More possibilities. Other promising areas include the Santa Barbara Channel off Southern California, the Deep Anadarko Basin in western Oklahoma, the Williston Basin on North Dakota's border with Canada and the Eastern Thrust Belt, a formation stretching between New York and Georgia created by conditions similar to those of the Rocky Mountain Overthrust.

The oil industry also remains keenly interested in the Atlantic Ocean off the East Coast of the U.S. despite a string of dry holes. Reasons: Drillers have found small but tantalizing deposits of natural gas and are encouraged by reports of oil discoveries off Canada's East Coast.

Hot Spots for Oil Drilling



The richest target of all is Alaska, where only a limited amount of drilling turned up the nation's largest oil discovery—the 9.6-billion-barrel Prudhoe Bay field on the North Slope. Although drilling is at a virtual standstill because of the federal government's slowness at leasing land for exploration, the U.S. Geological Survey estimates that the 49th state contains up to 49 billion barrels of undiscovered oil and 132 trillion cubic feet of natural gas.

Will the new burst of oil-and-gas drilling inside the U.S. free the country from dependence on imported fuels? Says Richard B. Powers of the Geological Survey's Denver office: "The Overthrust alone will never give us energy independence, but it will go a long way to helping us get there." □