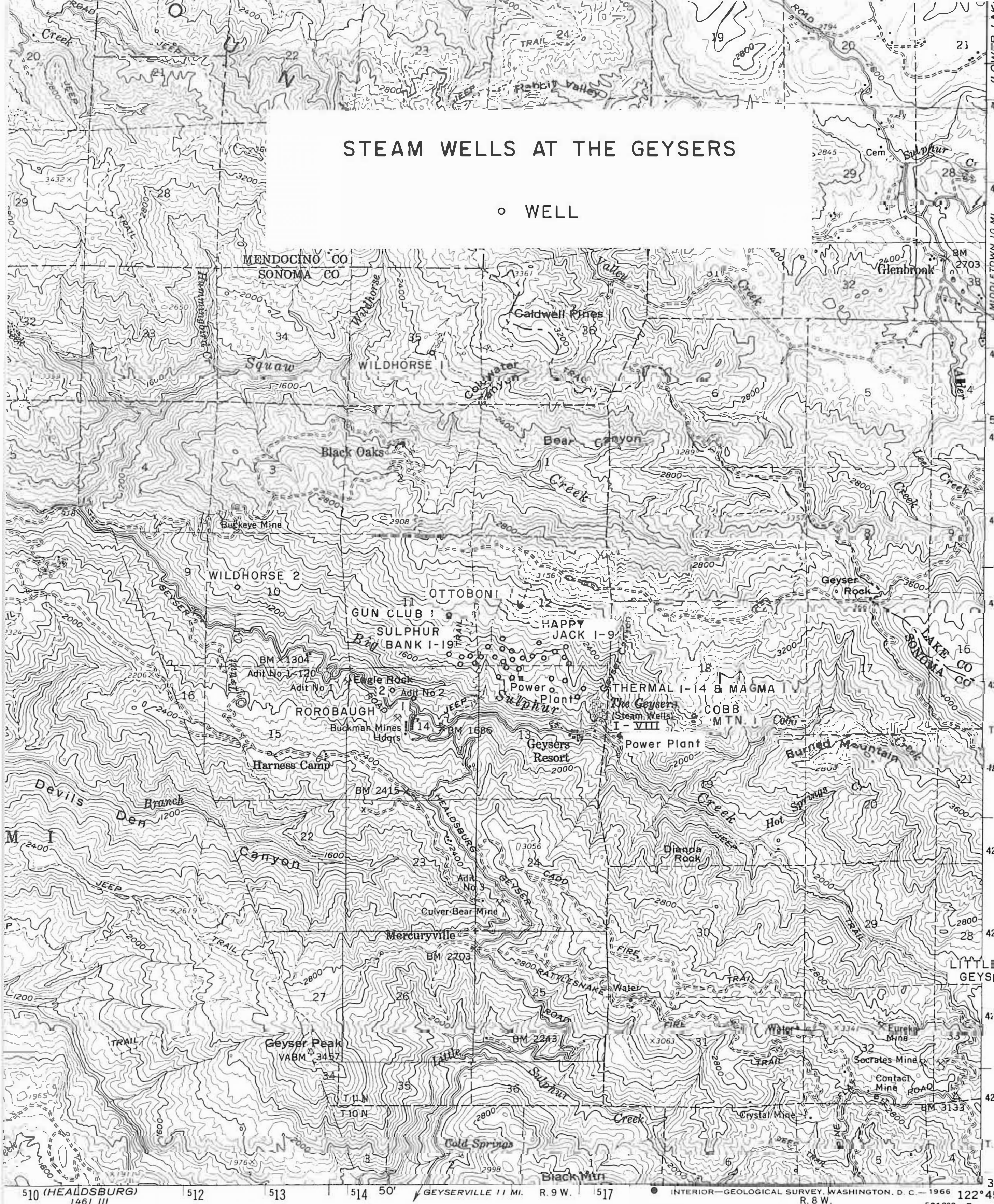
Northern California Geological Society

# Field Trip to The Geysers, Sonoma County, California

September 28, 1968

San Francisco, California




WELL LOCATIONS
J. B. KOENIG 9-20-68

SCALE 1:62500

CONTOUR INTERVAL 80 FEET
DOTTED LINES REPRESENT 20-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

UTM GRID AND 1959 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

# SE 1/4 KELSEYVILLE, CALIF.

BASE MAP BY U. S. G. S.

QUADRANGLE LOCATION

# Field Trip Guide to The Geysers, Sonoma County, California, September 28, 1968

by

James B. Koenig
California Division of Mines and Geology
Ferry Building
San Francisco, California 94111

There are no geysers at The Geysers. Despite this misnomer, the geothermal development is of significance for two reasons: first, this was the first geothermal field in the western hemisphere at which electric power **was** generated from steam; and, secondly, it is still the only steam field generating electric power in the United States.

Location. The Geysers geothermal area is about 75 air miles nearly due north of San Francisco, in the northeastern corner of Sonoma County, California, near its intersection with Lake and Mendocino Counties (see map). Clear Lake is about 15 miles to the northeast. The Mayacmas Mountains of the northern Coast Ranges trend northwest across the area, reaching elevations of over 4,000 feet. Northwest-flowing Big Sulphur Creek is at an elevation of about 1,600 at The Geysers resort. Access to the area is by paved, but narrow and twisting, roads from Cloverdale and from Geyserville.

Geology. The geology of the Kelseyville 15-minute quadrangle, in which the greater part of the geothermal area is located, was mapped partly by Bailey (1946) and wholly by McNitt (1968 and 1963).

The area is underlain by a thick sequence of graywacke, interbedded shale, basalt, and minor chert, and generally concordant serpentine and diabase bodies. These rocks usually are assigned to the Franciscan Formation of Late Jurassic and Cretaceous age. Franciscan rocks often are highly folded, fractured and sheared, to the point where few of the original bedding features can be recognized readily. A discussion of the nature and problems of the Franciscan Formation appeared in Bailey et al (1964).

McNitt (1968) questioned this picture of a chaotic, highly contorted Franciscan Formation:

> "In mapping the Kelseyville quadrangle .... it was possible to subdivide those rocks previously assigned to the Franciscan Group into two distinctive units. The younger unit consists of interbedded sandstone and shale and directly overlies the older unit, which is a dense graywacke interbedded with chert and basalt, and intruded or interbedded with basic igneous rocks. Although the contact between the upper and lower units

is not well exposed, both units dip, on the average, from 30° to 45° to the northeast, and, therefore, are believed to be generally conformable. Structural relief is insufficient in the quadrangle to expose the base of the lower unit, and the top of the upper unit has been removed by erosion. Measurements on structural cross sections indicate a minimum thickness of approximately 15,000 feet for the lower unit, and 10,000 feet for the upper unit."

Shales, siltstones and minor conglomerates of probable Early Cretaceous age are exposed to the southwest and northeast of the Kelseyville quadrangle. Lithologically, these are similar to the miogeosynclinal Cretaceous sedimentary rocks found at the western edge of the Central Valley. Most probably these rocks are in fault contact with the Franciscan rocks.

Around Clear Lake, locally, is the Cache Formation, a lacustrine sandstone and siltstone, which has been dated as late Pliocene on the basis of diatom identifications. Immediately above the Cache Formation, to the east and north of The Geysers, is a series of volcanic flows, domes and pyroclastic debris. This consists of obsidian, rhyodacite, dacite (including pyroxene dacite), andesite, and quartz-bearing olivine basalt. Unpublished radiometric ages of certain of these bodies indicate that volcanic activity ran from about 3 million years before the present to perhaps 50,000 years ago. Some volcanic activity may have been even more recent.

Recent landslide debris is common in and near fault zones, obscuring bedrock geology.

Regional geology is summarized by Koenig (1963).

Structurally, very different views of the Mayacmas Mountains have been expressed by different workers. All agree on the presence of major northwest-trending fault zones. McNitt (1968) described the Mayacmas Mountains as "a large horst, bounded on the northeast and southwest by structural, as well as topographic, depressions". These "depressions" are the areas of miogeosynclinal Cretaceous shales and siltstones. Within the Mayacmas Mountains, McNitt described a series of tilted, rotated fault blocks, downside generally on the southwest, repeating a gently folded sequence of Franciscan rocks. Cumulative throws on major faults are on the order of 10,000 to 20,000 feet.

Other workers, including Bailey, have described complexly folded, faulted and sheared zones within the Franciscan Formation. Major faults within the Mayacmas Mountains are described as normal; to the west faulting is described as strike-slip. Still other workers (including W.R. Dickenson, unpublished) have described thrust fault relationships in this and adjacent quadrangles. Generally, these geologists have described the miogeosynclinal Cretaceous rocks as being shallow, flat thrust plates, outliers from the homoclinal ridge at the western edge of the Central Valley. This is in sharp disagreement with McNitt's view that these miogeosynclinal Cretaceous rocks are preserved in down-dropped blocks or grabens.

Thermal activity. The region around Clear Lake, involving parts of Sonoma, Mendocino, Lake, Napa, and Colusa Counties, is noted for hot springs and wells, and mineralized cool springs. Several of these areas have become sites of resorts and health spas. Many have been studied, at least in passing, as potential sites for geothermal power development. The following table shows characteristics and drilling history for several of these thermal areas.

It is interesting to note that this general area of thermal manifestations coincides with a belt of mercury mineralization, an area of borated, carbonated and ammoniated ground waters, and with a major gravity low of some 25 milligals closure, centered just south of Clear Lake. It has been suggested that these are all related genetically to the Quaternary volcanism, and that, perhaps, a molten or near-molten body underlies portions of the region.

At The Geysers, most thermal activity is confined to the canyon of Big Sulphur Creek, or to the canyons of small tributary creeks, in a zone extending for roughly 5 miles in a southeasterly direction, from the "Big Geysers" to the "Little Geysers". There are at least 3 areas of fumaroles and steaming ground, plus more than a dozen hot springs, at temperatures ranging from 50°C to the boiling point. Two miles east of this zone is another series of hot springs (Castle Rock and Anderson Springs) at temperatures up to 73°C.

In 1927 it was estimated by Allen and Day that for an area of about 50 acres at The Geysers the discharge from hot springs was 5,000 gallons per hour. This surface discharge is not very large when compared to such hot springs as Thermopolis, Wyoming (over 700,000 gallons per hour at about 57°C), or Amedee Hot Springs, California (about 40,000 gallons per hour at 80° to 93°C). Surface discharge, therefore, may not be an adequate indication of subsurface heat content or reservoir volume. This is so especially where temperatures are high, and much heat and water release is by evaporation.

Geothermal development. The steam vents and hot springs of The Geysers were discovered by a bear hunter in 1847. Within a decade, a resort was built that achieved national prominence and flourished through the latter half of the 19th Century.

Plans to use the steam for agricultural and industrial processes were discussed repeatedly in the early days of this century. After the successful generation of electric power at Larderello, Italy, from natural steam, in 1904, plans were made to drill for additional steam at The Geysers. Between 1921 and 1925, eight wells (numbers I-VIII)

## Characteristics of selected thermal areas, northern Coast Ranges

| Area | Description | Drilling history |
|---|---|---|
| Calistoga | 18 mi. SE of The Geysers; 2-3 mile zone of hot springs and shallow hot wells; large total flow; resorts; minor greenhousing; max. surface T. of 78°C; shallow wells "boiling" | 3 wells drilled 1960-61 by Calistoga Power Co., to 900', 1100' and 2000+'; max. T. of 137°C; abandoned |
| Wilbur Springs | 25 mi. NE of The Geysers; 3 groups of hot springs in 5 mile zone -- Wilbur (20 springs, up to 72°C; 1700 gph at 62°C); Abbott mine (2 hot springs); Elgin mine (5 springs, up to 67°C); minor resorts; mercury workings | 2 wells; Thermal Power Co., 1965, to 1240'; Cordero-Worldwide, 1968, to 3700'; max. T. above 115°C; abandoned |
| Skaggs Springs | 15 mi. SW of The Geysers; 3 springs, moderate flow, max. T. of 57°C; minor resort; mercury workings | |
| Sulphur Bank mine | 15 mi. NE of The Geysers; 10 springs at sulfur and mercury workings; max. T. in mine 80°C; at surface 50°C; minor flow | 2 wells drilled by Magma Power Co. & assocs., 1961, to 1400' and 5000'; max. T. above 185°C; abandoned |
| Harbin Springs | 9 mi. E of The Geysers; 3 springs, highest 49°C; moderate flow; resort | |
| Fort Bragg | 150 mi. NW of The Geysers; geochemical and geophysical anomalies; no surface thermal effects; Branscomb "mud pots" (cool) 15 mi. NE | 2 wells drilled by Northern Plains Pet. Co., 1965, to 4000' and 1400'; max. T. of 50°C |
| Castle Springs | 6 mi. SE of The Geysers; 2 springs; moderate flow; max T. 73°C; resort | |
| Anderson Springs | 7 mi. ESE of The Geysers; 1-mile zone of 7 springs, to max. T. of 63°C; resort; mercury workings nearby | |
| Sonoma Valley | 25-30 mi. S of The Geysers; at least 13 hot wells, in 4 groups; max. T. of 48°C; resorts; homes; farms | |

were drilled, but the project failed for lack of adequate local demand for electric power. The deepest of these wells went to 640 feet. At least one still is capable of producing steam. None is in use currently; several have been plugged.

In the 1950's interest was renewed in geothermal power generation. Magma Power Company obtained a 99-year lease, in 1955, for thermally active lands along Big Sulphur Creek. With its partner, Thermal Power Company, six wells (Magma 1, Thermal 1 through 5) were drilled between 1955 and 1957. The deepest of these, Thermal 3, went to a depth of 1,404 feet. One well, Thermal 4, blew out, and, despite subsequent attempts over the years to seal the blowout, to quench it, and to relieve steam pressure by drilling additional wells nearby, still is blowing out of control.

Flow tests were made by Thermal Power Co. in December, 1957, which indicated total steam flow at wellhead of about 300,000 pounds per hour at 115 psig for four wells. Pacific Gas and Electric Company ran additional pumping tests in August, 1958, and, upon satisfactory completion, signed a contract for purchase of steam on October 30, 1958. Wells Thermal 6 through 11 were drilled in 1959. Thermal 11 was drilled directionally to intersect the blowout, Thermal 4; over one-quarter million gallons of cool water were injected to quench the blowout. This did not succeed, but Thermal 11 was completed as a steam production well.

Geothermal power generation became a reality in June 1960, when a 12,500 kw plant began generating electricity from some 250,000 pounds of steam per hour supplied by 4 wells. Thermal 11, drilled to aid in control of the blowout is one of the wells supplying steam to this first generating unit.

Since 1960, drilling has been to ever-greater depths. Thermal 12, in October 1961, was completed to 1,950 feet -- and is now considered to be a "shallow" well. Also, since 1960, drilling has moved out from the first site, an area of about 80 acres on the north bank of Big Sulphur Creek opposite The Geysers resort. In September 1961, the first of the Sulphur Bank series was drilled a mile to the northwest of known production.

The early wells of the Sulphur Bank series were not very successful overall. Most were comparatively shallow, with the exception of Sulphur Bank 4, which was deepened to 5,317 feet in 1965, and then abandoned. The mile of terrain between the Thermal and early Sulphur Bank series has, however, been drilled successfully: there are 19 Sulphur Bank and 9 Happy Jack series wells. These have been deeper wells, generally, averaging perhaps 2,500 to 3,000 feet. The deepest, Happy Jack 9, reached 6,091 feet total depth.

In 1964, partially to satisfy lease requirements, Thermal Power Co. drilled and completed two wells at "Little Geysers", an area of fumarolic and hot springs activity some 5 miles southeast of the initial site of exploration. This area is part of the structural and thermal "trend" on Big Sulphur Creek. Presently, the locus of geothermal activity has returned to the Little Geysers, with a third well recently completed at about 150,000 pounds per hour of steam, and a fourth well being drilled at this writing. Plans are to develop steam reserves sufficient for a 50,000 kw plant, for expansion of generating capacity during the 1970's.

Since the initial successes of Thermal Power Co.-Magma Power Co. in drilling steam wells, 3 additional companies have been active in drilling at The Geysers, 4 or more have drilled at other areas in the northern Coast Ranges, and at least 3 more companies have been active in general geothermal exploration.

In the summer of 1966, Union Oil Company drilled a successful well, Ottoboni 1, one-quarter mile north of the field, to a depth of about 5,300 feet. It was the deepest well to date, and the first in an area not marked by surface manifestations of heat release. The following winter Union and Magma-Thermal signed an agreement pooling their leases, and providing for joint development of the area. Union became the field operator for Magma-Thermal.

Geothermal Resources International, of Bakersfield, formed expressly for geothermal exploration, has drilled two successful deep wells to the southwest of the Sulphur Bank wells. These are the only wells located on the south side of Big Sulphur Creek. The first was to 6,676 feet; the second was to 6,730 feet.

Signal Oil and Gas Co. has drilled more adventurous wildcats and step-outs, and this is reflected in their successful completion of but one of three holes drilled. The first, at Caldwell Pines, $2\frac{1}{2}$ miles north-northwest of the main field, reached a depth of 8,175 feet. This is the greatest depth reached in the entire region. Temperatures of about 200°C were encountered, perhaps because of the Quaternary basalt plug located at Caldwell Pines, but commercial quantities of steam were not found. Cobb Mtn. 1, one-half mile east of The Geysers, was successful, at over 7,500 feet. Signal's third hole was nearly two miles west of the early Sulphur Bank wells, and was not commercially successful.

As defined by successful drilling, the field is in 2 segments: one, over 2 miles long and at least $\frac{1}{2}$ mile wide; the other, 5 miles to the southeast, covering a couple of hundred acres. The interval between the two field areas is untested, although hot springs issue at several places.

Extensive areas of the north Coast Ranges have been leased by the several companies active in geothermal exploration. This summer a geothermal test was drilled at Wilbur Springs, some 25 miles northeast of The Geysers, by Cordero Mining Co. (Sun Oil) and Worldwide Geothermal

Exploration Co. (Tex-Fel Petroleum). It reached over 3,000 feet in depth. An earlier test at Wilbur Springs, by Magma Power Co., in the fall of 1965, reached only 1,240 feet.

Following is a listing of wells drilled in the area of The Geysers. (See map for locations.)

| Well designation | When drilled | Status |
|---|---|---|
| I-VIII | 1921-1925 | Shut-in or plugged |
| Magma 1 | 1955, redrilled 1957 | Connected to Unit 1 |
| Thermal 1-14 | 1955-1963; 1 re-drilled 1967 | 5 connected to Units 1&2; 1 blowout; 1 plugged; others shut-in |
| Sulphur Bank 1-19 | 1961-1965; 2 re-drilled 1968 | 10 connected to Units 3&4; 1 plugged; others shut-in |
| Happy Jack 1-9 | 1965-1968 | 1 connected to Units 3&4; others shut-in |
| Ottoboni 1 | 1966 | Shut-in |
| Geysers Gun Club 1 | 1968 | Shut-in |
| Little Geysers, 2 wells | 1964 | Shut-in |
| Little Geysers, G.D.C. 65-28 | 1968 | Shut-in |
| Little Geysers, D.&V. 73-33 | 1968 | Drilling |
| G.R.I. Rorobaugh 1&2 | 1967-1968 | Shut-in |
| Signal Wildhorse 1&2 | 1967-1968 | Plugged |
| Signal Cobb Mtn. 1 | 1967 | Shut-in |

Power generation. Pumping tests and flow estimates suggest that wells completed satisfactorily to date by Magma-Thermal, Union, G.R.I., and Signal, when flowed simultaneously, are capable of producing at least 4,500,000 pounds of steam per hour at field pressures of 80-110 psig. As a rule of thumb, some 20 pounds of steam per hour will generate one kilowatt of power. Therefore, 225,000 kilowatts of electric power have been proven by drilling. Estimates of field potential have ranged to over 1 million kw.

Pacific Gas and Electric Co. remains the sole customer for geothermal steam. That company has just completed installation of its fourth generating unit, bringing total rated capacity of the geothermal power system to 82,000 kw. This is enough to supply the average power needs of a city of 90,000 people. P. G. & E. has announced 2 additional units to be completed in 1971 and 1972, raising capacity to 192,000 kw. Additionally, P. G. & E. has spoken of its interest in adding to the facility, in increments of 50,000 kw, after 1972. A lead-time of some 30 months is necessary, say P. G. & E. spokesmen, for plant construction.

In an attempt to speed up development of the geothermal potential, Geothermal Resources International has discussed plans to construct its own power generating plant. G.R.I. has held discussions with the Bureau of Reclamation concerning the possible sale of power to that agency, and to a league of eleven cities in California that operate their own power system. These cities include Alameda, Santa Rosa, and Ukiah. G.R.I. has spoken of a 300,000 kw system; this would require their drilling an additional 25 to 30 wells.

P. G. & E. pays 2.5 mils (1 mil equals 0.1 cent) per kw-hr generated from steam. Actual power generation costs are probably about 5 mils. Plant is to be amortized over 30 years.

Two powerhouses have been built, each with 2 turbine units. The steam collection lines for Units 1 and 2 (first powerhouse) are connected with wells Magma 1, Thermal 5, 7, 9, 10, 11. Before the deepening and improvement of Thermal 7, the plant was served also by Thermal 13 and 14. Units 3 and 4 collect steam from Sulphur Bank 7, 8, 10, 11, 12, 14, 15, 16, 17, 18, and Happy Jack 3. Units 5 and 6, when built in 1971 and 72, will probably be served by other wells of the Happy Jack series.

Technology. Geothermal drilling procedures are by no means standardized, but certain generalities can be noted. Well spacing has varied from as close as 50 to 100 feet in older portions of the field, to more recent wells spaced at 1 per 5 to 50 acres. Wildcats, of course, have been a mile or more from nearest production. Holes of about 26-inch diameter are drilled, and conductor pipe emplaced to depths of about 100 feet. Drilling initially is by mud-circulating rotary rigs, to depths of between 500 to 2,000 feet, whereupon a casing string of 9 5/8-inch to 13 5/8-inch is cemented. If no additional cool ground water is encountered, the hole remains uncased below this point. Additional ground water zones may require additional casing. Once water is sealed off, drilling is by rotary method, circulating compressed air. The main advantage of compressed air is that steam zones can be recognized immediately: mud tends to "bake" onto the hot formation, sealing off steam flow. Speed of drilling may be increased. A disadvantage is the fine size of cuttings recovered from the hole.

Cementing practices in some of the earlier wells were inadequate, causing plugging or even blowouts. Mechanical abrasion of casing and valves by sand particles entrained in high-velocity steam has been an additional problem. Blowout preventers and mufflers are standard for safety and noise control.

Drilling rates in the graywacke, shale, and basalt of the Franciscan Formation have ranged from very slow to moderate. A few feet to a couple of tens of feet per hour are common. Drilling and completion times in the last year or two have varied from 5 or 6 weeks to 7 months in one extreme case requiring several redrillings.

Wellhead orifice size is generally about 10 inches, varying with the casing size at each well. Steam pressure to the turbines is about 90 psig. The steam is put through mechanical separators to remove abrasive rock particles prior to entrance into the turbine. As the steam is dry, no water-separator is required. Analyses of steam from several wells shows less than 1% non-condensable gases, mainly $CO_2$, $CH_4$, $H_2$, $H_2S$, plus $N_2$, A, and $NH_3$. (Certain wells, including Sulphur Bank 4, appear to have higher quantities of these gases.) Condensing turbines are used for power generation, rather than non-condensing turbines, as up to twice the electrical power can be generated from steam in the former type. The 4 units will consume some 1 2/3 million pounds of steam per hour. Of the condensate, up to 900 gallons per minute of pure water are to be discharged into Big Sulphur Creek. The remaining water is to be circulated for cooling steam or in small part evaporates to the atmosphere.

Some wells, when shut-in, tend to deposit ammonium carbonate and other substances. Others tend to condense water on the casing walls, occasionally lowering fluid temperatures to the point where boiling cannot be sustained throughout the column. Therefore it is usual that for wells not connected to turbines the gate valves be left partially or wholly open.

Reservoir. Primary, lithologic permeability in Franciscan graywacke or shale or basalt is very low. Yet, the rates of flow of steam and the relatively rapid recovery of pressure after shutting-in a well suggest that a large steam reservoir exists. Permeability, therefore, probably exists in fault and shear zones, in zones of shattered graywacke, and perhaps in areas of solution activity. The expansive force of steam generation may additionally fracture the rocks or enlarge existing fractures.

Flow pressure, temperature, and volume of steam produced are related variables, so that production temperatures are not necessarily the same as reservoir temperatures. Reservoir temperatures probably are on the order of 250° - 280°C; shut-in pressures reach about 450-500 psig. The seeming independence of shut-in pressure with well depth suggests that for much (perhaps all) of the field the thermal fluid is in the steam phase. It is not known if appreciable water recharge into the field occurs, or where and at what depths the steam-water interface exists. It has been suggested that there is a steam "bubble", sealed off from water recharge by silica and calcium carbonate deposits. In such a case the steam would represent an exhaustable body of finite dimensions, with no appreciable replenishment. This view is, of course, subject to much debate.

McNitt, following Allen and Day, believes that the steam is "held down" by the overlying layer of cool ground water, and thereby is prevented from rising to the surface in great amounts. Hot springs and fumaroles generally occur along fault and shear zones, and represent leakage from the system. Most geologists working in geothermal areas believe that the water represented by the steam is of meteoric or connate origin. The juvenile magmatic component, if any, is slight. Isotopic fractionation by H. Craig indicates less than 5% juvenile fluid. Also, experimental work in New Zealand has shown that common rock types contain enough B, Cl, $NH_3$, F, $CO_2$, etc., to provide these materials in the quantities observed in geothermal steam or brine.

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