MINERAL INFORMATION SERVICE

STATE OF CALIFORNIA
DIVISION OF MINES
VOLUME 13 NUMBER 3
MARCH 1960

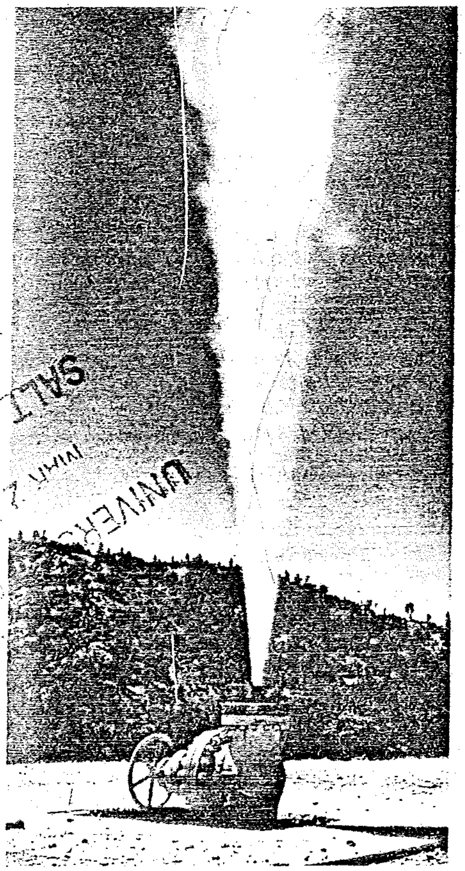
Geothermal Power

By JAMES R. McNITT

"It is ordered that a certificate of public convenience and necessity be and it is hereby granted Pacific Gas and Electric Company to construct, own, operate, maintain and use the geothermal steam—electric generating plant and transmission project described in this Application No. 40641."

This decision of the Public Utilities Commission of the State of California, dated the 7th of April, 1959, was of immediate concern to only a handful of men; but its effect has already been felt far beyond the borders of California. Indeed, men as far away as Italy, Guatemala, Mexico, Japan, and New Zealand have followed with intense interest the events which followed it.

The importance of this decision does not lie in the mere legality of granting a franchise, but in the credence it gives to an idea. Before the decision, this idea was a wild, promotional scheme; after the decision, it was a new, exciting, and, most important, a practical concept for the development of a natural resource to produce electric power. The purpose of this article is to tell briefly how this idea developed and what makes it work.



Magma No. 1 steam well at The Geysers, Sonoma County, California. Photo courtesy P. G. & E.

Geothermal power literally means earth-heat power. It is a well known fact that the temperatures within the earth are considerably higher than at its surface. This difference in temperature causes heat to flow from the interior of the earth to its surface where it is dissipated in the atmosphere. We are not normally aware of this heat flow because it has become one of those integral parts of our environment which we take for granted. If, however, molten rock which formed at great depths in the earth's crust, succeeded in working its way close enough to the earth's surface to produce volcanic activity, it would increase the quantity of heat flowing from the earth in a very obvious manner. But even after volcanic activity had ceased, a large amount of heat would remain locked in the hot, or perhaps still molten, rock lying quite close to the surface. This residual heat would slowly dissipate through the overlying rock and eventually escape into the atmosphere. Although the quantity of heat reaching the surface in areas of recent volcanic activity is greater than the average quantity for the entire earth's surface, it is still relatively small and difficult to detect.

If a fault intersects a body of hot, residual volcanic rock, lying at a shallow depth, the heat no longer dissipates slowly through the surrounding rock. The heated groundwater adjacent to the volcanic body, mixed with hot gases and steam coming from the volcanic rock itself, rises rapidly to the surface along the channel provided by the fault. This rapid increase in the quantity of heat flowing to the surface causes phenomena such as hot springs, geysers, and fumaroles which are typically associated with recent volcanic areas. As the hot water and steam rise to the surface, cold water, because of its greater density, flows downward to take its place. This water becomes heated in turn, and also rises to the surface. In other words, a huge convective heating system is formed above the buried volcanic rocks, and it is just this type of system which is utilized to produce geothermal power.

The hot water rising along a fault, like any water contained in a column, is subjected to the pressure of its own weight, which increases downward due to the increasing length of the overlying

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column of water. This increase of pressure raises the boiling point of the water progressively with depth, and allows it to remain in a liquid state at temperatures well above 100°C., the temperature at which it would boil at atmospheric pressure. At the relatively shallow depth of 1,000 feet, water would not boil until it reached 215°C. If a well is drilled deep into a channel which is conducting thermal fluids, the hot water is suddenly relieved of its overlying pressure and flashes into steam. The greater the depth at which the well taps the water, the higher will be the steam temperatures and pressures at the well head. In some cases, when the original heat content of the fluid is high and there is no surface water dilution, the steam may actually be superheated, i.e. heated above the boiling point temperature. Because no liquid water can exist under these conditions, the function of the well is not to relieve pressure on hot water, but to provide the steam an easy access to the surface. From the well, the steam can be piped to a generating plant where its thermal energy is converted to electrical power.

Geologists generally agree that geothermal fluids are a mixture of both magmatic water, that is, water coming directly from the molten rock, and ground water. They do not agree, however, on the relative importance of these two water sources. The study of isotopes in thermal waters may throw some light on this problem. After studying the relative abundance of the two oxygen isotopes, O^{18} and O^{16}, in the thermal waters at Steamboat Springs, Nevada, D.E. White of the U.S. Geological Survey estimated that the magmatic water content of the springs is less than 5%. Because so few thermal areas have been investigated in this manner, it is not known if this estimate can be applied generally, or if it is valid only in the Steamboat Springs area.

History of Geothermal Power Development

Larderello

The fumaroles and hot springs at Larderello, Italy, which is approximately 40 miles from Florence, were described as early as the 13th century. The first well to produce natural steam was drilled in 1904. By the late 1930's the Larderello fumarole area, which includes about 100 square miles, was producing 100,000 kw of electrical power. The German retreat of 1944, coupled with numerous allied bombings, however, completely destroyed the steam plants. The plants were rebuilt with U.S. aid, and by 1956, 262,000 kw of electrical power were being produced from 24 generating units. The present production is in excess of 300,000 kw.

The wells at Larderello, which range from 1,000 to 2,000 feet in depth, are drilled into early Tertiary and Mesozoic sedimentary rocks to intersect post middle Tertiary faults. These faults are the plumbing which taps the deeply buried magmatic heat source. The temperature of the steam varies from 266° F to 446° F and the pressure, which depends on the rate of steam flow, varies from 71 to 390 pounds per square inch. The natural vapor contains approximately 95% steam and 5% non-condensable gases, i.e., gases which remain in the vapor phase at comparatively low temperatures and pressures. Carbon dioxide accounts for about 80% of these non-condensable gases, and the remaining 20% consists of hydrogen, hydrogen sulfide, nitrogen, boric acid, ammonia, and

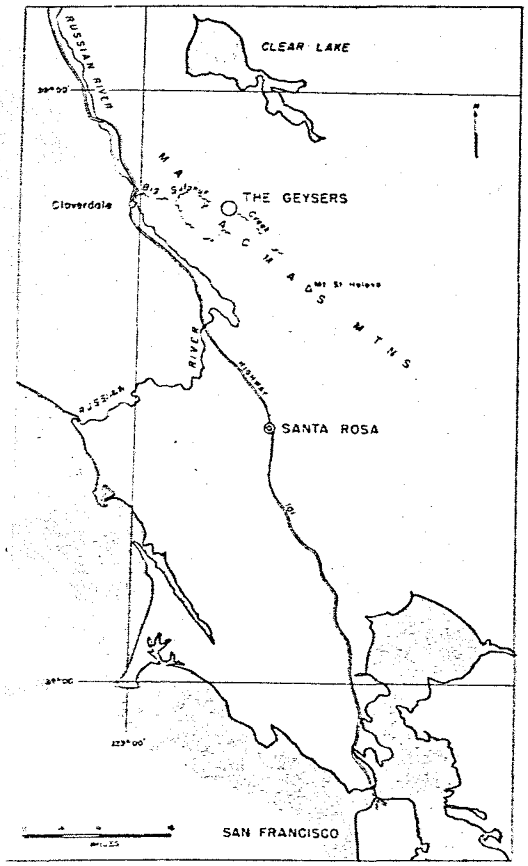
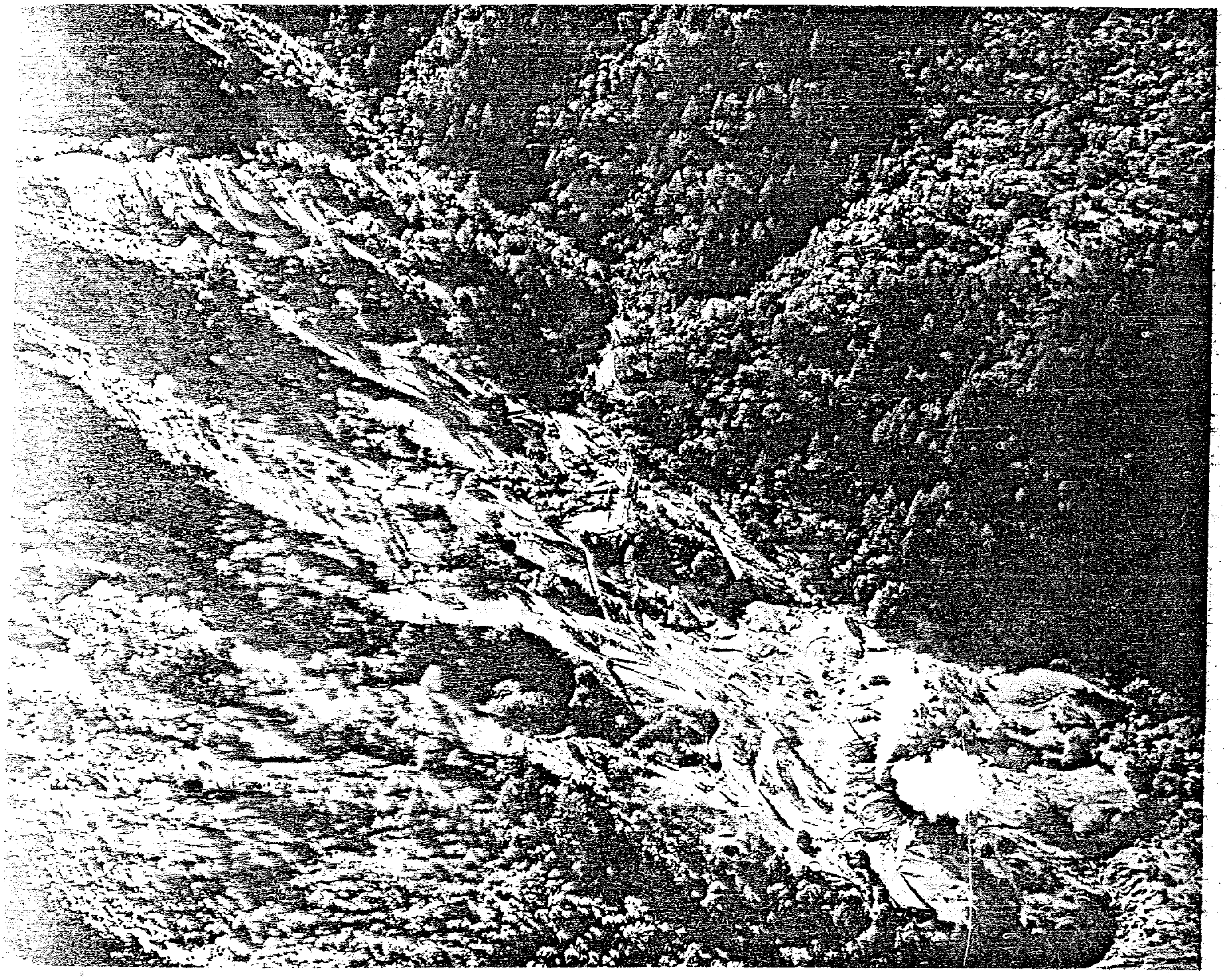


Figure 1. Index map showing location of The Geysers.



Big Sulphur Creek canyon, view southeast. The steam wells are shown at the lower right, and the power plant, still under construction, is seen in the center. Photo courtesy P. G. & E.

the rare gases helium and argon.

During the early development of the Larderello fields this comparatively high percentage of non-condensable gases in the steam created a serious engineering problem. Non-condensable gases decrease the efficiency of a turbine by increasing the condenser pressure, which should be as low as possible. In addition to this problem, and even more serious, was the corrosive nature of the boric acid. These two undesirable properties of the natural steam made it necessary to use heat exchangers in order to obtain secondary steam which was then fed to the turbines. The development of corrosion resistant alloys, and improvements in steam plant design, now make it possible to inject the natural steam directly into turbines. In fact, instead of being a hindrance, the non-condensable gases are now the bases for a profitable chemical industry. The Larderello Company is presently manufacturing the following by-products from the geothermal steam: boric acid, borax, carbon dioxide, boron carbide and sulfur.

Wairakei

The necessity for rapid development of power resources during the post-war period prompted the New Zealand government to initiate a geothermal power project at Wairakei, North Island in 1950. By 1954 eighteen wells were producing enough steam to generate 20,000 kw of electric power. These wells ranged from 574 to 3200 feet in depth. By 1958, 65,000 kw were being produced from 39 wells. The capacity of the whole Wairakei field, which is almost 50 miles long, has been estimated to be between 250,000 and 280,000 kw.

The geologic setting at Wairakei is slightly different from that at Larderello. At Wairakei, steep faults do not come to the surface, but are buried under a series of young volcanic and sedimentary rocks more than 3,000 feet thick. This volcanic-sedimentary rock series is contained in a northeast-trending graben structure and overlies a basement of graywacke. It is currently believed that faults in the

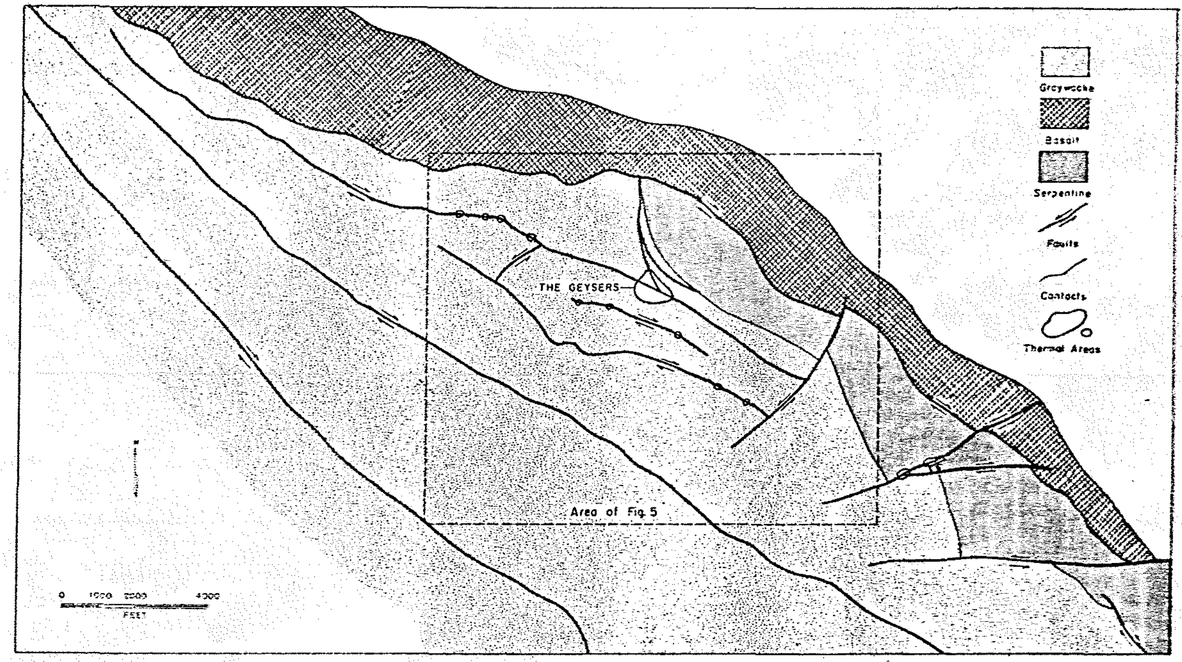


Figure 2. Generalized geologic map of fault zone along Big Sulphur Creek.

graywacke basement conduct high-temperature magmatic steam into the overlying rocks, which are quite porous and filled with groundwater. The heating of this groundwater sets up a convective geothermal system so that hot water escapes to the surface, and is replaced laterally by groundwater.

The amount and composition of the non-condensable gases in the thermal fluids at Wairakei are generally similar to the amount and composition of the non-condensable gases in the thermal fluids at Larderello. However, the high concentration of boric acid is not present at Wairakei.

Although Larderello and Wairakei have the most highly developed geothermal power projects in the world, two other countries are currently producing electricity from natural steam: Russia on the Kamchatka Peninsula, and Mexico in the State of Hidalgo. In recent years many other countries—Iceland, Fiji Islands, Chile, Nicaragua, El Salvador, Guatemala, Japan, and now the United States—have initiated geothermal power development programs.

California

The common occurrence of both recent volcanic activity and recent faulting makes California a promising area for the development of geothermal power. The Lassen Park-Shasta region is probably the most active thermal area in the state, but many other areas exist which may be potential sources of geothermal power. A few of the better known areas are Surprise Valley in Modoc County; the Mayacmas Mountains area of Lake and Sonoma Counties; the Casa Diablo area near Bishop; Coso Springs in Inyo County; Atascadero Springs in San Luis Obispo County; the Warner Hot Springs area in San Diego County; the Murrieta Hot Springs in Riverside County; and the Salton Sea area in Imperial County. Of these areas, the only one developed so far is The Geysers, in the Mayacmas Mountains of Sonoma County,

The Geysers (actually fumaroles) are located on the north bank of Big Sulphur Creek, approximately 16 miles upstream from its junction with the Russian River at Cloverdale (fig. 1). The hot springs and steam vents were discovered in 1847, and became a nationally known spa in the latter half of the 19th century. It was not until 1921, however, that J.D. Grant drilled the first steam well. By 1925, eight wells had been drilled. As is the fate of most visionaries, however, Grant and his associates were out of step with the march of time. Although sufficient steam was produced to establish the feasibility of the project, there was as yet no market for their product, and the project was abandoned. One of the more tangible results of Grant's project was The Geyser Development Company which was formed in the mid-20's. This company acquired the 5½-mile long strip of land bordering Big Sulphur Creek on which the fumaroles and hot springs are located.

Thirty years passed, and in 1955 Magma Power Company obtained a 99-year lease on approximately 3,200 acres of potentially "hot" ground. Between 1955 and 1957 Magma Power Company and its partner, Thermal Power Company, drilled six wells, and on the basis of flow tests taken in December 1957, Pacific Gas and Electric Company was approached with the proposal that it construct a steam-electric power plant at the Geysers. Further temperature and pressure tests, as well as feasibility and economic studies, were made by Pacific Gas and Electric and a price was determined for the steam. On October 30th, 1958, a contract between the producing companies and Pacific Gas and Electric was signed; and in April of 1959 the Public Utilities Commission of California delivered the decision quoted in the opening paragraph of this article. In May 1960, a 12,500 kw geothermal power plant will go into operation. This plant will be the first of its kind in the United States.

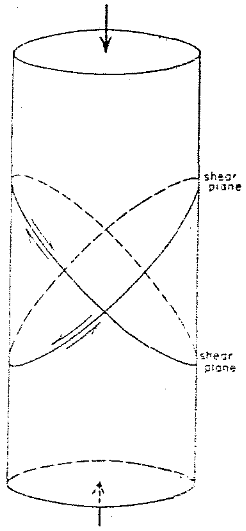


Figure 3. Fracture planes caused by compressive force. Arrows show the relative movement on planes.

Geology of The Geysers Area

As would be expected from the foregoing discussion, the geologic history of The Geysers region involves both recent volcanism and recent faulting.

The Mayacmas Mountains to the east of Cloverdale are composed of rocks of the Franciscan formation which strike N. 45°W. and have an average dip of 40° NE. This formation has never been accurately dated because of the lack of adequate fossil evidence, but indirect evidence suggests that it ranges in age from Late Jurassic to Late Cretaceous.

The rock units of the Franciscan formation are: basalt and graywacke, making up a conformable sequence in which the volcanic member ranges from approximately several hundred to 10,000 feet in thickness; cherts, most commonly occurring near the basalt-graywacke contacts; diabase plugs and serpentine sills which are intrusions into the sequence of sedimentary and volcanic rock; and metamorphic rocks which have been formed at serpentine contacts.

To the northeast of The Geysers, the Franciscan is unconformably overlain by the Plio-Pleistocene volcanic rocks which are so abundant in the Clear Lake area. The nearest Clear Lake volcanic rock occurring in the vicinity of The Geysers is the Cobb Mountain rhyolite, which caps a ridge approximately 5 miles to the northeast of Big Sulphur Creek.

A northwest-trending fault zone crosses the Franciscan rocks in the vicinity of Big Sulphur Creek. Although the faults have been mapped in detail for only 8 miles, the zone is known to extend considerably farther. The faults vary from approximately 70° to 90° in dip and their sense of movement is right lateral, i.e., as the observer faces the fault, the block on the far side of the fault plane has moved horizontally to the right with respect to the block on which the observer is standing. The clockwise rotation about a vertical axis of blocks within the fault zone is the principal evidence for right-lateral slip movement.

This fault zone has been the dominating factor in controlling the location of thermal areas in the Mayacmas Range. It is interesting to note that this same structure, during an earlier period of its history, also controlled the location of mercury mineralization in the Eastern and Western Mayacmas districts. The source of heat for the thermal areas, and probably the source for the mercury mineralization as well, is believed to be the same magma which produced the Clear Lake volcanic rocks only a few miles to the northeast.

Figure 2 is a simplified geologic map of the fault zone as it appears along the course of Big Sulphur Creek. Although the largest and most continuous faults trend northwest, the serpentine sill and the rocks adjacent to it have been displaced by northeast-trending left-lateral faults.

The geometry of these two fault sets is similar to the geometry of the shears obtained when a rock specimen is physically tested in the laboratory. Figure 3 shows diagrammatically how a brittle, homogeneous material will rupture when subjected to a simple compressive stress. The shear planes develop at approximately 45° to the axis of compression and the relative movement on these shears is shown by the arrows. Using this anology, it can be seen that northwest trending right lateral faults and northeast trending left-lateral faults can develop contemporaneously from horizontal compressive stress acting in a north-south direction.

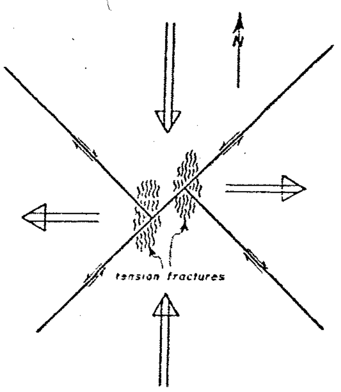
The northwest-trending contacts and bedding planes of the Mayacmas region are inherent planes of weakness; thus the northwest fault set dominates the northeast set. It is much easier for faults to develop along planes of weakness which already exist, rather than to form across them, especially when rupture in either direction will serve to relieve the compressive stress.

Where a large body of serpentine occurs in the fault zone a different situation develops. Serpentine is a weak rock and shears easily under stress as compared to basalt and graywacke. Unlike the graywacke, however, serpentine is a massive rock, and does not have preferentially oriented planes of weakness. Therefore, when the serpentine is faulted, both the northwest and northeast shear sets are equally well developed.

Strike-slip faults, whether right or left lateral, tend to remain tightly closed because the stress which formed them is compressional in nature. Although the rock mass breaks in order to relieve this stress, the stress itself tends to force the broken blocks together. How, then, can open channels form and remain open in a strike-slip fault zone? That such open channels do exist is indicated by the presence of thermal areas within the fault zone.

Figure 2 shows the location of these thermal areas with respect to the left- and right-lateral faults. Many small thermal areas are located along the north-

Figure 4. The intersection of a left lateral and right lateral fault. The large arrows show resolved stresses within the fault blocks.



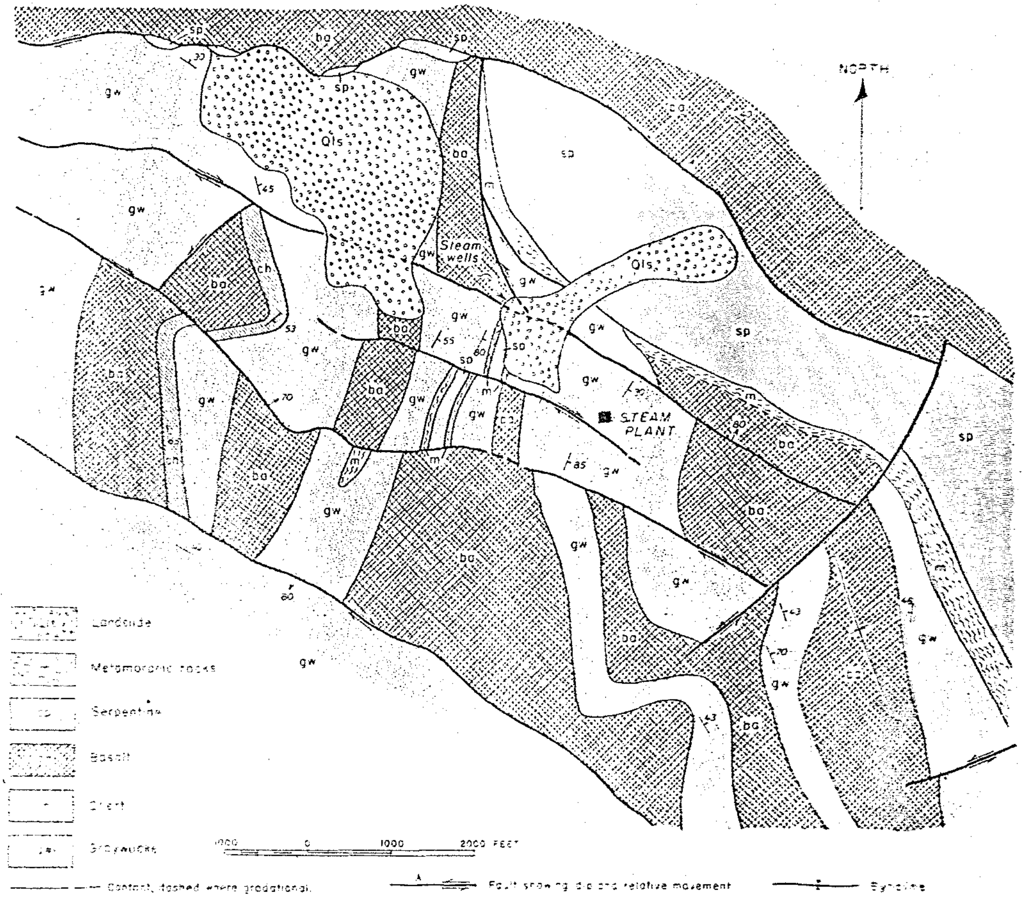


Figure 5. **Detailed geologic map of The Geysers area.**

west trending faults, but the larger fumaroles and hot springs are located near intersection points of the two fault sets. The reason that large thermal areas develop at these intersections can be illustrated diagramatically.

Figure 4 represents a right-lateral and left-lateral fault intersection, with arrows showing the relative movement along each fault. A resolution of the stresses within the east and west fault blocks results in an east-west tensional stress acting in a direction away from the fault intersection. A similar resolution of stresses in the north and south fault blocks shows that a north-south compressive stress is acting in a direction toward the fault intersections. The overall result of this stress pattern is to open up north-south oriented tension fractures at the intersection of the fault sets. These tension fractures are the channelways which allow the thermal fluids an easy access to the surface.

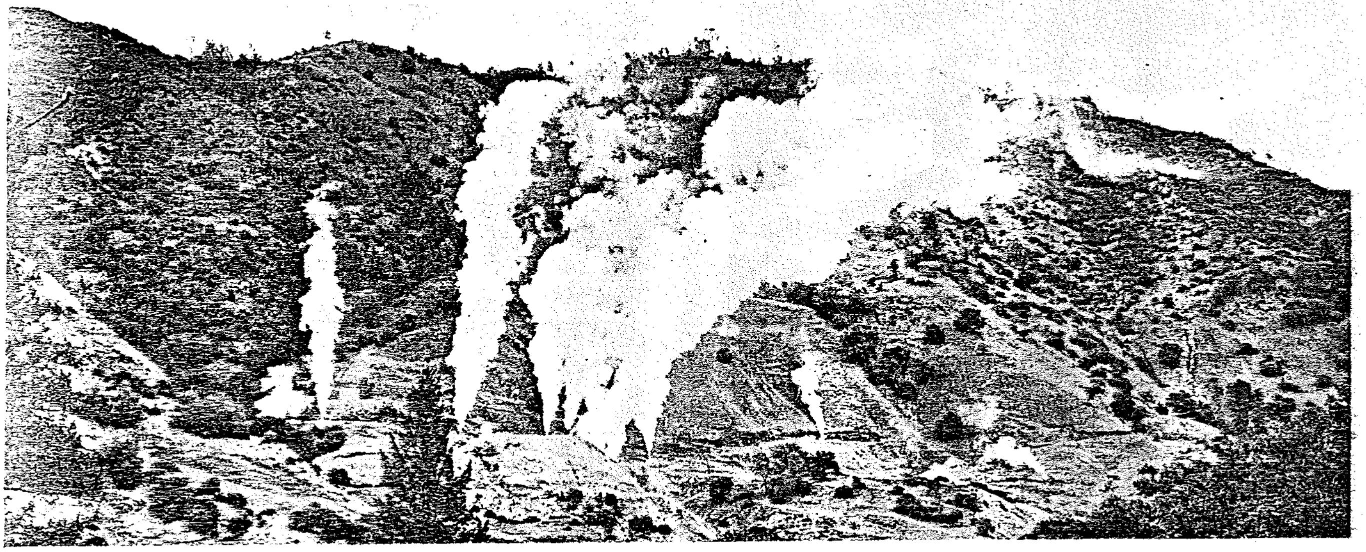
Figure 5 is a detailed map of The Geysers area, and illustrates some of the geologic structures which result from the type of faulting described above. The apparent right-lateral offset of chert, basalt and serpentine units is shown along several northwest trending faults. What is more significant, the map also illustrates the clockwise rotation of these units from their original northwest strike to a N. 20 E. attitude. Tensional fractures are developed in the steam well area which is located at the intersection of a left-lateral and right-lateral fault. The tensional nature of this immediate area is further demonstrated by the position of the triangular mass of graywacke, which is located directly northwest of the wells. Tension on the northwest-trending basalt-metamorphic contact permitted the graywacke wedge to be pushed northwest along the contact and into its present position.

From figure 2 it can be seen that thermal areas do not occur at all the fault intersections, and why only some of these intersections provide open channelways is still not known. It is probable however, that open channelways can be maintained on only the most recently active faults in the zone.

It is hoped that a better understanding of stress distribution and the manner in which the various rock types have adjusted themselves to this stress may be of help in future exploration for geothermal power in the Big Sulphur Creek area. Such an understanding would make it possible to project our knowledge of the controlling structures to greater depths and thereby produce steam at considerably higher pressures.

Recent Development

After Pacific Gas and Electric Company received approval for the geothermal power project from the Public Utility Commission in April of 1959, Thermal and Magma Power Companies drilled five more wells during the following summer. Holes ranging from about 800 feet to more than 1,000 feet in depth were drilled with a portable rotary rig similar to those



The Geysers thermal area as seen from the south side of Big Sulphur Creek. Photo by P. G. & E.

used in shallow oil fields. Approximately 300 feet of 13-inch casing was cemented in and a 12½-inch production hole was drilled below the casing. A specific "production horizon" has not as yet been detected, probably because of the steep nature of the controlling faults. It is hoped, however, that measurements of temperature gradients in the wells may help to determine specific production zones.

The area presently being drilled, which is defined by fumaroles, hot springs, altered or "bleached" ground, and the presently producing wells, is approximately 800 feet long and 300 feet wide. Although the wells have an average spacing of about 150 feet, interaction between adjacent wells is thought to be slight.

One of the major production problems thus far encountered was the blow-out of Thermal No. 4 well. This well was drilled on a flat bench about a hundred feet back from a steep drop-off. While the well was being drilled, steam began to seep from the side of the bench below the wellhead. In a few days the steam enlarged its own escape route until a blow-out was formed which measured approximately 5 or 6 feet in diameter. In the last 2 years, successive attempts to seal off the escape of steam have not been successful. In October of 1959, however, a 550-foot well was directionally drilled to intersect Thermal No. 4 well below its connection with the blow-out. This new well succeeded in diverting much of the escaping steam and, in fact, it is now one of the better producing wells in the area. The consequent reduction of steam pressure in the blow-out should make it possible eventually to stop the uncontrolled steam seepage at well No. 4. It is hoped that extensive grouting around well sites before the actual drilling begins will eliminate such problems in the future.

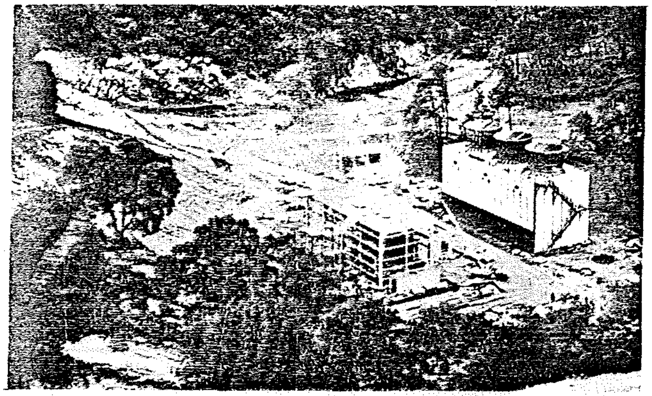
The amount of steam which flows from the wellhead is controlled by a manually operated valve. The quantity of steam flow in turn determines the pressure of the steam at the wellhead. Figure 6 shows how the well pressures decrease when the wells are opened to allow a higher rate of steam flow. The wellhead temperature is in turn dependent on the steam pressure. This is shown by the following readings taken on three of the wells in September of 1958.

Pressure (lbs./sq. inch)	Temperature (degrees F.)
59.7	337
62.4	339
75.4	358
94.2	363
104.1	357
132.1	370

It is interesting to note that these temperatures are consistently higher than the temperature of saturated steam for each corresponding pressure. In other words, the steam at The Geysers contains a significant amount of superheat. This means that unless the steam is subjected to pressures considerably higher than the pressure measured at the wellhead, a liquid phase cannot exist in the well, and all the thermal fluid will be in the vapor form.

The presence of superheated steam is an extremely important factor in the economic development of geothermal power. One of the major problems in maintaining steam wells in other areas is the deposition of calcite in the producing well. After a period of years the calcite deposit builds up enough to actually cut off the supply of steam. The calcium and carbon dioxide which form this calcite are carried into the wells as solutes dissolved in water. When the water flashes into steam due to the sudden decrease of pressure in the well, the calcium and carbon dioxide can no longer be carried in the liquid phase and calcium carbonate is deposited. If the steam is superheated, however, there is no liquid phase to carry the calcium into the well, and of course, there is no calcification. This is substantiated by the fact that the older wells at The Geysers have been producing for more than 35 years without any visible evidence of calcification.

Because the steam pressure drops when the flow is increased, there is a point at which the greatest efficiency can be obtained with a given combination



The Geysers power plant nearing completion. The turbine house is shown in lower center, and the cooling towers in right center. Photo by Dan McMillan.

of flow and pressure. It has been decided that the turbine would be operated at 100 lbs. per square inch which necessitates a wellhead pressure of 115 p.s.i. The 15 pound pressure drop is due to friction during transmission from the wellhead to the power plant, a distance of approximately 1,300 feet. The measured steam flow in 1958 at 115 p.s.i., for three of the wells which will serve the generating unit is shown below:

Well	Steam flow (lbs/hr.)
Magma no. 1	111,000
Thermal no. 5	82,000
Thermal no. 2	26,000
Total	219,000

The 12,500 kw generating unit will require about 250,000 lbs. per hour, therefore one or two additional wells will be required to provide sufficient steam for the unit.

Utilization

The steam produced at The Geysers has two highly desirable characteristics for use in a steam turbine: (a) it has a comparatively low content of noncondensable gases and (b) it is superheated.

As was mentioned earlier, one of the more serious problems at Lardarello is the comparatively high percentage of non-condensable gases as well as boric acid in the steam. These problems are minimized at The Geysers since the average non-condensable gas content in the steam is only 0.75 percent by weight and no boric acid is present. The relative percentages of the non-condensable gases are shown below:

Gas	Weight %
Carbon dioxide	88.73
Methane	5.49
Hydrogen	.74
Nitrogen	1.29
Hydrogen sulfide	2.96
Ammonia	.79

Chemical tests made by Pacific Gas and Electric Company indicated that the pH of the circulating water in the system would not go below 6.4 or above 7.8. Corrosion tests verified that several types of stainless steel could easily withstand the corrosive agents in the steam.

The turbine for the plant at The Geysers is designed for 100 p.s.i.g. and 348° F inlet steam conditions, which amounts to approximately 11° F superheat. The fact that the steam is superheated eliminates the problem encountered at Wairakei of having to separate water from the steam before it enters the turbine. Superheated steam is also desirable because it contains more heat energy than saturated steam and, therefore, will produce more power at the same pressure.

The generating plant, which is scheduled to begin operation in May 1960, will have an output of 12,500 kw. Since it will not be necessary to conserve the steam condensate, barometric condensers, which mix the condensate with the cooling water, will be used. An interesting feature of this cooling system is that less water is lost by evaporation than is supplied by the condensed steam, and consequently no external water will be necessary for the cooling make-up. The amount of water which will overflow from the cooling tower is 12 percent to 40 percent of the steam condensate, depending on atmospheric conditions. The plant site has been designed so that a second 12,500 kw unit can be easily installed when a sufficient quantity of steam has been developed to supply a second turbine.

The electrical energy produced at the power plant will be fed into the Pacific Gas and Electric Company system over a new 60 kw transmission tap which will tie into the existing Fulton-Hopland 60 kw circuit approximately 10 miles from the plant.

Conclusion

The utilization of natural steam to produce electric power has been found feasible in five areas

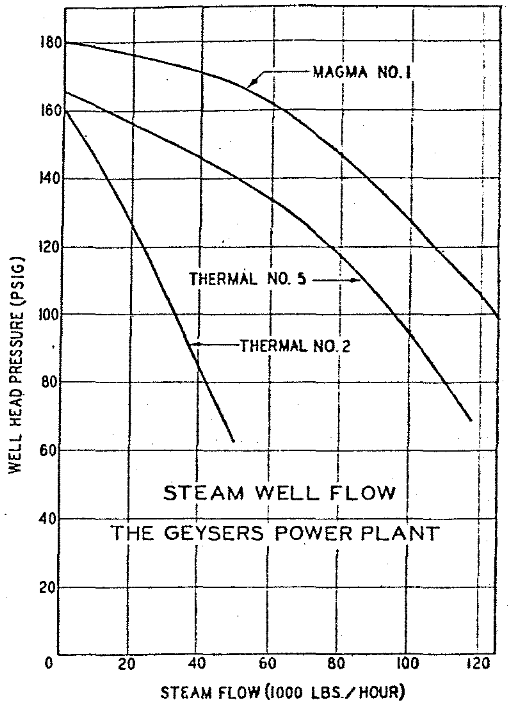


Figure 6. Steam flow-wellhead pressure curves. Measurements made in July and August 1958.

of the world: Italy, New Zealand, Russia, Mexico, and at The Geysers, California. Although the amount of geothermal power which The Geysers power plant will produce is small compared to the power produced in Italy and New Zealand, rapid development of the present producing site and active exploration in the state may well change this picture in the near future. Recent volcanism and faulting, which are responsible for the occurrence of natural steam, have played a major role in the geologic history of the west coast. A better understanding of these processes through detailed mapping of the areas in which they have been active is the next step toward the development of this new natural resource in California.

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Division of Mines Conducting Shale Survey

The Division of Mines is currently conducting a statewide investigation of the expansible shale, clay, and slate resources of California. This study includes the collection of geological and engineering data on the active quarries throughout the state and detailed field examinations of the raw materials in those marketing centers which are distant from present producers. This work will be conducted by Mr. John L. Burnett through the San Francisco office of the Division of Mines.

Expanded shale is used as a lightweight aggregate in concrete blocks and structural concrete. Although this material is more expensive than common sand and gravel, its light weight and superior insulating qualities cause it to be more desirable than common aggregate for many applications.

Expanded shale is manufactured by placing certain types of common shale into a furnace which rapidly heats the material to a temperature of 1800° F. to 2100° F. During this process the shale partially melts and becomes slightly plastic. The volume is then increased owing to the expansion of gases which are formed within the shale. The finished product contains many small air bubbles which reduce the weight per unit volume of the material.

There are six active producers of expanded shale in California. The market for this material is expected to be greatly enlarged in the future due to the acceleration of construction throughout the state. This increased demand may be satisfied by enlarging the capacity of existing plants and establishing new plants in other marketing areas. One of the main objectives of the present study is to provide private industry with basic engineering and geological information on the reserves of expansible shale in California.

San Jose has been chosen as the first marketing area to be studied in detail. Shale and interbedded sandstone are found in the hills which lie to the east and west of the San Jose-Gilroy area. The shale usually is a dark-colored, fine-grained sedimentary rock of marine origin. Some of the shale has been changed through metamorphism to form the metamorphic rocks phyllite and slate.

Preliminary research being conducted at the Division of Mines Laboratory has indicated that there may be a close correlation between the expansibility of these shales and their content of reducing agents, particularly organic carbon. Organic carbon is readily removed during surface weathering and therefore, degree of weathering must be considered in prospecting for shale deposits in the San Jose area. Shale bodies which are thoroughly weathered probably would not be a desirable raw material and, in general, surface material does not expand as readily as fresh shale that is found at depth.

The Division of Mines would appreciate receiving any contributions of technical information that might be useful in a project of this type. This office will also provide any information that is at its disposal to a potential producer or consumer of expanded shale.