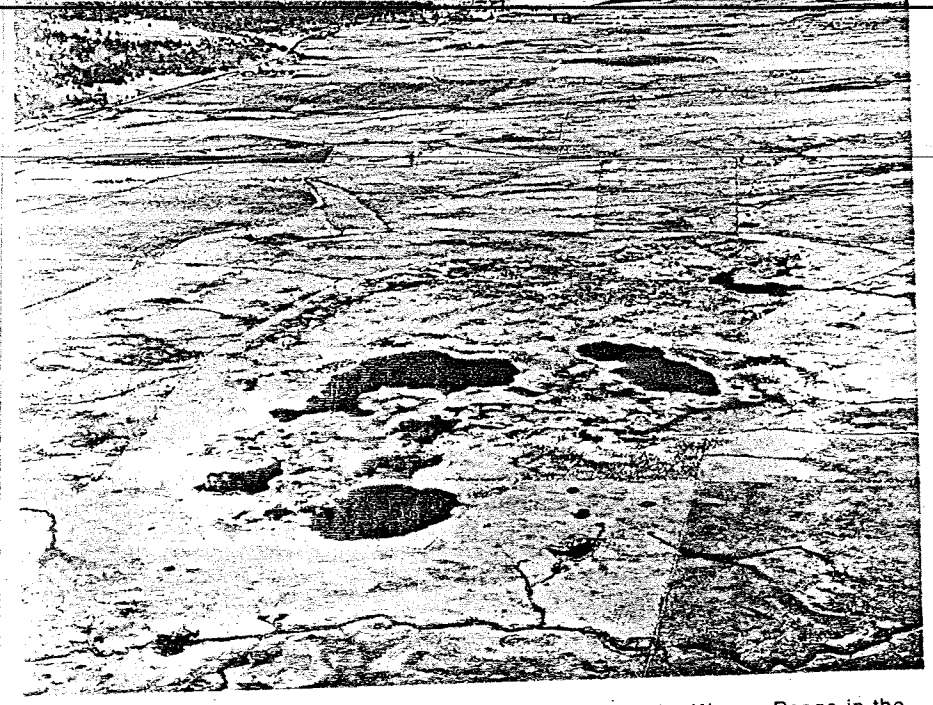

View northward along the west side of Surprise Valley with the Warner Range in the background. In March 1951, mud volcanoes were erupted violently at the hot springs area about 2 miles northeast of Lake City, California. Residual mud craters from this eruption can be seen in the foreground. The hot springs, which are located about a half mile east of the fault scarp bounding the Warner Range and Surprise Valley, have been quiet since the 1951 eruption. *California Department of Water Resources photo by R. E. Franson, December 1960*

GEOTHERMAL ACTIVITY IN SURPRISE VALLEY

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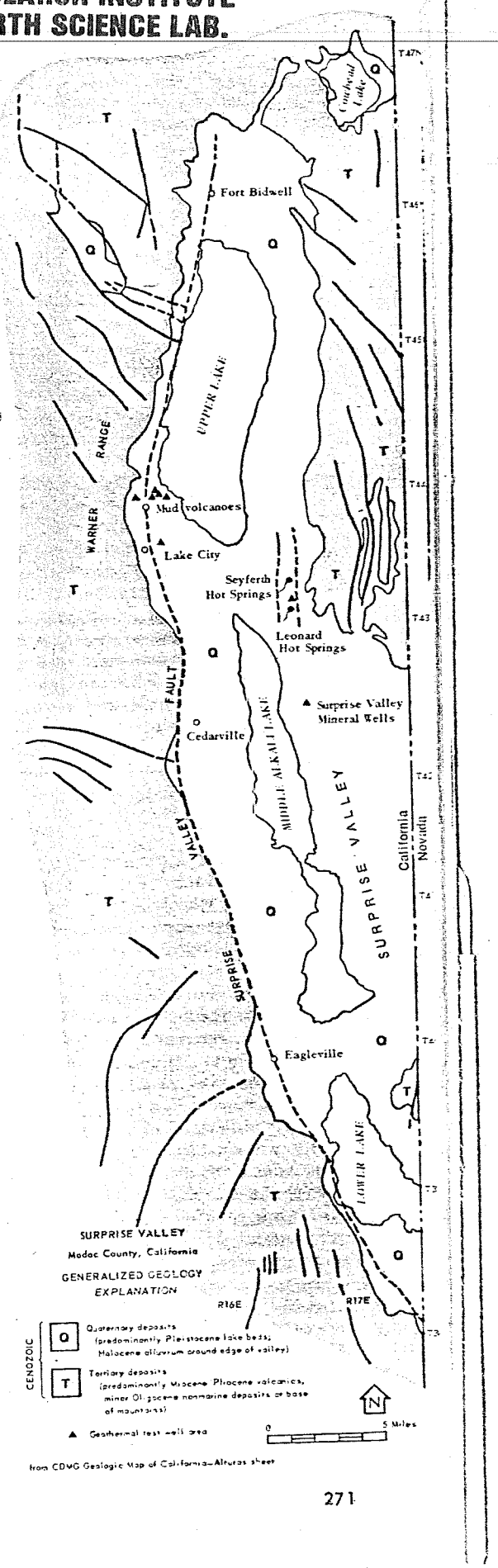
Geologic Setting

Geothermal activity refers to the surface expression of the Earth's subterranean heat energy, such as volcanic eruptions, geysers, hot mineralized springs, and fumaroles. In Surprise Valley numerous hot springs along the fault scarps and hot flowing artesian wells in the valley provide conclusive evidence that a heat source underlies this area at a relatively shallow depth. Geothermal activity is always associated with geologically recent volcanic or fault activity, since tectonic forces generate the heat.

In Surprise Valley the heat source is probably Late Cenozoic volcanic rocks which are still hot at a depth of only a few thousand feet beneath the valley. The last volcanic activity in the area occurred in late Pliocene time when the Warner Range basalt flows were extruded. Later, sometime during the early Pleistocene, large scale faulting created a depressed valley. During the wet cycles of the Pleistocene, when a lake occupied the valley, several thousand feet of sediment were deposited. Geophysical surveys have revealed that bedrock beneath the valley is faulted and tilted with the subsurface features ranging from a few hundred feet to over 5,000 feet beneath the valley fill.[1]

Hot Springs

In Surprise Valley the faults and fractures, which parallel the general north-south trend of the valley and pass beneath the valley floor, provide migration zones for water. Water percolating downward from the surface into the deep strata is heated by contact with the hot subterranean rocks. Minerals are dissolved out of the rock



from CDMG Geologic Map of California—Alturas sheet

Lake City hot springs area where mud volcanoes were erupted in March 1951. The springs are surrounded by an overgrown grass tule marsh covering about 10 acres. The low, light-colored ridges, were formed by ejecta from the 1951 explosions. The ridges have been eroded to about 4-6 feet above the valley floor. The spring water is a sodium sulfate type. From time to time a shallow lake is formed by surface water filling the craters created by the eruptions. *Photo by Marshall J. Reed, July 1973*

strata through which the water migrates. After the water is heated, it rises through faults and fractures to the Earth's surface and appears at fumaroles (steam vents) or hot mineralized springs.[5]

In some areas of Surprise Valley, such as Menlo and Old Leonard Baths, and Cedar Plunge, the hot springs and flowing artesian wells have been utilized for mineral baths. The water is generally of poor quality for drinking because the content of total dissolved solids (TDS) is over 1000 milligrams per liter. The U. S. Public Health Service recommends that the TDS be no more than 500 milligrams per liter for desirable drinking water. The mineralized spring water along the western fault scarp in the valley is usually high in calcium carbonate. Thermal artesian wells east of Middle Alkali Lake and along the southern and western edge of Upper Lake yield nonpotable water with a high concentration of sulfate and lesser amounts of chloride and bicarbonate. A few wells and springs along the fault zone west of Lower Lake yield water with a high concentration of fluoride and boron. In other parts of Surprise Valley, wells yield excellent fresh, warm water (25 degrees Celsius) which is generally suitable for most uses.[6]

Mud-Volcano Eruptions

On 1 March 1951 during the night, and 2 March in the early morning hours, a group of hot springs in a tule marsh about 2 miles northeast of Lake City erupted and mud particles were thrown about a mile into the air. Mud cones reached a height up to 15 feet above the valley floor. A total mass of about 300,000 tons was involved in the eruptions and fine debris was scattered by wind 4 miles to the southeast. This geothermal activity was described as mud-volcano eruptions.[7] By noon on 2 March 1951, the thermal activity consisted of boiling mud pots with clots of mud occasionally thrown 10 to 20 feet high.

Mud volcanoes can be caused by a sudden release of water and steam under pressure or by the quiet discharge of viscous mud. The "volcanic" cones form as the water and steam pressure extrude and pile up water-saturated fine clays and sediments from shallow depth. The morphology of the mud cones erupted in a hot springs area appears similar to that of miniature volcanoes; generically the name is inaccurate because there is no introduction of material, such as lava, from a source at depth.

At the time of the mud eruptions (1951), local residents heard loud noises and felt a series of tremors, similar to those felt during an earthquake. However, no earthquake was recorded.

Prior to 1951 the hot springs had been quiescent. Water temperatures and the amount of flow of the hot springs before the eruptions are not known. Although no previous violent eruptions at the Lake City hot springs were recorded, aerial photos taken in September 1946 show several cones of mud volcanoes, which indicate past activity.

The area of the mud eruptions is now a hot water marsh with some occasionally active mud pots. The unconsolidated sediments that formed the mud cones during the 1951 eruption have been eroded to ridges 4 to 6 feet high. A shallow lake is created seasonally in the residual craters or depressions by surface runoff and by seepage from the springs.

Hot springs which have formed mud volcanoes also are found in Shasta County (Lassen Volcanic National Park), Inyo County (Coso Hot Springs), and Imperial County (Salton Sea). All of these mud volcanoes occur in basins similar to Surprise Valley, which contain fine clastic sediments of Quaternary age.

Geothermal Steam Act

In 1970 under the Geothermal Steam Act, the U. S. Geological Survey designated areas of subsurface heat-related activity throughout the United States as Known Geothermal Resources Areas (KGRAs). Many of these areas were already being investigated by power companies. Surprise Valley was one of the 15 localities in California (totaling 260,000 acres) where development of geothermal resources (natural steam and/or hot brines) appeared to be a possibility from geologic evidence.[3]

Close-up of a small mud cone formed on one of the ridges shown in the photo above. The center vent is about 2 feet in diameter. The temperature of the water standing in the opening is about 96.5 degrees Celsius, which is above the boiling point at the altitude of the spring. *Photo by Marshall J. Reed, July 1973*

Seyferth hot springs on the east side of the valley. Some hot springs occur on the valley floor in areas overlying subsurface fault traces. Seyferth hot springs have a temperature of about 85 degrees Celsius. *Photo by Marshall J. Reed, July 1973*

Geothermal Resources Recovery

Steam or hot brines are recovered from underground reservoirs by use of oil and gas well drilling and development techniques. Steam can be channeled to generate electricity, and minerals can be extracted from brines. Another by-product potential, the use of desalted brine water as a source of irrigation water, is being investigated.

The minimum temperature necessary to operate a steam geothermal power plant is 180 degrees Celsius. Natural steam is currently being used in California to generate electric power at The Geysers in Sonoma County, where the maximum subsurface temperature is 280 degrees Celsius at a pressure of 34 atmospheres. At Niland, California, in the Imperial Valley, brine with a high concentration of sodium chloride in solution has been produced from hot water wells, and calcium chloride from the brine has been marketed as an additive for drilling muds used in the oil and gas industry.[3]

Geothermal Testing in Surprise Valley

Eight test wells have been drilled to explore the geothermal potential of Surprise Valley. The first test well was drilled in July 1959 in the area east of the mud-volcano eruptions near Lake City. The recorded bottom-hole temperature was 125 degrees Celsius at a depth of 1968 feet. A well in the same general locality drilled in 1962 had a recorded bottom-hole temperature of 140 degrees Celsius at a depth of 2148 feet. A test well drilled into one of the mud craters blew out at 92 feet, expelling boiling water and causing the drilling rig to cave in. One driller suffered an injured arm and the location was abandoned without further testing.

In December 1972 another geothermal test well was drilled in the area west of the mud volcanoes. This test well, drilled through volcanic sediments to a depth of 4543 feet, had a static bottom-hole temperature of about 150 degrees Celsius, the highest temperature encountered in the 8 tests in Surprise Valley. This exploration hole is being deepened for further temperature-gradient testing.[2]

In November 1973 a geothermal test well, drilled approximately in the center of the valley floor southeast of Lake City, encountered about 7000 feet of sedimentary fill. This well confirmed the great thickness of valley fill, which had been estimated from geophysical studies to be in excess of 5000 feet.

Geothermal exploration test wells have been proposed also at the south end of Middle Alkali Lake in Surprise Valley near Eagleville, California. Three geothermal test wells will be drilled to a depth of about 6000 feet in this locality. A permit for one of these wells has been issued by the Modoc County Planning Commission and the California Division of Oil and Gas.[2]

Further exploration and testing will be necessary before the potential of Surprise Valley for any type of geothermal production can be proven.

Leonard hot springs on the east side of the valley floor. These springs have a temperature of 61.8 degrees Celsius. *Photo by Marshall J. Reed, July 1973*

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