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HYDROGEOLOGY OF THE THERMAL LANDSLIDE

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ABSTRACT

The large Thermal Landslide overlies the initial area of geothermal development at The Geysers. The landslide is waterbearing while the underlying Franciscan formation bedrock units are essentially non-waterbearing except where affected by hydrothermal alteration. Perched ground water moving through the landslide is heated prior to discharge as spring flow.

INTRODUCTION

The Geysers geothermal field is located in the Mayacamas Mountains about 25 miles north of Santa Rosa in Northern California (Figure 1). The initial area that was developed for geothermal steam was on the north side of Big Sulphur Creek and east of Geysers Canyon (Figures 2 and 5). It is in this area, which is now referred to as the Thermal area, where much of the geothermal manisfestations including fumaroles, hotsprings, and altered ground are located.

The lower portion of the Thermal Landslide (Figure 2) overlies the Thermal area where the initial eight geothermal wells were drilled during the 1920's and where wells Magma 1 and Thermal 1 through 12 were drilled in the 1950's and 1960's.

BEDROCK CONDITIONS

The Thermal Landslide is underlain by the Franciscan formation of Upper Jurassic to Cretaceous age. The formation consists of a heterogeneous assemblage of sedimentary, volcanic, and ultrabasic intrusive rock units, all of which occur in the Thermal area.

Within the immediate Thermal Landslide area, there are three principal northwest trending rock units (Figure 2). All three units outcrop on the southwest flank of Ottoboni Ridge and underlie the Thermal Landslide. The three units are: 1) a greenstone unit which underlies the crest and upper flank of the ridge; 2) a serpentinite unit in the central portion of the ridge flank halfway between Big Sulphur Creek and the ridge crest; and, 3) a graywacke unit which underlies the lower portion of the ridge flank to Big Sulphur Creek and beyond. The greenstone unit is poorly permeable while the serpentinite unit is essentially impermeable. The graywacke unit varies from being essentially impermeable where unaffected by hydrothermal alteration to locally permeable along secondary openings associated with hydrothermal alteration.

Detailed geologic mapping at a scale of 1" = 100' and 1" = 200' indicated that bedrock in the Thermal Landslide area was subjected to four stages of Cretaceous to mid Tertiary deformation involving faulting and shearing.

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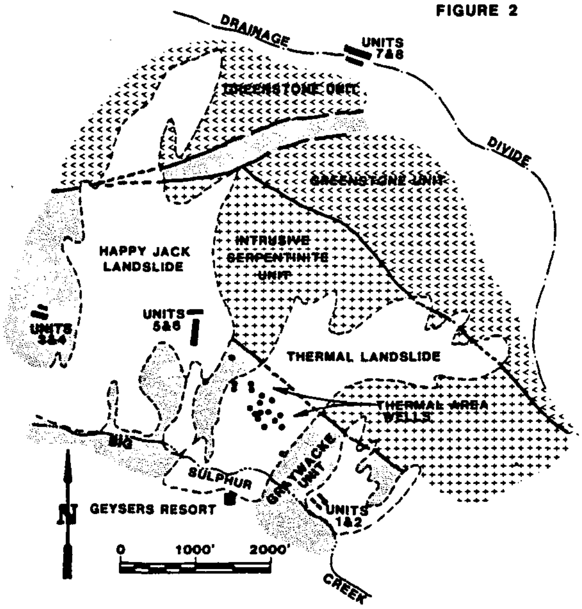
Hydrothermally altered rock occurs from the graywacke-serpentinite contact down to Big Sulphur Creek. Rock bodies within the graywacke unit trend northerly across Big Sulphur Creek but are only altered on the northeast side of the creek and northwest of Units 1 and 2. The surface distribution of hydrothermally altered rock indicates that its occurrence is partly controlled by topography, rock type, and the bedrock structural features of fault and shear zones.

FIGURE 2



GEOLOGIC MAP OF THE THERMAL LANDSLIDE AREA

DESCRIPTION OF THE THERMAL LANDSLIDE

Overlying the Franciscan formation bedrock units is the permeable Thermal Landslide. The Thermal Landslide extends from the higher elevations of Ottoboni Ridge to the terrace-like area at The Geysers Resort across Big Sulphur Creek (Figures 2 and 5). The upper scarp is at elevation 3,050 feet, while the landslide toe is at Big Sulphur Creek, elevation 1,375 feet. Length of the landslide is about 4,400 feet.

The landslide has a crude "hour glass" shape. It is 1,000 feet wide at the toe area along Big Sulphur Creek; 1,100 feet where Thermal 4 is located; about 700 feet in the center; and, about 1,500 feet at the widest part of the scarp.

The landslide was deposited on an undulating surface of gullies and low ridges, giving it a variable thickness with a maximum of about 150 feet near well Thermal 4.

An estimated 90 percent of the landslide debris is serpentinite rock fragments derived from failure of the serpentinite unit underlying the upper portion of the landslide. As shown on the attached geologic map, (Figure 2), the greenstone which overlies the serpentinite is a minor debris source. Only serpentinite debris was encountered in the exploratory borings drilled in the lower portion of the landslide.

Woodward-Clyde Consultants felt that at least two major landslide events occurred to produce the Thermal Landslide. The older landslide deposits may be a few tens of thousands of years in age. They underlie the terrace-like area above the section of Geyser Canyon between Arsenic and Boric Acid Springs and are exposed in the channel of Big Sulphur Creek. Older landslide deposits also occur southeasterly of Thermal 6. Most of the older landslide deposits may have been removed by erosion when the last large landslide event, a debris avalanche, occurred about 13,000 years ago (Woodward-Clyde's estimate). Volume of the 13,000 year old debris avalanche landslide may have exceeded 50,000,000 cubic meters judging from the large indentation which remains in the greenstone and serpentinite rock units upslope.

OCCURRENCE, RECHARGE, AND MOVEMENT OF GROUND WATER

Scarp and Main Body

The drainage area upslope of the Thermal Landslide scarp encompasses about 100 acres. Most of the scarp area exposes the poorly permeable greenstone bedrock with subordinate graywacke. Precipitation falling on this area exceeds 60 inches per year and runs off in well developed surface drainages. There appears to be minor infiltration into bedrock and deep percolation. The 1" - 200' scale topographic map shows an intermittent stream channel above the Thermal Landslide scarp but no defined stream channels across the landslide debris. Although stream flows have not been measured, these observations indicate that most of the surface flows are rapidly infiltrated into the landslide debris.

Once infiltrated into the scarp area, the water percolates downward to mound as perched to semi-perched ground water at the base of the landslide. The water then moves slowly downslope within the landslide.

Lower Portion

The lower portion of the Thermal Landslide is underlain by hydrothermally altered graywacke bedrock. It is in this area where natural discharge of steam from bedrock occurs, where hot springs discharge from the landslide, and where all the Thermal area wells were drilled.

The toe area of the landslide is drained by Geyser Creek along the west side of the landslide and also by a drainage in the center of the landslide by Magma 1 and Thermal 6. Surface drainages are nonexistent along the east side of the older landslide debris except where bedrock is exposed.

Considerable surface flow occurs in Geyser Canyon. Prior to 1978, Geyser Creek had incised its channel to bedrock between the main road crossing and Big Sulphur Creek (Figure 4). In most of this section, the creek follows the western edge of the landslide and had incised a channel through the lowermost toe of the landslide, leaving an erosional remnant on the west side of the canyon (Figure 4). Geyser Canyon had been incised to bedrock in the area now covered by 100 feet or so of debris from the January 16, 1978 Landslide.

Perennial stream flows occur in the lower portion of Geyser Canyon. The incision to bedrock allows for spring discharges of perched ground water from the base of the landslide.

Stream flow measurements during 1980 and early 1981 were taken at the downslope edge of the landslide body. Measurements in the main part of Geyser Canyon indicate that much of the early rainfall is infiltrated into the main body of the landslide and stored as perched water. On January 1, 1981, stream flows were only four gpm. All of this was spring flow entering at the culvert intake. Immediately upstream, the drainage was dry for several hundred feet. After significant rainfall in late January, base flows increased to 700 to 1,000 gpm and were averaging 500 gpm in early February.

The drainage by Magma 1 and the center of the landslide was dry until the December 2-3, 1980, storm. The storm produced considerable runoff in adjacent drainages and near flood conditions in Big Sulphur Creek. However, there was very little flow in the Magma 1 drainage indicating rapid infiltration of incident precipitation when the landslide is still fairly dry and when water can be stored. Flows were nonexistent or a bare trickle following the storms on December 31, January 9, and January 16. On February 23 after significant rainfall, flows were only 15-20 gpm in the Magma 1 drainage, even though much higher flows were measured in most of the other tributaries to Big Sulphur Creek. On February 3, however, flows had increased to about 400 gpm four days after heavy rainfall when other similar Big Sulphur Creek tributary flows were declining. We interpret the large delayed flows to mean that the landslide was able to absorb a very large percentage of the early rains, and the delay was the time required for the perched water to move down through the landslide.

Source of the perched water in the lower portion of the landslide is mainly subsurface inflow from upslope and the main body of the landslide. Other sources are condensate from steam ascending from depth through secondary openings in the graywacke bedrock and incident precipitation.

PERCHED WATER LEVELS

Perched water level data was meager prior to November, 1981. Woodward-Clyde Consultants had encountered water at 80 feet in their Boring No. 1 (May 20, 1977). Union encountered water at six feet in Boring No. 1 and at two feet in Boring No. 2 (both drilled on November 23, 1979) in the lower portion of the landslide below Thermal 4. Other water level data prior to November, 1982, is that from the two seismic refraction surveys in 1976 and 1977 across the landslide.

Six exploratory borings were drilled in the Thermal Landslide during November, 1981, for the primary purpose of developing perched water level information. Since that time, three of the borings (T-2, T-3, and T-5) have been equipped with the continuous water level recorders. The water level recorders have confirmed the other observations that perched water levels are influenced greatly by seasonal rainfall and respond rapidly (within a few hours) to heavy rainfall. Figures 3 and 4 present the water level records of the T-2 and T-3 monitoring wells.

DISCHARGE OF GROUND WATER FROM THE THERMAL LANDSLIDE

Hot perched ground water is mainly discharged as spring flow from the exposed landslide base in both Geysers Canyon and at Big Sulphur Creek (Figure 5). Allen and Day in their 1920's report recognized the two groupings of hot springs but did not realize the groupings were along the exposed perimeter of a landslide. However, they also suspected the source to be from near surface ground water as they stated:

> "The majority of hot springs of The Geysers come to the surface at low points where drainage water would be expected to emerge; all of them indeed are so situated that if they were cold springs one would find nothing illogical in their relation to the topography. Steam vents on the other hand, while they sometimes follow the creek beds, occur also in situations where no logical relation to topography is apparent."

Adjacent to Big Sulphur Creek are four major springs where the perched water within the landslide is discharged. These include a spring at about a 1,510 foot elevation between the foot bridge and Thermal 12; a spring area at about a 1,430 foot elevation, above the north end of the foot bridge; a spring area in the reactivated portion of the landslide 150 feet northwest and upslope of the foot bridge at an elevation of 1,470 to 1,500 feet; and a spring area 150 feet from the confluence of Geysers Canyon and Big Sulphur Creek at an elevation of 1,400 feet. All these springs have perennial flow which varies seasonally from trickles to rates of several tens of gallons per minute. A rough estimate of the maximum combined flow from the toe of the landslide from these four spring areas is in excess of 200 gpm.

The other major area where the perched ground water discharges is Geyser Canyon. Most of Geyser Canyon was incised to bedrock prior to the January 16, 1978 landslide and before the landslide the base of the Thermal Landslide was exposed along the majority of the Geyser Canyon, allowing for spring discharges into the creek.

After the January, 1978 landslide (Figure 5), data was collected on the remaining springs in Geyser Canyon. At that time, about 20 separate springs were located. Four of the springs described in the Allen and Day report were covered by the January 16, 1978 landslide.

A small amount of ground water in the lower part of the landslide is temporarily infiltrated into secondary bedrock openings under the landslide. This water is rapidly heated to steam which is then vented to the atmosphere from wells and fumaroles. Indications that some perched water from the landslide percolates into bedrock and the underlying steam reservoir come from the water level records of monitoring well T-2 (Figure 3). After the rainy season, water levels in T-2 declined gradually, as expected. When the water levels reached a certain level in late summer, the water level decline accelerated, indicating loss into the Thermal reservoir.

The ground water from the main body of the landslide is at or near normal temperature where it enters the toe area by way of subsurface inflow. Temperature of the springs where the main road crosses Geyser Canyon are about 70°F, which is only slightly above the average annual temperature. As the perched ground water flows over hot bedrock in the Thermal Reservoir area, it is heated before being discharged at the landslide toe. The temperatures of the springs generally vary from about 130°F to boiling.

A program to measure temperature changes of the springs discharging from the Thermal Landslide was initiated in September, 1982. As expected, the temperature changed seasonally but in unexpected ways. The springs discharging above Big Sulphur Creek by the foot bridge decreased in temperature, those discharging to Big Sulphur Creek by Geyser Canyon remained constant in temperature, while those discharging to lower Geyser Canyon increased in temperature during the same fall to winter period.

SUMMARY

The large Thermal Landslide at The Geysers overlies the Thermal area of the Geysers geothermal reservoir. Many surface manifestations of the reservoir are covered by the landslide. The landslide debris is water bearing and perched water within the landslide is heated by the discharge of heat from the reservoir. Many hot spring discharges from the exposed base of the landslide are found in Geyser Canyon and the Big Sulphur Creek area.

<u>References</u>

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McLaughlin, R.J., "Preliminary Geologic Map or the Geysers Steam Field and Vicinity, Sonoma County, California"; 1974.

Ridley, A. and Vantine, J., "Geologic Exploration Methods for Siting Power Plants and Other Structure in Landslide and Hydrothermally Altered Terrain at The Geysers"; in 'Geothermal Resources Council Transactions', Vol. 2; July 1978.

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FIGURE 3

TB2
1982–1984 WATER LEVELS AT TB-2 AND RAINFALL

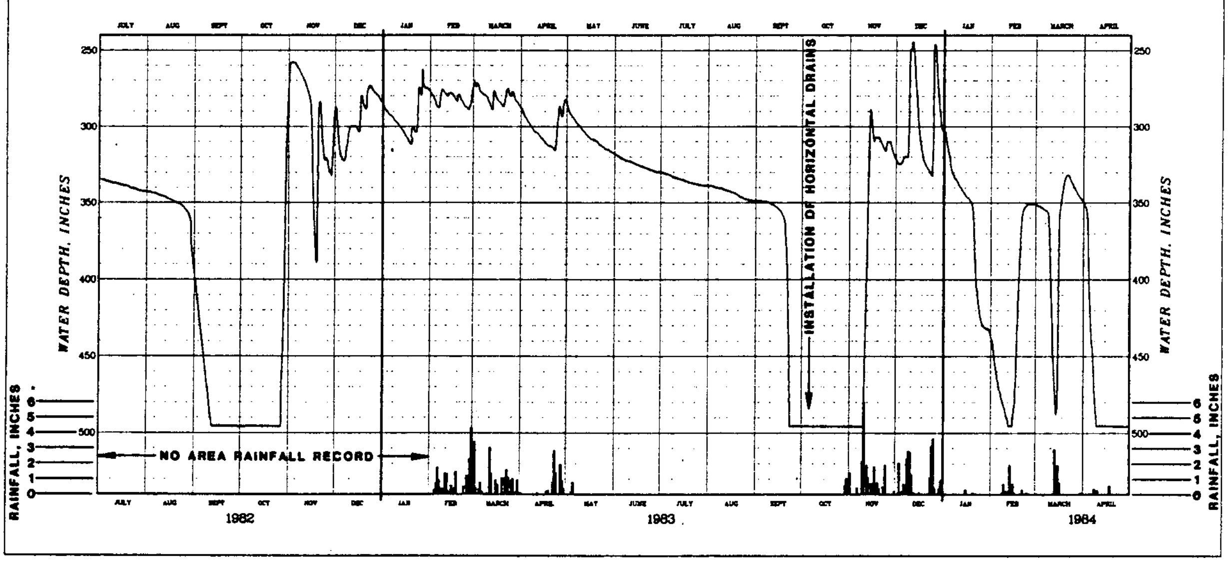
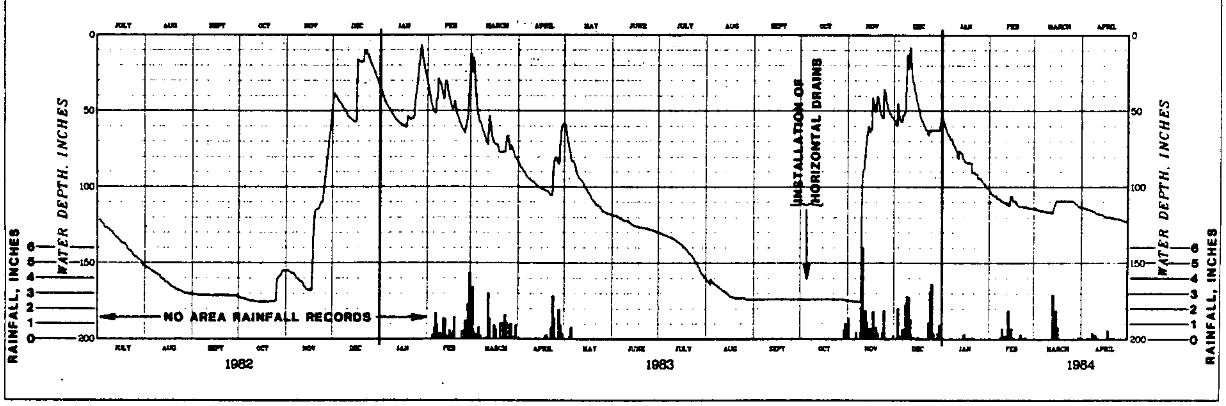
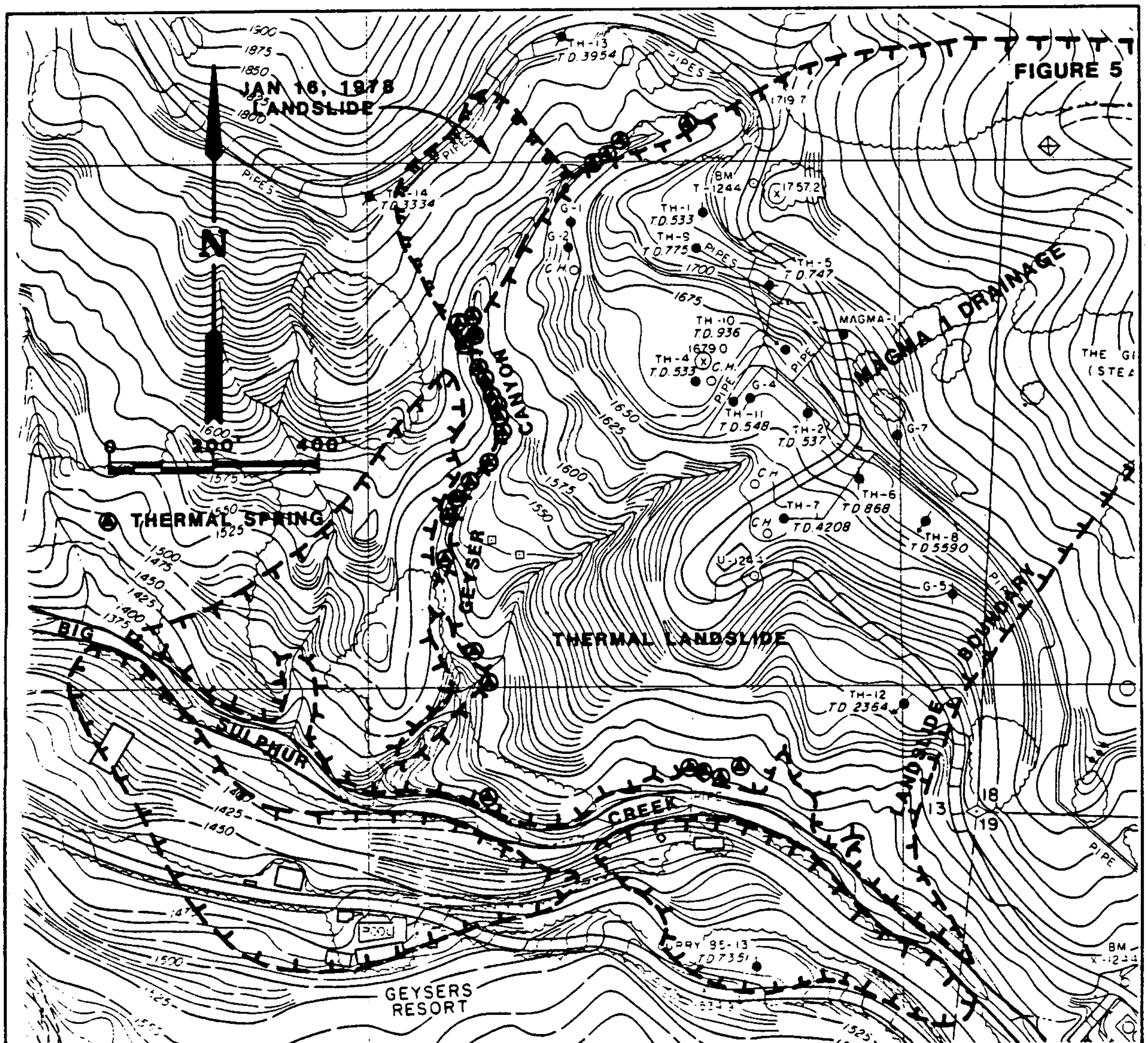


FIGURE 4

TB3
1982–1984 WATER LEVELS AT TB-3 AND RAINFALL





LOCATION OF THERMAL SPRINGS IN GEYSER CANYON AND ALONG BIG SULPHUR CREEK