GEOTHERMAL STEAM POTENTIAL OF THE MOUNT LASSEN AREA

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INTRODUCTION

Only one exploratory well for geothermal steam has been drilled to date in the Mount Lassen region. It was not successful. Despite this, the potential for commercial geothermal development remains high, based on:

1) the recency of volcanic eruptions;

2) the intensity and nature of fumarolic activity; and

3) by anology with other geothermal fields, the composition and structure of the volcanic pile at Lassen Volcanic National Park.

USES AND REQUIREMENTS OF A GEOTHERMAL FLUID

Geothermal fluids have a wide range of potential uses. These are dependent upon the physical state of the geothermal fluid, and its temperature, enthalpy, flow pressure and volume. The most widely discussed use is in the generation of electric power. Other uses include space heating, saline water conversion, and as process heat in a wide range of chemical, industrial, and agricultural applications. In general, space heating can make use of large volumes of hot water at temperatures as low as 50°C. Saline water conversion becomes effective with large volume steam or hot water flow at temperatures of at least 100°C. Industrial and agricultural uses require steam or hot water temperatures of at least 100°C, and in many cases over 150°C. Electric power generation rarely can be accomplished economically at temperatures below 170°C; most producing fields have reservoir temperatures above 200°C.

Geothermal fluids cannot be transported appreciable distances without heat loss. This tends to restrict space heating, saline water conversion, and process heat applications to those areas where industry, agriculture and population centers are located. Electric power, however, commonly is generated at great distances from its consumers. Therefore, noting the geography and regional setting of the Mt. Lassen area, it can be assumed that, except for the local heating of resorts and ranches, only electric power generation remains a commercial possibility. (And even this would be subject to an agreement with the National Park Service, as most of the high-potential areas lie within the Lassen Volcanic National Park.)

To be commercially exploitable for electric power generation, therefore, a geothermal field must have a base temperature of at least 170°C, and must produce fluid with enthalpies of more than 250 calories per gram (approximately 450 BTU/lb). In high-enthalpy fields (such as that at The Geysers in Sonoma County, with enthalpy of about 670 calories per gram) the geothermal fluid is converted entirely to steam. Other fields produce a steam-water mixture. Flow pressures of at least 5 kilograms per square centimeter (about 70 lbs per square inch), and steam volumes of at least 4,500 kilograms per hour (about 10,000 lbs per hour) must be attained to warrant commercial development. A well such as this would have the electric-power equivalent of 1,500 to 2,000 KW, enough to supply the needs of about 2,000 people. Generally, it is uneconomic to construct power generating stations with capacity of less than 10,000 KW. This would require about 7 wells of the capacity described above.

THE IDEALIZED GEOTHERMAL FIELD

Several factors must be present to support a high temperature and long-lasting geothermal field. There must be an adequate source of heat, such as a cooling igneous intrusive body. There must be a continuous supply of water to carry heat upward to depths shallow enough to be drilled. And there must be a sufficient reservoir of permeable or fractured rocks to allow movement of water on a scale large enough to sustain discharge of steam in fumaroles or wells. Additionally, it is useful that there be an impermeable overburden above the reservoir to prevent over-rapid dissipation of heat and water. And it is also useful that recharge of water into the geothermal system approximately balance discharge from wells and fumaroles, to prevent excessive draw-down of the system. Water-deficient systems may be extremely high temperature, but do not lend themselves to commercial development of steam. Systems with too high a through-put of water may not reach temperatures high enough for commercial development.

The life of a geothermal system depends ultimately upon the ratio of withdrawal to replacement. The life of individual wells may be shortened by deposition within the well, and by improper reservoir management. Experience indicates a minimum 10 to 15 years of life for a properly engineered and managed well.

THERMAL EMISSIONS IN THE MOUNT LASSEN AREA

The Lassen area was visited in 1909 and 1910 by Gerald A. Waring, several years before the volcanic eruptions of 1914-1915. His descriptions of pre-eruption thermal activity appeared in the classic U.S. Geological Survey Water-Supply Paper 338, "Springs of California". A.L. Day and E.T. Allen studied the Lassen Peak area between 1914, the year of the first eruptions, and 1923. Their results appeared in "The volcanic activity and hot springs of Lassen Peak", Carnegie Inst. of Washington Publication 360, issued in 1925. This is the definitive work on hot springs activity of the region. The results had been summarized the previous year by Day and Allen in "The source of the heat and the source of the water in the hot springs of the Lassen National Park", which appeared in the Journal of Geology. Howell Williams' famous paper, "Geology of the Lassen Volcanic National Park, California", appeared in 1932 in the University of California Publications in Geological Sciences. Williams summarized the state of thermal activity and hydrothermal alteration in the Park in the late 1920s. Additional data on hydrothermal alteration were provided by C.A. Anderson, in 1935, in "Alteration of the lavas surrounding the hot springs in Lassen Volcanic National Park". This appeared in The American Mineralogist. Since then relatively little has been published on this subject, although the existing data are tabulated in U.S. Geological Survey Professional Paper 492, "Thermal springs of the United States and other countries of the world", published in 1965. (This volume serves as a handbook to geothermal phenomena the world around.)

There are at least 7 areas of thermal activity (depending upon how the counting is done) within an irregular area of about 60 square kilometers (15 square miles) to the south and southeast of Mount Lassen. These are shown on the topographic map of Lassen Volcanic National Park, part of which appears as Fig. 5

The names of the thermal areas have changed repeatedly, with the result that it is not always clear to which thermal spot an author referred. Additionally, several areas of former or extinct thermal activity were cited by several of the authors. These include, of course, the summit of Mount Lassen and of Chaos Crags, now quiescent. To complicate this matter further, several places with names suggestive of thermal activity have, in reality, no present-day thermal emissions. Among these misnomers are Hot Rock, Cold Boiling Lake, Little Hot Springs Valley, and White Sulphur Spring, although Little Hot Springs Valley was cited by Anderson as an extinct fumarole locality.

The major thermal areas are described in the following paragraphs.

Bumpass Hell. (Also known as Bumpass Hot Springs.)

Over 20,000 square meters in area, this area comprises extensive fumaroles, boiling springs and mud pots. Outflow varies with snow cover or run-off, averaging perhaps 370 liters per minute. There is extensive hydrothermal alteration of bedrock, and deposition of sulphur crystals. Water is strongly to moderately acid, with the sulfate to chloride ratio approaching infinity. Allen and Day reported this to be the most intensive area of fumarolic activity, with temperatures reaching

117.5°C in one fumarole. Activity in 1891 was considered to be still greater than in 1923.

Boiling Springs Lake. (Also called Boiling Lake and Tartarus Lake.)

A stream-fed pool of perhaps 50,000 square meters, surrounded by mud pots and hot springs near the boiling point, it has a surface temperature of perhaps 50°C. Its basin is green with hot-water algae; discharge from the pool is seasonal. There is abundant deposition of pyrite within the lake. Waring reported decreased activity from 1908 to 1910.

Devil's Kitchen.

A perennial cold stream flows through this area of fumaroles, mud pots, and hot springs. Temperatures to 94°C, the boiling point at this elevation (1,800 meters), were measured by Allen and Day. Outflow of warmed water reaches about 200 liters per minute. Analyses of the water showed very high silica and sulfate-chloride ratio, and pH ranging from acid to mildly alkaline.

Drake's Hot Springs. (Also known as Drake's Springs, Drakesbad, and Drake Hot Springs.)

Four main springs, at temperatures of 43°C to 62°C, have been made the site of a major resort. There is a small warm, carborated spring one kilometer to the west. Water analyses showed high sulfate, no chloride, and moderate silica.

Terminal Geyser. (Also called The Geyser.)

This is not a true geyser, in that the surging of water in this boiling spring lacks periodicity: it is continuously ebullating. However, Allen and Day reported that others had observed an occasional periodic spouting to 2 meters. This no longer occurs. Waring wrote that activity had decreased markedly from the 1870s to 1910, but suggested choking of the main orifice with rocks as a cause. There are 6 springs in the group, with temperatures measured as high as 95°C, slightly above boiling. Outflow seasonally reaches 30 liters per minute. The 1962 geothermal test well was drilled a few meters to the northwest of this spot to a depth of almost 400 meters (1,285 feet). Apparently the ebullation diminished greatly after the drilling, at least temporarily.

Sulphur Works. (Also called Tophet, Soupan, and Supan Hot Springs, and Supan's Springs.)

Visible along the main road through Lassen Park, this is an area of fumaroles, hot springs, and mud pots. Outflow probably is less than 15 liters per minute. Rocks are extensively coated with sulphur, deposited from the steam which issues at temperatures up to 94°C. The area of intensive hydrothermal alteration measures about 5,000 square meters. Apparently the area called Mill Creek and Upper Mill Creek Hot Springs by Allen and Day comprised Sulphur Works plus 2 or 3 smaller hot springs located 1½ kilometers north of Sulphur Works. Allen and Day also referred to a cool, carbonated spring in this area.

Morgan Hot Springs. (Also known as Morgan Springs; includes Growler Hot Spring, 1 kilometer to north.)

This area lies 4 to 5 kilometers south of the southern boundary of the park. It contains one of the few true geysers in North America. Waring reported widely varying temperatures and rates of flow from the geyser, reflecting periodicity of eruption. The geyser flows from amidst a group of some 25 hot springs scattered along a north-south line for nearly 600 meters. Total outflow exceeds 300 liters per minute. Highest measured temperature exceeded 95°C.

SPECULATIONS ON GEOTHERMAL STEAM POTENTIAL

Several factors present at the Lassen thermal areas suggest a high potential for geothermal power development.

First, of course, is the recentness of volcanic eruptions at Mount Lassen and adjacent peaks, although it must be added that volcanic activity per se is not a definite indicator of a useful geothermal reservoir. Some active volcanic fields are too hazardous to justify exploration and development work; at others the heat dispersal is so episodic or rapid that no useful geothermal reservoir exists.

The most recent eruptions of Lassen, in 1914-1915, were preceded by eruptions at Chaos Crags and Cinder Cone within historic time, and by earlier Holocene and Pleistocene eruptions at several places in the Park. This suggests that magmatic batching is a continuous process in this region, and implies that a vast heat reserve is available at relatively shallow depths.

Worldwide, there is a close association of volcanism and recoverable geothermal fluids. More specifically, dacitic-rhyolitic domes, flows and tuffs, often surrounding or filling caldera-form structures, are found at many of the great geothermal fields of the world. Examples of this are given in Table 1.

Table 1. Lithology and structure of selected geothermal fields.

Field	Lithology, Age, Structure	Commercial Production
The Geysers, California	Pleistocene rhyodacite domes, obsidian flows, basalt plugs; fractured reservoir	yes
Yellowstone National Park, Wyoming	Pleistocene and Holocene rhyolite tuffs, obsidian flows, basalt flows; caldera	no
Wairakei, New Zealand	Pleistocene ignimbrites; caldera or similar collapse	yes
Tatun, Taiwan	Pleistocene andesite and dacite flows, and dacitic tuff-breccias	no
Pauzhetsk, USSR	Quaternary dacite tuffs and agglomerates, and andesite tuff breccia; structural trough	yes
Mono Lake - Long Valley, California	Pleistocene and Holocene ignimbrites, perlite and obsidian domes, basalt cinder cones; structural collapse	no
Valles Caldera, New Mexico	Pleistocene rhyolite flows and tuffs and obsidian flows; caldera	no
Salton Sea, California	Pleistocene and Holocene perlite and obsidian domes, and basalt flows and cinder cones; structural trough	no
Lassen Volcanic National Park	Pleistocene and Holocene dacite domes, basalt cinder cones and flows, rhyolite and rhyodacite, and other andesite; caldera-form structural low	no

Many others could be cited. However, not all geothermal fields exhibit this relationship: andesitic and even basaltic volcanism has been reported to be prominant in certain areas, and in others the realtionship to volcanic rocks is obscure, as at Larderello, Italy and Beowawe, Nevada. Often, too, basalt flows and cinder cones are among the youngest recognized volcanic features, as at Cinder Cone, near Mt. Lassen. In these cases, though, the geothermal reservoir usually is associated with the rhyolitic-dacitic rocks. Often the older, volumetrically vast portion of the volcanic range is andesitic, as in the Cascade Range, where 70% or more of the rocks by volume are andesites.

There are four probable reasons why the dacite-rhyolite volcanism is more commonly associated with geothermal fluids. First, of course, these are generally the youngest of the volcanic rocks in an area of Quaternary volcanism, and therefore are more likely still to hold residual heat. Second, the zone of melting of rhyolites is much closer to the surface than is the melting zone of basalts. Thus, the heat reservoir is more likely to be within the range of economic exploration. Third, the rhyolite and dacite flows, tuffs, and breccias seem to form suitable reservoir and trap structures more often than do basalts. The fourth reason lies with the nature of cooling of these rocks. Viscosity is a function of silica content: high-silica melts are more viscous than low-silica melts. High fluidity of basalts allows them to move further and to expose greater surface to the air or to surface rocks and water. Thus, despite their higher temperatures of crystallization, basalts tend to lose their contained heat more readily than do acidic rocks.

Several chemical indicators have been recognized as reflecting sub-surface or reservoir conditions beneath fumarole and hot springs areas. When these indicators are applied to the Lassen area, many suggest reservoir conditions favorable for geothermal power development. For example, Craig observed that isotopic ratios of oxygen and hydrogen of waters from the Lassen area showed O^{18} and deuterium enrichment patterns almost identical to surface emissions at such proven geothermal fields as The Geysers, Larderello, Salton Sea, and Yellowstone Park, and different from lower-temperature phenomena. Further, silica contents of hot springs waters from the Lassen area exceed 250 ppm in places. Fournier and Rowe wrote that under certain conditions, which appear to be met in the Lassen area, this might indicate reservoir temperatures of over 170°C. The sulfate-chloride ratios of these geothermal fluids approach infinity. This, too, is considered to be a favorable indicator. It is reasoned that if a boiling phase exists in the sub-surface, highly volatile elements, such as sulfur and fluorine, will be liberated along with steam, whereas less volatile chlorine will be concentrated in the residual fluid. Of course, a steam phase in the sub-surface suggests temperatures sufficiently high for exploration. The presence of extensive carbonate deposits, such as travertine terraces, is considered to be an unfavorable indicator, as the solubility of carbon dioxide decreases with increasing water temperature. Thus, systems carrying large quantities of carbon dioxide, or depositing extensive travertine, may reflect cooler reservoir conditions than desirable. Appreciable CO_2 is found only in the cooler springs at Drakesbad and at the alkaline springs at Devil's Kitchen. Allen and Day concluded, further, that the acid-sulfate springs represented hotter source than the alkaline or neutral springs. These, and other chemical data, therefore, suggest a exploration target of some magnitude.

To supply the necessary heat energy for geysering, White suggested that a likely minimum reservoir temperature for geyser systems would be 150° to 170°C. Exploratory drilling in several geyser systems has revealed temperatures up to, and in excess of, 200°C. By analogy, the geyser at Morgan Hot Springs and Terminal Geyser may reflect similar reservoir temperatures.

The unsuccessful geothermal test at Terminal Geyser raises some questions. Maximum downhole temperature was measured to be only 129°C. However, a lost-circulation zone, encountered at about 200 meters may have been the fault or fissure feeding Terminal Geyser. A deeper test, perhaps to 1,000 meters and offset to intersect this fissure at bottom-hole, might be more successful. Certainly further geophysical and geochemical exploratory work would be in order.

Allen and Day also wrote that the temperature of crystallization of the 1914-1915 dacites was probably less than 850°C. Subsequent cooling must have dissipated appreciable heat: witness the cessation of steam from Lassen Peak and Chaos Crags. Yet, because of the nature of the volcanic field at Mount Lassen, and because of the chemical and physical indicators of sub-surface conditions, an appreciable geothermal reservoir may remain beneath the fumarole and geyser areas.

(Getting leases from the Park Service, or from private land owners, for exploration is another matter beyond the scope of this brief paper!)

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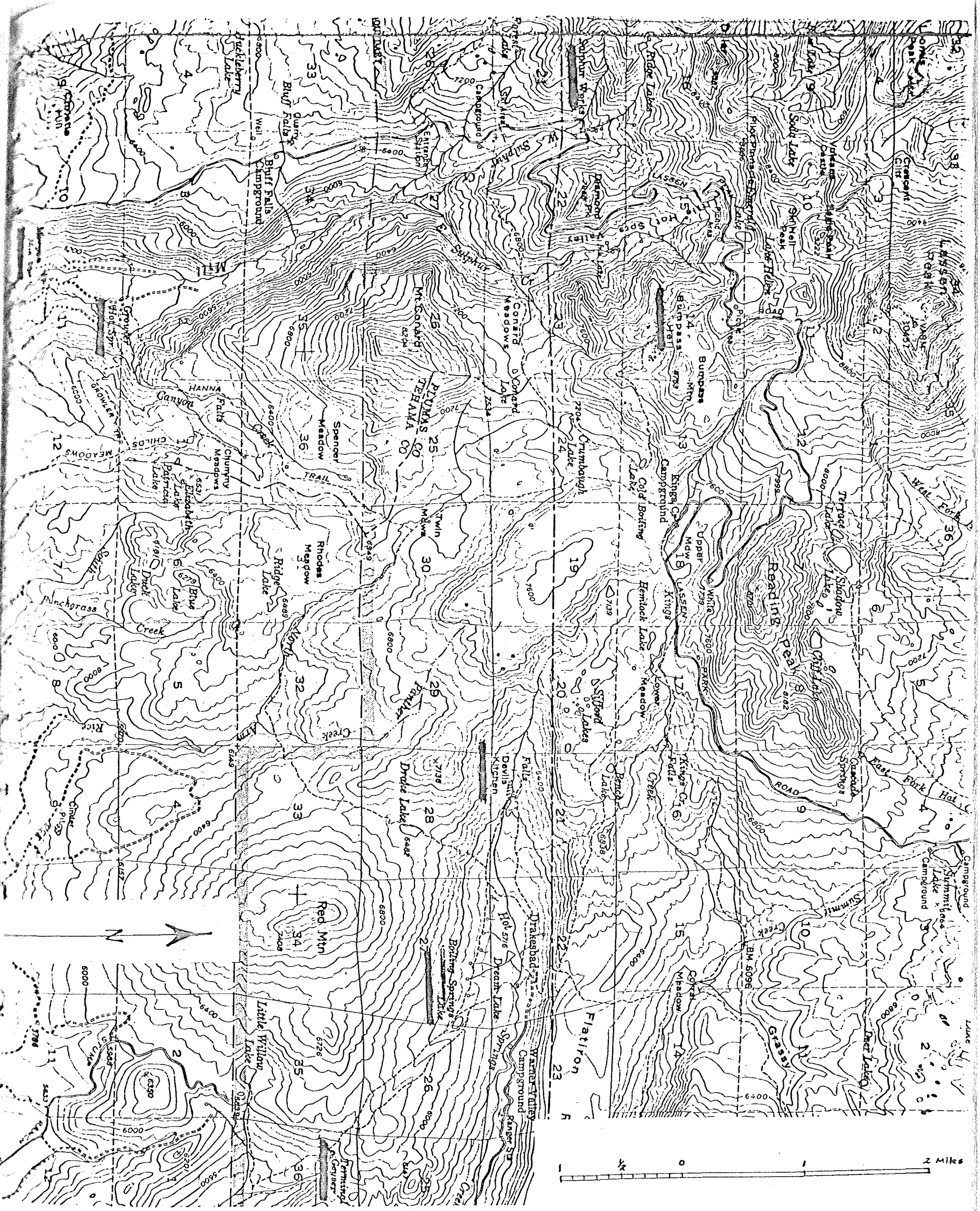

Figure 5. Topographic map of Lassen Peak and vicinity, showing areas of thermal phenomena.