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MASTER

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GEOTHERMAL ENERGY DEVELOPMENT FROM THE SALTON TROUGH TO THE HIGH CASCADES

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INTRODUCTION

The current program in Geothermal Energy Development at the Lawrence Berkeley Laboratory (LBL) began in 1973 in response to the national goal of developing alternate energy sources. To stimulate industrial development of geothermal resources for electric power generation the U.S.A.E.C. requested that LBL begin research and investigations in several areas. These were: an assessment of geothermal sites in northern Nevada for a proposed 10 MW demonstration plant; development of a binary-fluid power plant for moderate temperature, low-salinity brines; and various geochemical and geophysical studies related to the chemistry and thermodynamics of brines and reservoir rocks. An additional support project, the National Geothermal Information Resource (GRID), commenced with the responsibility for compiling data on geothermal energy and developing a computer-based storage and retrieval system for this information.

Since 1973 the national program approach has been modified. The AEC was ultimately incorporated into the Department of Energy (DOE), and the original geothermal group at LBL has grown into the Earth Sciences Division; now involved in research outside geothermal program areas. A simplified organization chart of the LBL Geothermal Energy Group and its relation to DOE and other organizations is shown in Figure 1.

Since the inception of the program, a number of LBL geothermal projects have been completed and terminated. Overall, the scope of the LBL geothermal work has grown primarily through the addition of the Reservoir Engineering and Subsidence Programs for which LBL serves as the lead-laboratory. Despite policy changes from Washington and several reorganizations within the Division of Geothermal Energy, the focus of LBL work remains on resources belonging to the convective hydrothermal type. Resources of this type are being exploited worldwide. One of the best known examples of this type is The Geysers in California, and we expect that convective hydrothermal systems will have the greatest impact on the U.S. energy picture for some years to come.

Due to geography, experience and other factors, LBL's work has also focused on resources in the states bordering the Pacific Ocean, resources extending from the known reservoirs in the Salton Trough to potential reservoirs in the High Cascades of Oregon.

The map in Figure 2 shows the principal sites where LBL has been or is currently involved in some aspect of geothermal energy development. The types of activities pursued at each site are shown symbolically, subdivided into three general classifications:

a. Exploration Technology
b. Reservoir Engineering
c. Utilization and Conversion Technology

It is beyond the scope of this paper to discuss our activities and their relationship to geothermal development at each site. I will therefore limit this discussion to current work in two contrasting geological environments.

(a) The Cerro Prieto Geothermal Field - Salton Trough, Baja California
(b) Mt. Hood Volcano, High Cascades, Oregon.

Cerro Prieto Geothermal Field

The Cerro Prieto geothermal reservoir is the southern most of several known reservoirs lying within the Salton Trough. The Trough, considered by many to be one of the major geothermal resource areas in the world, is a graben-like depression, 50 km wide, bounded by the San Jacinto and San Andreas fault systems in the southwest and northeast, respectively. The trough is also cut by numerous other NW-SE strike-slip faults whose locations have been determined from drilling and earthquake studies. The trough, yet subsiding at the rate of a few cm/yr, is filled with up to 6 km of post-Oligocene coarse-clastic continental, and marine sediments capped by younger deltaic sands, gravels and siltstones. The heat source is believed to be magmatic. Aeromagnetic evidence suggests igneous bodies at depths of 2100 to 3100m in the Salton Sea area. Volcanic rocks outcrop are relatively minor: Obsidian Buttes on the south end of the Salton Sea and the small Cerro Prieto volcano, which lends its name to the nearby geothermal field.

Presently, commercial developers in the U.S. are well advanced in their plans to begin reservoir and power plant demonstrations at reservoirs at Niland, East Mesa, Brawley and Heber. These will come on-stream in the 1980-1982 period. However, the Comision Federal de Electricidad (CFE) of Mexico has operated the Cerro Prieto geothermal field since 1973 and it remains yet the only water-dominated geothermal field generating electric power in North America (Figure 3). Currently, 16 producing wells supply 750 tons of steam per hour to generate 75MW. At the same time, 1500 tons of brine per hour are disposed into an evaporation pond. Continued exploratory drilling has extended the boundaries of the field north and eastward, and a second 75MW plant is scheduled to start operation in February 1979. Despite nearly constant exploration and development activity since the early 1960's, the ultimate size and productivity of the field has not been determined. Production is expected to be doubled again to about 300 MW by 1984, but the ultimate production rate could be far larger.

How large no one is prepared to guess yet. However, it appears that the reservoir is capable of producing more power than needed in Baja California, and U.S. utilities could be buying geothermally-produced electric power from CFE in the fairly near future.

In July 1977 a cooperative agreement was signed between CFE and DOE to conduct a study of the field. LBL serves as project coordinator for DOE. The project includes studies of the geologic, hydrogeologic, geochemical and geophysical characteristics of the field, as well as reservoir engineering and subsidence. The objective of this work, from the DOE perspective, is to develop a thorough understanding of the nature and magnitude of the resource and to determine the impact of exploitation on changes in local seismicity and subsidence. The knowledge gained could prove invaluable to U.S. geothermal developers in the Imperial Valley.

Also important is the question handling the present 1500 tons/hr of brine. Surface disposal and evaporation may not be the best solution to the brine management problem. Currently, 260×10^9 cal/hr in separated water represents the total wasted thermal energy. Various proposals have been made regarding the brines:

(a) Continued reliance on evaporation ponds,
(b) Evaporation ponds with extraction of lithium and potassium from the evaporite, and
(c) Injection of waste water back into the reservoir.

Injection of separated water back into the reservoir, if feasible, would not only solve the disposal problem but could significantly lengthen the productive life of the field; providing an additional source of thermal water recharge, reducing subsidence and maintaining reservoir pressure. At present, an observed decrease in reservoir pressure is a prime concern to CFE.

CFE has conducted various laboratory studies to evaluate alternative injection methods: cold or hot injection, with open, closed or mixed systems. The purpose of these tests is to establish the scale-forming tendencies. There has been an understandable reluctance by CFE to proceed too rapidly into actual injection field tests because of the fear of well plugging or, worse, ruining reservoir porosity around the injection well. However, with LBL assistance, CFE is preparing to make such tests this year.

One of the aspects of injection addressed by LBL is modeling the heat transfer - mass flow by means of a two-dimensional steady-state flow model (Tsang, Bodvarsson, Lippmann and Rivera, 1978). This model, which assumes constant fluid properties; i.e., it ignores chemical reactions, simulates a system of N production and M injection wells in a horizontal aquifer. For the calculations it was assumed that 50 percent of the produced water (1,375 m^3/hr) is injected through 3 or 4 wells in an aquifer 250m thick. The breakthrough time is the time it takes for the cold water thermal front to appear at the production wells. Because the cooler injected water extracts heat from hotter reservoir rocks, the thermal front moves 2 to 5 times slower than the hydrodynamic front. A temperature of 100°C was used for the "cold" injected water and 250°C was assumed for the reservoir. Figure 4 shows one of several cases modeled using a combination of existing non-producing wells, designated by an M, and new injection wells, designated by an X. The dashed lines are streamlines and the solid lines are the thermal fronts after 5, 20 and 50 years. The numbers indicate the breakthrough time in years and therefore provide an upper limit on the productive lifetime of the field. Natural hydrologic flow was ignored in these calculations, although this parameter could have been accepted into the model had it been known.

Although Cerro Prieto is not truly representative of geothermal reservoirs in the Salton Trough, they all differ in temperature, salinity, and brine composition, it is hoped that the results from tests at Cerro Prieto will help solve potential problems that U.S. producers in the Imperial Valley will face.

The First Symposium on the Cerro Prieto Geothermal Field was organized by LBL and held in San Diego last September. Approximately 500 attendees heard 30 papers which are now being assembled into a Proceedings volume in English and Spanish.

Mt. Hood, Oregon

In distinct contrast to the Salton Trough, the Pleistocene-Holocene volcanoes of the High Cascade Range, extending from Mt. Lassen, California into southern British Columbia, represent a largely unknown and untested geothermal resource. Figure 5 shows the distribution of Quaternary volcanics and the stratovolcanoes. We see represented here a major thermal event which began some tens of thousands of years ago and which continues, although weakly, to the present.

The Mt. Hood stratovolcano developed on a thick sequence of Pliocene andesite and basalts which had been assymmetrically folded and thrust faulted by tectonic stress, maximum compressive stress was horizontal north-south (M. Beeson, 1979, personal communication). North-south tensional fractures, some dike-filled, also were created and some of these probably served as the conduits for later andesites which constitute the cone. There is no discrete heat flow anomaly yet recognized for the volcano. Instead it occurs in a narrow (50-mile-wide) north-south belt of high heat flow values (2.0-2.5 hfu) with lower values as 1.0 hfu in the Willamette Valley to the west and 1.5 hfu values to the east (D. Blackwell, 1979, personal communication).

In 1977 DOE initiated a jointly-sponsored program with the U.S. Geological Survey, the U.S. Forest Service and the Department of Geology and Mineral Industries (DOGAMI), Oregon to assess the geothermal potential of Mt. Hood. Although a complete assessment was well beyond the scope of the project, the main objectives were to learn which exploration techniques are applicable and how to apply them in this complex geological setting where basic information was sparse or lacking. It was also hoped that through a limited drilling program of shallow and moderate depth holes, enough could be learned about the thermal regime and subsurface geology to guide commercial developers.

Mt. Hood was selected mainly because of federally-owned land and its proximity to Portland, 60 miles to the west. It is hoped that sufficient quantities of hot water will be found to supply space-heating and industrial processes in the Portland area.

The program was coordinated by DOGAMI and consisted of various geological, geophysical and geochemical studies, including drilling. Table 1 lists the studies and the responsible organizations. LBL had responsibilities for (a) geochemistry and (b) electromagnetic surveys.

The geochemical work included sampling and analyses of warm and cold spring waters, country rocks, and fumarolic gases to determine the temperatures at depth in circulating hydrothermal systems, and the hydrologic pathways. Waters were analyzed for trace and major elements by gamma-ray spectrometric, neutron activation, and X-ray fluorescence techniques at LBL, for oxygen and hydrogen isotope ratios by mass spectrometry at Saclay, France. Gases from the fumaroles were analyzed by the USGS in Menlo Park.

The only warm water surface manifestation occurs at Swim Springs 6 miles south of the summit (Figure 6). There, several orifices discharge a low volume of water with temperatures of 10°C - 15°C. A total thermal discharge of 0.5 MW from the springs has been estimated, compared with 3 MW thermal output from the summit fumaroles (J. Robison, 1979, personal communication).

The chemistry suggests that most of the water at the Springs is meteoric water which entered the system at a point high on the mountain. LBL and Oregon workers have proposed a hydrologic model in which this water is heated by proximity to the mountain's central conduit system, then moves quickly down-gradient, mixing as it flows with cold near-surface meteoric waters. Chemical geothermometers and mixing model calculations suggest alkali and silica equilibration temperatures of water entering the Swim system of 104°C - 170°C (Wollenberg, et al., 1979). In sufficient quantity, water at this temperature could be used for local space heating (ski lodges, etc.) as well as other direct heat applications between Mt. Hood and Portland. Currently, one utility, Northwest Natural Gas, is looking into this possibility and they have drilled a 4000-foot well west of the mountain at Old Maid Flat. The well penetrated and bottomed in pre-Mt. Hood volcanics. Although the bottom-hole temperature was high enough for space heating applications, the volcanics were unfractured and little water entered the hole.

Three other drill holes have been attempted near Timberline Lodge located midway between the summit and Swim Springs. Drilling has proven extremely difficult and no significant information has been obtained below the coldwater hydrologic "washout." On the flanks of the volcano this washout occurs in a zone extending from surface to depths of at least 220m due to a strong flow of isothermal, cold meteoric water (2°C) moving down-gradient in a porous and permeable ash and block flow. Not only does the hydrology make drilling difficult, but it also completely masks the true heat flow and temperature gradient.

One way to probe through the cold isothermal surface layers without drilling is by means of electrical resistivity surveys. LBL has performed two types of surveys on the mountain: (a) magnetotellurics (Goldstein and Mozley, 1978) which utilizes natural low-frequency electromagnetic energy and (b) controlled-source EM (Morrison, et al., 1978) which depends on a strong man-made source of low-frequency energy. Because of the geological complexity present, the reduced and processed data are generally difficult to interpret. A concerted effort is underway to interpret these data using new computer codes for 2- and data using new computer codes for 2- and 3-dimensional earths. However, on the northeast side of the mountain, close to the Cloud Cap eruptive center (age 12,000± y.B.P.) we have interpreted what appears to be an intriguing anomaly (Figure 7). Below the cold and resistive near-surface zone, we interpret a conductive and possibly warmwater zone at about 600m. A second conductive zone begins at 2 km and extends downward for an undetermined depth. We have recommended that a hole be drilled in this area to test the electrical anomaly, and there is the possibility that a hole can be drilled this year.

Beginning this year, the U.S.G.S. will begin a Regional Cascade Program, seeking evidence for geothermal resources over the entire length of the High Cascades. The Mt. Hood work will be channeled into that program, and we expect that LBL, through DOE, will participate in the program.

In conclusion, I only wish to say that this paper is intended to give a general overview of LBL's geothermal energy development work, and to discuss a small part of this work in relation to two current projects. Because of the required brevity, only a few points could be mentioned. Nevertheless, I hope that this talk conveys an idea of LBL's work in the national geothermal energy program and its relationship with other government research organizations.

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Wollenberg, H.A., R.G. Bowen, H.R. Bowman and B. Strisower, 1979, Geochemical studies of rocks, waters and gses at Mt. Hood, Oregon: Lawrence Berkeley Laboratory, LBL-7092 (in preparation).

FIGURE CAPTIONS

Figure 1. A simplified organization chart of the LBL Geothermal Energy Group and its relation to other governmental organizations. (XBL 791-7337)

Figure 2. Location map showing principal sites and types of investigations conducted by the LBL Geothermal Energy Group since 1973. (XBL 791-7338)

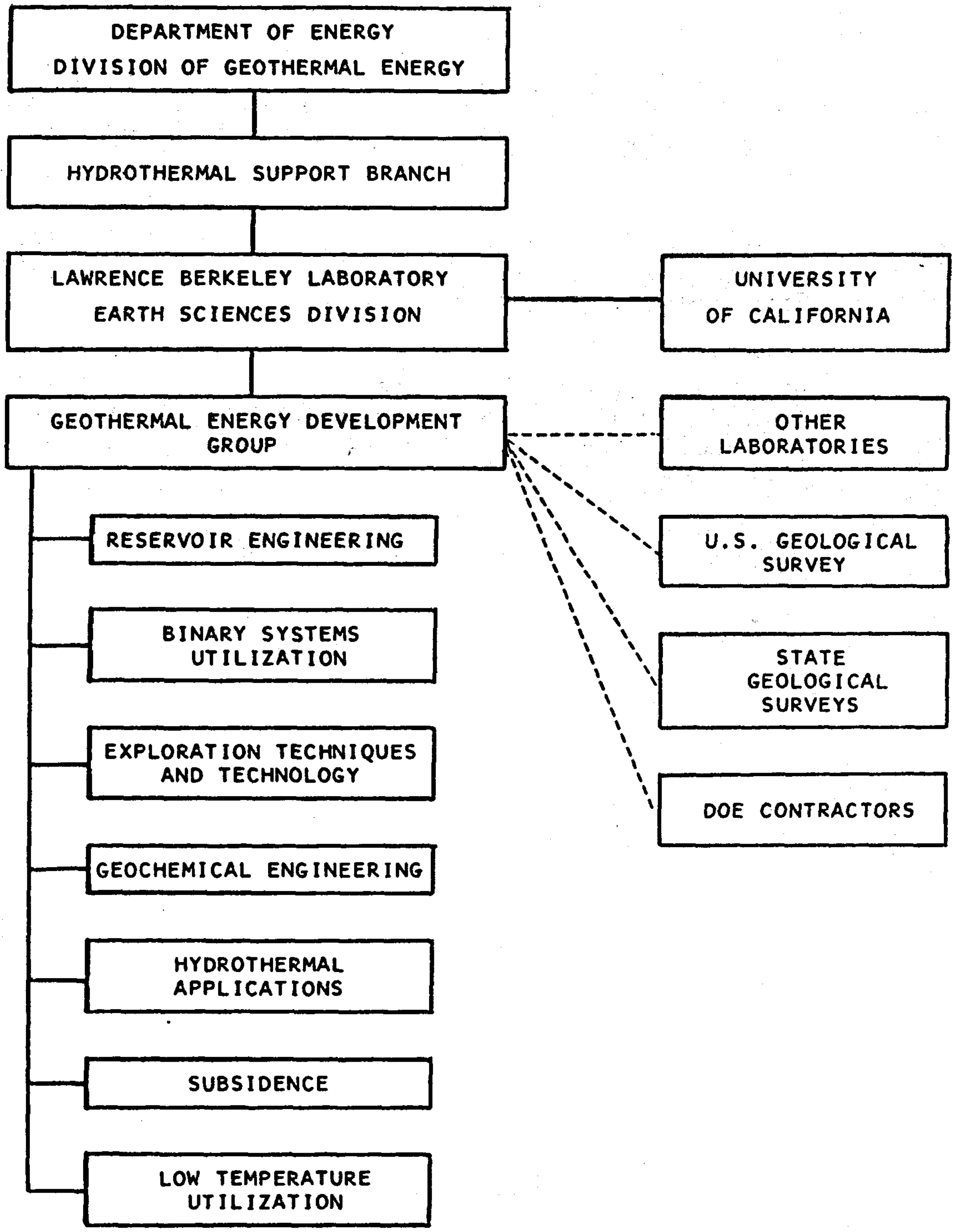
Figure 3. Plant and well locations at the Cerro Prieto Geothermal Field. Proposed wells have been completed and proposed power plant No. 2 will begin start-up operations in February 1979. (XBL 7710-10241)

Figure 4. Calculated breakthrough times of the thermal front due to injection of 50 percent of present brine production. (After Tsang et al.,19780). (XBL 783-486)

Figure 5. Distribution of Quaternary volcanics and stratovolcanoes of the High Cascade Range. (XBL 784-665)

Figure 6. A simplified location map of the Mt. Hood area. (XBL 784-644)

Figure 7. One-dimensional (layered earth) interpretation of magnetotelluric data taken at the Cloud Cap station. Dashed lines indicate a plausible family curves accounting for ambiguities introduced by surface inhomogeneities, such as local terrain variations. (XBL 785-805)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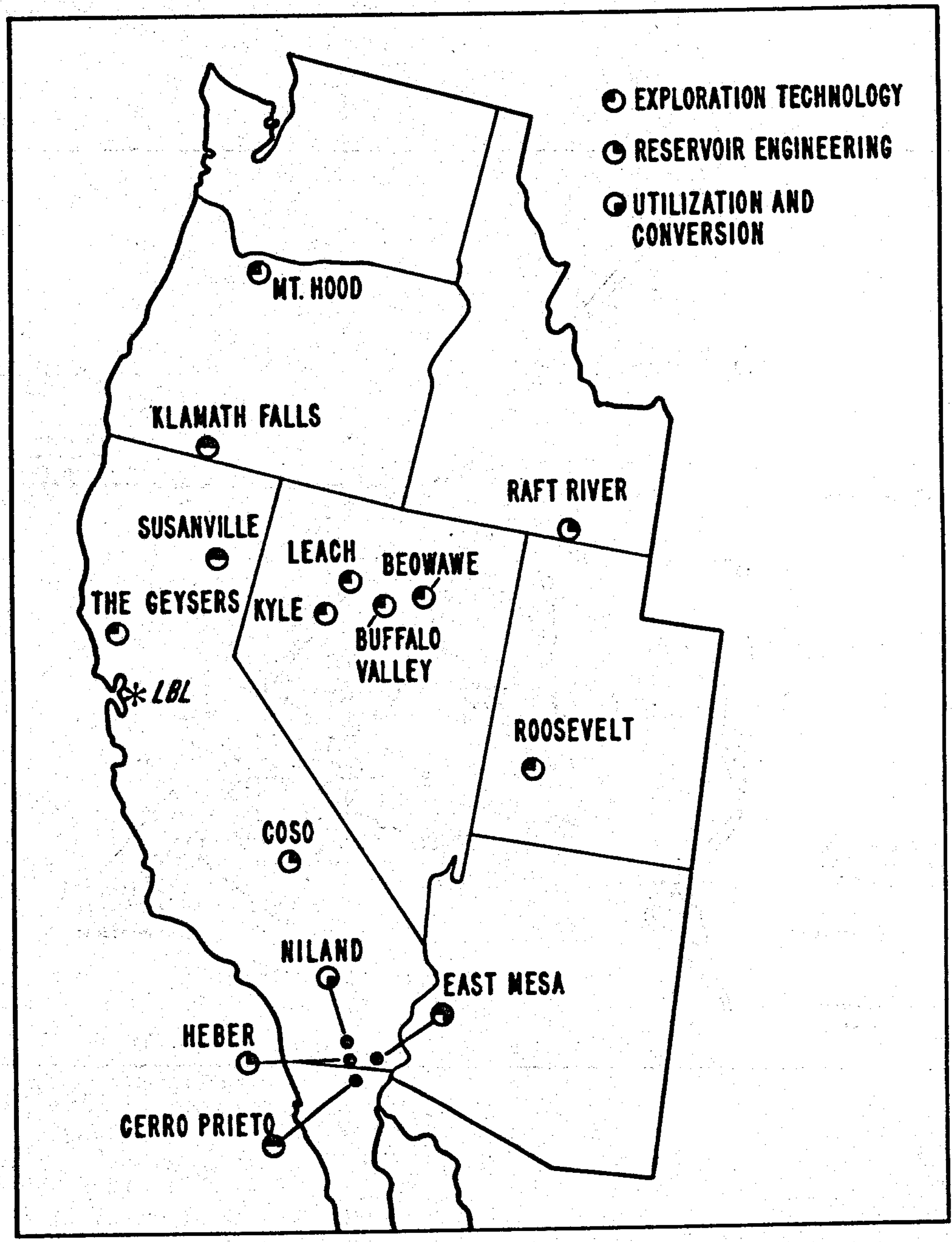
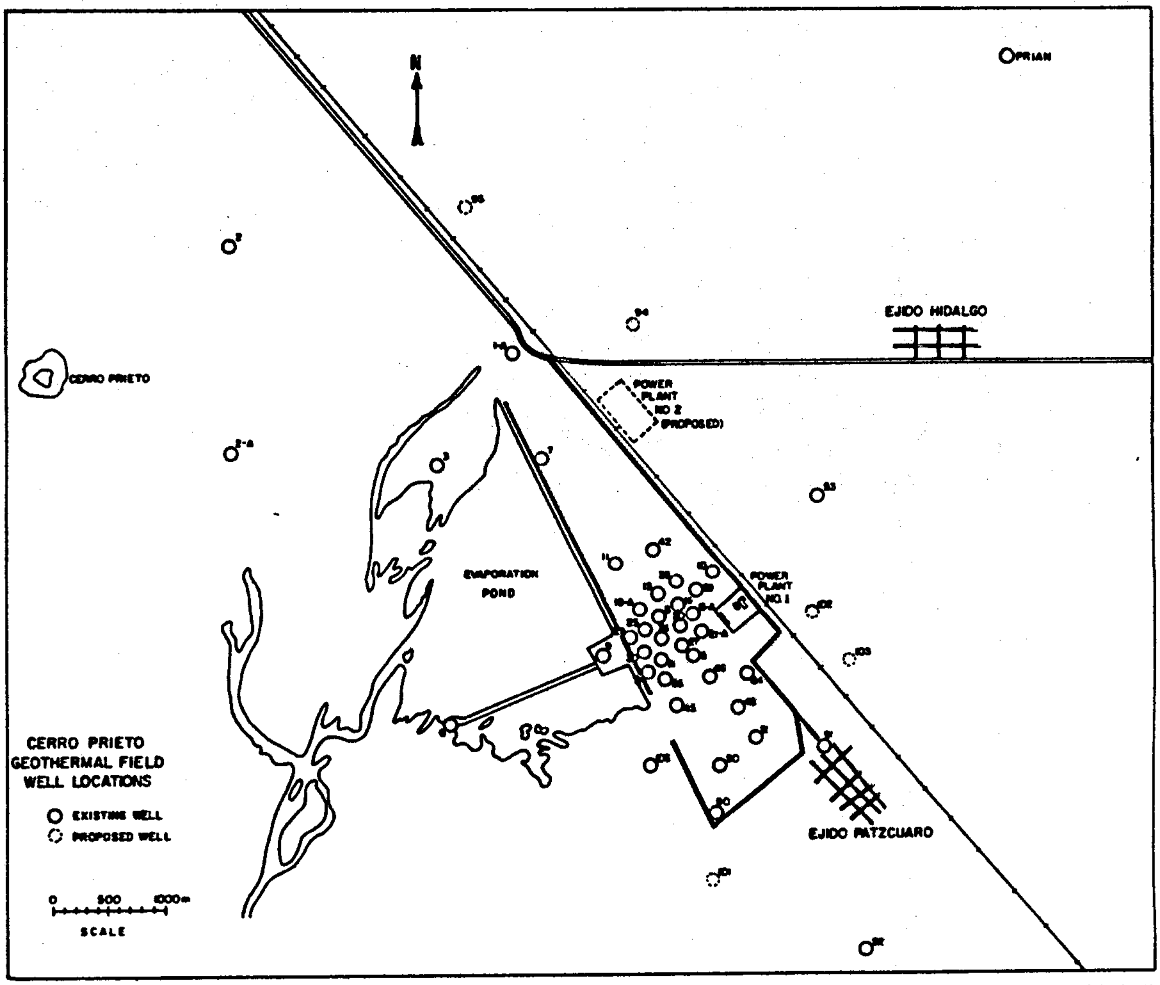
SUBSIDENCE
LOW TEMPERATURE UTILIZATION

XBL 791 - 7337



LBL GEOTHERMAL PROJECT SITES

XBL 791-7338



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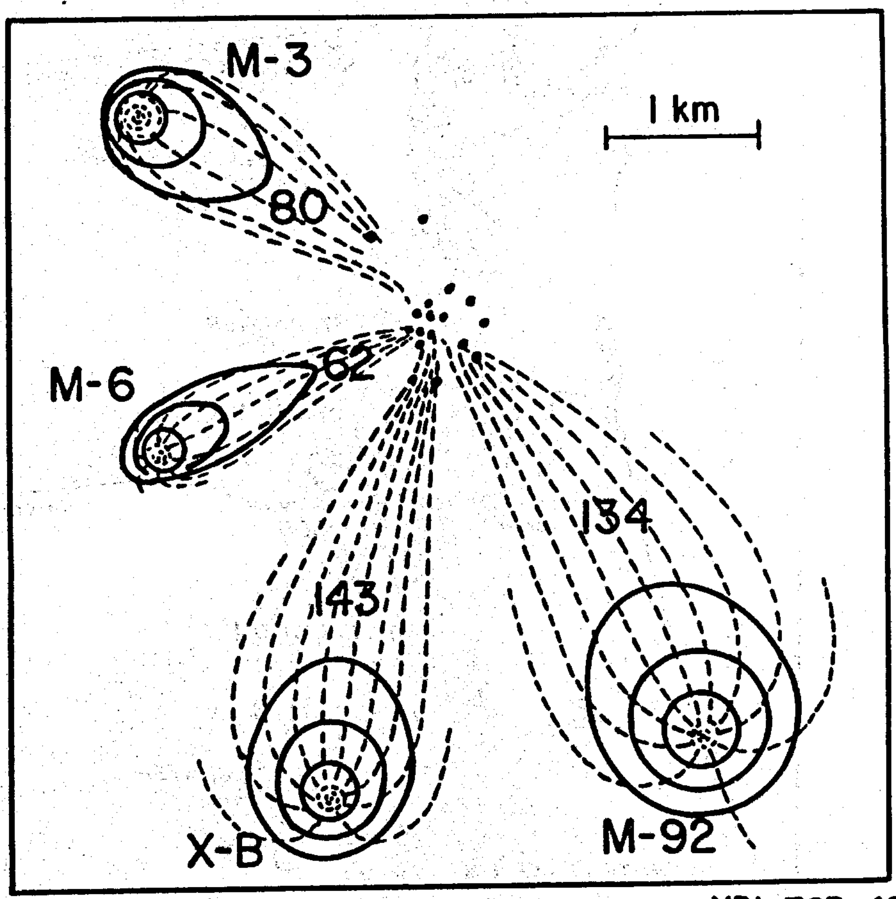

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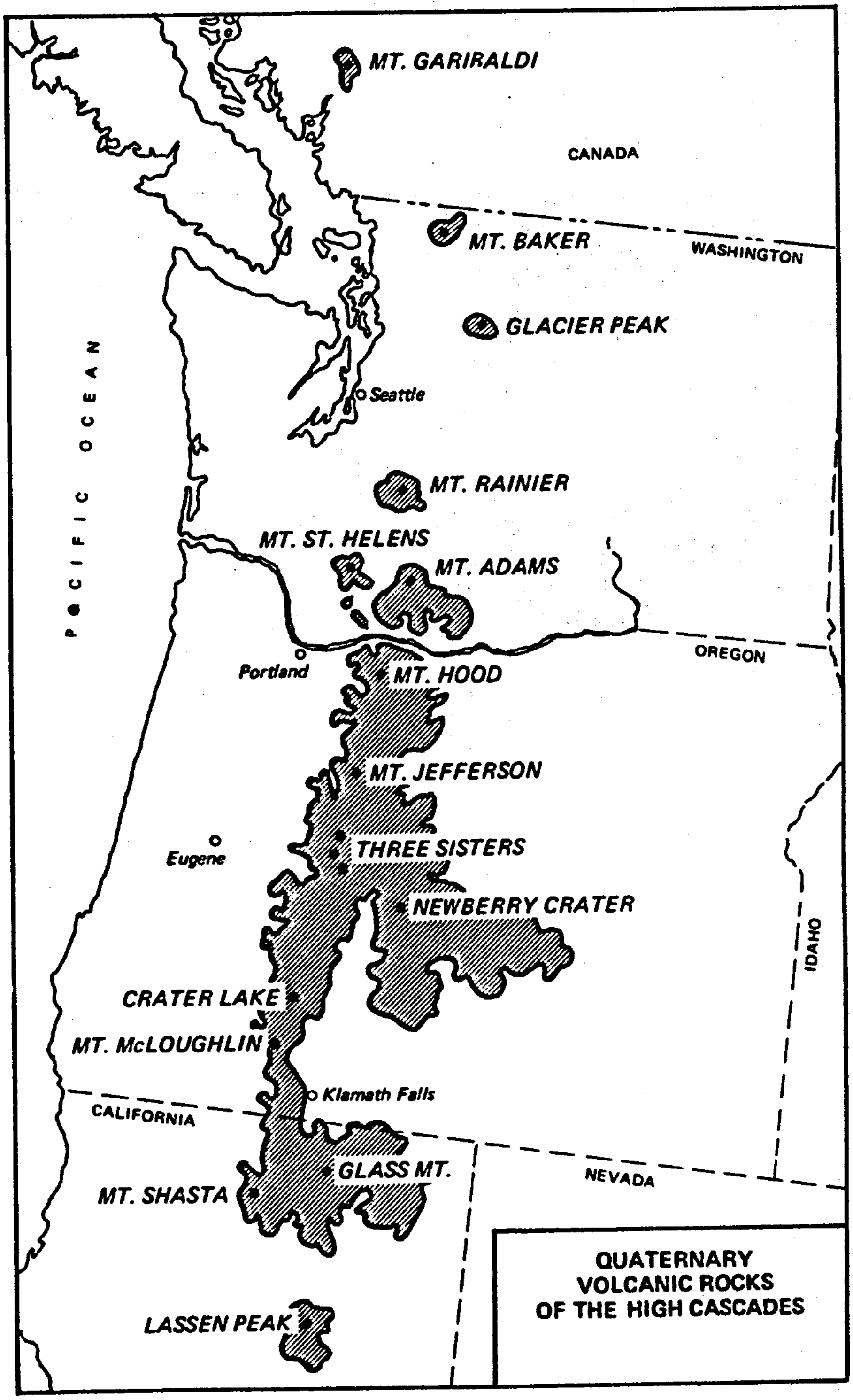
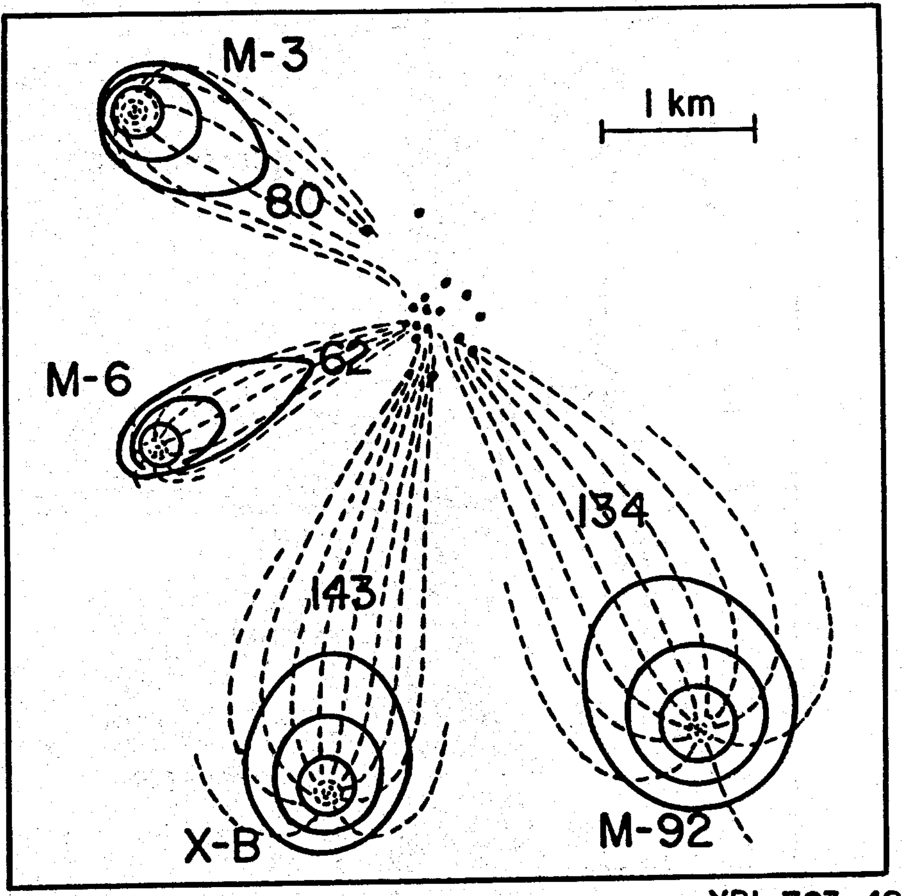


QUATERNARY
VOLCANIC ROCKS
OF THE HIGH CASCADES

XBL 784-665



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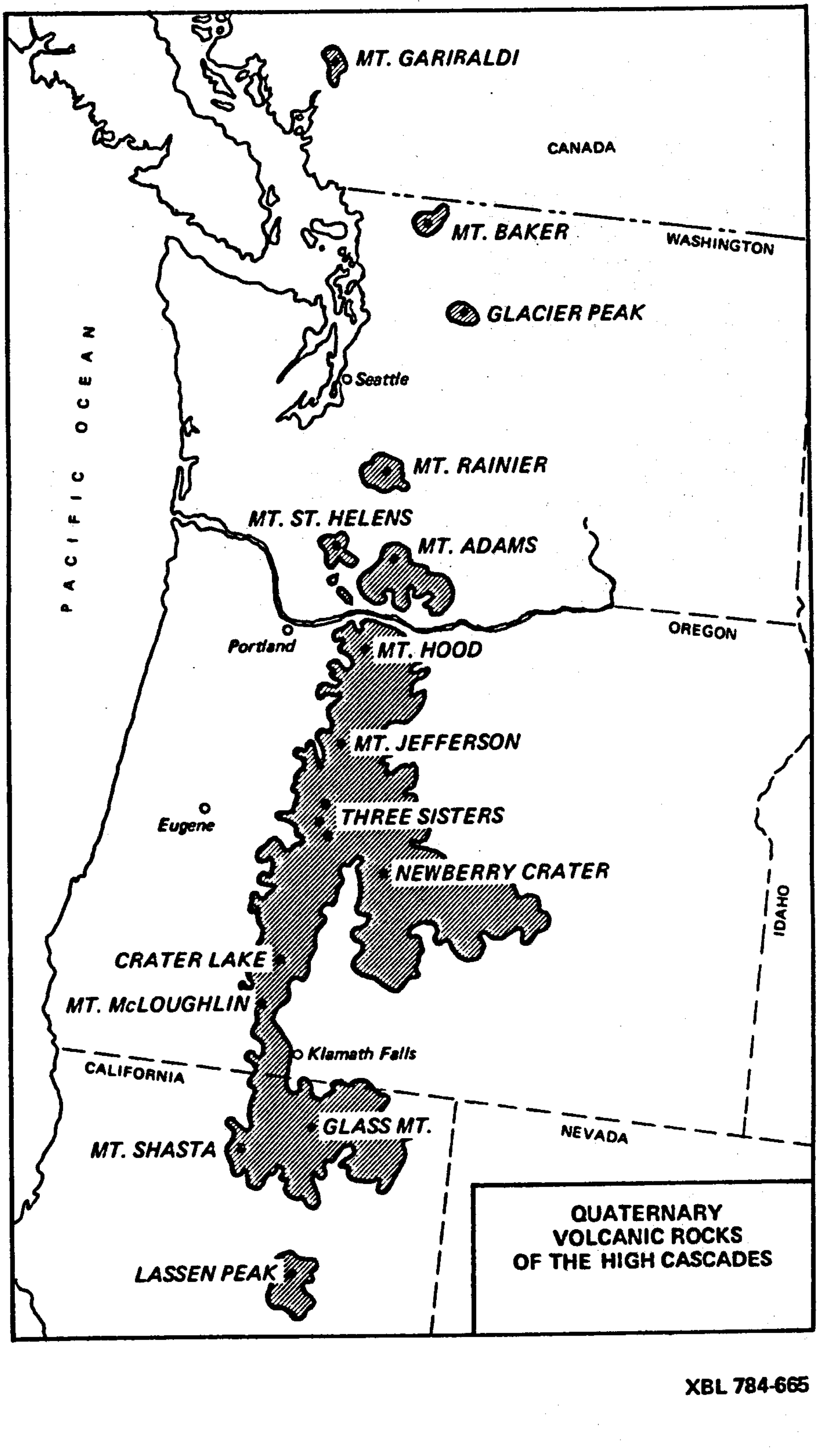
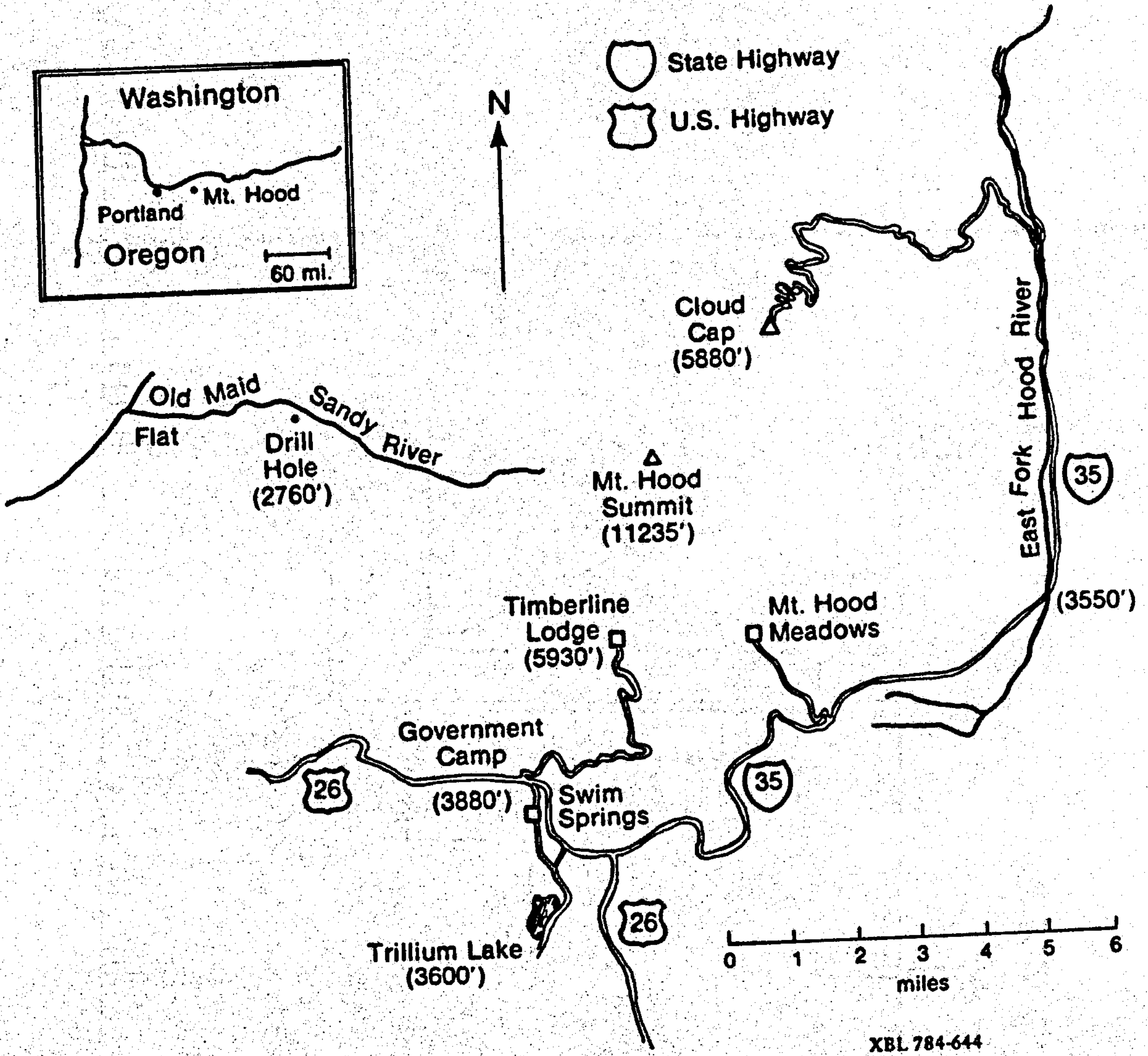
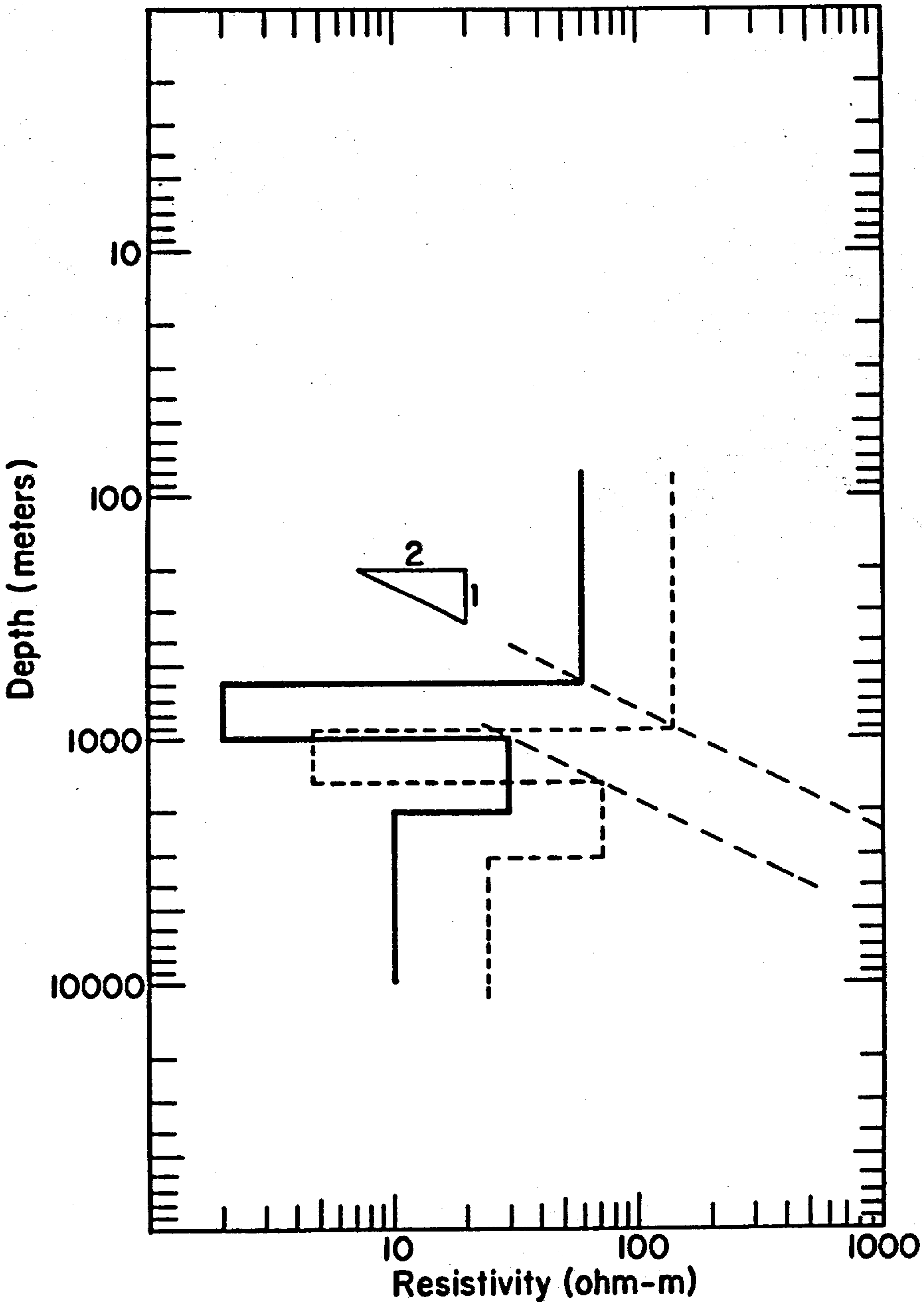


QUATERNARY VOLCANIC ROCKS OF THE HIGH CASCADES

XBL 784-665


Washington
Portland
Mt. Hood
Oregon
60 mi.
N
State Highway
U.S. Highway
Cloud Cap (5880')
Old Maid Flat
Sandy River
Drill Hole (2760')
Mt. Hood Summit (11235')
East Fork Hood River
35
(3550')
Timberline Lodge (5930')
Mt. Hood Meadows
Government Camp
26
(3880')
Swim Springs
35
26
Trillium Lake (3600')
0 1 2 3 4 5 6
miles

XBL 784-644



Depth (meters)
10
100
1000
10000
2
1
10
100
1000
Resistivity (ohm-m)

XBL 785-805

Table 1

MT. HOOD GEOTHERMAL PROJECT

A.	GEOLOGY	
	Columbia River Basalt Stratigraphy	Portland State University
	Mt. Hood Geology	University of Oregon
	Hydrology	USGS
B.	GEOPHYSICS	
	Aeromagnetic Studies	USGS
	Gravity	Oregon State University
	Seismic Studies	USGS
	Electrical Resistivity	LBL
	Self Potential	USGS
	Remote Sensing	USGS
	Rheology	Oregon State University and Portland State Universities
C.	GEOCHEMISTRY	
	Fumorales and Hot Springs	LBL, DOGAMI
D.	DRILLING	
	Drilling and Logging	DOGAMI