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MAGNETOTELLURIC INVESTIGATIONS AT MT. HOOD, OREGON

N. E. Goldstein, E. Mozley, T. D. Gamble and H. F. Morrison

LAWRENCE BERKELEY LABORATORY
BERKELEY, CALIFORNIA 94720

Introduction

In 1977 the Department of Energy (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, Oregon (DOGAMI) to assess the geothermal potential of Mt. Hood and thereby stimulate commercial exploration of this and other young strato-volcanoes of the High Cascade Range in the Pacific Northwest. Mt. Hood was selected for study for several reasons. Its proximity to Portland, 60 miles to the west, assures a nearby energy market should exploration and development efforts prove successful. As most of the land is federally controlled under the U. S. Forest Service access problems are minimal. Finally, there is some geological evidence at surface of a geothermal resource at shallow to moderate depths.

Geology

The Pleistocene-Recent cone, composed mainly of andesite flows and interlayed pyroclastic and reworked clastic debris, rises 2500m above a base of Pliocene andesites and basalts of undetermined thickness. After the main phase of cone building but prior to extensive glaciation, two satellitic vents, in excess of 12,000 years, developed in the north and northeast slopes (The Pinnacle and Cloud Cap, respectively) and were the sources of several olivine andesite flows (Wise, 1968). While glaciers were filling many of the valleys (about 12,000 y.b.p.) a large dome was extruded near the summit (Crandall and Rubin, 1977). Vast quantities of hot rocks and ash were expelled, mixed with the snow and ice, and avalanched down the southern flank to form extensive blankets of hornblende dacite debris. After nearly 10,000 years of relative dormancy another dome erupted, producing $1.5 km^3$ of dacitic debris. A smaller dacitic dome may have erupted 250 to 300 y.b.p. In the historical past minor eruptions may have occurred in 1805 and 1859, but details are sketchy and these events added little new material to the volcano (Harris, 1976).

Present-day heat sources are believed to be associated with the more recent dacitic eruptions, within the last 300 years (Wise, 1977). A current heat source is indicated by the 20 or so fumaroles near the summit. These occur in brecciated rock at the margin of the hornblende andesite plug-dome called Crater Rock. Hot water or steam reservoirs could exist within the cone, heated by the dacitic magma column, and/or at greater depth within fractured volcanics underlying the cone (Wise, 1977).

A minor thermal manifestation occurs six miles south of the summit at the Still Creek Campground where several orifices discharge warm waters. This has led to the speculation that there is a deep-going plumbing system bringing heated waters to the surface. However, evidence for faulting is scant there and elsewhere around the mountain. The only possible major fault is one that follows the north-south trending East Fork of the Hood River, bounding the volcano on the east.

Survey Planning

The Lawrence Berkeley Laboratory (LBL) was asked to plan, manage, and interpret the results of electrical surveys for the Mt. Hood project. After considering the methods available for obtaining deep resistivity information, magnetotellurics was chosen as the only practical method for an initial survey. Galvanic resistivity was dismissed because of the insuperable problems of laying out long wires and cables in the area. Audio-frequency magnetotellurics (AMT) was considered risky because the high near-surface conductivities associated with the pyroclastic and clastic debris might too severely limit the depth of exploration. Controlled-source electromagnetic methods were also considered, but the appropriate equipment was not yet available.

An ad hoc committee of geophysicists from laboratories and industry was convened to discuss and plan an MT survey. The consensus was that although MT seemed to be the best method available, there would be serious problems related to data acquisition and interpretation. The obvious problems, later verified by experience, were (a) difficulty in interpreting the data due to the complexity of the geology, (b) difficulty in siting stations due to terrain and access, (c) bias errors caused by electric dipoles whose lengths are short compared to the dimensions of surface inhomogeneities, and (d) cultural noise, mainly from vehicles. Of these access would be the major problem for we would have no easy means for putting stations in the most important area, within a one or two-mile radius of the summit, i.e., directly above the most likely reservoir region. Unlike some other volcanoes there was scant to no evidence for ring and radial fracturing that might suggest reservoir regions below the lower, more accessible slopes of the volcano.

In later field work we would also discover very high contact resistances (15 kΩ to 50 kΩ) caused delays in installing many of the electric dipoles. Moreover, we discovered very strong self-potential voltages, three to five volts over distances of 150m, which are most likely due to streaming potentials caused by water flow down a steep hydrologic gradient (D. Hoover, personal communication). At one station the self-potential voltage was so high that the orthogonal electric dipoles had to be rotated to find an orientation of lower potential that could be nulled by the SP bucking circuit.

The telluric-magneto telluric (T-MT) approach was selected to mitigate the general access problem and to reduce the per-station cost. In T-MT a tensor MT base station is operated simultaneously with several distant telluric stations, or remotes. Magnetic data from the base are combined in calculations with remote telluric data to provide an equivalent MT sounding at the remotes. The resulting impedances at the remotes are strictly valid only if the magnetic field is uniform over the area, a situation not expected in complex geological settings. However, we planned to reoccupy some remotes with base stations to check the validity of T-MT results.

It was also decided to use both a reference magnetometer and an electric dipole reference in the survey area following an experimental practice described by Gamble, Goubau, and Clarke (1977, 1978). In this procedure uncorrelated field noise, which causes serious errors in bands of low signal strength, is eliminated by using reference channel data in the calculation of impedances. One solves for the Z_{ij} impedance elements by forming cross spectral terms only in which uncorrelated noise must average to zero. Using a magnetic reference, for example, the Z_{xx} term in the impedance tensor is solved as

$$Z_{xx} = (\overline{E_x H_{xr}^*}\ \overline{H_y H_{yr}^*} - \overline{E_x H_{yr}^*}\ \overline{H_y H_{xr}^*})/D$$

where H_{xr}^* and H_{yr}^* are the complex conjugates of the Fourier transforms of the reference channels and

$$D = \overline{H_x H_{xr}^*}\ \overline{H_y H_{yr}^*} - \overline{H_x H_{yr}^*}\ \overline{H_y H_{xr}^*} .$$

It is a property of the technique that the values Z_{ij} are independent of reference field magnitude and phase, and therefore one needs no precise knowledge of gains and phase shifts in the telemetry link.

Data were to be collected in overlapping bands covering the 0.002 to 40 Hz range. The survey was planned in two phases, allowing time between phases for assessment of results.

Geonomics, Inc., a geophysical contractor with offices in Berkeley, was selected to perform the survey and process the data conventionally. LBL, assisted by the Engineering Geoscience Group at U. C. Berkeley retained responsibility for reference magnetometer/dipole processing and overall data interpretation.

Phase I Survey

The Phase I work was limited to the south side of Mt. Hood between the Timberline Lodge (elevation 5900') and Trillium Lake (elevation 3800'), six miles away. This area was chosen in the hope of delineating some structural/resistivity features related to the warm water emanations at the Still Creek campground. Remote telluric stations were also planned on the Palmer glacier, up to the 8000' elevation, but severe man-made noise associated with the Timberline Lodge and the ski lifts precluded this. MT stations were sited close together, one to three kilometers apart, to obtain sufficiently dense information needed to resolve three-dimensional structures.

Each set-up consisted of a base station, two remote telluric stations and a reference magnetometer station. The latter was maintained on Multorpor Mountain throughout the survey. Data from remote stations were radio telemetered to the base and 12 channels of data were band-pass filtered, amplified, multiplexed, digitized, and recorded on tape. Twenty-nine stations were occupied but severe noise problems due to grounded power lines, particularly near Timberline Lodge, resulted in generally poor data quality. The data showed a strong north-south two-dimensionality with a resistive block somewhere to the east. The station over the Still Creek campground was anomalous, showing uniformly low resistivities throughout the frequency range.

Phase II Survey

It was decided to acquire regional MT data in Phase II. Clusters of stations were occupied around the mountain, excluding the Wilderness Area in the northwest quadrant. One cluster was centered around the ~15,000 y.b.p. side vent at Cloud Cap. The station closest to the vent was clearly anomalous, showing a definite low resistivity region at shallow depth. This zone disappears with distance downslope from the vent.

Two clusters of stations straddle the possible fault zone of the East Hood River; no MT evidence for faulting was detected.

One cluster was sited east of the Phase I survey area to help define the location of the north-south structure inferred from the earlier results. No evidence of this faulting was detected. However, all stations seemed to indicate some degree of structural two-dimensionality, directed radially into the mountain. This effect may reflect the radial build-up of the cone from successive flows.

The final cluster was located in Old Maid Flat, west of the mountain.

Future Plans

All of the MT data will be reprocessed using the reference magnetic channels so that gaps in the sounding curves, due to poor coherencies, can be filled in. Interpretations based on two and three dimensional models will be attempted, and detailed investigations will be made in selected areas. Controlled-source EM measurements are planned this year around the Still Creek campground and Cloud Cap, where MT anomalies occurred, and above on the Palmer glacier where a strong SP anomaly was detected by D. B. Hoover of the U. S. Geological Survey.

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