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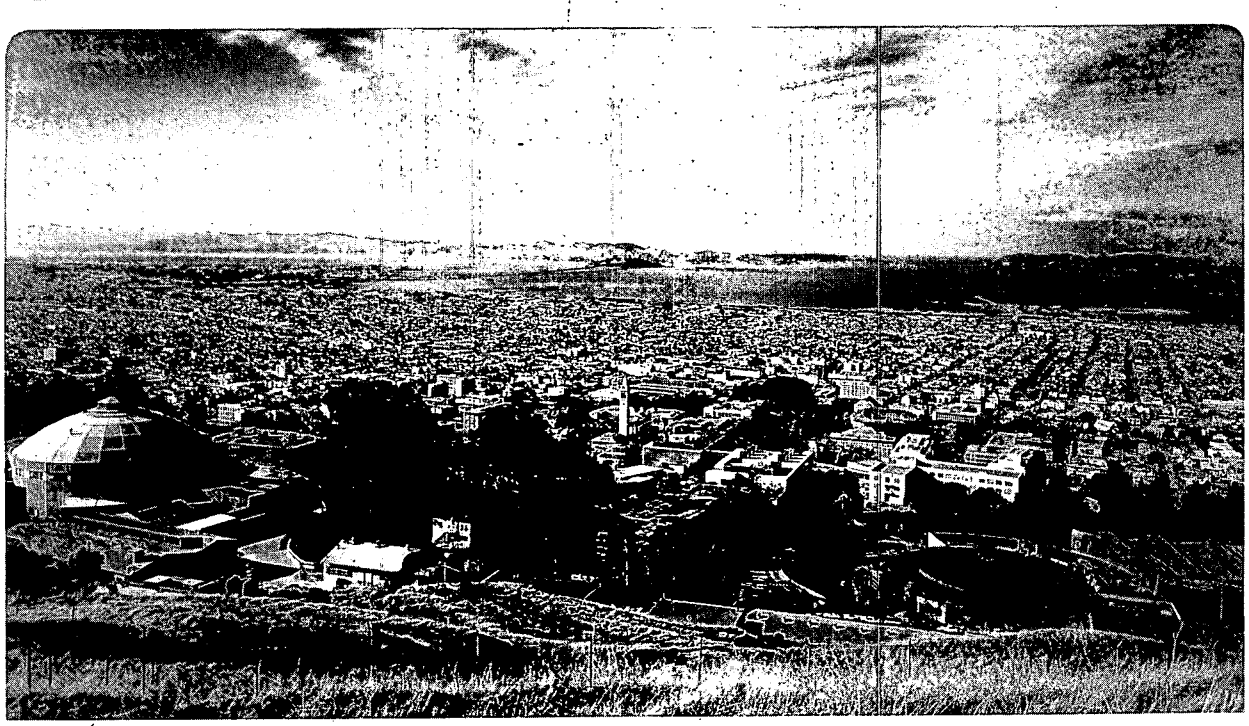

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A CORE HOLE IN THE SOUTHWESTERN MOAT OF THE LONG VALLEY CALDERA: EARLY RESULTS

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Abstract

A continuously cored hole penetrated 715m into the southwestern moat of the Long Valley caldera. Temperatures in the post-caldera deposits increase rapidly with depth over the upper 335m to 202°C, then remain nearly isothermal into the Bishop Tuff to the bottom of the hole. The depth to the Bishop is the shallowest, and the temperatures observed are among the highest in holes drilled in the caldera. The hole identifies a potential geothermal resource for the community of Mammoth Lakes, constrains the position of the principal heat source for the caldera's hydrothermal system, and serves as access for monitoring changes in water level, temperatures, and fluid chemistry.

Introduction

Intensive investigations in the Long Valley caldera (Figure 1) have considered the caldera's volcanic petrology, seismic and volcanic hazards, hydrothermal resource potential, and potential for energy resource recovery from relatively shallow magma bodies. With respect to the latter consideration, attention has focused on the area underlain by the resurgent dome (Rundle, et al., 1986). However, the western and

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southwestern portions of the caldera are both the most volcanically active and the least explored areas within the caldera. An understanding of the hydrothermal regime of the western moat may be the key to understanding the origin of, and circulation within the present-day hydrothermal system within the Long Valley caldera.

Concepts of the Long Valley hydrothermal circulation system have most recently been described by Sorey (1985) and Blackwell (1985). On the basis of temperature reversals in wells, there appear to be one or more zones of hot water flowing eastward beneath the south moat from Casa Diablo (CD on Figure 1) at an altitude of approximately 2100m. The flow is in aquifers within and above the welded Bishop Tuff. The temperature in this region decreases from about 170°C in wells that supply the geothermal electric power plant at Casa Diablo Hot Springs to less than 70°C near Lake Crowley. Test drilling on and around the resurgent dome and to the east of the dome to depths of 2100m has failed to encounter temperatures as high as those measured in the shallow aquifer at Casa Diablo. Prior to drilling of the core hole described in this report, the only direct evidence of hot-water reservoirs beneath the western moat was the high temperature gradient in the bottom part of the 716m-deep PLV-1 well. The analyses by Sorey (1985) and Blackwell (1985) along with reservoir temperature estimates based on chemical geothermometer calculations applied to thermal water from Casa Diablo indicated, however, that a reservoir at temperatures above 200°C existed beneath the western moat and was the source of thermal fluids at Casa Diablo and to the east. A possible heat source for the postulated west moat reservoir was suggested to be hot intrusive rocks associated with the southern extension of the 600-year-old Inyo volcanic chain of dikes, craters, and flows described by Miller (1985).

Drill hole information indicates that zones of deep fluid circulation no longer exist beneath the resurgent dome and that hot springs and fumaroles on or around the dome are fed from relatively shallow aquifers connected by lateral flow to a source reservoir within the Bishop Tuff beneath the western moat. Therefore, if a residual magma chamber is in place beneath the central part of the caldera, it does not represent a significant heat source for the present-day hydrothermal system, and if magma is present at depths as shallow as 4–5 km beneath the resurgent dome, it has not been in place long enough to influence the overlying ground water system. The resurgent dome is made up primarily of rocks that were extruded 630,000 to 680,000 years ago, and the last eruptions near the dome were ~ 300,000 years ago, (Bailey and Koeppen, 1977). In contrast, evidence of intrusive and extrusive magmatic activity along the Inyo volcanic chain as recently as 550 – 650 years ago lends support to the inference that the heat source for the present day hydrothermal system is magma associated with this chain beneath the western moat. A southern projection of the Inyo-Mono system terminates at Mammoth Mountain, a large, predominantly rhyodacite volcanic dome, of 200,000 to 50,000 year age, on the caldera's southwestern rim. Phreatic explosion craters on the north and northeast flanks of Mammoth Mountain may be contemporaneous with the most recent Inyo volcanic chain eruptions (Miller, 1985).

Given this setting, it was evident that one or more new drill holes were needed in the caldera's western moat to provide confirmation of the models of the present-day hydrothermal system. It was therefore proposed to drill a hole near the Shady Rest Campground to provide information on the presence of a hot-water reservoir within the Bishop Tuff beneath the southwestern moat. The high temperature gradient in well PLV -1, located 2.5 km to the northwest of Shady Rest (Figure 1) suggested that such a reservoir might exist. Data from a 155m test hole drilled in 1984 near Shady Rest for the Mammoth County Water District (Guacci and McCann, 1984) suggested that shallow zones of thermal water occur above the Bishop Tuff. The source of this water could provide energy for space heating in Mammoth Lakes. For this reason Mono County and the California Energy Commission contributed financially to the Shady Rest drilling effort. Industry interest was also focused on the western moat. Unocal Geothermal was actively exploring the Inyo Craters area, ~ 6 km northwest of Shady Rest, and drilled a ~ 1800m – deep test hole (# 44–16) in the late fall of 1985. This hole intersected a hot zone with temperatures up to 218°C in the Bishop Tuff, at depths of 915 to 1175m. This hot zone is immediately underlain by a much cooler zone in precaldera volcanic rocks (Suemnicht, 1987).

Coring and Related Activities

The Shady Rest hole was spudded-in on May 5, 1986 and completed on June 17. Its configuration is shown in Figure 2. The hole was rotary drilled to 92m, and a 12.7 cm diameter surface casing installed. The hole was then cored at 9.6 cm diameter to a total depth of 715m. Core recovery exceeded 90%. The core now resides at the DOE's repository at Grand Junction, Colorado.

Difficulties were encountered in completing the hole; sloughing, squeezing, and lost circulation prevented installation of casing over the full 715m depth. Attempts to redrill and recover the portion of the hole below 245m resulted in a "new" hole, diverging from the original at 241m (Fig. 2). The "new" hole was cored to a depth of 426m, where N-sized casing (6 cm I.D.) was cemented in and filled with water.

Following repeated temperature surveys to determine an equilibrium profile, a ~ 3m section of the casing at a depth of 340m within the high-temperature zone was perforated in mid-October 1986. This provided access for fluid sampling of the hot aquifer. Immediately upon perforation, ~ 2000*l* of cold water were pumped into the hole to prevent flashing, should communication with the formation cause excessive draw-down of the hole's water column, and to assess the permeability of the perforated zone. Flashing did not occur, as the water level rapidly fell to a depth of 146m, then gradually rose to stablize at 134m. In mid-November 1986, another temperature survey was made and the fluid in the hole bailed to ensure the presence of formation water. Then, in collaboration with scientists at the Sandia and Los Alamos National Laboratories, fluid samples were obtained at perforation depth by a downhole sampler and from a depth of approximately 150m with the bailer.

Early Results

Lithologic units encountered are shown in Figure 3 and a provisional geologic section in Figure 4. The upper glacial till is underlain by rhyolitic white to light gray pumiceous tuff, the Moat Rhyolite of Bailey and Koeppen (1977). The Moat Rhyolite overlies harder gray, flow-banded Early Rhyolite, containing a zone of volcaniclastic lakebed deposits. The lower portion of the hole is in predominantly welded ash-flow tuff (the Bishop Tuff). Numerous steeply-dipping open fractures, lined by quartz and calcite covering sulfide minerals (Figure 5), are preserved in core from the lower ~ 400m portion of hole, the high temperature zone. The depth to the top of the Bishop is the shallowest encountered in holes in the caldera.

An equilibrium temperature profile, together with projected bottom-hole temperatures measured during drilling, are plotted in Figure 3. The temperature increases fairly regularly, interrupted by two apparently cooler water zones at 120 and 245m, to ~ 160°C at a depth of ~ 330m. Temperatures then rise abruptly to 202°C at 335m, where a lost circulation zone in the fractured, silicified Early Rhyolite was encountered. Below this zone the projected bottom-hole temperatures indicate a nearly isothermal pattern, mostly between 190 and 200°C, that extends into the Bishop Tuff and to the bottom of the hole.

The relative position of the Shady Rest thermal profile with respect to those of PLV-1 and the deep test hole at Casa Diablo Hot Springs is shown in Figure 6. When plotted on the same elevation scale we see that the upper part of the high-temperature zone at Shady Rest is at nearly the same elevation as the upper high-temperature zone at Casa Diablo, while the zone of increasing temperature near the bottom of hole PLV-1 is at a somewhat lower elevation. The similarity in the elevations of the high-temperature portions of the Shady Rest and Casa Diablo profiles and the difference in water-level elevation between these two areas suggest that hot water is moving southeastwardly from Shady Rest to Casa Diablo through the Early Rhyolite section. However, as indicated on the geologic section, Figure 4, the flow path may be interrupted by one or more faults. The lower zone of thermal water flow evidenced by the temperature reversal in well M-1 within the Bishop Tuff may also be fed by lateral flow from the Shady Rest area.

Preliminary chemical analyses and calculated geothermometer temperatures from a fluid sample are compared with analyses of a Casa Diablo geothermal well fluid in Table 1. The similarities in most of the chemical concentrations and in ionic ratios

Table 1. Preliminary chemical analyses[a] and geothermometer temperatures of Shady Rest fluid, compared with fluids from a Casa Diablo well.

	Shady Rest[b]	Casa Diablo[c]
Na	369	350
K	43	36
Ca	7.4	1.2
Li	2.8	2.6
Cl	280	270
SO_4	159	120
B	12	11
SiO_2	250	250
$\delta^{18}O$	−14.3	−14.8
Na/K/Ca geothermometer temperature (°C)	214	224

[a]In milligrams per liter.

[b]Bailed sample, analysis by USGS.

[c]Well MBP-3, sampled 7/12/85, analysis by USGS.

suggest that the Shady Rest fluids are the predominant consituents of fluid flowing through the Casa Diablo geothermal field. The higher Ca concentration at Shady Rest is probably due to the abundant calcite that lines the open fractures of the high temperature zone (Figure 5). Calculated Na/K/Ca chemical geothermometer temperatures for the Shady Rest and Casa Diablo well samples are higher than those measured down-hole, but are similar to the temperature measured at Unocal's 44-16 hole (218°C).

Future Activities

The core has been described in detail. Planned investigations of core include alteration mineralogy, $^{87/86}Sr$ and $^{12/13}C$ measurements on fracture calcite, and $^{18/16}O$ and H/D determinations on fracture minerals and whole-rock specimens. Uranium-series disequilibrium will be investigated in intervals indicated by gamma-ray logs. Major- and trace chemical constituents of fluid and gases will be analyzed, and measurements of fluid inclusion temperature wil be attempted.

As with the fluids sampled at Casa Diablo Hot Springs, chemical geothermometer temperatures based on major-element concentrations suggest that still hotter conditions will be encountered at depth to the west of Shady Rest. If this expectation holds, there is good rationale for siting a deeper hole that would penetrate through caldera fill and into Sierra Nevada basement rock to investigate the source of heat for the hot fluids. The high temperature encountered in the Bishop Tuff in the aforementioned Unocal hole (44-16), together with the immediately underlying relatively cold zone, suggest that stratified hydrothermal conditions occur west of Shady Rest. The hot water at 44-16 could be moving northward from the vicinity of Mammoth

Mountain, through fractured Bishop Tuff, while colder water, recharged from the Sierra Nevada, moves more easterly in the underlying pre-caldera Tertiary volcanic and Paleozoic metamorphic rocks. In this respect the Mammoth Mountain area remains as one primary location for the next hydrothermal drilling target. Alternatively, hot water could be moving both eastward and westward from a source area between Shady Rest and 44-16, suggesting that a deep (1 1/2 – 2 km) hole in this location should also be considered. A hole will be cored in the summer of 1987 to intersect the dike(s) of the Inyo Chain, ~ 1 km west of 44-16 (John Eichelberger, personal communication 1987). Temperature measurements and fluid samples from this hole will also be valuable in determining the hydrothermal setting of this part of the western moat.

It was the consensus of participants at the 1984 Long Valley Hydrothermal Workshop (Sorey, et al., 1984) that a 1 to 2 km-deep hole should be drilled to resolve the critical question of the flow paths in the hydrothermal system of the western moat area and the location of the associated heat source. In this respect, the Shady Rest hole described here can be considered a "stepout" west of Casa Diablo, to test the rationale for the deeper hole. Though the Shady Rest hole does not penetrate deeply enough to satisfactorily delineate the characteristics of the hydrothermal system in the western moat, it does confirm the presence of 200° + water, and provides access to hydrologic and geochemical information otherwise unobtainable until a deeper hole is drilled. Such information will prove invaluable in siting and determining the depth of the deeper hole.

Acknowledgement

The Shady Rest project was sponsored by the U.S. Department of Energy's Office of Basic Energy Sciences, the California Energy Commission, Mono County, and the U.S. Geological Survey. Drilling, coring and hole completion were ably accomplished by the Tonto Drilling Company, surpervised by personnel of DOE's Geosciences Research Drilling Office at Sandia National Laboratories. Fluid sampling and chemical analyses were aided greatly by personnel of the Los Alamos National Laboratory. Transportation and curation of core were coordinated by DOE's curatorial office at Grand Junction, Colorado. Lawrence Berkeley Laboratory activities were done through U.S. Department of Energy Contract No. DE-AC03-76SF 00098.

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Figure Captions

Figure 1. Map of Long Valley caldera showing locations of deep test wells (open circles) and active thermal features on or around the resurgent dome (hot springs shown as filled circles with tails, fumaroles shown as filled triangles). The Shady Rest core hole described in this report is designated SR. Geologic base from Bailey and Koeppen (1977). The area around well M-1 is designated Casa Diablo Hot Springs.

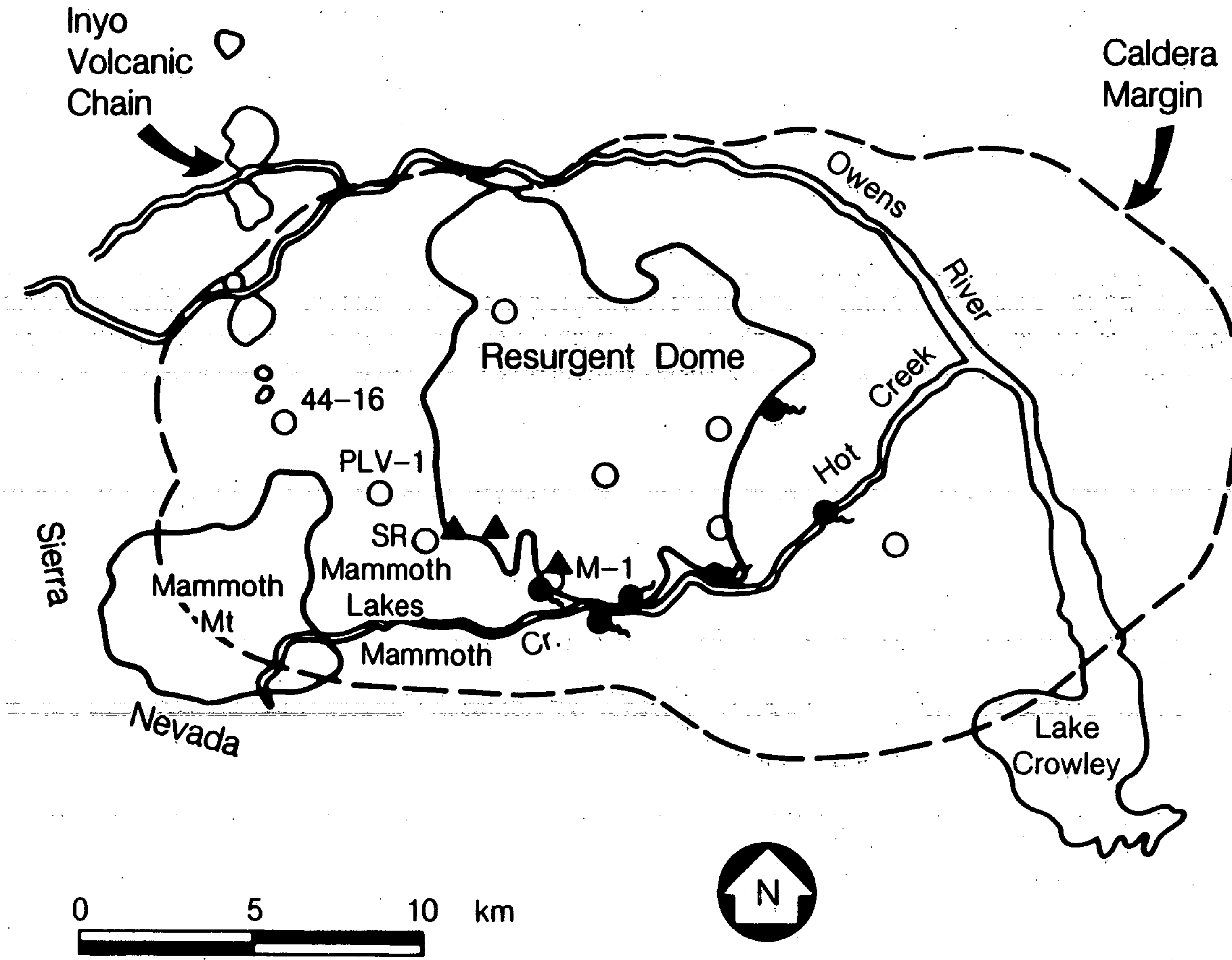
Figure 2. Completion diagram of the Shady Rest hole.

Figure 3. Equilibrium temperature profile (7/7/86) with projected temperatures from bottom-hole measurements made during coring, together with a lithologic diagram of the Shady Rest hole.

Figure 4. Geologic section from the eastern flank of Mammoth Mountain, through Shady Rest, to Casa Diablo Hot Springs. TH-9 is a water supply test well drilled by the Mammoth County Water District.

Figure 5. Core from Bishop Tuff section, showing an open fracture lined by calcite-quartz (light), rimmed by a darker zone of sulfide minerals.

Figure 6. Comparison of thermal profiles at PLV-1, Shady Rest, and the Casa Diablo deep test hole.



XBL 872-9938

Figure 1

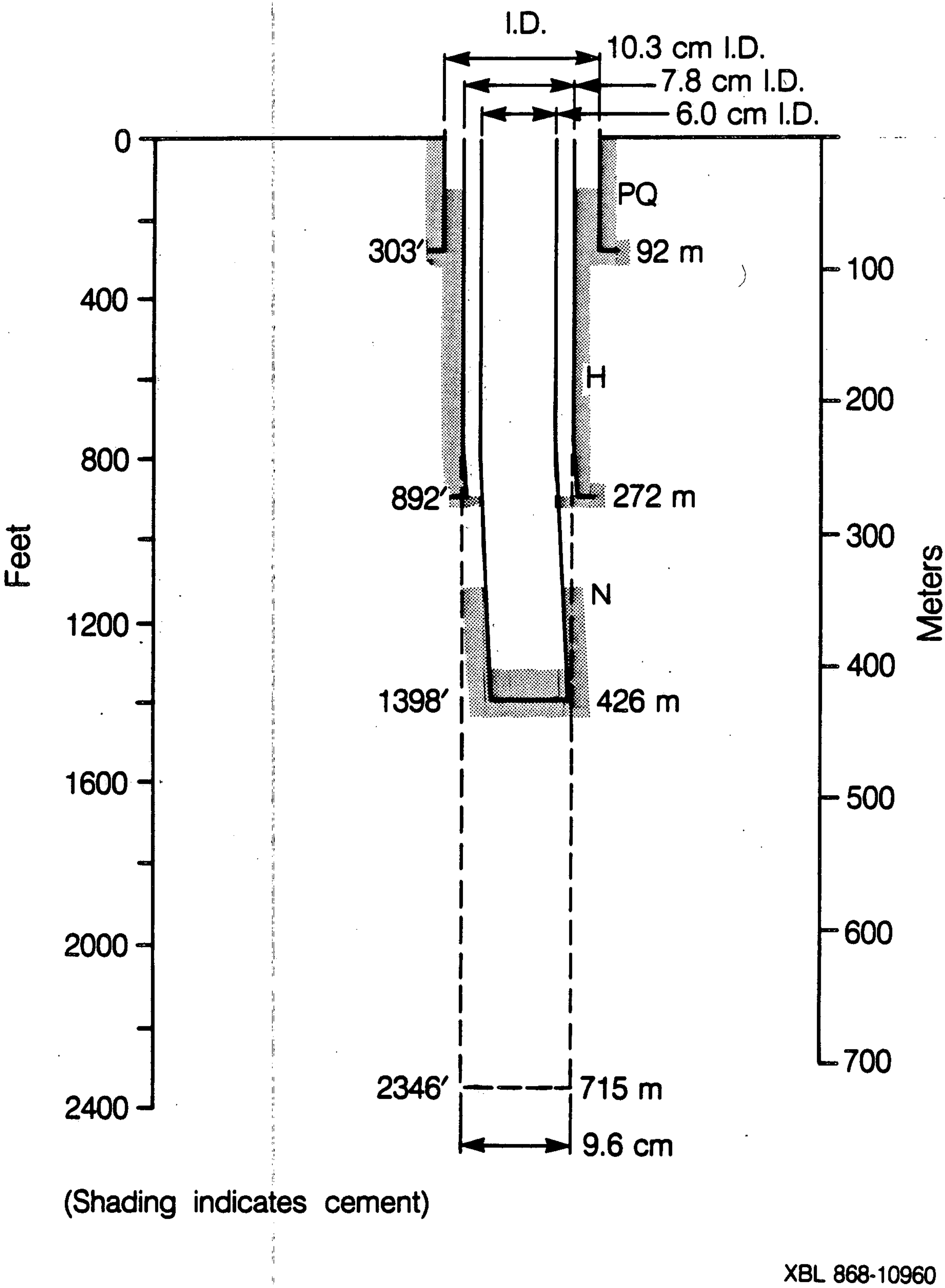

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Figure 2

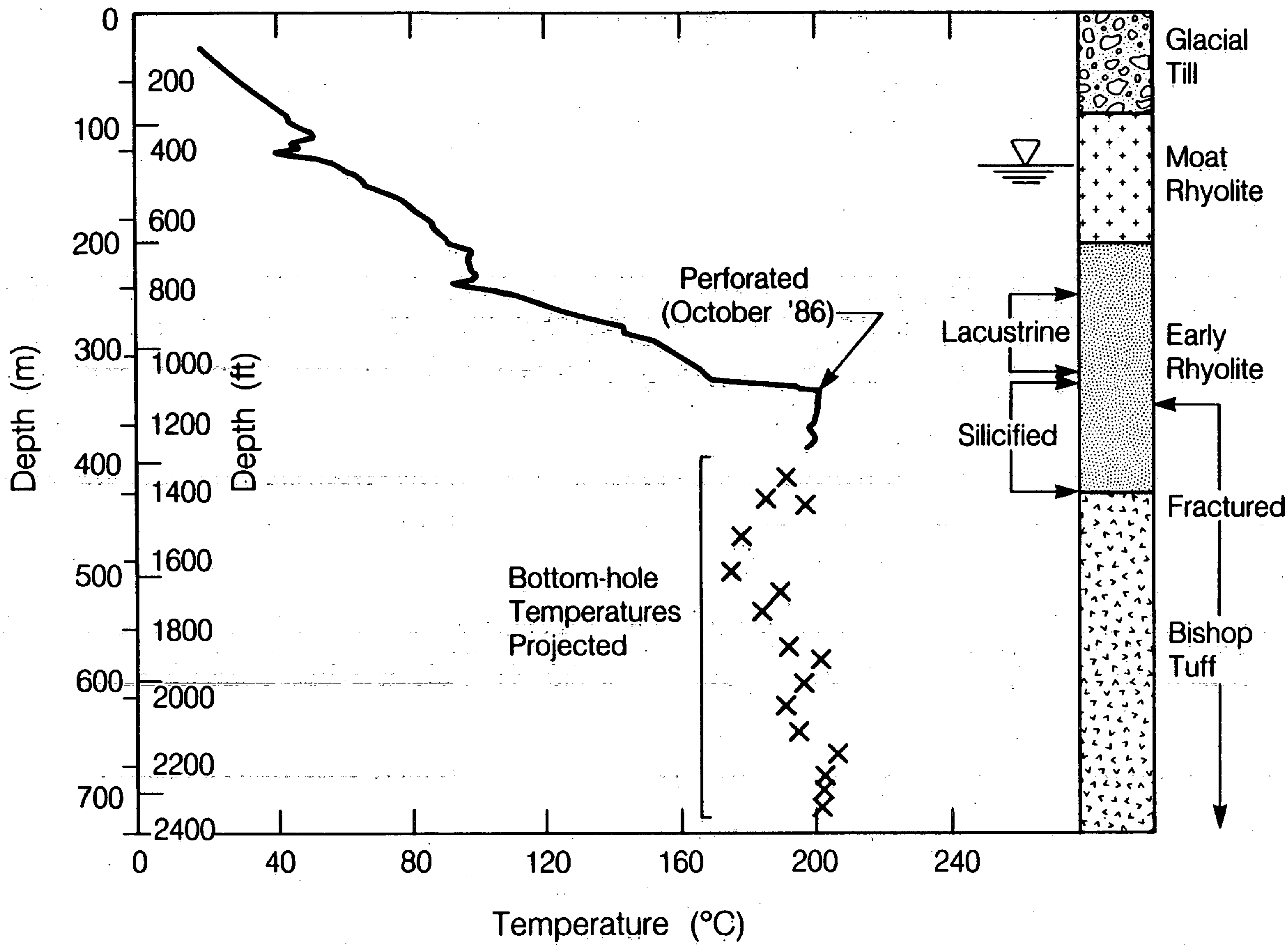

Figure 3

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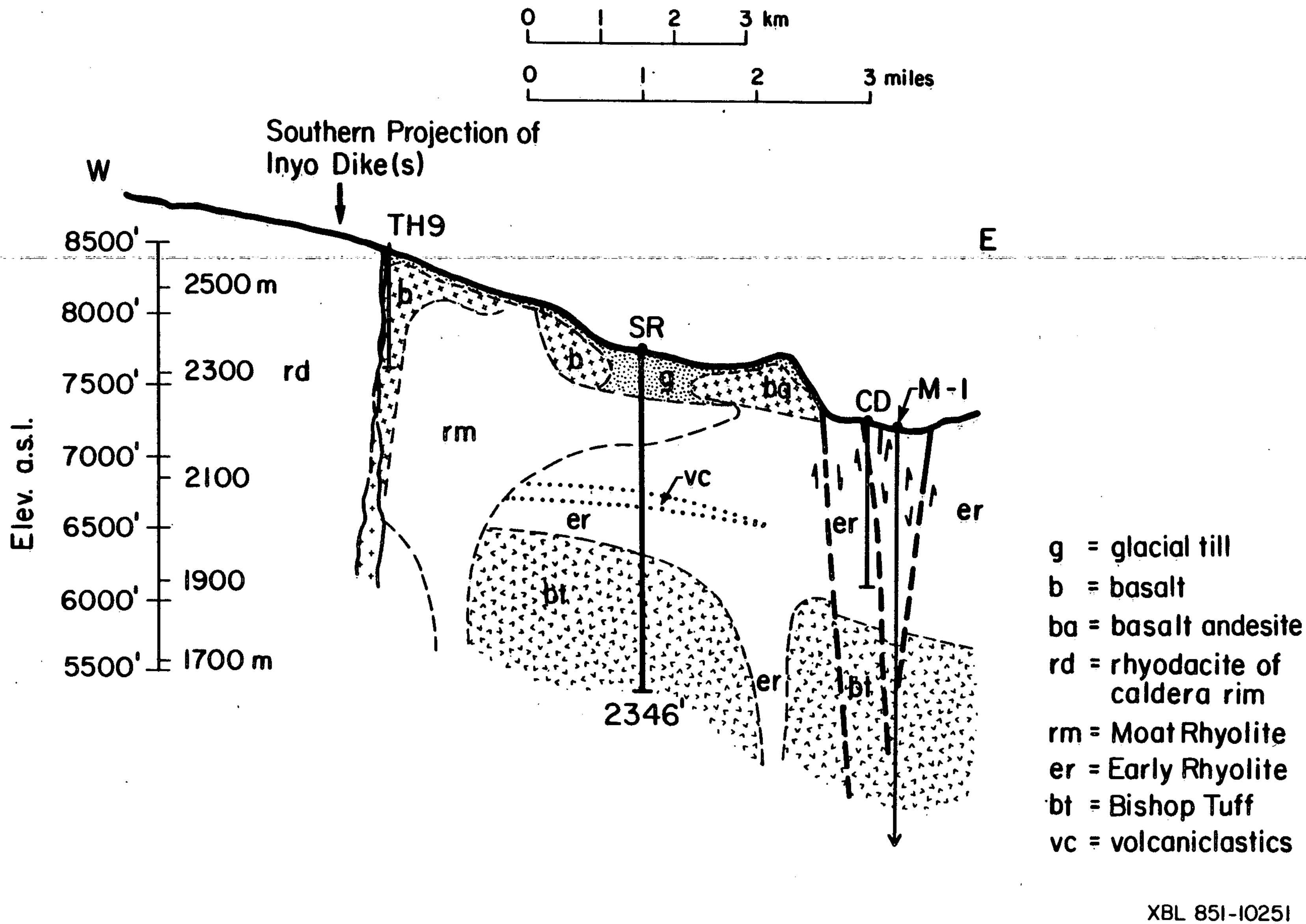
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Southern Projection of Inyo Dike(s)
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2500 m
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2100
1900
1700 m
Elev. a.s.l.
rd
rm
b
g
ba
vc
er
bt
2346'
g = glacial till
b = basalt
ba = basalt andesite
rd = rhyodacite of caldera rim
rm = Moat Rhyolite
er = Early Rhyolite
bt = Bishop Tuff
vc = volcaniclastics
XBL 851-10251

Figure 4

XBC 873-1637

Figure 5

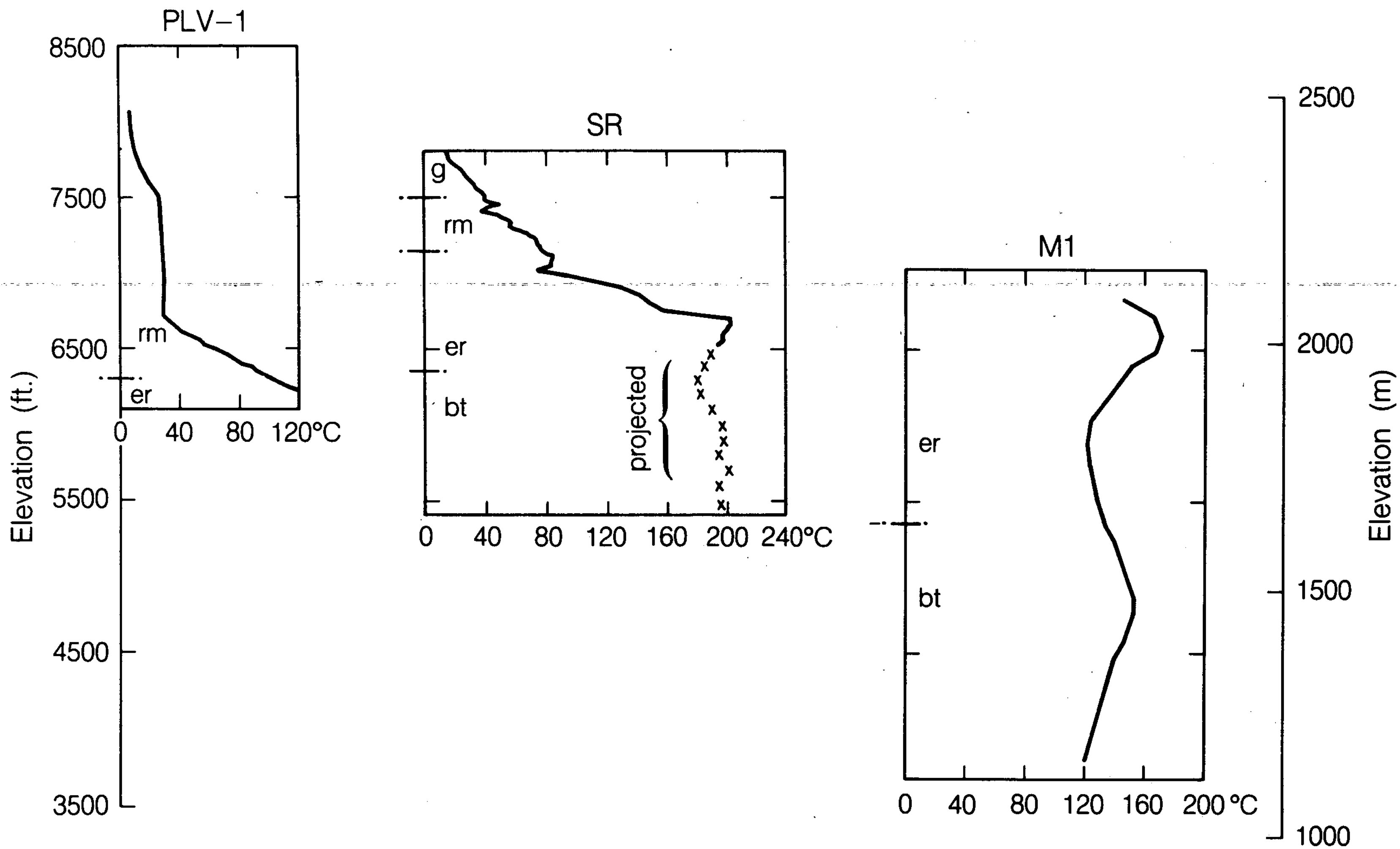

Figure 6

XBL 868-10958