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SCIENTIFIC DRILLING IN THE VALLES CALDERA MAGMA-HYDROTHERMAL SYSTEM, NEW MEXICO

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The 20-km-diameter, 1.13 Ma Valles caldera (Fig. 1) formed during catastrophic eruption of ~300 km³ of high-silica rhyolite ignimbrite. Growth of a central resurgent dome soon after caldera formation was followed by repeated moat eruptions of rhyolitic domes, flows, and pyroclastic deposits from 1.06 to 0.07 Ma (Smith and Bailey, 1968; Spell and Harrison, 1993; Toyoda et al., in press). A geothermal reservoir circulates within fractured intra-caldera tuffs and pre-caldera volcanic and sedimentary rocks at depths of 0.5 to 2.5 km. Reservoir fluids are 210 to 300°C and are neutral-chloride in character (2 to 10 x 10³ mg/kg Cl). Various types of fumaroles and hot springs discharge throughout the caldera region. Valles caldera is a type example of a resurgent caldera and contains a type example of a liquid-dominated geothermal reservoir.

Three scientific core holes (VC-1, VC-2A, VC-2B) were drilled at Valles caldera from 1984 to 1988 as part of the U.S. Continental Scientific Drilling Program (CSDP). These holes (Goff et al., 1992) obtained 3,146 m of continuous core at temperatures as high as 295°C (Table 1). Hydrothermal fluids were produced from each hole at specific depths and structural/stratigraphic horizons (Fig. 2). Structural resurgence did not apparently occur after formation of the earlier, comparably-sized Toledo caldera (1.50 Ma) because intra-caldera ignimbrites from each caldera-forming eruption do not show stratigraphic unconformities in core. The ignimbrites are separated by intervals of sandstone, various breccias, and surge deposits (Hulen et al., 1991). Locally, the ignimbrites display extremely lithic-rich horizons (≤90 modal-%) which may imply foundering of the caldera walls during ignimbrite eruptions or proximity to ring-fracture vents (Gardner et al., 1989).

Intra-caldera tuffaceous units and pre-caldera volcanic, sedimentary, and crystalline rocks show pervasive hydrothermal alteration (WoldeGabriel and Goff, 1992). Host rocks show intense isotopic exchange with hydrothermal fluids. Alteration assemblages are controlled by temperature, permeability, fluid composition, rock type, and depth. A generalized distribution from top to bottom of the system consists of argillic, phyllic, propylitic and calc-silicate assemblages. Typical alteration minerals in phyllic and propylitic zones are quartz, calcite, illite, chlorite, epidote, and pyrite whereas common vein minerals consist of the above minerals plus fluorite, adularia, and wairakite. Argentiferous pyrite, pyrrargyrite, molybdenite, sphalerite, galena, chalcopyrite, arsenopyrite, stibnite, barite, and tetradymite (?) have been found at various depths in the Valles system (Goff et al., 1992).

Fluid inclusion studies show that the above mineral assemblages formed from liquid water (0 to 5.5 equiv. wt-% NaCl) at temperatures ranging from 175 to 310°C, depending on location in the system. Fluid inclusion studies also show that the top of the liquid-dominated zone has descended, leaving behind a low-pressure vapor cap (Hulen et al., 1987; Goff et al., 1992).

The geothermal reservoir circulates within fractured intra-caldera tuffs and pre-caldera volcanic and sedimentary rocks. Small volumes of hydrothermal fluids are also encountered in fractured Paleozoic and Precambrian rocks beneath the caldera floor. Acid-sulfate hot springs and fumaroles originate from subsurface boiling of volatile components from the hydrothermal system. A hydrothermal outflow plume flows out of the caldera in the subsurface to the southwest and produces derivative hot springs of neutral-chloride chemistry (Goff et al., 1988). Fluids are composed of deeply circulating waters of primarily meteoric origin that have a mean residence time in the reservoir of 3 to 10 k.y. (Shevenell

Fig. 1: Generalized geologic map of Valles caldera region showing locations of major features and CSDP core holes (from WoldeGabriel and Goff, 1992).

Table 1. Significant facts about Valles caldera CSDP core holes.

Hole	Date Drilled	Target Depth (m)	Final Depth (m)	Target Temp (°C)	Maximum Temp. (°C)	Core Recov. (%)	Fluid Samples
VC-1	Aug.-Sept., 1984	600	856	150	184	>95	In-situ: 483 m, 537 m
VC-2A	Sept., 1986	500	528	200	212	>98	Flowing: 490 m
VC-2B	July-Oct., 1988	1750	1762	300	295	>99	In-situ: 1753 m Flowing: 663 to 1454 m

Fig. 2: Photo of VC-2B erupting two-phase fluid from 225°C at beginning of flow test in November, 1990.

and Goff, in press). Magmatic/mantle components that enter the present hydrothermal system include excess ^3He and possibly some H_2O , C, and S.

One of the most interesting horizons drilled occurs at Sulphur Springs where cores from 25 to 125 m consist of quartz-sericitized tuff that is hydrothermally brecciated and cemented with molybdenite, quartz, illite, fluorite, and pyrite. Molybdenite locally runs 0.56 wt-% and K/Ar dates on illite suggest deposition at ~0.66 Ma. This mineral assemblage was deposited from dilute liquid water at ~225°C but it now resides in an interval of the hydrothermal system where fractures are filled with low-pressure vapor (Hulen et al., 1987; WoldeGabriel and Goff, 1992).

Dating of various deposits, veins, and altered rocks indicates the Valles hydrothermal system was created ~1.0 Ma and has been continuously active to present. However, the vapor zone was formed about ~0.5 Ma after breaching of the southwestern caldera wall, sudden draining of intra-caldera lakes, and lowering of hydraulic head on the hydrothermal system (Fig. 3).

Fig. 3: Diagrams showing partial evolution of Valles caldera hydrothermal system. 3a, Period from 1.05 to 0.5 Ma; resurgence complete; continued eruption of northern moat rhyolites; initiation of large-scale, intracaldera hydrothermal circulation; hot spring activity inside and outside caldera; travertine formation in San Diego Canyon; molybdenite deposition beneath Sulphur Springs. 3b. Period from 0.5 to 0.4 Ma; caldera lakes drain; deep canyon cutting in upper San Diego Canyon and southwest moat; liquid-dominated hydrothermal system descends; vapor cap forms; travertine depositions in San Diego Canyon ceases (from Goff et al., 1992).

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