SOME RESULTS FROM CONTINENTAL SCIENTIFIC DRILLING PROGRAM CORE HOLE VC-2A, VALLES CALDERA, NEW MEXICO, USA

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VC-2A is the second in a series of scientific bores that are designed to investigate the magma-hydrothermal system of Valles caldera, a resurgent cauldron in northern New Mexico (Fig. 1) (Goff and Nielson, 1986). The primary objective of VC-2A was to penetrate the vapor cap above, the "interface" between, and the top of a liquid-dominated hydrothermal system. Secondary objectives were to study possible mechanisms of resurgence near the structural intersection of the western ring-fracture zone and the resurgent dome and to study possible mechanisms of ore deposit formation in a large silicic caldera. Technical objectives were to obtain continuous core while reaching a depth of at least 500 m and a temperature of at least 200°C.

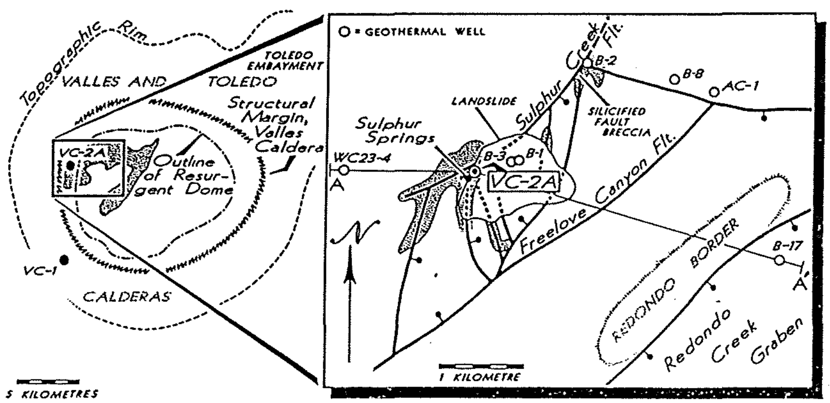

Fig. 1. Location map showing position of Continental Scientific Drilling Program core hole VC-2A relative to Sulphur Springs area of Valles caldera. Stippled area on left shows extent of active or recent surficial alteration. Stippled area on right delineates areas of argillic and advanced argillic acid-sulfate alteration. Circles are well sites. A-A' = cross section shown in Figure 4 (from Hulen et al., 1987).

VC-2A successfully attained its objectives. The core hole was started on September 5, 1986 and was completed in 24 days. Recovery of HQ core (62 mm diameter) exceeded 98% throughout the length of the bore. Total depth is 527.7 m and the bottom hole temperature is 212°C. A standard diamond core rig (Longyear 44) was modified to perform coring operations. Because VC-2A was cored into the acid-sulfate hot spring system at Sulphur Springs (T≤94°C, ph≥0.5 at 2540 m elevation), the upper part of the core hole was designed with 3 heavy casings utilizing acid-resistant cement. Additional requirements included a blowout preventor, special H_2S monitoring equipment and innovations for retrieval of wireline core in a geothermal environment (Goff et al., 1987). Core logs and a detailed overview have been published by Starquist (1988) and by Hulen et al. (1988), respectively. About 50 researchers including a few outside the USA are presently working on volcanological, geophysical, and geochemical studies of the core and fluids from VC-2A. The discussion that follows highlights only information bearing on the evolution and geochemistry of the Sulphur Springs system.

GENERAL INFORMATION

The configuration of the Sulphur Springs hydrothermal system, based on results from VC-2A, consists of an acid sulfate condensation layer (with pH <1.5) no more than 5 m thick, a vapor zone extending to roughly 240 m depth, a "transitional" layer or "cap rock" that extends from ~240 m to 490 m, and a liquid-dominated zone at the bottom.

The stratigraphy of VC-2A (Fig. 2) consists entirely of moderately to intensely altered landslide debris, volcaniclastic sediments, and ignimbrites that comprise a caldera-fill sequence in the western Valles caldera. From 21.6 to 66.5 m, the hole penetrates the Upper Tuffs of Nielson and Hulen (1984; <1.12 m.y.). From 82 to 356 m and from 362 to 478 m, the

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hole penetrates two members of the Bandelier Tuffs (Smith and Bailey, 1966; 1.12 and 1.45 m.y.). Beneath this is a quartz-poor tuff interval that may correlated with the Lower Tuffs of Nielson and Hulen (>1.45 but <3.6 m.y.).

The uppermost colluvium and landslide debris are locally altered to kaolinite with accompanying pyrite, sulfur, and sulfate minerals deposited in a low-temperature, low-pH environment (Charles et al., 1986). Surprisingly, abundant illite persists to the top of the hole, suggesting that the acid sulfate alteration is superimposed on an older high-temperature alteration assemblage. To a depth of about 150 m, the main secondary phases are quartz, illite, and pyrite in host rocks laced with open fractures lined with prismatic quartz. Molybdenite and fluorite are important minor constituents, and rhodochrosite, chalcopyrite, and sphalerite occur in trace amounts. Molybdenite is strongly concentrated between 25 m and 125 m. Below 150 m the rocks are conspicuously grey-green, with illite, chlorite, calcite, quartz, pyrite, and scattered fluorite as the obvious secondary phases.

MAXIMUM AGE OF SULPHUR SPRINGS SYSTEM

Although the alteration phases, veins, and fractures indicate a very complex paragenetic history for the hydrothermal events at Sulphur springs (Hulen et al., 1988), the maximum age of alteration is less than 1.12 m.y. because it occurs in intracaldera tuffs. By separating illites from different horizons in the core, Woldegabriel et al. (in press) obtained a K/Ar age of 0.98±0.02 m.y. (n=4) that may indicate the initial age of the Sulphur Springs portion of the Valles hydrothermal system. Other workers have obtained more approximate ages of 1.0 m.y. for the beginning of overall hydrothermal activity associated with the caldera (Goff and Shevenell, 1987; Ghazi and Wampler, 1987).

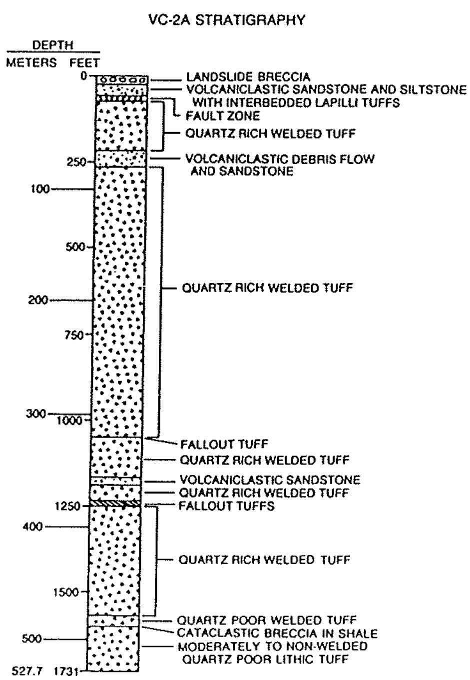

Fig. 2. Stratigraphy of VC-2A.

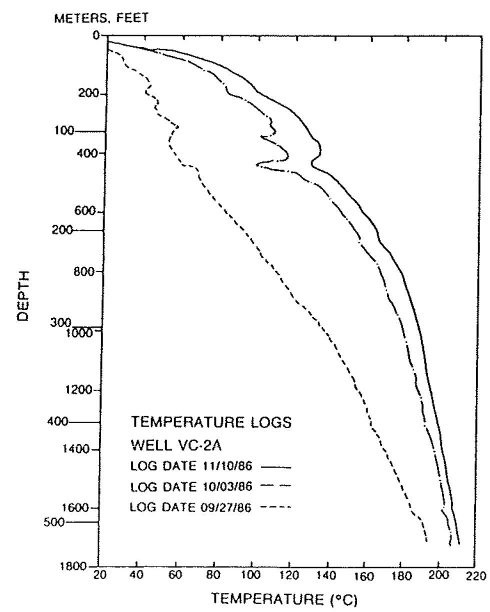

Fig. 3. Temperature logs of VC-2A showing post-drilling thermal recovery.

FLUID CHEMISTRY OF LIQUID-DOMINATED ZONE

A series of temperature logs obtained in the sealed, water-filled liner of VC-2A, soon after completion (Fig. 3), show rapid thermal recovery within a month. A small lost-circulation zone at 490 m in the temperature logs correlates with a rubble zone in the core, which was believed to be a fluid entry in the liquid-dominated reservoir. In May 1987, the 490-m zone was perforated and VC-2A was stimulated. After several small flow tests in which about 8×10^4 ℓ of water were produced, fluid from the 490-m zone reached chemical and isotopic stability by August 1987. The geochemistry of this fluid is similar to other neutral-chloride fluids produced from wells in other parts of the caldera (Table 1) although there are differences in bulk chemistry and isotopic composition. Previous studies have noted subtle chemical and isotopic differences in the reservoir fluids of Valles caldera (Smith and Kennedy, 1985; Truesdell and Janik, 1986; Goff et al., 1988) and it appears that fluids at Sulphur Springs represent yet another slightly unique fluid.

One new correlation revealed by Table 1 is that from west to east across the caldera, chloride content and TDS decrease, stable isotope values of water become lighter, and strontium isotope ratios decrease. Because Tertiary to Precambrian "basement" rocks are progressively down-dropped from west to east into the caldera depression, the correlations above may result from less interaction of hydrothermal fluids with basement rocks from west to east (Fig. 4).

TABLE 1: COMPARATIVE GEOCHEMISTRY OF SELECTED HYDROTHERMAL FLUIDS, VALLES CALDERA, NEW MEXICO[a]

Well[b]	Temp. °C	SiO_2	Na	K	Ca	Mg	Li	HCO_3	SO_4	Cl	B	As	δD	$\delta^{18}O$	$(^{87}Sr/^{86}Sr)_m$
VC-2A	210	322	1888	309	5.5	0.43	18.8	57	56	2945	18.2	1.81	-74.4	-7.1	0.718670
Baca-15	267	441	1196	261	12.4	0.02	15	48	29	2093	17	2.3	-84	-8.7	0.709412
Baca-13	278	546	1146	244	3.4	0.04	17	168	42	1897	17	1.6	-86	-10.0	0.708423

[a] Chemical values in mg/kg, isotopic values in ‰ relative to SMOW; chemical and isotopic data from Baca-13 and Baca-15 from White (1986); strontium isotope ratios from Baca-13 and Baca-15 from Vuataz et al. (1988); VC-2A data previously unpublished; all values corrected for steam flash where appropriate.

[b] Wells are arranged from west to east across the caldera in descending order.

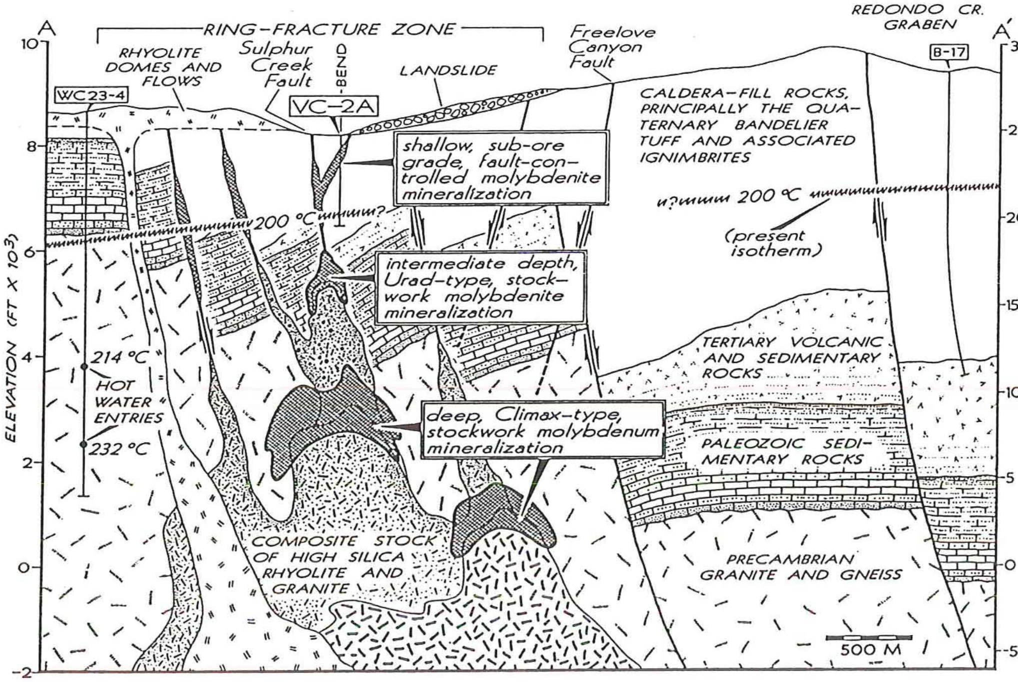

Fig. 4. Interpretive east-west cross section (see Fig. 1 for location) through western ring fracture zone of Valles caldera, showing possible relation of VC-2A molybdenite occurrence to deeper, hypothetical stockwork molybdenite mineralization (from Hulen et al., 1987). Baca-13 and Baca-15 (Table 1) are located east of section shown.

MOLYBDENUM MINERALIZATION

Shallow, sub-ore grade molybdenite mineralization was penetrated by VC-2A from 25 to 125 m depth (Hulen et al., 1987). The molybdenite (MoS_2) is an unusual, poorly crystalline variety that occurs in vuggy veinlets and breccia cements associated with ilsemannite ($Mo_3O_8 \cdot nH_2O$) and alteration minerals described above. Analyses of selected samples from this zone range from

0.14 to 0.56 wt-% equivalent MoS_2. Fluid-inclusion data from quartz and fluorite suggest that this assemblage was deposited from dilute fluids (0.2 to 0.5 equivalent wt-% NaCl) at temperatures of 195 to 215°C. Geochemical modeling using the SUPCRT data base indicates that under restricted pH and fO_2 conditions at 200°C, the molybdenite and associated phases would be in equilibrium with hydrothermal fluids now circulating in the caldera. Because the molybdenum mineralization was deposited from liquid water but now occurs in a zone where low-pressure vapor fills fractures, the surface of the liquid-dominated reservoir has descended since the deposit was formed. On the other hand, the salinity and bulk composition of the liquid-dominated reservoir have not changed drastically since the deposit was formed ≤0.98 m.y. ago.

CONCLUSIONS

The hydrothermal system at Sulphur Springs is merely one of several present subsystems within the Valles caldera. Hydrothermal activity has been continuously occurring within the caldera for the last one million years and deep reservoir fluids have not changed significantly in composition during this period (see also Goff and Shevenell, 1987). However, the presence of the molybdenum deposit at shallow depths within VC-2A indicates that major hydrologic changes have occurred in the hydrothermal system as it has evolved. It is hoped that further research on VC-2A and other bores will shed more light on the detailed evolution of the Valles hydrothermal system.

ACKNOWLEDGMENTS

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