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SCIENTIFIC CORE HOLE VALLES CALDERA # 2b (VC-2b), NEW MEXICO: DRILLING AND SOME INITIAL RESULTS

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ABSTRACT

Research core hole VC-2b, the third in the U.S. Department of Energy's Continental Scientific Drilling Program efforts in the Valles caldera, was continuously cored to 1.762 km on the western flank of the caldera's resurgent dome in 1988. Bottom hole temperature is about 295°C within Precambrian (1.5 Ga) quartz monzonite, deep within the liquid-dominated portions of the Sulphur Springs hydrothermal system. VC-2b may be the deepest, hottest, continuously cored hole in North America. Core recovery was 99.2%. The only major drilling problems encountered were when temperatures at the bit exceeded 225°C below depths of about 1000 m. The result of these conditions was loss of viscosity and/or lubricity in the mud, apparently caused by breakdown of the high temperature polymers.

Lithologies in caldera-fill indicate the drill site may be proximal to ignimbrite vents and that an intracaldera lake with temperatures approaching boiling formed soon after the caldera itself. Structural correlations between VC-2b and the 528-m-deep companion hole VC-2a indicate the earlier Toledo caldera (1.45 Ma; Otowi Member tuffs) and even older Lower Tuffs caldera experienced no structural resurgence similar to the 1.12 million year old Valles caldera. The hydrothermal system penetrated by these bores consists of a shallow vapor-rich cap, which has evolved from an earlier 200°C liquid-dominated system, overlying stacked, liquid-dominated zones up to about 300°C. Geochemistry of mud returns collected during drilling suggests chloride-rich geothermal fluids were entering the bore and mixing with the drilling fluids in the fractured lower Paleozoic and Precambrian sections.

INTRODUCTION

The 1.12 million year old Valles caldera of north-central New Mexico, well known as an example of resurgent calderas (e.g., Smith and Bailey, 1968; Smith, 1979) and for its high temperature hydrothermal systems (e.g., Dondanville, 1978; Goff and Grigsby, 1982), has been the focus of drilling for scientific purposes since 1984 (Goff and Gardner, 1988; Gardner et al., 1989). To date, three scientific core holes have been successfully completed in the caldera (Figure 1), all with the general objectives of understanding the current state and evolution of the hydrothermal systems, structural and magmatic evolution of the caldera, and past and active deposition of ore minerals by hydrothermal activity. VC-2b, completed to 1.762 km and 295°C (Figure 2 and Figure 3) in October, 1988, is possibly the deepest, hottest, continuously cored hole in North America, and is the most recent and ambitious of Continental Scientific Drilling Program (CSDP) efforts in the caldera. VC-2b was designed as a deep companion hole to the 528-m-deep VC-2a (Goff et al., 1987; Hulen et al., 1987). VC-2b was drilled about 0.6 km from VC-2a and the acid-sulfate altered area known as Sulphur Springs, near the intersection of the western flank of the caldera's resurgent dome and main ring fracture zone (Figure 1). Goff et al. (1985) proposed a model of the Sulphur Springs hydrothermal system which consisted of a shallow vapor-rich cap to depths of about 500 m, overlying stacked liquid-dominated reservoirs ranging in temperature from 200° to about 300°C. VC-2a confirmed the shallow portions of the model, with bottom hole in the top of a liquid-dominated zone at 212°C, separated from the vapor-rich cap by a zone of very densely welded tuff and tightly sealed fractures. VC-2b's objectives were to obtain continuous core through a complete sequence of caldera-fill, Tertiary sedimentary rocks, and Paleozoic sedimentary rocks, with bottom hole at least 200 m into Precambrian crystalline basement. Bottom hole would thus be either in the conductive zone beneath hydrothermal convection or in a poorly explored portion of the system suspected to be circulating within the basement rocks. In addition to continuous core, scientific objectives required minimal contamination of thermal aquifers by drilling fluids and a stable borehole on completion that would allow limited flow testing and re-entry for fluid sampling, logging, and other in-hole experiments.

Results of hydrothermal mineralization and alteration studies in VC-2b to date are discussed in separate papers (Hulen et al., 1989; Hulen et al., this volume).

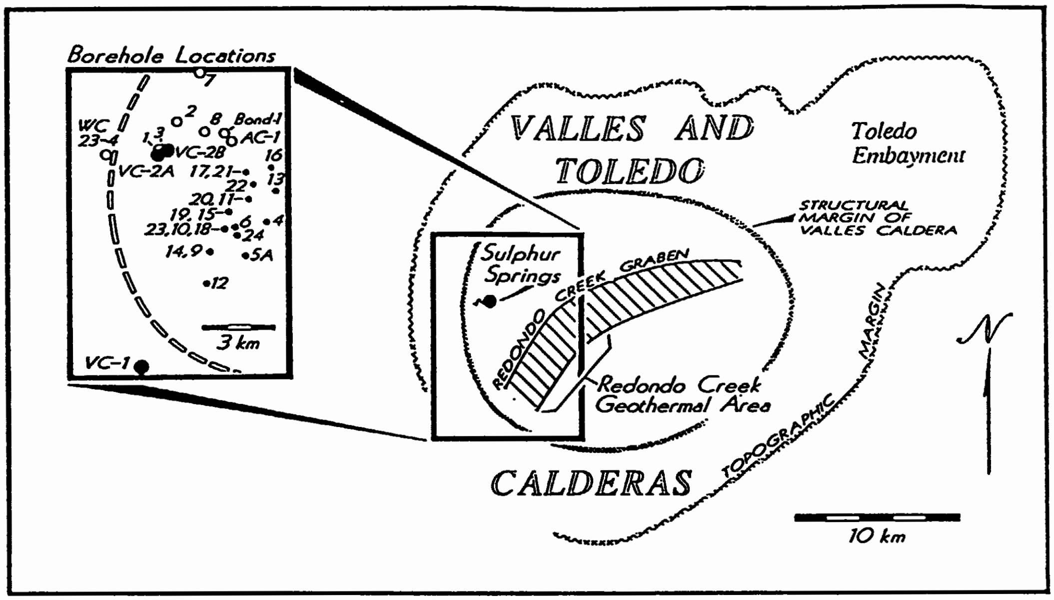

Figure 1. Location map showing positions of scientific core holes (larger closed circles, inset at left) and geothermal wells (open circles and small, closed circles) completed to date in the Valles caldera complex (from Hulen and Gardner, 1989).

DRILLING

The requirements of the VC-2b scientific objectives, along with the planned depth, anticipated downhole temperatures, possibilities of incompetent formations, and safety/environmental considerations, all indicated that a conservative approach to the coring operations was appropriate. Consequently, a Universal 5000 (Figure 4), one of the biggest wireline diamond drills available, and the heavy-duty CHD series drill rods were used. A loading chamber was constructed that allowed pressure control of, and mud pumping into, the hole at all times except when adding a rod. Standard oil field blow out prevention equipment was employed. A computer driven H_2S detection and alarm system operated at all times, relatively large volumes of water were maintained for emergency well control, and all site personnel were extensively trained in emergency procedures including rescue in toxic atmospheres. An on-line system continuously recorded mud flow rates, temperatures, and well head pressures. Downhole temperatures were monitored throughout the coring operations with maximum reading thermometers and/or temperature sensitive solder tabs on the wireline overshot. We believe these temperatures provide a coarse estimate of temperatures seen by the bit. Weekly monitoring of the geochemistry of fluids from local hot springs, water wells, and rivers clearly showed the drilling operations had no impact on near surface waters (Meeker et al., in prep). Additionally, the geochemistry of the drilling mud was monitored periodically to assist in identification of thermal aquifers encountered during coring.

VC-2b was cored and completed in 100 days, which includes about 10 days of rig mobilization and demobilization and site clean up. Table 1 provides a brief summary of VC-2b coring operations, and Figure 3 is a diagram of the completed core hole (Lysne and Jacobson, in press). Overall core recovery was 99.2% with most losses occurring in the shallow, friable landslide debris in the top 30-40 m of the hole. The coring of VC-2b went very smoothly. The only persistent problems encountered were below about 1000 m where downhole temperatures during coring began to exceed about 225°C. The effects of these temperatures, or perhaps combined effects of temperature and depth, were most pronounced in the performance of the drilling mud. Solids, such as bentonite, in the mud were deemed to be dangerous in the small annulus of the core hole at these temperatures, and high temperature polymers, obtained from a variety of vendors, broke down resulting in loss of lubricity and/or viscosity. The mud performance allowed the rods to be turned easily at low speeds, but rod chatter and high torque became significant at normal drilling speeds. Both directly and indirectly the poor performance of the mud adversely affected penetration rates and drove up costs.

CSDP efforts utilizing wireline diamond coring in geothermal areas have shown the technique can be a very cost-effective means of exploration. Indeed, industry exploration strategies appear to have been influenced by the high yield of unambiguous information and the hydrothermal successes of the continuously cored CSDP holes. Serious problems, such as truly high temperature muds, persist, however, that while not insurmountable currently hamper realization of the full potential of diamond coring in geothermal areas.

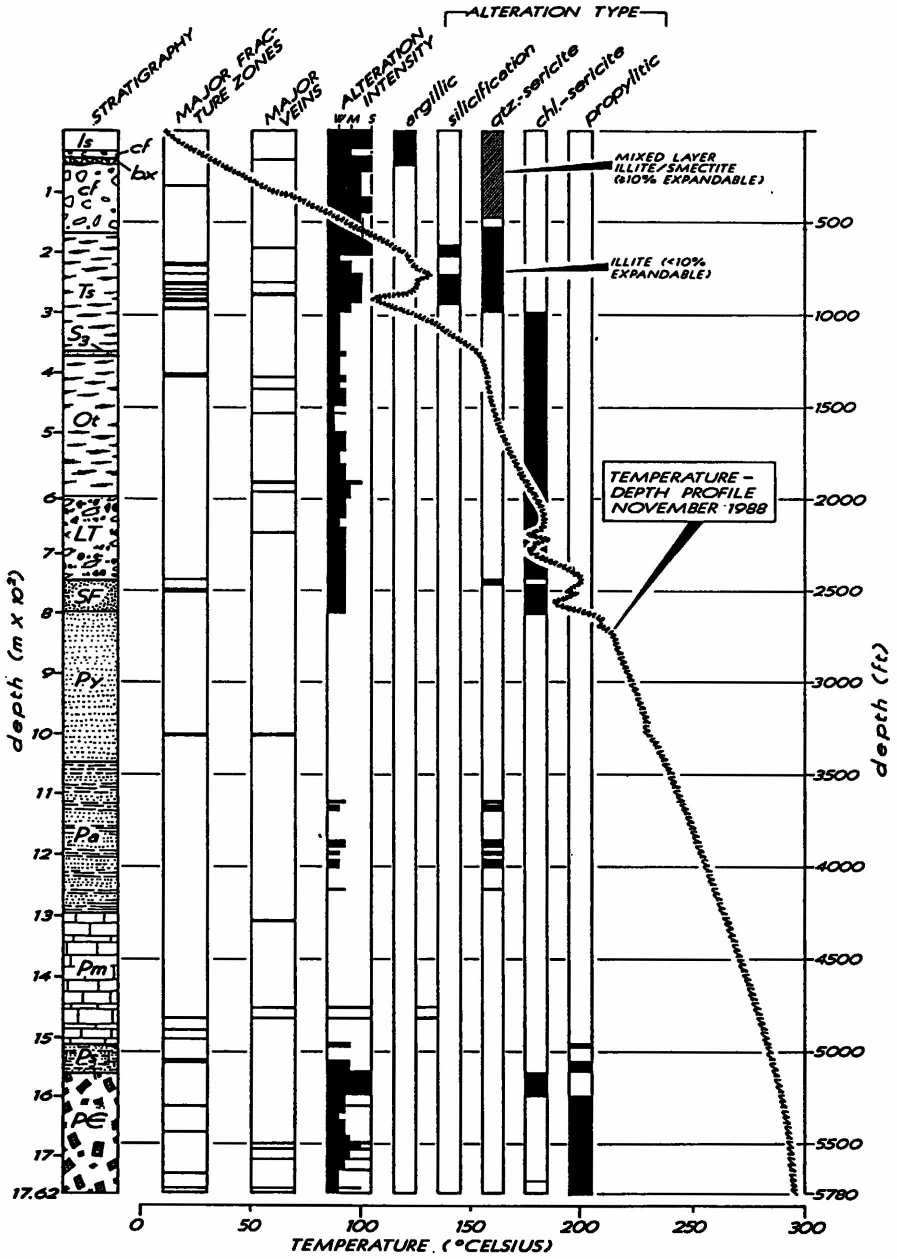

Figure 2. Summarized geologic log for CSDP core hole VC-2b, Sulphur Springs area, Valles caldera, New Mexico (ls = landslide; cf = caldera-fill clastic rocks; bx = hydrothermal breccia; Ts = Tshirege Member of Bandelier Tuff; S_3 = S_3 clastic deposits; Ot = Otowi Member of Bandelier Tuff; LT = Lower Tuffs; SF = Santa Fe Group sandstone; Py = Permian Yeso Fm.; Pa = Permian Abo Fm.; Pm = Penn. Madera Limestone; Ps = Penn. Sandia Fm.; PC = Precambrian quartz monzonite). (Figure from Hulen and Gardner, 1989.)

STRATIGRAPHY AND STRUCTURE

The stratigraphy encountered in VC-2b is shown, generalized from the log of Hulen and Gardner (1989), in Figure 2. The sequence consists of variably altered Quaternary volcanic and volcaniclastic intracaldera rocks, Tertiary sedimentary deposits, Paleozoic red beds and carbonates, and Precambrian quartz monzonite. In general, the stratigraphic sequence fits well with those previously recognized within the caldera and the Jemez Mountains region (Smith et al., 1970; Nielson and Hulen, 1984; Gardner et al., 1986). The top 168 m of the caldera-fill sequence consists of interbedded accretionary lapilli tuffs, coarse clastic breccias, and fine-grained lacustrine rocks that exhibit hydrothermal alteration that apparently pre-dates soft sediment deformation. These relations imply that a lake, with temperatures approaching the boiling

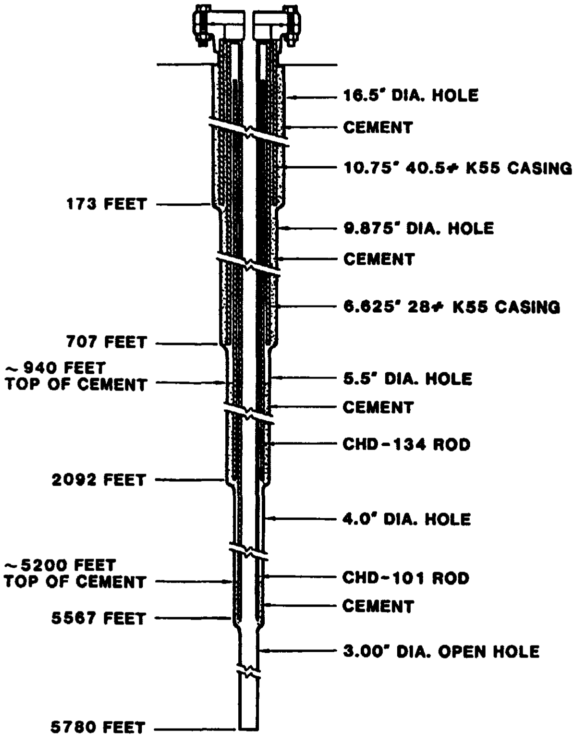

Figure 3. Schematic drawing of the completed VC-2b core hole (from Lysne and Jacobson, in press).

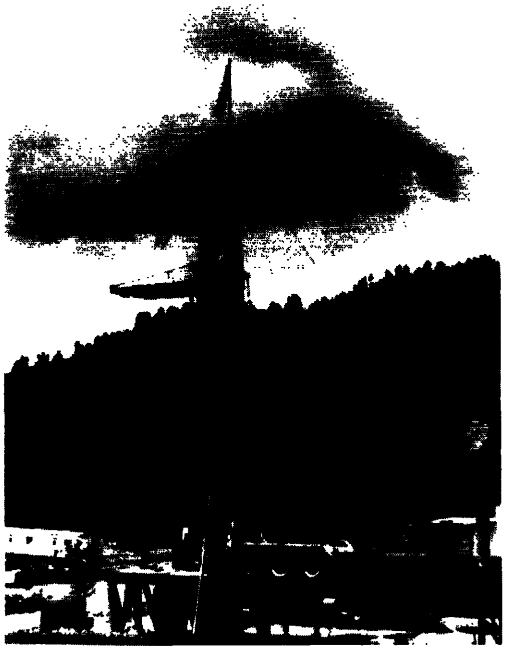

Figure. 4. Rigging up the Universal 5000 drill at VC-2b.

point of water, developed soon after caldera formation (about 1 Ma?), and the newly formed caldera walls were shedding debris flows into the lake while small volume eruptive activity continued. We recognize three "members" of the Bandelier Tuff in VC-2b. Interestingly, each of these major ignimbrite units contains extremely lithic-rich horizons (up to 90 modal percent) which may imply proximity to ring fracture vents, or the foundering of the caldera walls as they developed simultaneously with ignimbrite venting.

VC-2b was sited less than 100 m from two of the first geothermal production wells drilled in the Valles caldera, Baca-1 (T.D. 780 m) and Baca--3 (T.D. 670.5 m). Interestingly, below depths of about 300 m nothing stratigraphically correlates among the three boreholes. On the other hand, correlations between VC-2b and continuously cored VC-2a 0.6 km away are excellent. We believe that during the drilling of Baca-1 and Baca-3 there was severe downhole contamination occurring which resulted in homogenization of cuttings from various stratigraphic levels and misinterpretation of the entire sequence penetrated as volcaniclastic sediments (see reports in Dondanville, 1971). In geothermal exploration of the caldera, good constraints on the stratigraphy are important because portions of the hydrothermal system(s) appear to be stratigraphically controlled (see below) and volcaniclastic and sedimentary horizons are at least locally significant thermal aquifers.

Structure encountered in VC-2b is far more complicated than what was penetrated by nearby VC-2a. In VC-2a several major high angle (?) faults were recognized, but low angle slip along major stratigraphic contacts was common. Apparently independent of faults, all syn- or pre-Valles caldera rock units in VC-2a dip at about 45°, whereas post-caldera units have dips of 10° to 15°. In VC-2b apparently high angle faults that correlate to some mapped on the surface (Goff and Gardner, 1980) have been recognized, but low angle slip appears to have occurred on a number of major detachment-like faults. These low angle faults are not restricted to stratigraphic contacts, and have caused rotations of a number of large blocks. Post-Valles caldera units in VC-2b also have shallow dips. Goff et al. (1981) and Heiken et al. (1986) demonstrated that the Valles and Toledo calderas are coincident. Nielson et al. (1989) show that the smaller Lower Tuffs caldera is very near the VC-2a and VC-2b drill sites. Thus, we interpret the structural relations in VC-2a and VC-2b to indicate that the Lower Tuffs caldera (>1.45 Ma) and the Toledo caldera (1.45 Ma) experienced no structural doming during resurgence. Most tilting of units, low angle faulting, and/or slumping seen in VC-2a and VC-2b occurred in one event, during structural doming of the Valles caldera at about 1 Ma.

Table 1. Drilling Operations, VC-2b Core Hole (from Lysne and Jacobson, in press.)

Drilling Day	Drilling Operation
0 to 5	Mobilize rig to site, set up and spud hole using CHD-134 (134 mm) core barrel and rods.
6 to 11	Core to 173 ft, ream hole to 16.5 in., set and cement 10.8 in. casing, install and test BOP, and hang 6.6 in. casing to reduce rod whip.
12 to 24	Core CHD-134 to 707 ft, ream hole to 9.9 in., set and cement 6.6 in. casing, install and test BOP.
25 to 43	Core CHD-134 to 2092 ft, cement the CHD-134 rods in place as casing (no cement returns). The top of the rods was set 12 ft below the surface to allow for expansion during flow tests.
43 to 88	Core CHD-101 (101 mm) to 5567 ft, cement the bottom 370 ft of the 101 rods to the formation and hang in tension from the surface to counteract thermal expansion effects during flow tests.
89 to 94	Core NQ (76 mm) to total depth at 5780 ft, remove rods leaving open hole at bottom of the well.
95 to 100	Demobilization and clean up.

THE SULPHUR SPRINGS HYDROTHERMAL SYSTEM

The present configuration of Sulphur Springs hydrothermal system consists of three main zones: a vapor-rich cap above about 500 m which has evolved from a liquid-dominated precursor since 0.66 Ma (Goff et al., 1987; Hulen et al., 1987; Woldegabriel and Goff, 1989); a liquid-dominated reservoir (200° to 225°C) residing in the lower portions of the volcanic sequence and underlying Tertiary sedimentary rocks; and, a zone of poorly connected, fluid-filled fractures in the lower Paleozoic and Precambrian sections that range in temperature up to 300°C. In a gross sense, zones of the system appear to be largely lithologically--if not stratigraphically--controlled with the vapor cap being separated from the underlying liquid-dominated reservoir by an interval of very densely welded tuff and/or tightly sealed, fractured ignimbrite. More dramatically, the Permian red bed sequence (799 m to 1.296 km) appears to be impermeable except for a few fluid paths provided by sparse open fractures. The Santa Fe Group sandstone appears to be a potential stratigraphic aquifer, showing as a large lost-circulation zone on the temperature logs (Figure 2). Preliminary fluid inclusion data (see Hulen et al., this volume and Hulen et al., 1989) suggest that the fluids responsible for mineralization and alteration within and below the Paleozoic section become more saline and hotter with depth. Temperature estimates, based on these data, closely match the current temperature profile. During drilling, large spikes in the chloride content of the drilling mud returns occurred (Meeker et al., in prep.) that correlate directly with large open fracture networks in the lower Paleozoic and Precambrian sections (Figure 5). A recently collected downhole fluid sample from 1.752 km shows effects of dilution by the fresh water left in the bore on completion. In spite of the dilution, the sample contains 6.2 B, 1.7 Br, 11.5 Ca, 762 Cl, 138 K, 4.8 Li, 462 Na, and 256 Si (all values in mg/kg). Ratios of B/Cl, Br/Cl, and Li/Cl match those of fluids from other parts of the Valles hydrothermal system. Na/K and Na-K-Ca geothermometer temperatures are about 340°C and 320°C, respectively. SiO_2 geothermometer temperature is low due partly to dilution. Thus, it appears that within the zone below the Tertiary rocks, relatively saline liquids circulate within poorly connected fractures, but probably do not constitute a widespread geothermal reservoir of nearly homogeneous composition.

THE FUTURE

The science team involved in a variety of studies on different aspects of VC-2b and the Valles caldera currently consists of about 100 researchers from government research organizations, industry, and universities from around the world. Research on core and fluid samples, as well as flow testing and in-hole experiments, are expected to continue for several years. Samples remain available to any scientist with valid research interests. In October, 1989, an open workshop will be held in Los Alamos to evaluate results of past scientific drilling and related activities and develop a revised long-range plan for CSDP at Valles caldera. Future proposals may include continuously coring to 5 km and 500°C in the resurgent dome of the caldera, with bottom hole in the recently crystallized roof of the sub-caldera pluton.

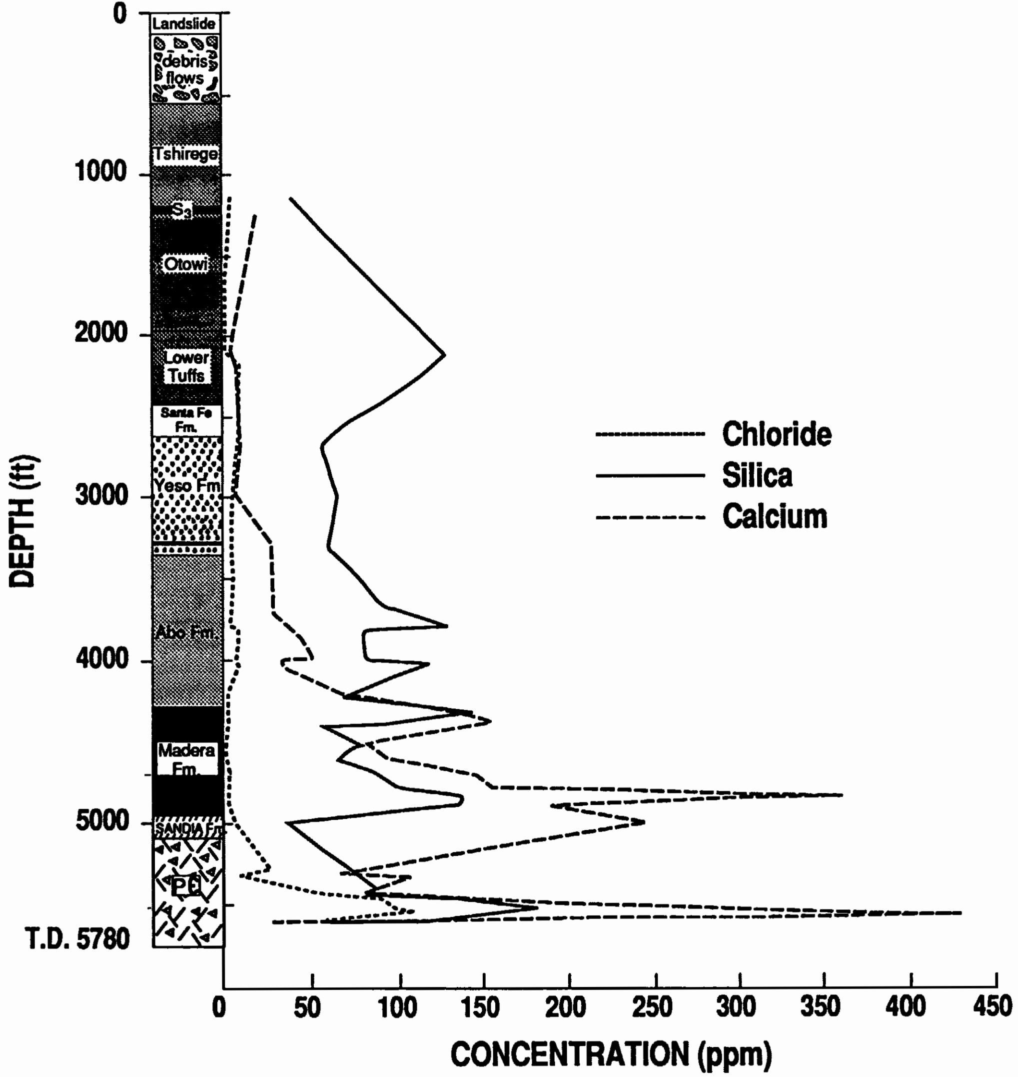

Figure 5. Concentrations of several chemical species in drilling mud returns versus depth. Spikes in lower Madera Formation and below are probably the result of geothermal fluids entering the bore and mixing with the drilling mud.

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