CONF-850801--31

LA-UR--85-1005

DE85 009640

TITLE: HISTORY AND RESULTS OF VC-1, THE FIRST CSDP COREHOLE IN VALLES CALDERA, NEW MEXICO

AUTHOR(S): Fraser Goff, ESS-1
John Rowley, ESS-1
Jamie N. Gardner, ESS-1
Ward Hawkins, ESS-1
Sue Goff, ESS-1
Larry Pisto, Tonto Drilling Services
Gene Polk, NL Baroid

SUBMITTED TO: GRC, 1985, Int'l. Symposium on Geothermal Energy, August 26-30, 1985, Kailua, Kona-Hawaii

Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

FORM NO. 836 R4
ST. NO. 2629 5/81

DISCLAIMER

DISCLAIMER

HISTORY AND RESULTS OF VC-1, THE FIRST CSDP COREHOLE IN VALLES CALDERA, NEW MEXICO

Fraser Goff*, John Rowley*, Jamie N. Gardner*, Ward Hawkins,* Sue Goff*, Larry Pisto**, and Gene Polk***

*ESS-1, Los Alamos National Laboratory, Los Alamos, NM 87545
**Tonto Drilling Services, Inc., Salt Lake City, UT 84104
***N. L. Baroid, Inc., Sandia Park, NM 87047

ABSTRACT

Valles Caldera #1 (VC-1) is the first Continental Scientific Drilling Program (CSDP) corehole drilled in the Valles caldera and the first continuously cored hole in the caldera region. The objectives of VC-1 were to penetrate a hydrothermal outflow plume near its source, to obtain structural and stratigraphic information near the intersection of the ring-fracture zone and the pre-caldera Jemez fault zone, and to core the youngest volcanic unit inside the caldera (Banco Bonito obsidian, 0.13 Ma). VC-1 penetrates 298 m of moat volcanics and caldera-fill ignimbrites, 35 m of pre-caldera volcaniclastic breccia, and 523 m of Paleozoic carbonates, sandstones and shales, with over 95% core recovery. Hydrothermal alterations are concentrated in sheared, brecciated and fractured zones from the volcaniclastic breccia to total depth with both the intensity and rank of alterations increasing with depth. Alterations consist primarily of clays, calcite, pyrite, quartz, and chlorite, but chalcopyrite has been identified as high as 518 m and molybdenite has been identified in a fractured zone at 847 m. Thermal aquifers were penetrated at various intervals from about 510 m on down.

INTRODUCTION

Valles caldera (Figure 1) has been a priority site since the earliest planning phases of the CSDP because of its size, youth, preservation, hydrothermal system and available data base (CSDC, 1984). After a number of workshops, a proposal was written to the U.S. DOE, Office of Basic Energy Sciences to initiate shallow corehole drilling at Valles caldera and other Thermal Regime sites. Although nearly two years were needed to totally formulate the project, VC-1 was completed on Sept. 3, 1984 after 35 days of rig time (Goff et al., 1984; GEOTIMES, Feb. 1985). The object of this paper is to summarize the coring operations and preliminary scientific results of this first CSDP effort in Valles caldera.

HISTORY OF VC-1

To achieve the project goals, continuous core was required from complex intracaldera volcanic rocks and faulted precaldera rocks with the hope of encountering hot (120°C) hydrothermal fluids. Of major technical importance was the need to procure a coring subcontractor with demonstrated experience in the use of blowout preventers (BOP), high-temperature drilling muds and cements, and exploration oriented rig operations (Rowley et al., in prep.).

When the final schedule for VC-1 was established (June, 1984), an on-site management team and well sitters were organized to oversee the coring operations. This group totaled about

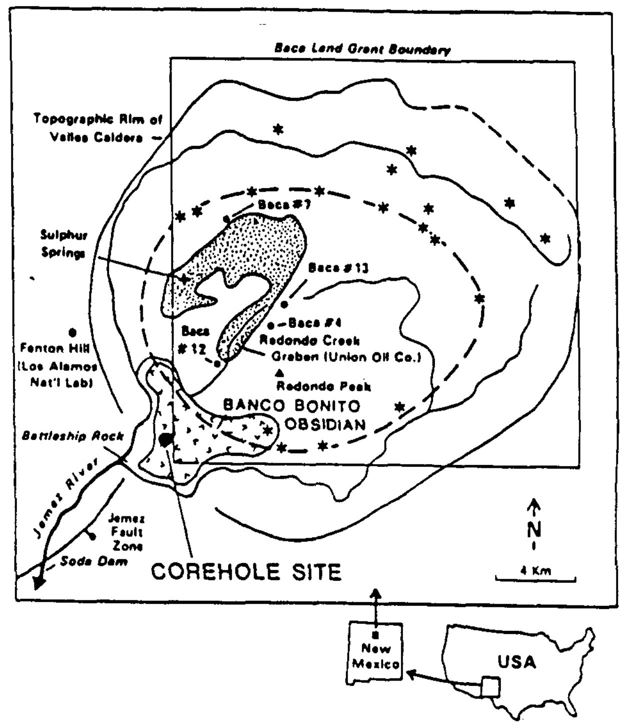

Figure 1.
Location map of Valles caldera and VC-1 corehole; V-pattern shows Banco Bonito obsidian flow, stipple-pattern shows area of intense intracaldera acid-sulfate alteration, stars denote intracaldera rhyolite vents and heavy dashed line shows the inferred posi- tion of the Valles ring-fracture zone.

20 people who were trained to record, clean, label, and box the core according to prescribed methods and instructed in standard and emergency operating procedures. A specific site was agreed upon by the U.S. Forest Service and Los Alamos in a forested valley between two large pressure ridges on the Banco Bonito flow. After the site was laid out, a cellar was dug for the corehole, a trailer was hauled to the site for use by the well-sitters, and a 10,000-gal tank was set in place for the water supply.

Coring

VC-1 was a 24-hr/day, 7-day/wk operation in which all crews worked 12 hr shifts. Coring operations as a function of depth and time are displayed in Figure 2 and are described in detail by Rowley et al. (in prep.). The original coring plan was based on a proposed depth of 650 m and temperature of 120°C. The target depth was reached about 10 days ahead of schedule, and the average advance rate was 25.9 m/day during the 33 days of rig operations.

After initial rotary drilling to 3.0 m, a surface conductor having 16.5 cm OD was cemented in place below the cellar floor. Once the cement hardened and was drilled out, HQ coring (9.73 cm OD) commenced into very broken, pumiceous rhyo-obsidian on the top of the Banco Bonito flow. Lost circulation occurred immediately and never returned, thus, cuttings were never collected during the entire coring project. At 122 m depth, the hole was reamed to 14.3 cm diameter with a tricone bit in preparation for the first string of casing. A casing

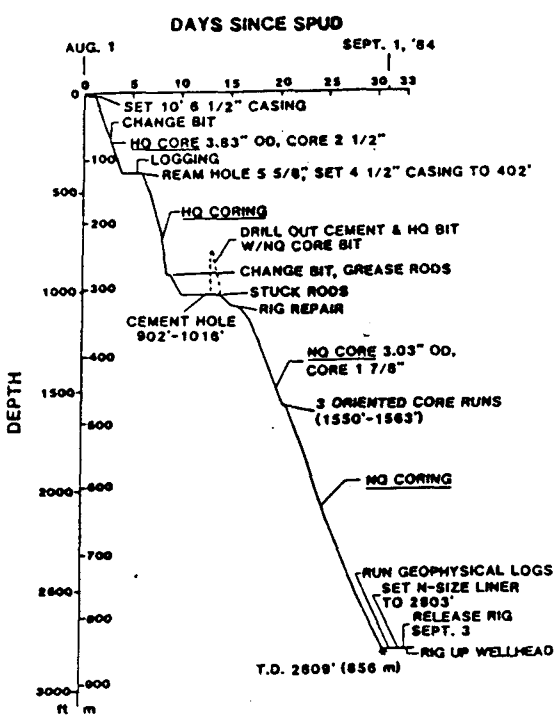

Figure 2. Diagram showing VC-1 coring history as functions of time and depth.

shoe was screwed on the bottom of the 11.4 cm OD casing which was then used to ream through a bridge at 37 m to total depth. This casing formed a solid structural tie for mounting the BOP and prevented drilling fluids from contaminating shallow warm aquifers known to circulate near the base of the Banco Bonito obsidian.

Once the first casing string was cemented and the BOP attached, HQ coring resumed through moat and caldera-fill volcanics at a rate of nearly 60 m/day. At 310 m depth, the core tube became stuck in the core barrel while coring through volcanic breccia. In order to free the core tube, an attempt was made to pull the coring string (rods) but they got stuck in the hole at 275 m. The core tube was finally fished from the core barrel with a special adapter fabricated on-site, but the rods remained firmly planted in the hole. Thus, a decision was made to cement in the HQ bit and rods and to drill through with an NQ core bit (7.70 cm OD). After this was accomplished, coring proceeded slowly with light bit pressure through the cement plug from 275 to 310 m to keep the bit from wandering out of the original hole.

Following this brief delay, NQ coring resumed through the volcanic sequence into the Permian Abo Formation at 334 m. From experience gained in other wells around the region, clay horizons in the Abo were notorious for squeezing in on drill strings. To combat this problem, the drilling mud was modified to retard swelling of clays and the Abo was cored without any problems. Coring continued into Pennsylvanian Madera Limestone at 422 m and operations stopped briefly to take oriented cores (473 to 477 m). These cores were immediately placed on-site into instruments that measured stresses and relaxation rates (Dey et al., 1984).

Coring through the Madera continued and by day 23 of operations, the primary objectives of VC-1 had been satisfied. Because funds remained and the hole was coring beautifully, a decision was made to attempt to core into Precambrian basement. Unfortunately, coring passed the 760 m interval, still in Madera Limestone, and the temperature rose steadily to roughly 140°C. At 808 m, the formation changed rather sharply from limestone to a conglomerate-sandstone-shale sequence identified as Pennsylvanian Sandia Formation. This unit, which is of variable thickness, fills an irregular erosion surface on Precambrian basement in the region. On the night of day 30, the core bit began to stick in brecciated Sandia shale, and it was decided to terminate coring so as not to jeopardize the success of the hole or overtax the budget. Final depth of VC-1 at 4 a.m., September 1, 1984 was 856.2 m (2809 ft).

Logging and Completion

After the core string was pulled from the hole, an attempt was made to run a suite of geophysical logs. This was delayed because clay zones in the Abo Formation squeezed into the corehole forming several bridges. To ovecome this, a casing shoe was attached to the N-rods, and they were run back into the bottom of the corehole to ream out the bridges. Temperature, natural gamma, and neutron logs were then completed inside the rods. The rods were then pulled in 150 m increments and the remainder of the logs (density, caliper, S-P, resistivity) were run below the rods in each newly exposed open-hole interval. Logging in this fashion was completed up to the bottom of the Abo, about 427 m. A preliminary comparison between the logs and the stratigraphy can be found in Rowley et al. (in prep.).

The corehole was finished by attaching a dull NQ core bit to a worn-out set of rods and running them as deep as possible (854.4 m) to act as a solid liner. A cement slurry was then pumped to the bottom followed by a plug and the liner filled with fresh water. The rig was released on 1:15 p.m., 3 September 1984, and a gate valve was installed on the wellhead the next day.

Core Recovery and Curation Procedures

Average core recovery for VC-1 exceeds 95%, an excellent record. Low recovery in the upper 45 m of the well reflects the broken condition of the flow-top of the Banco Bonito obsidian. Lower in the well, particularly in Madera Limestone, core occasionally slipped out of the core barrel in 1- to 3-m lengths. Extra core (E-core) was taken at several intervals when core from a previous run was lost and then picked up by the next core run. By and large, core recovery was poorest in fractured, brecciated, or clayey intervals.

Core was protected under DOE's Curatorial Guidelines and Procedures (S. Goff, in press). All personnel handling core at the drill site worked under the direction of the CSDP Sample Manager and were trained in curation procedures. Well-sitters were responsible for transferring core from the core barrel to the core box, core labeling and numbering, and renumbering broken core. Every 20 ft, a 15-cm piece of core was preserved for physical property measurements by wrapping in aluminum foil and dipping in beeswax. A comprehensive field form was completed immediately after each core run.

Core Bit Performance

Core bit performance for the drilling of VC-1 was also excellent. Only five bits were used, Table I. The HQ size core bits had lower bit life, four were used to a depth of 309.7 m. The rock above this depth, especially the Banco Bonito obsidian resulted in slow and difficult coring and rather rapid bit wear. Only a single NQ bit was used from 309.7 m to total depth. The bit type selected, an oversize Longyear Green, series 1, impregnated is generally considered suitable for medium hard, abrasive rock.

TABLE I

CORE BIT RECORD SUMMARY VC-1

Bit No.	Interval Cored (ft)	Type and Size*		Bit O.D. (in.)**	Core (in.)
1	10 - 242	Inpreg.*	HQ	3.83	2-3/4 core diam.
2	242 - 400	"	"	"	"
3	400 - 917	"	"	"	"
4	917 - 1016	"	"	"	"
5	1016 - 2809	"	NQ	3.03	1-7/8 core diam.

*Longyear - Green Series 1, for medium hard, abrasive rock, diamond impregnated matrix

**The 3.83 and 3.03 in.-O.D. bits are oversize; conventional diameters for H and N are 3.782 and 2.98 in., respectively.

Drilling Fluid

A significant part of the excellent core recovery experienced in the VC-1 project can be attributed to the drilling fluid program. The fluid additives program is summarized in Figure 3, which also records efforts to stabilize formations, such as the Abo, to maintain a clean hole and to sustain high core quality and good recovery rates. The drilling plan for VC-1 assumed that complete loss of circulation would be experienced for the entire drilling project. The drill rig was equipped with drilling-fluid tanks and and a hydraulically driven mud pump with a capacity of about 2.7 m^3/h. Therefore with continuous fluid loss, about 65.6 m^3/day (17,300 gal/day) of water would be used.

It was especially important that an adequate water supply be available on-site so that the borehole would not run dry. Dry hole conditions significantly increase the risk of borehole wall instability, caving, and sloughing into annulus between the drill rods and borehole wall. In addition, a dry hole increases the occurrence and severity of rod vibrations from friction, which must be countered by withdrawing (tripping) the rods and applying rod grease. Interrupting the coring operations for rod withdrawal increases the risk of hole caving, reduces core quality, and introduces unproductive time. It was therefore very desirable to maintain a significant fluid level in the hole and to provide a sufficient hydrostatic head. Water supply decisions and assumptions of complete lost circulation were based upon previous drilling experience in the Valles caldera area. Actual total water usage was 986.6 m^3 for the 24 active days of coring operations for an average rate of usage of 39.8 m^3 (10,500 gal/day).

PRELIMINARY RESULTS AND INVESTIGATIONS

Stratigraphy and Structure

VC-1 (Figure 3) penetrates 298 m of intracaldera volcanics, 35 m of Tertiary volcaniclastic breccia that pre-dates caldera

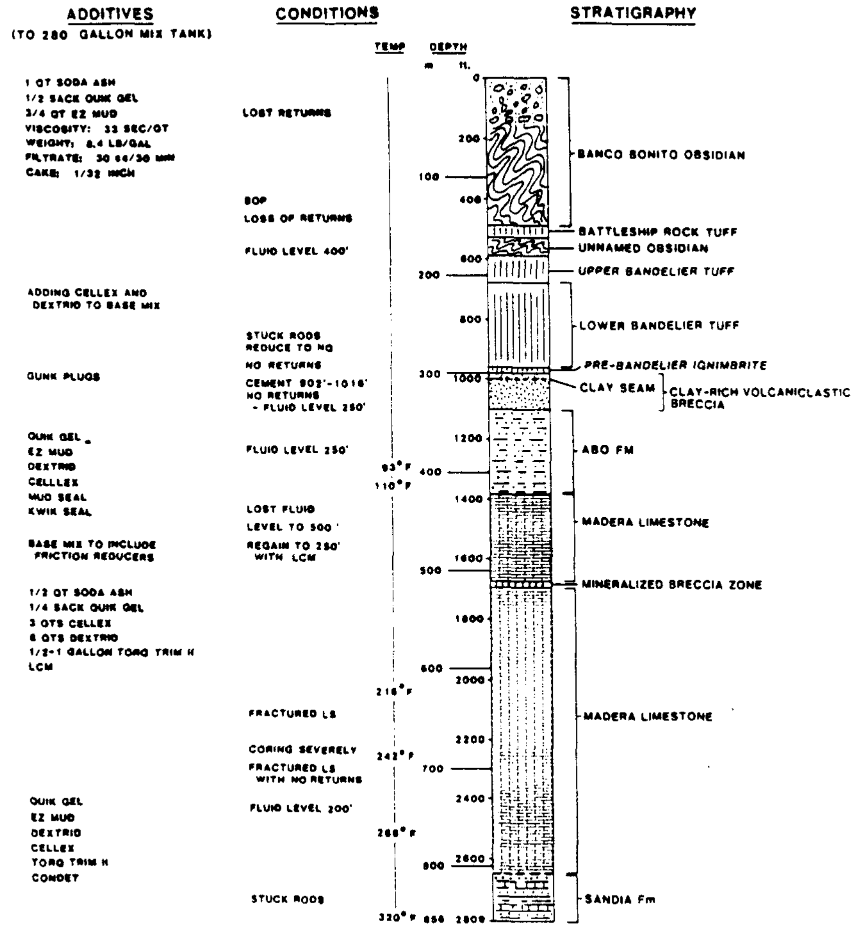

Figure 3. Stratigraphy and mud program of VC-1, Valles caldera, New Mexico.

formation, 91 m of Permian Abo Formation, 381 m of Pennsylvania Madera Limestone, and 40 m of Pennsylvanian Sandia Formation. These Paleozoic lithologies correlate well with cuttings from the Jemez Springs geothermal well and with outcrops exposed in San Diego Canyon southwest of the caldera (Goff et al., 1981). Based on stratigraphic comparisons, coring of VC-1 stopped roughly 20 m short of Precambrian basement. The Madera Limestone is approximately 100 m thicker than expected, partly due to a 25° SE dip on the Paleozoic section. Detailed examination of the Madera by D. Wachs (Israeli Geol. Survey) has not revealed a repeated section due to reverse faulting, but VC-1 is located on the northwest (upthrown) side of the Jemez fault zone, which is buried by relatively unfaulted caldera moat volcanics. Thus, it is possible that some of the additional thickness of lower Paleozoic rocks is caused by the corehole penetrating sheared and brecciated strata adjacent to a fault. Another explanation of the thick Paleozoic section could be that unknown growth fault(s) lying southwest of VC-1 caused slight thickening of local Madera rocks during Paleozoic time.

The volcanic section in VC-1, which includes a suite of relatively young moat volcanics in the southwestern ring-fracture zone, also yielded some surprises. The Banco Bonito obsidian (149 m thick) is four times thicker than the nearest exposure 0.3 km away in the NE wall of San Diego Canyon, suggesting that it filled a paleo-valley in the Valles caldera moat. In contrast, the Battleship Rock Tuff, which is over 100 m thick in San Diego Canyon is only 12 m thick in VC-1. A previously unknown obsidian flow 19 m thick underlies Battleship Rock Tuff and has a K/Ar age determination of 0.356 ± 0.061 Ma on biotite (M. Shafiqullah, Univ. Arizona). The lower volcanic sequence consists of extremely lithic-rich, very densely welded upper and lower Bandelier Tuff interpreted as probable intracaldron facies, and a pre-Bandelier ash-flow that was probably erupted from a nearby vent WNW of VC-1.

A volcaniclastic clay-rich breccia 35 m thick underlies the main volcanic sequence. This breccia consists of about 1 m of black to brown andesitic soil at the top and grades into poorly sorted rock containing angular andesite and subordinate dacite, rhyolite, and basalt fragments in a variegated clay matrix. This

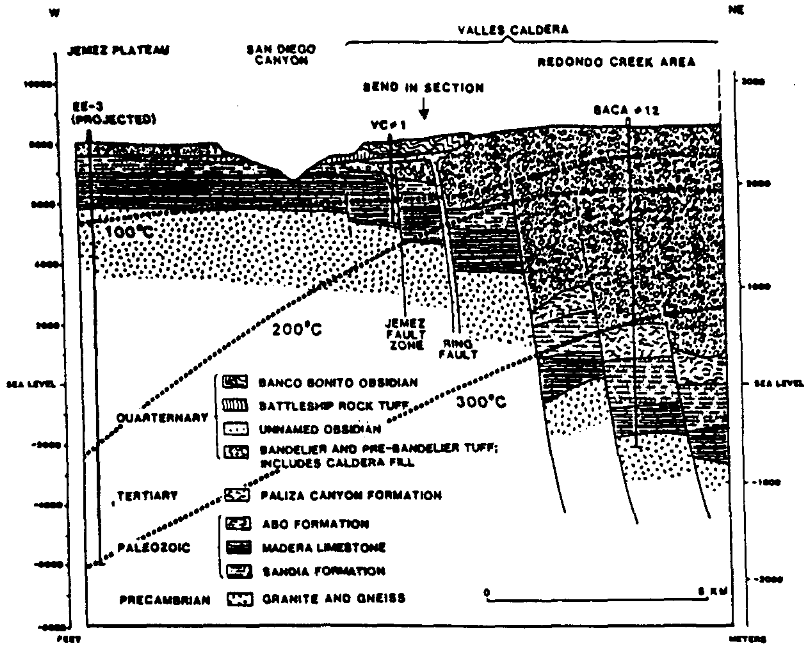

Figure 4. Schematic cross-section of southwestern Valles caldera region, New Mexico showing stratigraphy, structure, and temperature isotherms.

unit is interpreted to be an altered colluvium shed from surrounding volcanoes of Tertiary Keres Group (13 to 6 Ma; Gardner and Goff, 1984) into a paleo-San Diego Canyon or some similar valley along the evolving Jemez fault zone. The unit clearly predates volcanic events associated with Valles and Toledo calderas.

The volcaniclastic breccia and underlying Paleozoic rocks are faulted, sheared, and mineralized. From examination of oriented cores from Madera Limestone at 476 m, the Paleozoic section in VC-1 strikes approximately N35E and dips 25 SE as opposed to the gentle NE dip observed in Paleozoic rocks of upper San Diego Canyon. We believe this deformation is caused by drag along buried fault(s) of the northeast-trending Jemez fault zone.

A cross-section that runs E-W from the Jemez Plateau through VC-1 into the Valles moat zone and then bends northeast into the Redondo Creek graben area is shown in Figure 4. The section is based on nearly 7 km of known stratigraphy from wells EE-2 (Laughlin, 1981), VC-1, and Baca #12 (Nielson and Hulen, 1984) and clearly displays the abrupt structural and stratigrahic changes that are associated with the collapse and post-collapse volcanism of Valles caldera. The thin volcaniclastic breccia at the bottom of the volcanic sequence is not shown to emphasize that thick piles of Keres Group andesite flows occur both inside and outside the caldera but are missing in VC-1.

Hydrothermal Alterations and Thermal Regime

Mineralization observed in VC-1 core is most intense along shears, fractures, and faults from the volcaniclastic breccia on down. Although the alterations have yet to be examined in detail, they consist primarily of clays, calcite, pyrite, quartz, and chlorite. There is a general increase in the intensity and rank of alteration mineral assemblages with depth. As an example, a particularly altered and mineralized sample of green brecciated Sandia Formation from 846.7 m is considered to represent phyllic-grade alteration (J. Hulen, UURI). Besides chlorite, phengite, and pyrite, this breccia contains fracture coatings of molybdenite (MoS_2) and anomalous concentrations of Pb, Cu, and Zn (R. Hagan, Los Alamos). Chalcopyrite ($CuFeS_2$) has been identified in a quartz vein cutting the upper Sandia Formation (L. Maassen, Los Alamos) and from fractured Madera Limestone as high as 515 m.

Thermal aquifers were apparently encountered at several horizons in the lower half of the corehole judging from positive excursions in the thermal gradient profile (Figure 5). The volcaniclastic breccia acts as a relatively impermeable barrier separating cool aquifers in the porous intra-caldera volcanic sequence from thermal aquifers in the Paleozoic sequence. The average thermal gradient from 350 to 750 m is 210°C/km and is amazingly linear. This gradient corresponds to a conductive heat flux of approximately 10 HFU (J. Sass, USGS). Presently, the wellhead builds up minor gas pressure, thought to be mostly CO_2 released from the thermal aquifers.

Figure 4 shows temperature isotherms on the cross-section of the southwestern caldera area that were drawn from measured temperatures and gradients. The isotherms strikingly display the change in thermal regime from convective hydrothermal up-flow and lateral flow inside the caldera to conductive heat flow outside the caldera. The boundary between these two thermal regimes occurs in the vicinity of VC-1, and this figure depicts how important this corehole will

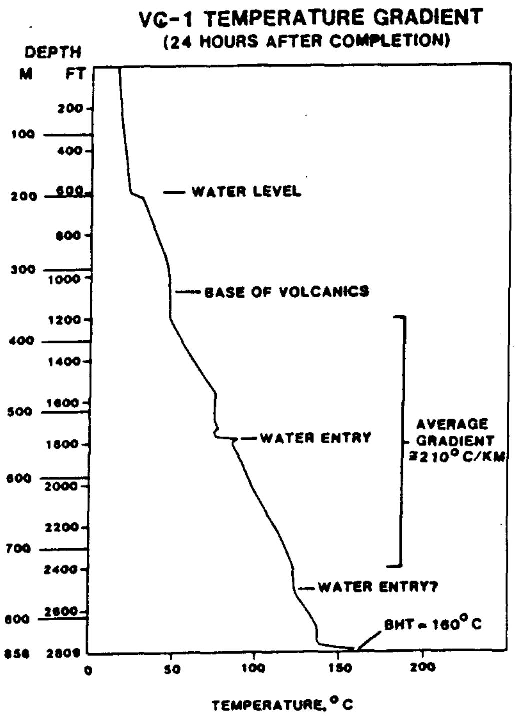

Figure 5. Temperature gradient of VC-1.

be to our understanding of the Valles thermal regime.

CONCLUSIONS

The excellent core quality obtained from the VC-1 operations confirms the utility of coreholes for scientific investigation of hydrothermal systems (Benoit, 1984). Initial scientific results from the VC-1 core and borehole have provided new insights into the structure of the Valles caldera and nature of the associated hydrothermal system. Extensive analyses of core samples are in progress, and hydrologic tests in VC-1 are planned for the summer of 1985.

The preliminary results have encouraged preparation of a CSDP-Thermal Regimes proposal for extensive deep coring in the Valles caldera. These efforts should provide detailed understanding of caldera processes, and thus further knowledge of the generation, evolution, and exploration of hydrothermal reservoir systems and associated ore deposits.

ACKNOWLEDGMENTS AND DISCLAIMER

Many thanks to the numerous well sitters who volunteered their time to VC-1. Cathy Stephenson, U.S. Forest Service, Jemez Springs, New Mexico, assisted us with our permitting procedures. The help of Union Oil Co., Santa Rosa, California and Baca Land and Cattle Co., Abilene, Texas is also acknowledged. VC-1 was funded by the Office of Basic Energy Sciences, U.S. DOE. Reference to any specific company, product name, or service does not imply approval or recommendation of these products or services by the University of California (Los Alamos National Laboratory) or the U.S. DOE to the exclusion of others that might be suitable.

REFERENCES

Benoit, W.R., 1984. Initial results from drillholes PLV-1 and PLV-2 in the western moat of the Long Valley Caldera, Trans. GRC 8, pp. 397-402.

Continental Scientific Drilling Committee, 1984. A national drilling program to study the roots of active hydrothermal systems related to young magmatic intrusions, Nat. Acad. Sci. Press, Washington, D.C., 41 pp.

Dey, T., Kranz, R. and Holcomb, D., 1984. Stress measurement from Valles caldera corehole no. 1, EOS Trans. AGU, 65, no. 45, pp. 1119.

Gardner, J.N. and Goff, F., 1984. Potassium-argon dates from the Jemez volcanic field: implications for tectonic activity in the north-central Rio Grande rift, New Mex. Geol. Soc. Guidebook 35, pp. 75-81.

Goff, F., Rowley, J., Gardner, J., Hawkins, W., Goff, S., Charles, R., Pisto, L., White, A., Eichelberger, J., and Younker, L., 1984. Valles Caldera #1, a 856-m corehole in the southwestern ring-fracture zone of Valles Caldera, New Mexico, EOS Trans. AGU 65, no. 45, pp. 1096.

Goff, F., Grigsby, C.O., Trujillo, P.E., Counce, D., and Kron, A., 1981. Geology, water geochemistry and geothermal potential of the Jemez Springs area, Canon de San Diego, New Mexico, J. Volcan. Geoth. Res. 10, pp. 227-244.

Goff, S., (in press), Curatorial Policy guidelines and procedures for the Continental Scientific Drilling Program, Los Alamos National Laboratory Informal Report, 9 pp.

Hulen, J.B., and Nielson, D.L., 1982. Stratigraphic premeability in the Baca Geothermal system, Redondo Creek area, Valles Caldera, New Mexico, Trans. GRC, 6, pp. 27-30.

Laughlin, A. W., 1981. The geothermal system of the Jemez Mountains, New Mexico, and its exploration, in Geothermal Systems: Principles and Case Histories, edited by L. Rybach and L. J. P. Muffler, pp. 295-320, Wiley, New York.

Polk, G., 1983. Correct drilling fluids for shallow geothermal exploration can reduce total well costs, GRC Workshop on Shallow Geothermal Wells, Jan., 1983, Reno, NV.

Rowley, J., Goff, F., and Hawkins, W. (eds.), (in prep.). Drilling report - first CSDP/Thermal Regimes core hole project at Valles caldera, New Mexico (VC-1), Los Alamos Nat. Lab. Informal Report.