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WELLS:

VC-1, VC-2A, & VC-2B

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

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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.

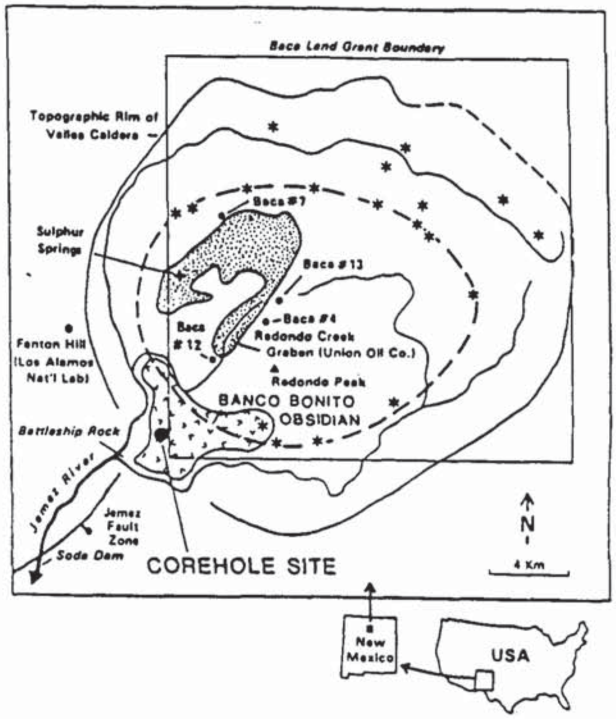

Figure 1.
Location map of Valles caldera and VC-1 corehole; V-pattern shows Banco Bonito obsidian flow, stipple-pattern shows area of intense intracaldera acid-sulfate alteration, stars denote intracaldera rhyolite vents and heavy dashed line shows the inferred posi- tion of the Valles ring-fracture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

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

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

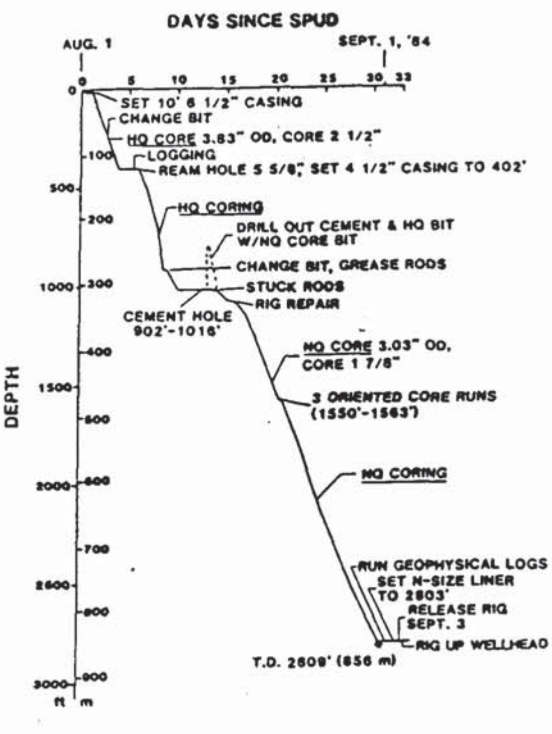

Figure 2. Diagram showing VC-1 coring history as functions of time and depth.

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

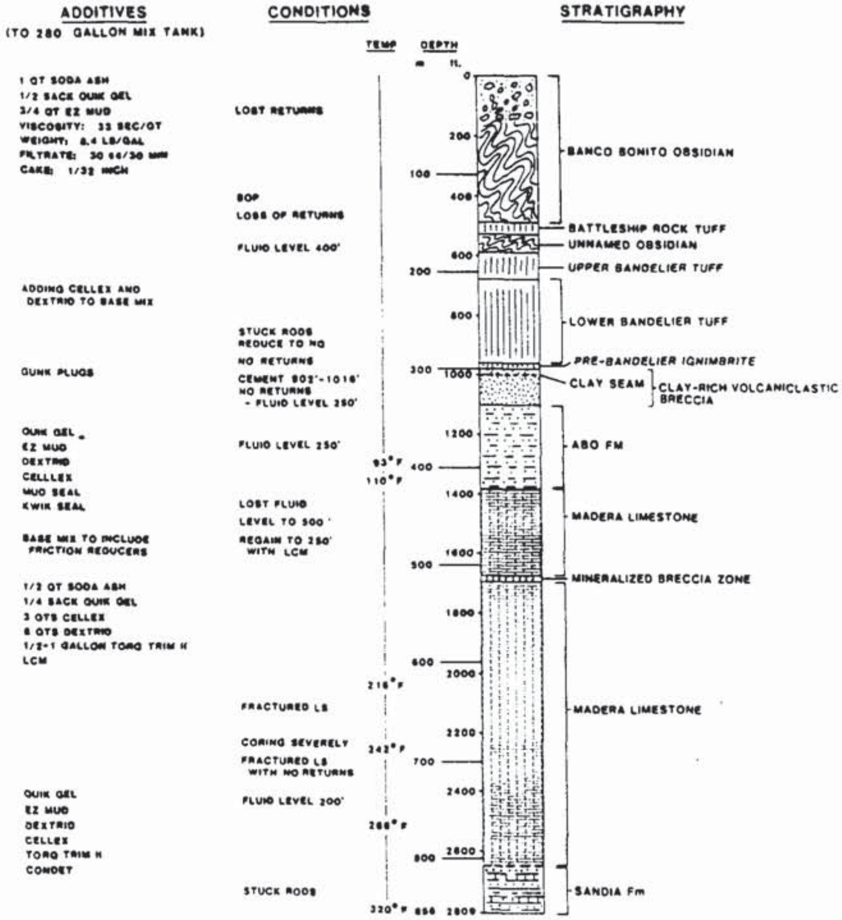

Figure 3. Stratigraphy and mud program of VC-1, Valles caldera, New Mexico.

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

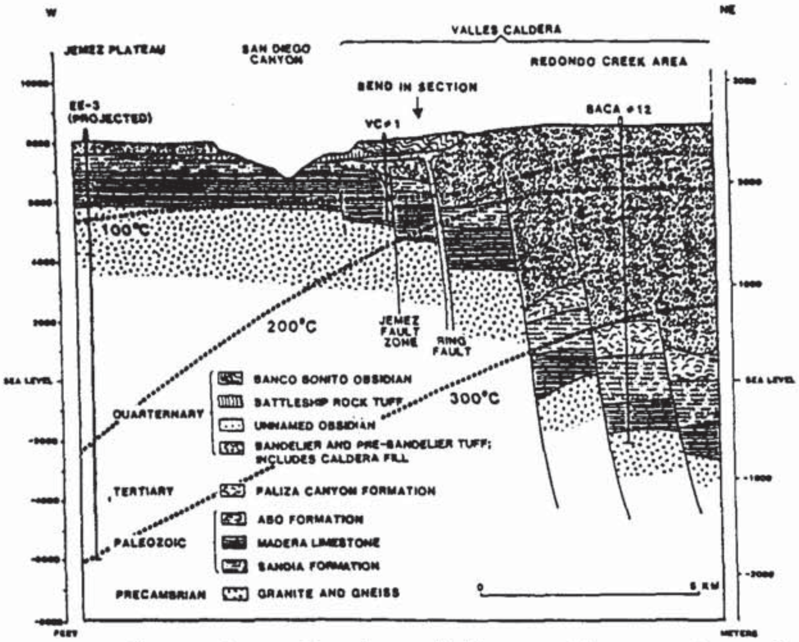

Figure 4. Schematic cross-section of southwestern Valles caldera region, New Mexico showing stratigraphy, structure, and temperature isotherms.

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

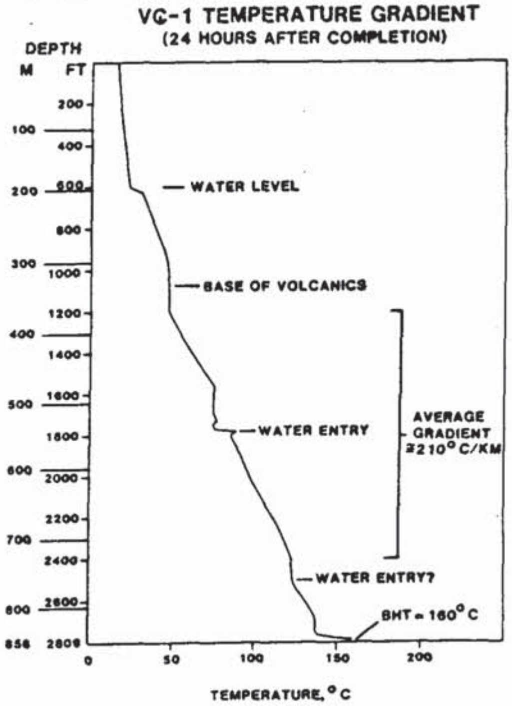

Figure 5. Temperature gradient of VC-1.

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.

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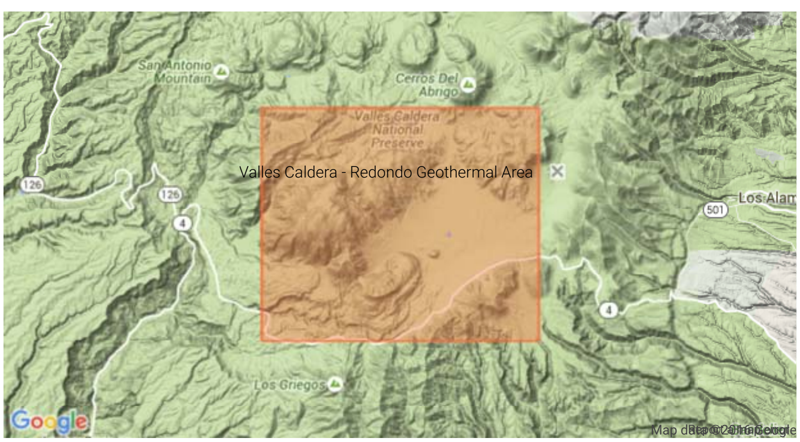
GEOTHERMAL ENERGY

Valles Caldera - Redondo Geothermal Area

Contents



Area Overview

Geothermal Area Profile

Location:	New Mexico
Exploration Region:	Rio Grande Rift
GEA Development Phase:	None
Coordinates:	35.867980437393°, -106.51545532227°

Resource Estimate

Mean Reservoir Temp:		
Estimated Reservoir Volume:		
Mean Capacity:		
USGS Mean Reservoir Temp:	275°C	[1]
USGS Estimated Reservoir Volume:	6 km³	[1]
USGS Mean Capacity:	100 MW	[1]

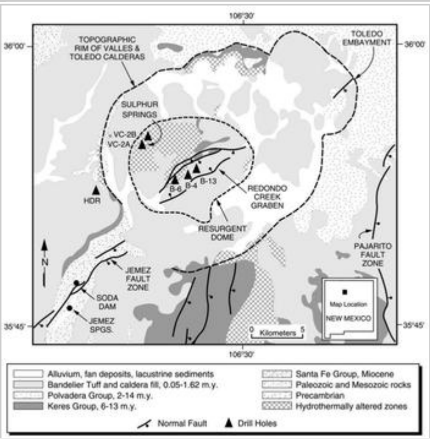


Figure 1. Map showing the locations of the Redondo, Sulphur Springs, and Jemez Springs geothermal areas and of the Fenton Hill HDR Project of the Valles Caldera. Modified from Goff and Janik (2002) Figure 2.[2]

The Valles Caldera is located in the Jemez Mountains volcanic field of north-central New Mexico. Valles is the type example of a resurgent caldera system,[3] and is host to a long-lived < 300°C geothermal system.[4] Documentation of hot spring occurrences of the Jemez Plateau dates back to before 1913, and includes descriptions of discharges at Jemez Springs and Sulphur Springs.[5] From 1968 – 1970, the U.S. Geological Survey (USGS) conducted several early studies describing the caldera geology, stratigraphy, and structure.[6][7][8] Bailey et al. (1969) originally described the intracaldera volcanic stratigraphy as (from youngest to oldest) the Banco Bonito, El Cajete, and Battleship Rock Members of the Valles Rhyolite based on surface mapping of the caldera. The caldera stratigraphy has since been refined based on surface geologic mapping and lithologies from scientific drill holes.[9][10][11][12] Numerous geochronology studies have also contributed to the interpreted stratigraphy and eruptive history of the caldera. Ages of spring deposits, eruptive units, and core samples of vein minerals and altered host rocks have been determined through 14C,[8][13] K-Ar,[6][10][14][15][16] Ar-Ar,[17][18][19][20][21][22] U series,[23] [24][25][26] thermoluminescence,[13] and Electron Spin Resonance (ESR)[27][28] dating methods. The U.S. government purchased the caldera in 2000 and designated it the Valles Caldera National Preserve, with the intention of protecting its unique geology and scenic beauty while promoting scientific investigations including the preparation of detailed geologic maps.[29][30]

The naturally occurring hydrothermal system at Valles is subdivided into the Redondo, Sulphur Springs, and Jemez Springs geothermal areas based on the distribution of springs and fumaroles, past geothermal exploration projects, and scientific drilling programs. Surface discharges at Redondo and Sulphur Springs are fed by upwelling fluids from chemically distinct, isolated reservoirs beneath the caldera floor. Waters from these reservoirs also feed the Jemez Springs system outside the caldera walls to the southwest, reaching the springs primarily by structurally controlled lateral outflow and by more minor flow through Paleozoic strata. The locations of these geothermal areas and the Fenton Hill Hot Dry Rock (HDR) Project are shown in Figure 1.

The Redondo Geothermal Area--formerly known as the Baca Geothermal System or Baca Geothermal Field during the time that Unocal owned the geothermal lease[31]--is located in the southwestern portion of the Valles Caldera beneath the Redondo Peak’s resurgent dome. Union Oil Company (Unocal) drilled a series of 24 wells into a portion of this resurgent dome, which yielded a considerable amount of data regarding the subsurface stratigraphy, structure, and temperature of the Redondo Reservoir.[32] Reservoir fluids sampled from the Bandelier Tuff in drill hole Baca-13 are hydrothermal brines that contain up to 1910 mg/L Cl-.[33][34] Maximum temperature encountered over the course of the project was 342°C in the deepest well, Baca-12, which was drilled to a depth of 3.2 km. The project was ultimately abandoned when the overall volume of the reservoir proved to be too small for commercial development.

History and Infrastructure

Operating Power Plants: 0

No geothermal plants listed.

Add a new Operating Power Plant

Developing Power Projects: 0

No geothermal projects listed.

Add a new Developing Power Project

Power Production Profile

Gross Production Capacity:	
Net Production Capacity:	
Owners :	
Power Purchasers :	
Other Uses:	

Ownership of Baca Location No. 1, which encompassed Valle Grande, Valle San Antonio, Valle Santa Rosa, and Redondo Creek, was awarded to the family of Francisco Tomás Baca in 1860 as a part of an exchange that settled a dispute over the land rights to what was then known as the Town of Las Vegas.[35] Ongoing disagreements over ownership, inheritance, and outside interests in the increasingly partitioned land claim led to numerous commercial, legal, and occasionally bloody disputes during the late nineteenth century. Ownership of various claims within the land package changed hands several times during this period. The caldera has been the site of numerous logging operations since gold and silver were discovered south of the property in 1889, which spurred demand for timber needed for major mines and boomtowns that subsequently sprang up in the area. Logging activities were concluded in 2001 following the U.S. government's purchase of the Baca Location No. 1 in 2000. The caldera has also been used as grazing land for horses, cattle, and sheep by various parties throughout its ownership history, with operations continuing through 2002. A complete history of ownership and development of the Valles Caldera can be found in Merlan and Anschuetz (2007).[35]

Geothermal exploration at Valles began in 1959 when Unocal drilled a series of wells into a portion of the Redondo Peak Resurgent Dome as a part of a development program within what was known as the Baca Project Area (now referred to as the Redondo Geothermal Area). Drilling results defined a high temperature reservoir beneath the resurgent dome; however, the overall volume of the system was ultimately deemed to be too small for commercial development and the project was abandoned in 1983. Drilling activities were continued as a part of the Continental Scientific Drilling Program (CSDP) between 1984 and 1988, during which time three core holes (VC-1, VC-2A, and VC-2B) were drilled to better understand the stratigraphy, structure, hydrothermal alteration, and subsurface architecture of the Valles Caldera. An additional core hole, VC-3, was drilled in 2004 as part of the GLAD5 project to investigate major climatic changes and glacial/interglacial cycles recorded in lacustrine sediments below Valle Grande. While the findings of this shallow core hole are significant with respect to paleoclimate research, they pose little relevance to the exploration for geothermal resources.

Redondo Area Timeline

1913: Hot springs documented at Valles Caldera.[5]

1860: Francisco Tomás Baca is given ownership of Baca Location No. 1.[35]

1889: Gold and silver discovered south of Valles Caldera.[35]

1959: Unocal purchases lease for the Baca Geothermal Field. The company drills several wells into the Redondo Peak Resurgent Dome.[32][31][33]

1968-1970: USGS Investigations at Valles Caldera.[6]

1983: Unocal abandons the Valles Caldera exploration project.[32]

1984-1988: The VC-1, VC-2A, and VC-2B core holes are drilled at Valles Caldera under the Continental Scientific Drilling Program.[31]

2000: U.S. government designates Valles Caldera as a National Preserve.[29][30]

2004: The VC-3 core hole is drilled at Valles Caldera under the GLAD5 project.[22]

Regulatory and Environmental Issues

Click "Edit With Form" above to add content

Future Plans

The U.S. government purchased the caldera in 2000 and designated it the Valles Caldera National Preserve.[29][30] The preserve was established in order to protect the caldera's unique geology and scenic beauty, and to promote scientific investigations into the nature of resurgent calderas, of which Valles Caldera is the type example. Several studies have since been conducted that have yielded considerable information regarding the geologic history of the caldera, the formation and drainage of post-eruption intracaldera paleolakes, and the paleoclimate of the region; these studies have resulted in the preparation of detailed geologic maps. These investigations are ongoing, and will continue to refine scientific understanding of the processes governing caldera systems.

Exploration History

First Discovery Well

Completion Date:	
Well Name:	
Location:	
Depth:	
Initial Flow Rate:	
Flow Test Comment:	
Initial Temperature:	

Field, chemical, and isotopic data for 95 thermal and nonthermal waters in and around the Valles Caldera were collected by Goff et al. in 1982 to help interpret the geothermal potential of the Jemez Mountains region and to provide background data for investigating problems in hydrology, structural geology, hydrothermal alterations, and hydrothermal solution chemistry.[36] Temperature, pH, and flow rate data were collected in the field, and all samples were analyzed for their chemical compound and major element contents. Select samples were also analyzed for their D and 18O isotope contents. The sampling program documented the locations of numerous hot springs, fumaroles, and wells in the region around the Valles caldera, and included:

- 22 samples from Jemez Springs
- 15 samples from Sulphur Springs
- 13 isolated samples from the Redondo area.

Twenty-four wells were drilled into a portion of the Redondo Peak Resurgent Dome from 1959 to 1983 by Unocal as a part of a geothermal exploration and development program within what was known as the Baca Project Area (now referred to as the Redondo Geothermal Area). In 1984, Nielson and Hulen described the intracaldera volcanic stratigraphy in the vicinity of Redondo Peak based on detailed logging of subsurface samples from these wells, which provided insights that improved interpretation of the internal structure of the resurgent dome.[32] Maximum temperatures of 342°C were encountered in the deepest Unocal well, Baca-12, drilled to a depth of 3.2 km.

A series of core holes were drilled from 1984 to 1988 as a part of the CSDP to better understand the stratigraphy, structure, hydrothermal alteration, and subsurface architecture of the Valles Caldera. Numerous studies have reported the results from these core holes, which include the VC-1 core hole drilled at Redondo Creek and the VC-2A and VC-2B core holes at Sulphur Springs.[37][38][39] [38][40] [37][41][38][42] [43][44] [45] [46] [47] The CSDP has greatly improved understanding of the intracaldera subsurface stratigraphy and structure, helped define the intracaldera reservoirs and the hydrothermal outflow plume along the Jemez Fault Zone, facilitated measurement of bottom hole temperatures, and allowed for the description of alteration and ore deposit analogues associated with the active hydrothermal system.

Wilt and Haar (1986) carried out a series of geophysical surveys at the Redondo and Sulphur Springs geothermal areas within the caldera in hopes of outlining deep drilling targets.[48] These included telluric profiles, magnetotelluric sounding, DC resistivity, gravity, and electromagnetic sounding surveys that were integrated to help define the electrical structure in the reservoir region(s). The most useful of these were the telluric profiles and the magnetotelluric sounding data sets since those surveys provided a good penetration depth. Resistivity models were principally constructed from these data and were tested against the other geophysical data sets. Magnetotelluric results indicate a deep, low resistivity anomaly at the western edge of the caldera that is potentially associated with deep hot fluids. Density log data from Redondo Creek indicate three major density units within the well section that were differentiated for modeling purposes: a surface layer of caldera fill, lake deposits, and other recent alluvium (2.12 g/cm^3); the Bandelier Tuff and underlying volcanic and sedimentary units (2.3--2.5 g/cm^3); and the basement unit, consisting of the lower Paleozoic and the upper Precambrian (2.65 g/cm^3). Geophysical and well data were used to construct computer models that provide a general guide to subsurface structure; these models are useful for identifying large-scale changes. On the basis of geophysical and well data, the authors made three estimates of reservoir dimensions.

In 1995, Roberts et al. described the experimental details, data analysis, and forward modeling for scattered-wave amplitude data recorded during a teleseismic earthquake survey performed in the Valles Caldera in the summer of 1987.[49] Twenty-four high-quality teleseismic events were recorded at numerous sites along a line spanning the ring fracture and at several sites outside of the caldera. A modification of the Aki-Lamer method was used to model the amplitude data. Results confirmed the presence of a shallow attenuating anomaly; they were used to estimate the quantitative parameters defining it. Teleseismic monitoring continued into the summer of 1994 through the Jemez Tomography Experiment (JTEX), a multidisciplinary effort to understand the structure of the Jemez volcanic field below the Valles Caldera. Steck et al. (1998) integrated data from several active and passive seismology, geology, gravity, and electromagnetic studies to produce a detailed 3-D model of the subsurface deep beneath the caldera. Inversion of 4,872 teleseismic P wave relative arrival times allowed for successful imaging of the Toledo Embayment (assumed to have formed during the collapse of the Toledo Caldera) and revealed a region that contains at least 10% melt between 5 and 15.5 km depth underlying the active hydrothermal features on the west side of the caldera. This low-velocity zone is thought to represent a new pulse of magma into the crust rather than residual Bandelier magma. Low velocities were also detected near the crust-mantle boundary, and are thought to relate to partial melting of the upper mantle and subsequent underplating of basaltic melt in the upper mantle and/or lower crust.

A Master's thesis study completed in 2004 by Erin H. Phillips helped to refine understanding of the post-collapse history of the Valles caldera.[22] The research utilized 40Ar/39Ar age dating to investigate the maximum time window of resurgence and rate of uplift of Redondo Peak, the timing of eruption of the Deer Canyon and Redondo Creek rhyolites, and how these eruption ages relate to changes in the magma chamber prior to and during resurgence. In addition, the study investigated the ages of several megabreccia blocks within the Valles Caldera. Goff et al. (2006) produced detailed geologic maps of the southern half of the Valles Caldera and surrounding area as a contribution to the New Mexico State Map Program.[30] Geologic mapping and differentiation of the intracaldera rocks has since been used to guide detailed elemental analysis of previously unrecognized zeolitic alteration in post-eruption lithologic units. Chipera et al. (2008) made further contributions to the differentiation of lacustrine and volcaniclastic lithologic units within the caldera and characterized shallow zeolitic alteration associated with formation of the post-eruption intracaldera paleolake.[50] Roughly 80 samples of fresh and altered rocks from early volcanic and lacustrine rock units were collected from the middle to the lower flanks of the resurgent dome and from various locations in the caldera moat to study mineral abundances using X-ray powder diffraction analysis (XRD), examine specific mineral texture/morphology using scanning electron microscopy (SEM), and determine the trace element geochemistry of representative Valles zeolites using electron microprobe analyses (EPMA). The sample set included:

- 20 samples of upper Bandelier Tuff
- 20 samples of intracaldera fluvial/lacustrine rocks
- 30 samples of Deer Canyon lavas, Deer Canyon tuffs, and Redondo Creek lavas
- 10 samples of moat lacustrine deposit rocks.

The distribution of zeolites throughout the earliest Valles Caldera rocks is non-uniform and therefore subeconomic, with high concentrations of zeolites occurring rarely in isolated outcrops. Characterization of the zeolites revealed that mordenite and clinoptilolite are the most commonly occurring zeolites at the Valles Caldera. Erionite, an extremely carcinogenic zeolite linked with mesothelioma, was not identified at Valles Caldera, confirming that the zeolites present at Valles do not pose health and safety risks for those who visit the Valles Caldera National Preserve.

Well Field Description

Well Field Information

Development Area:	
Number of Production Wells:	
Number of Injection Wells:	
Number of Replacement Wells:	
Average Temperature of Geofluid:	
Sanyal Classification (Wellhead):	
Reservoir Temp (Geothermometry):	
Reservoir Temp (Measured):	
Sanyal Classification (Reservoir):	
Depth to Top of Reservoir:	
Depth to Bottom of Reservoir:	
Average Depth to Reservoir:	

Unocal drilled 24 wells into a portion of the Redondo Peak Resurgent Dome from 1959 to 1983 as a part of a geothermal exploration and development program within what was known as the Baca Project Area (now referred to as the Redondo Geothermal Area). In 1984, Nielson and Hulen described the intracaldera volcanic stratigraphy in the vicinity of Redondo Peak based on detailed logging of subsurface samples from these wells, which provided insights that improved interpretation of the internal structure of the resurgent dome. Maximum temperatures of 342°C were encountered in the deepest Unocal well, Baca-12, which was drilled to a depth of 3.2 km.

The VC-1 core hole drilled at Redondo Creek and the VC-2A and VC-2B core holes drilled at Sulphur Springs as part of the CSDP from 1984 to 1988 have been the subject of numerous studies of the stratigraphy, structure, hydrothermal alteration, and subsurface architecture of the Valles Caldera.[37][38][39] [38][40] [37][41][38][42] [43][44] [45] [46] [47] An additional core hole, VC-3, was drilled in 2004 as part of the GLAD5 project to investigate major climatic changes and glacial/interglacial cycles recorded in lacustrine sediments below Valle Grande. While the findings of this shallow core hole are significant with respect to paleoclimate research, they pose little relevance to the exploration for geothermal resources.

Research and Development Activities

The natural geothermal reservoirs within the Valles Caldera have not been developed for commercial electricity production although the field is capable of producing about 20 MWe.[2]. However, the adjacent Fenton Hill HDR Project to the west has been the subject of some of the first reservoir engineering, fluid circulation/recovery, and power generation experiments with applications in Enhanced Geothermal Systems (EGS).

Technical Problems and Solutions

The Fenton Hill HDR Project was the first development project of its kind, and so faced a number of unique challenges that may be used to inform the design and implementation of future EGS projects. The most prominent technical issue was the orientation of the induced fracture pattern in the Phase II reservoir, which initially failed to promote hydraulic communication between the injection and production wells. This issue stemmed from the fact that the injection and production wells at Fenton Hill were drilled prior to fracturing hot crystalline reservoir rocks, which resulted in poor connectivity between the wells and low recovery of the heated fluid. The injection well (EE-3A) was ultimately redrilled to intersect the fracture network produced in the Phase II reservoir.[51]

Perhaps the most crucial lesson gained from the Fenton Hill HDR Project is that the stimulated volume of hot rock should be fractured from the initial borehole prior to the drilling of production boreholes near the long-axis boundaries on either side of the ellipsoidal seismic reservoir volume. To first drill two boreholes and then try to connect them by hydraulic fracturing, as was initially attempted at the site, is nearly impossible. The use of two production wells would also (in theory) double the productivity of the Phase II reservoir and would allow for a sustained thermal power production level of about 20 MW over a period of at least 15 years.[52] Additionally, a second production well would allow for maintenance of even higher reservoir pressures, which would result in greater dilation of the flowing joints and reduce the body impedance while also constraining additional reservoir growth.[53][54]

Geology of the Area

Geologic Setting

Tectonic Setting:	Extensional Tectonics, Rift Zone	
Controlling Structure:	Caldera Rim Margins, Fault Intersection, Stratigraphic Boundaries	[55] [9] [56]
Topographic Features:	Caldera Depression, Horst and Graben, Resurgent Dome Complex	
Brophy Model:	Type C: Caldera Resource	
Moeck-Beardsmore Play Type:	CV-2a: Plutonic - Recent or Active Volcanism	

Geologic Features

Modern Geothermal Features:	Fumaroles, Hot Springs	[56]
Relict Geothermal Features:	Zeolitic Alteration	[50]
Volcanic Age:	Pleistocene, 1.25 Ma	[22]
Host Rock Age:	Mississippian-Pennsylvanian; Pleistocene, 1.6 to 1.25 Ma	[21] [22]
Host Rock Lithology:	Limestone-Madera Formation “MIPu”; Rhyolitic tuff-Intracaldera Bandelier Tuff (upper Tshirege “Qbt” and lower Otowi “Qbo” members); Caldera Fill Rhyolite (shallow)	[34]
Cap Rock Age:		
Cap Rock Lithology:		

Regional Setting

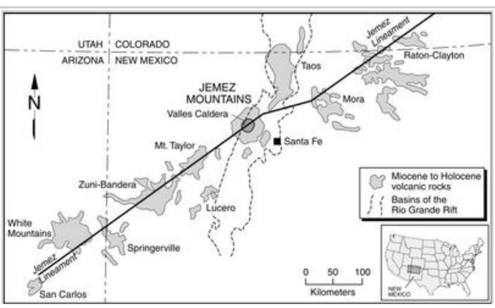


Figure 2. Location map of the Valles Caldera, north-central New Mexico. The caldera lies at the intersection of the Jemez lineament and the Rio Grande Rift. Modified from Goff and Janik (2002).[2]

The Valles Caldera is a Quaternary volcanic collapse feature with a diameter of 22 km.[57] It was formed by the latest catastrophic volcanic eruption in the Jemez Mountains volcanic field of north-central New Mexico at 1.25 Ma.[21][22] The caldera itself is situated at the intersection of the Jemez Lineament and the western edge of the Rio Grande Rift. The Rio Grande Rift is a major extensional feature consisting of a series of north-trending asymmetric sedimentary basins separated by transfer and scissor fault zones that stretches over 1,000 km from Leadville, CO to Chihuahua, Mexico.[58][59][60][61][62] Rifting was preceded by northeast-southwest compression that created foreland basins and uplifted fault blocks during the Late Cretaceous Laramide Orogeny.[63] This period was followed by a shift to backarc extensional tectonics during the Cenozoic, with formation of the Rio Grande Rift beginning at about 30 Ma and lasting until approximately 18 Ma. Extension also initiated a minor period of primarily basaltic volcanic activity that produced large shield volcanoes, cinder cones, fissures, flood-basalts, and tuffaceous ash layers.[64] Rifting continued during a second period of tectonic activity lasting from approximately 10 Ma to 3 Ma, and was accompanied by a major period of volcanism beginning approximately 5 Ma.

Igneous rocks of the Rio Grande Rift formed during this time contrast sharply with those of the Jemez volcanic field. A series of basaltic through rhyolitic eruptions between 16.5 Ma and 40 ka[10][28] form a northeast-trending chain of volcanic centers that define the Jemez Mountains volcanic field, which lies along the Jemez Lineament.[57] The Jemez Lineament is thought to be a major zone of weakness in the lithosphere and is not defined by a single through-going fault of fracture.[62] Figure 2 shows the locations of the Valles Caldera, Rio Grande Rift, and Jemez Lineament in north-central New Mexico.

Stratigraphy

An estimated volume of 400-475 km^3 of high-silica rhyolitic ignimbrite was produced by each of the caldera-forming eruptions of the Jemez Mountains volcanic field, and was deposited as a non-welded to densely welded tuffaceous unit (the Bandelier Tuff) of varying thickness that covered the surrounding topography.[57][3][32][65][66] Ignimbrites deposited during the explosive formation of the Valles and Toledo calderas are exposed at Valles and throughout the surrounding region, and consist of the upper Tshirege (Qbt) and lower Otowi (Qbo; c.a. 1.6 Ma[21][22]) members of the Bandelier Tuff, commonly referred to as the upper and lower Bandelier Tuffs, respectively.[32] The most recent 40Ar/39Ar date on the upper Bandelier Tuff is 1.256+0.010 Ma,[22] and defines the timing of eruption of the Valles Caldera. Volcanics exposed throughout the Jemez Mountains volcanic field are largely unaltered, although both fresh and hydrothermally altered tuffs are present in the caldera center and topographic rim.[67] Drill holes and gravity investigations within the caldera indicate that the caldera depression is filled by as much as 2,000 m of densely welded ignimbrite[32] and that the caldera is asymmetric, being considerably deeper in the east than in the west.[68] The La Cueva member (Qblc), recently redefined as the basal member of the Bandelier Tuff, is a lithic-rich, pumiceous, rhyolitic ignimbrite that is traceable for nearly 20 km in San Diego Canyon to the southwest of the caldera.[11] The Bandelier Tuff is underlain by porphyritic dacite and andesite domes and lava flows (Ttu, Tpa), and Tertiary basin-fill sediments and volcaniclastic deposits of the Santa Fe Group (Ts, Tsf, Tscu) to the east. These rocks thin beneath the western side of the caldera, and are underlain by Permian strata (Pu), Mississippian-Pennsylvanian sedimentary rocks (MIPu, including the Madera Formation limestone), and Precambrian crystalline basement rocks (pC) of the Colorado Plateau.

Shortly after the eruption of the upper Bandelier Tuff, erosion of the caldera walls formed talus slopes, alluvial fans, and debris flow deposits that thin towards the center of the crater. During this time, an intracaldera lake formed, depositing laminated to bedded lacustrine sediments (Qvs). The floor of the caldera began to rise, forming the Redondo Peak Resurgent Dome, and relatively small volumes of rhyolite lava and tuff erupted from the caldera center.[3] These steeply- to moderately-dipping rock units overlie the upper Bandelier Tuff, and are exposed along the middle and lower flanks of the resurgent dome.[30] Co-resurgence eruptive members of the Valles Rhyolite include the porphyritic Deer Canyon Lava (Qdc) and lithic tuff (Qdct) and the overlying Redondo Creek Lava (Qrc), all of which are interbedded with lacustrine and debris flow deposits (Qdf). The most recent 40Ar/39Ar dates range from 1.25+0.02 to 1.26+0.02 for the Deer Canyon lavas and 1.21+0.02 to 1.26+0.04 Ma for the Redondo Creek lava, limiting the duration of co-resurgence volcanism to approximately 27 ka after formation of the caldera.[22] The Valles Rhyolite also includes a series of post-resurgence moat rhyolites that overly the Redondo Creek lavas;[22] they erupted between 1.23 Ma and about 40 ka.[50]

These units form a series of rhyolitic flow and dome complexes that are distributed in a counterclockwise arc beginning with the oldest dome on the eastern side of the caldera and the youngest dome located southeast of Redondo Peak.[20] From oldest to youngest, these eruptive units are the Cerro del Medio (Qvdm), Cerros del Abrigo (Qvda), Cerro Santa Rosa (Qvsr), Cerro San Luis (Qvsl), Cerro Seco (Qvse), San Antonio Mountain (Qvsa), and South Mountain (Qvsm) members of the Valles Rhyolite.[11][12] Recent geologic mapping of the caldera has revealed that deposition of post-resurgence moat rhyolites was accompanied by at least three periods of lacustrine sedimentation (Ql) at roughly 0.8 Ma, 0.5 Ma, and 55 ka.[29][30][12] The East Fork Member of the Valles Rhyolite represents the most recent series of volcanic units erupted between about 60-40 ka, and includes the Battleship Rock Ignimbrite (Qvbr), El Cajete Pyroclastic Beds (Qvec), and the Banco Bonito Flow (Qvb).[13][28] These units were recognized during initial geologic mapping of the caldera, and are concentrated in the southwestern moat zone adjacent to Redondo Peak and South Mountain.[8][11] Rocks of the East Fork Member are texturally distinct and are readily distinguishable in the field: the Battleship Rock Ignimbrite consists of a sequence of pyroclastic deposits that form a prominent cliff where the Jemez River forks to the east; the El Cajete Pyroclastic Beds are a series of mantle-bedded air fall deposits made up of pumice lapilli and blocks; and the Banco Bonito Flow is a porphyritic obsidian flow deposit that fills the southwestern caldera moat.[8] The subsurface stratigraphy of the Valles Caldera in the vicinity of the Redondo Peak Resurgent Dome is shown in Figure 3 (below).[12]

Structure

The eruption of approximately 440 cubic kilometers[66] of upper Bandelier Tuff and concurrent collapse of the Valles Caldera resulted in extensive faulting and down-to-the-north displacement along a ring-fracture zone of the south caldera wall.[30] The position of the ring-fracture zone is inferred from the arcuate distribution of rhyolitic domes of the Valles Rhyolites Formation, which are arranged in a counterclockwise manner with the oldest dome (Cerro del Medio) located on the eastern side of the caldera and the youngest dome (South Mountain) located just southeast of the Redondo Peak Resurgent Dome.[20] Gravity and drill hole data indicate that maximum displacement on Precambrian basement is on the order of several kilometers and increases beneath Valle Grande toward the eastern sector of the caldera.

Uplift of the Redondo Peak Resurgent Dome following the collapse of the caldera represents an additional structural style.[3] The caldera-filling ignimbrite that makes up Redondo Peak was uplifted at least 1000 m, resulting in intense faulting that formed the northeast-trending medial (or keystone) Redondo Creek Graben and several associated cross faults.[69][30] Resurgence also resulted in the formation of several cross faults along the margins of Redondo Peak, segmenting the adjacent caldera-filling volcaniclastic and sedimentary units into distinct fault blocks. The orientation of the graben and the elongation of the resurgent dome are both on strike with the northeast-trending Jemez fault zone, suggesting these features developed preferentially along pre-existing rift structures.[30] The subsurface structure and lithologic units of the Valles Caldera are shown in Figure 3. It should also be noted that early post-caldera lavas, tuffs, and interbedded lacustrine and debris flow deposits show steep dips and variable thicknesses in adjacent fault blocks, suggesting that resurgence occurred relatively early in the caldera history.[3][69]

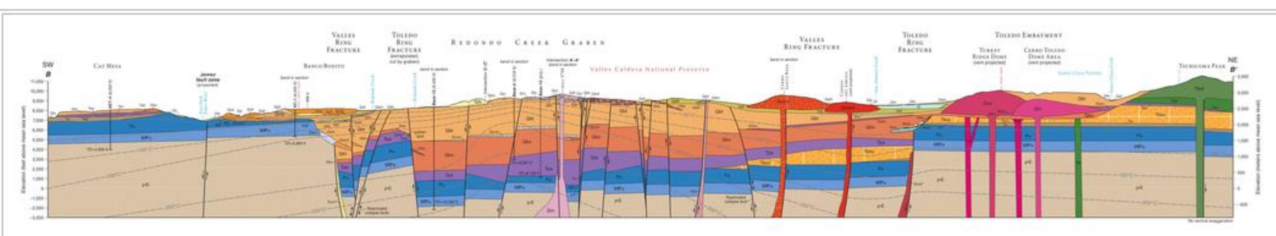


Figure 3. Southwest-northeast cross section through the Valles Caldera. The section transects the Valles and Toledo ring fracture zones, the Redondo Creek Graben, and the Jemez Fault Zone on the southwestern margin of the caldera.[12]

Hydrothermal System

The age of the Valles Caldera hydrothermal system has been dated to be about 1 Ma,[24] indicating rapid initiation of hydrothermal activity following formation of the caldera at 1.25 Ma.[21][22] Reservoir geofluids encountered during drilling within the caldera are neutral-chloride waters (on the order of several thousand mg/L Cl-) between 250-300°C [56] that contain approximately 5000-18,000 mg/kg total dissolved solids.[31] These fluids are interpreted to be deeply circulating old meteoric waters,[56] and do not resemble any of the surface hot springs within the caldera in terms of their chemical composition.[9] Isotopic and thermal data indicate the hydrothermal system is dominated by relatively recent meteoric recharge that reaches depths of 2-3 km and temperatures of about 300°C.[56] 36Cl/Cl ratios indicate that these fluids evolve into highly saline geothermal brines by leaching chloride from Precambrian basement and Paleozoic rocks, and limit subsurface residence times to <100,000 years.[34] Geofluids then become entrained in convective upflow along faults and fractures to depths of 500-600 m, and then flow laterally to the southwest along the Jemez fault.[55][9][56] The 20-km-long fault system serves as a conduit that channels thermal waters away from the upflow plume, resulting in hot springs and other surface manifestations of variably mixed hydrothermal fluids outside the caldera wall.[31] As such, the Jemez Fault Zone serves as the principle discharge from the Sulphur Springs and Redondo reservoirs that feeds the neutral-chloride hot springs at Soda Dam and at Jemez Springs in San Diego Canyon along the Jemez River, although some discharge outside the caldera results from limited lateral flow through permeable Paleozoic strata.[70][31][9] In contrast, hot and cold springs in the western moat zone of the caldera have lower temperatures below 40°C, lower Cl- concentrations between 2-7 mg/L, and are thought to be recharged by recent meteoric waters that are variably heated by shallow circulation through the ring fracture zone of the caldera.[9] Dates on the travertine deposits of the Soda Dam area indicate that the outflow plume has been part of the Valles hydrothermal system for approximately 10^6 years, and that travertine formation occurred in at least three distinct episodes of deposition.[24]

Heat Source

The heat source of the Valles Caldera Geothermal System is thought to be a silicic-magma chamber whose explosive eruption and subsequent collapse formed the Valles and Toledo calderas. Teleseismic surveys have detected a low velocity zone between 5 and 15.5 km that underlies the active hydrothermal features on the western side of the caldera.[71] This region is conservatively estimated to contain at least 10% melt that is thought to represent a new pulse of magma into the crust, and may contribute to the heat flux of the caldera system.

Geofluid Geochemistry

Geochemistry

Salinity (low):	5.4	[36]
Salinity (high):	1910	[36] [34]
Salinity (average):	1435	[70] [36] [34]
Brine Constituents:	Cl-; HCO_3 and SO_4 (measured in springs that resemble reservoir fluid composition); minor major and trace element constituents	[70] [36] [34]
Water Resistivity:		

Numerous geochemical investigations have been conducted at Valles between 1982 and 2002, and include major/trace element and isotopic analyses of water and gas samples taken from hot springs, cold seeps, fumaroles, and wells throughout the caldera. Water chemistry studies were carried out to help interpret the geothermal potential of the Jemez Mountains region and to provide background data for investigating problems in hydrology, hydrothermal alterations, and hydrothermal solution chemistry;[36] to investigate the applicability of 36Cl- as a tracer isotope for determining fluid pathways; to help determine the origin of chloride in the geothermal system;[33][34] and better understand the fluid composition, thermal history, and fluid-rock mass transfer rates in the Redondo Geothermal Reservoir.[72][73] Sampling and analysis of gas collected from springs, fumaroles, and wells was designed to improve understanding of the geologic setting of gas features with respect to the caldera, to investigate variations in gas compositions that occurred during drilling and flow testing of the Valles scientific wells, and to compare Valles gases with those at other geothermal sites.[2]

Investigations into the fluid composition and thermal history of the Redondo geothermal reservoir indicate the presence of a normal enthalpy, lower-chloride fluid and an excess enthalpy, higher-chloride fluid enriched in deuterium and 18O.[72] These distinct chemical properties can be explained by adiabatic cooling or boiling of fluids at 170°C during upward convection along the central fault system in the reservoir, followed by conductive reheating during downward movement. Computer-based chemical modeling using the EQ3NR code indicates stability with the quartz-albite-K mica-epidote-chlorite-calcite-anhydrite-pyrite mineral assemblage, which is in agreement with observed minerals in well cuttings. Together, these results imply a constant temperature range of 260–320°C during evolution of the Redondo Reservoir. Despite these results, the overall volume of the system was ultimately deemed to be too small for commercial development. Estimates of fluid-rock mass transfer rates in the reservoir based on equilibrium constraints, fluid reservoir volume, and discharge rates suggest that fluid residence time is approximately 2,000 years, or <0.2% of the total age of the hydrothermal system.[73] These results are suggestive of a geochemically and isotopically open system, in which Cl was the only aqueous component not controlled by mineral equilibrium.

In 1988, Goff et al. integrated stratigraphic, temperature gradient,[46] hydrogeochemical, hydrologic, and geologic data from VC-1 and from select geothermal test wells of the Fenton Hill HDR and Redondo geothermal projects in order to construct a comprehensive hydrologic and temperature gradient model of the hydrothermal outflow plume issuing from the western margin of the Valles Caldera.[31] Hydrochemical data from aquifers sampled in the VC-1 core hole confirmed the existence of the outflow plume. Combination of this data with previous datasets showed that the outflow at Valles is complex, and is fed by at least two major fluid reservoirs (the Redondo and Sulphur Springs Reservoirs). Discharge rates, thermal gradients, relative heat flow estimates, and mixing relationships suggest that 25-50% of the lateral flow occurs along vertical conduits associated with the Jemez Fault Zone, with subordinate flow occurring in horizontal, semipermeable Paleozoic strata overlying Precambrian crystalline basement rocks. Paleozoic strata are nonhomogeneous in their lithology and so function as poorly connected zones of lateral flow, such that there is no single unique thermal aquifer outside of the western margin of the caldera.

Several other geochemical studies were performed on the regional scale, and encompass the Jemez Springs, Sulphur Springs, and Redondo components of the hydrothermal system. Analysis of 36Cl- isotopes and interpretation of 36Cl/Cl ratios of waters sampled from three meteoric-dominated springs, seven high-temperature drill holes, and six surface hot springs indicates that deeply circulating meteoric waters derive their high chloride contents from Precambrian basement and Paleozoic rocks before ascending into more shallow volcaniclastic reservoirs, and that residence times for these waters are <100,000 years.[34] 36Cl/Cl ratios also confirm previous classifications of the sampled waters as meteoric or thermal waters.[56]

In 2002, Goff and Janik reviewed geochemical results from approximately 80 gas analyses of samples obtained from fumaroles, springs, and wells over the previous two decades to better understand the geologic setting of gas features with respect to the caldera, to investigate variations in gas compositions that occurred during drilling and flow testing of the Valles scientific wells, and to compare Valles gases with those at other geothermal sites, including the Yellowstone and Long Valley calderas.[2] The study confirmed that Valles gases are chemically and isotopically similar to those in other volcanic-hosted geothermal systems, and that the gases are in apparent equilibrium at temperatures >200°C. Relative proportions of Ar, He, and N2 are similar to those measured at hot spot locations such as Yellowstone and Kilauea. He R/Ra values of 4-6 within the caldera are suggestive of mantle/magmatic degassing whereas R/Ra values of ≤0.7 outside the caldera reflect a He input dominated by U/Th decay in crustal rocks. Major gas components of the caldera surface discharges remained relatively constant during sampling and well stimulation, and generally resemble gas compositions of the geothermal wells. This excludes the Footbath acid spring, whose gas composition changed noticeably during six years of drilling and flow testing of the VC-2A and VC-2B wells. The study also revealed that Valles Caldera gases contained relatively little CH4 and N2 compared to other geothermal systems hosted within sedimentary rocks, suggesting that organic carbon and nitrogen in Paleozoic and Miocene strata were depleted during 13 million years of magmatism in the Jemez Volcanic Field.

NEPA-Related Analyses (0)

Below is a list of NEPA-related analyses that have been conducted in the area - and logged on OpenEI. To add an additional NEPA-related analysis, see the NEPA Database.

Download CSV *No NEPA-related documents listed.*

Exploration Activities (46)

Below is a list of Exploration that have been conducted in the area - and cataloged on OpenEI. Add a new Exploration Activity

Page	Technique	Activity Start Date	Activity End Date	Reference Material
Analytical Modeling At Valles Caldera - Redondo Geothermal Area (White, 1986)	Analytical Modeling		1986	• Chemical and isotopic characteristics of fluids within the Baca Geothermal Reservoir, Valles Caldera, New Mexico
At Valles Caldera - Redondo Geothermal Area (Goff & Grigsby, 1982)			1982	• Valles Caldera Geothermal Systems, New Mexico, U.S.A.
Caliper Log At Valles Caldera - Redondo Geothermal Area (Rowley, Et Al., 1987)	Caliper Log	1984	1984	• Drilling Report- First CSDP (Continental Scientific Drilling Program) Thermal Regimes Core Hole Project at Valles Caldera, New Mexico (VC-1) • Core Lithology, Valles Caldera No. 1, New Mexico
Compound and Elemental Analysis At Valles Caldera - Redondo Geothermal Area (Chipera, Et Al., 2008)	Compound and Elemental Analysis		2008	• Zeolitization Of Intracaldera Sediments And Rhyolitic Rocks In The 1.25 Ma Lake Of Valles Caldera, New Mexico, USA
Compound and Elemental Analysis At Valles Caldera - Redondo Geothermal Area (Gardner, Et Al., 1986)	Compound and Elemental Analysis		1986	• Stratigraphic Relations and Lithologic Variations in the Jemez Volcanic Field, New Mexico
Compound and Elemental Analysis At Valles Caldera - Redondo Geothermal Area (Goff, Et Al., 1982)	Compound and Elemental Analysis		1982	• Geochemical Data for 95 Thermal and Nonthermal Waters of the Valles Caldera - Southern Jemez Mountains Region, New Mexico
	Compound and Elemental Analysis	1982	2002	

Page	Technique	Activity Start Date	Activity End Date	Reference Material
Compound and Elemental Analysis At Valles Caldera - Redondo Geothermal Area (Janik & Goff, 2002)				▪ Gas Geochemistry Of The Valles Caldera Region, New Mexico And Comparisons With Gases At Yellowstone, Long Valley And Other Geothermal Systems
Compound and Elemental Analysis At Valles Caldera - Redondo Geothermal Area (Musgrave, Et Al., 1989)	Compound and Elemental Analysis		1989	▪ Selected Data from Continental Scientific Drilling Core Holes VC-1 and VC-2A, Valles Caldera, New Mexico
Compound and Elemental Analysis At Valles Caldera - Redondo Geothermal Area (White, Et Al., 1992)	Compound and Elemental Analysis		1992	▪ Mass Transfer Constraints On The Chemical Evolution Of An Active Hydrothermal System, Valles Caldera, New Mexico
Conceptual Model At Valles Caldera - Redondo Geothermal Area (Gardner, 2010)	Conceptual Model		2010	▪ Rhyolites and Associated Deposits of the Valles-Toledo Caldera Complex
Conceptual Model At Valles Caldera - Redondo Geothermal Area (Goff, Et Al., 1988)	Conceptual Model		1988	▪ The Hydrothermal Outflow Plume of Valles Caldera, New Mexico, and a Comparison with Other Outflow Plumes
Conceptual Model At Valles Caldera - Redondo Geothermal Area (Shevenell, Et Al., 1988)	Conceptual Model		1988	▪ Lithologic Descriptions and Temperature Profiles of Five Wells in the Southwestern Valles Caldera Region, New Mexico
Core Holes At Valles Caldera - Redondo Geothermal Area (Fawcett, Et Al., 2007)	Core Holes	2004	2004	▪ Two Middle Pleistocene Glacial-Interglacial Cycles from the Valle Grande, Jemez Mountains, Northern New Mexico ▪ A 200 kyr Pleistocene Lacustrine Record from the Valles Caldera Insight: From Environmental Magnetism and Paleomagnetism
Core Holes At Valles Caldera - Redondo Geothermal Area (Goff, Et Al., 1986)	Core Holes	1984	1984	▪ Initial results from VC-1, First Continental Scientific Drilling Program Core Hole in Valles Caldera, New Mexico ▪ Core Lithology, Valles Caldera No. 1, New Mexico ▪ Selected Data from Continental Scientific Drilling Core Holes VC-1 and VC-2A, Valles Caldera, New Mexico ▪ Altered Tectonic and Hydrothermal Breccias in Corehole VC-1, Valles Caldera, New Mexico ▪ Lithologic Descriptions and Temperature Profiles of Five Wells in the Southwestern Valles Caldera Region, New Mexico ▪ Drilling Report- First CSDP (Continental Scientific Drilling Program) Thermal Regimes Core Hole Project at Valles Caldera, New Mexico (VC-1)
Density Log At Valles Caldera - Redondo Geothermal Area (Rowley, Et Al., 1987)	Density Log	1984	1984	▪ Drilling Report- First CSDP (Continental Scientific Drilling Program) Thermal Regimes Core Hole Project at Valles Caldera, New Mexico (VC-1) ▪ Core Lithology, Valles Caldera No. 1, New Mexico
Density Log At Valles Caldera - Redondo Geothermal Area (Wilt & Haar, 1986)	Density Log		1986	▪ A Geological And Geophysical Appraisal Of The Baca Geothermal Field, Valles Caldera, New Mexico
Direct-Current Resistivity Survey At Valles Caldera - Redondo Geothermal Area (Wilt & Haar, 1986)	Direct-Current Resistivity Survey		1986	▪ A Geological And Geophysical Appraisal Of The Baca Geothermal Field, Valles Caldera, New Mexico

Page	Technique	Activity Start Date	Activity End Date	Reference Material
Exploratory Well At Valles Caldera - Redondo Geothermal Area (Nielson & Hulen, 1984)	Exploratory Well	1959	1983	▪ Internal Geology and Evolution of the Redondo Dome, Valles Caldera, New Mexico
Field Mapping At Valles Caldera - Redondo Geothermal Area (Bailey, Et Al., 1969)	Field Mapping		1969	▪ Stratigraphic Nomenclature of Volcanic Rocks in the Jemez Mountains, New Mexico
Field Mapping At Valles Caldera - Redondo Geothermal Area (Goff, Et Al., 2011)	Field Mapping	1971	2011	▪ Geologic Map of the Valles Caldera
Fluid Inclusion Analysis At Valles Caldera - Redondo Geothermal Area (Sasada, 1988)	Fluid Inclusion Analysis		1988	▪ Microthermometry of Fluid Inclusions from the VC-1 Core Hole in Valles Caldera, New Mexico
Gamma Log At Valles Caldera - Redondo Geothermal Area (Rowley, Et Al., 1987)	Gamma Log	1984	1984	▪ Drilling Report- First CSDP (Continental Scientific Drilling Program) Thermal Regimes Core Hole Project at Valles Caldera, New Mexico (VC-1) ▪ Core Lithology, Valles Caldera No. 1, New Mexico
Ground Gravity Survey At Valles Caldera - Redondo Geothermal Area (Wilt & Haar, 1986)	Ground Gravity Survey		1986	▪ A Geological And Geophysical Appraisal Of The Baca Geothermal Field, Valles Caldera, New Mexico
Isotopic Analysis At Valles Caldera - Redondo Geothermal Area (Goff, Et Al., 1982)	Isotopic Analysis-Fluid		1982	▪ Geochemical Data for 95 Thermal and Nonthermal Waters of the Valles Caldera - Southern Jemez Mountains Region, New Mexico
Isotopic Analysis At Valles Caldera - Redondo Geothermal Area (Janik & Goff, 2002)	Isotopic Analysis-Fluid	1982	2002	▪ Gas Geochemistry Of The Valles Caldera Region, New Mexico And Comparisons With Gases At Yellowstone, Long Valley And Other Geothermal Systems
Isotopic Analysis At Valles Caldera - Redondo Geothermal Area (Phillips, 2004)	Isotopic Analysis-Rock		2004	▪ Collapse and Resurgence of the Valles Caldera, Jemez Mtns, NM- 40Ar/39Ar Ages of Megabreccia Blocks and Age Constraints on Timing and Duration of Resurgence
Isotopic Analysis At Valles Caldera - Redondo Geothermal Area (Phillips, Et Al., 1984)	Isotopic Analysis-Fluid		1984	▪ 36Cl as a tracer in geothermal systems- Example from Valles Caldera, New Mexico
Isotopic Analysis At Valles Caldera - Redondo Geothermal Area (White, 1986)	Isotopic Analysis-Fluid		1986	▪ Chemical and isotopic characteristics of fluids within the Baca Geothermal Reservoir, Valles Caldera, New Mexico
Isotopic Analysis At Valles Caldera - Redondo Geothermal Area (White, Et Al., 1992)	Isotopic Analysis-Fluid		1992	▪ Mass Transfer Constraints On The Chemical Evolution Of An Active Hydrothermal System, Valles Caldera, New Mexico
			1989	

Page	Technique	Activity Start Date	Activity End Date	Reference Material
Isotopic Analysis- Fluid At Valles Caldera - Redondo Geothermal Area (Musgrave, Et Al., 1989)	Isotopic Analysis-Fluid			▪ Selected Data from Continental Scientific Drilling Core Holes VC-1 and VC-2A, Valles Caldera, New Mexico
Magnetotellurics At Valles Caldera - Redondo Geothermal Area (Wilt & Haar, 1986)	Magnetotellurics		1986	▪ A Geological And Geophysical Appraisal Of The Baca Geothermal Field, Valles Caldera, New Mexico
Modeling-Computer Simulations At Valles Caldera - Redondo Geothermal Area (Roberts, Et Al., 1995)	Modeling-Computer Simulations	1987	1995	▪ A Shallow Attenuating Anomaly Inside The Ring Fracture Of The Valles Caldera, New Mexico
Modeling-Computer Simulations At Valles Caldera - Redondo Geothermal Area (Wilt & Haar, 1986)	Modeling-Computer Simulations		1986	▪ A Geological And Geophysical Appraisal Of The Baca Geothermal Field, Valles Caldera, New Mexico
Neutron Log At Valles Caldera - Redondo Geothermal Area (Rowley, Et Al., 1987)	Neutron Log	1984	1984	▪ Drilling Report- First CSDP (Continental Scientific Drilling Program) Thermal Regimes Core Hole Project at Valles Caldera, New Mexico (VC-1) ▪ Core Lithology, Valles Caldera No. 1, New Mexico
Pressure Temperature Log At Valles Caldera - Redondo Geothermal Area (Rowley, Et Al., 1987)	Pressure Temperature Log	1984	1984	▪ Drilling Report- First CSDP (Continental Scientific Drilling Program) Thermal Regimes Core Hole Project at Valles Caldera, New Mexico (VC-1) ▪ Core Lithology, Valles Caldera No. 1, New Mexico
Reflection Survey At Valles Caldera - Redondo Geothermal Area (Musgrave, Et Al., 1989)	Reflection Survey		1989	▪ Selected Data from Continental Scientific Drilling Core Holes VC-1 and VC-2A, Valles Caldera, New Mexico
Resistivity Log At Valles Caldera - Redondo Geothermal Area (Rowley, Et Al., 1987)	Single-Well and Cross-Well Resistivity	1984	1984	▪ Drilling Report- First CSDP (Continental Scientific Drilling Program) Thermal Regimes Core Hole Project at Valles Caldera, New Mexico (VC-1) ▪ Core Lithology, Valles Caldera No. 1, New Mexico
Self Potential At Valles Caldera - Redondo Geothermal Area (Rowley, Et Al., 1987)	Self Potential	1984	1984	▪ Drilling Report- First CSDP (Continental Scientific Drilling Program) Thermal Regimes Core Hole Project at Valles Caldera, New Mexico (VC-1) ▪ Core Lithology, Valles Caldera No. 1, New Mexico
Teleseismic-Seismic Monitoring At Valles Caldera - Redondo Geothermal Area (Nishimura, Et Al., 1997)	Teleseismic-Seismic Monitoring	1993	1993	▪ Heterogeneous Structure Around the Jemez Volcanic Field, New Mexico, USA, as Inferred from the Envelope Inversion of Active-Experiment Seismic Data
Teleseismic-Seismic Monitoring At Valles Caldera - Redondo Geothermal Area (Roberts, Et Al., 1991)	Teleseismic-Seismic Monitoring	1987	1987	▪ A Low-Velocity Zone in the Basement Beneath the Valles Caldera, New Mexico
Teleseismic-Seismic Monitoring At Valles Caldera - Redondo Geothermal Area (Roberts, Et Al., 1995)	Teleseismic-Seismic Monitoring	1987	1987	▪ A Shallow Attenuating Anomaly Inside The Ring Fracture Of The Valles Caldera, New Mexico

Page	Technique	Activity Start Date	Activity End Date	Reference Material
Teleseismic-Seismic Monitoring At Valles Caldera - Redondo Geothermal Area (Steck, Et Al., 1998)	Teleseismic-Seismic Monitoring	1993	1994	▪ Crust and Upper Mantle P Wave Velocity Structure Beneath Valles Caldera, New Mexico- Results from the Jemez Teleseismic Tomography Experiment
Water Sampling At Valles Caldera - Redondo Area (Rao, Et Al., 1996)	Water Sampling	1996	1996	▪ Sources Of Chloride In Hydrothermal Fluids From The Valles Caldera, New Mexico- A 36Cl Study
Water Sampling At Valles Caldera - Redondo Geothermal Area (Goff, Et Al., 1982)	Water Sampling		1982	▪ Geochemical Data for 95 Thermal and Nonthermal Waters of the Valles Caldera - Southern Jemez Mountains Region, New Mexico
Water-Gas Samples At Valles Caldera - Redondo Geothermal Area (Janik & Goff, 2002)	Water-Gas Samples	1982	1998	▪ Gas Geochemistry Of The Valles Caldera Region, New Mexico And Comparisons With Gases At Yellowstone, Long Valley And Other Geothermal Systems
Well Log Data At Valles Caldera - Redondo Geothermal Area (Shevenell, Et Al., 1988)	Well Log Data		1988	▪ Lithologic Descriptions and Temperature Profiles of Five Wells in the Southwestern Valles Caldera Region, New Mexico

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61. ↑ New K-Ar Dates from Basalts and the Evolution of the Southern Rio Grande Rift
62. ↑ [62.0] [62.1] Rio Grande Rift- an Overview
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67. ↑ Geologic map of the Sulphur Springs Area, Valles Caldera Geothermal System, New Mexico
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72. ↑ [72.0] [72.1] Chemical and isotopic characteristics of fluids within the Baca Geothermal Reservoir, Valles Caldera, New Mexico
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List of existing Geothermal Resource Areas.

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