Hydrothermal Activity and Travertine Deposits in Valles Caldera

Paul Withers

Valles Caldera is the youngest major episode (1.0 – 0.13 Mya) of the Jemez volcanic field (>13 – 0.13 Mya.) The high heat content and subsurface temperatures associated with shallow, crystallizing magma in this pluton cause convection of hot ground waters in overlying rock. This water leaches minerals from subsurface rocks and forms hot springs and fumaroles. Heat flow within Valles Caldera is approximately 4 times greater than a typical continental crustal value of 80 mWm^{-2}.

Analysis of water, surface geology, and 40 drill holes lead to a model for the Valles Caldera hydrothermal system [fig]. Some fluids escape in acid springs and mud pits (Sulphur Springs) within the caldera. Some flow laterally southwest from the caldera, dissolving Palaeozoic limestone, until they escape in hot springs in the Soda Dam area.

The mineral-laden hot springs precipitate mineral deposits as they cool, specifically travertine. Travertine is a freshwater, calcium carbonate deposit. We saw lots of travertine, or tufa if you prefer, in Havasupai Canyon. Bacteria, via their effects on the partial pressue of CO_2, can be important in its deposition.

One such deposit is Soda Dam, a 100 m long, 25 m wide formation that extends across the narrow San Diego Canyon of the Jemez River and has an estimated volume of 15,000 m^3 [figs]. Travertine was being deposited on Soda Dam until the NM Highways Dept blasted a notch in it around 1970. Now it is slowly disintegrating. Approximately 20 hot springs and thermal seeps presently occur in the Soda Dam area. The Main Spring occurs in a dynamited notch at the northwest end of Soda Dam on the west side of NM State Highway 4 where it issues from a shear zone between Precambrian granite-gneiss and vertically standing Palaeozoic rock. Its temperature remained constant at 47 – 48 ^oC during 1973 – 1987. Total discharge in the Soda Dam system has averaged ~ 1000 litres/min over the past century. Chemically, the Soda Dam hot springs contain 1500 mg/kg HCO_3, 1500 mg/kg Cl, 340 mg/kg Ca, and 25 mg/kg Mg out of a total dissolved solids content of 4600 mg/kg. The high Ca and Mg values indicate the presence of dissolved Palaeozoic limestone.

Thermal waters issue from various points along the base of Soda Dam, from sheared rock on the west side of the highway, and from several mounds of travertine within and adjacent to the river just downstream. A warm spring (Hidden Warm Spring, 32 ^oC) flows from a marshy flat 100 m upstream on the east side of the river. A very picturesque spring issues from a 1 m high mound of travertine inside a cave at the southeast end of Soda Dam (Grotto Spring, 32 ^oC.) All springs presently deposit travertine.

Three nearby deposits of travertine (A, B, C in a figure) are substantially older than Soda Dam and provide constraints on the evolution of the hydrothermal system. A has a volume of 13 million m^3 (1000 times larger than Soda Dam), B has a volume of 3000 m^3 (5 times smaller than Soda Dam) and C is smaller than 30 m^3. The range of ages found in samples from A is ~ 0.5 – 1.0 My old (^{234}U-^{238}U), in samples from B and C is ~ 50 – 110 ky old (^{230}Th-^{234}U), and Soda Dam samples range from 0 – 5 ky old (^{230}Th-^{234}U). C and O isotope measurements suggest that the maximum temperature of the Soda Dam hot spring system has never been much greater than the current temperature and probably no greater than 60 ^{o}C. A is located at an elevation ~ 100m above Soda Dam and B/C are ~ 20m above Soda Dam.

Three constraints follow from age determinations and stable isotope data:
1) The hydrothermal system was established relatively soon after formation of the Valles Caldera and its lateral outflow has operated for at least 1.0 My.
2) The deep circulation of hydrothermal fluids and buffering capacity of Palaeozoic limestone have caused the isotopic composition of the hot springs water to vary negligibly during that time.
3) The temperature of the Soda Dam hot springs has probably never been greater than 60 ^{o}C.

We can suggest the following evolution of the Valles Caldera hydrothermal system, noting that we appear to have episodic travertine deposition despite constant plumbing. Travertine deposition in A (large volume, high elevation) began soon after the formation of Valles Caldera 1.1 Mya. Lacustrine deposits in Valles Caldera suggest that a lake existed within Valles Caldera from this time until 0.5 Mya, and then escaped via a breach in the southwest wall of the caldera by 0.4 Mya, cutting upper San Diego Canyon and lowering the water table. The loss of hydraulic head caused deposition of travertine to cease. 0.1 Mya the last rhyolite eruption in Valles Caldera partially filled the breach in the caldera and reactivated the hot springs for a short time, forming B and C (small volume, slightly elevated above Soda Dam.) A recent thermal pulse (for which the evidence is unconvincing) then initiates the current depositional phase.

If you want to be argumentative:
Why are these episodes correlated with climatic events such as glaciation?
Why are B and C, deposited over a period of 50 ky, so much smaller than Soda Dam?
Are these all the travertine deposits that were ever formed due to this caldera?
Is there really a thermal pulse causing Soda Dam?

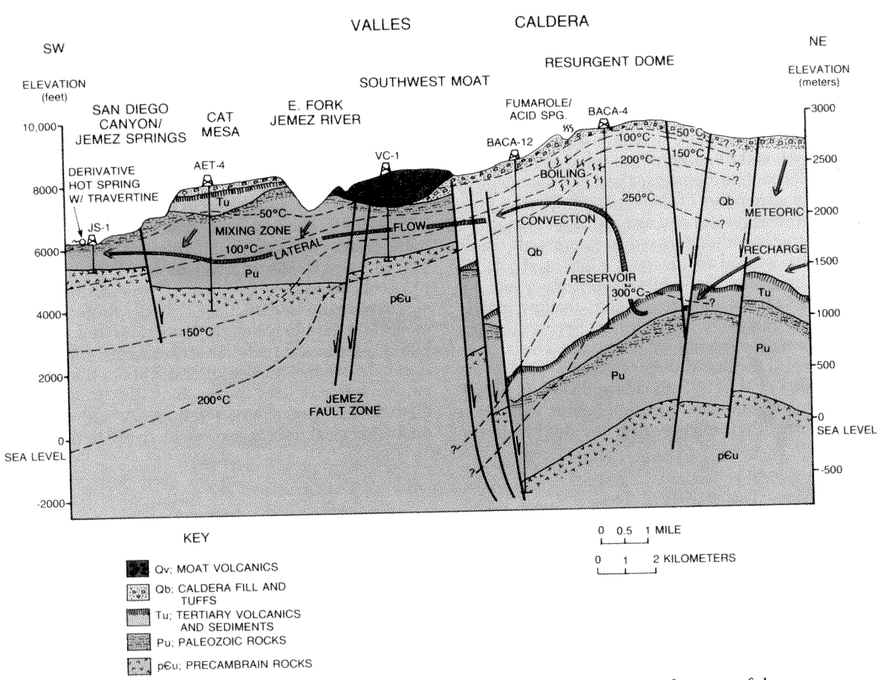
The Valles/Toldedo Caldera complex, Jemez Volcanic Field, New Mexico, 1990, Heiken et al, Ann. Rev. Earth Planet. Sci, **18**, 27-53.

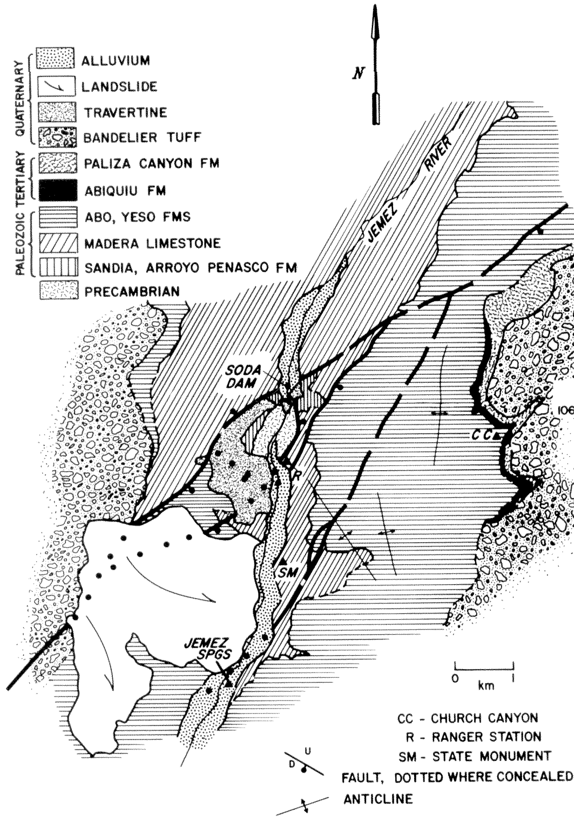
Evolution of a mineralized geothermal system, Valles Caldera, New Mexico, December 1994, Goff and Gardner, Economic Geology, **89**, (8), 1803-1832.

Travertine deposits of Soda Dam, New Mexico, and their implications for the age and evolution of the Valles Caldera hydrothermal system, August 1987, Goff and Shevenell, GSA Bull., **99**, (2) 292-302.

Tufa Dams of Havasupai Canyon, Ingrid Daubar, PTYS594 Field Trip Handout, September 1999.

Event	Age
1. Eruption of Tshirege Member, Bandelier Tuff; formation of Valles caldera	1.13 Ma
2. Uplift of resurgent dome; eruption of early rhyolites	~1.0 Ma
3. Eruption of northern arc of postcaldera moat rhyolites	1.04–0.45 Ma
4. Initial formation of Valles hydrothermal system and voluminous travertine deposite at Soda Dam	~1.0 Ma 1.0 Ma >0.97 Ma
5. Initial formation of Sulphur Springs part of hydrothermal system	≤1.09 Ma
6. Formation of Sulphur Springs molybdenite deposit	≥0.66 Ma
7. Breaching of SW caldera wall; deep erosion of SW caldera moat zone	~0.5 Ma
8. Cessation of voluminous travertine deposition at Soda Dam	~0.5 Ma 0.48 Ma
9. Initial formation of vapor zone above liquid-dominated hydrothermal system	≤0.5 Ma
10. Eruption of southern cluster of postcaldera moat rhyolites	0.49–0.13 Ma
11. Partial filling of SW caldera breach	≤0.65 Ma <0.5 Ma
12. Formation of hydrothermal calcite veins along Jemez fault zone beneath SW caldera moat	>400–95 Ka
13. Second period of travertine deposition at Soda Dam	110–60 Ka
14. Last pulse of thermal activity at Fenton Hill (SW caldera margin)	40–10 Ka
15. Final period of travertine deposition at Soda Dam	7 Ka to present





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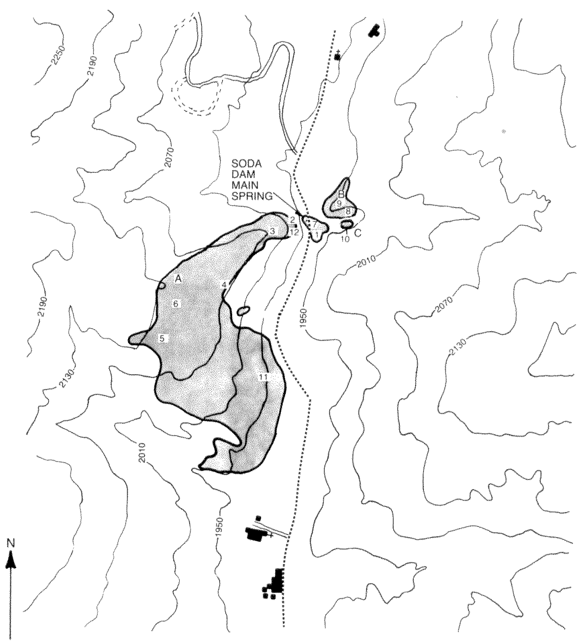

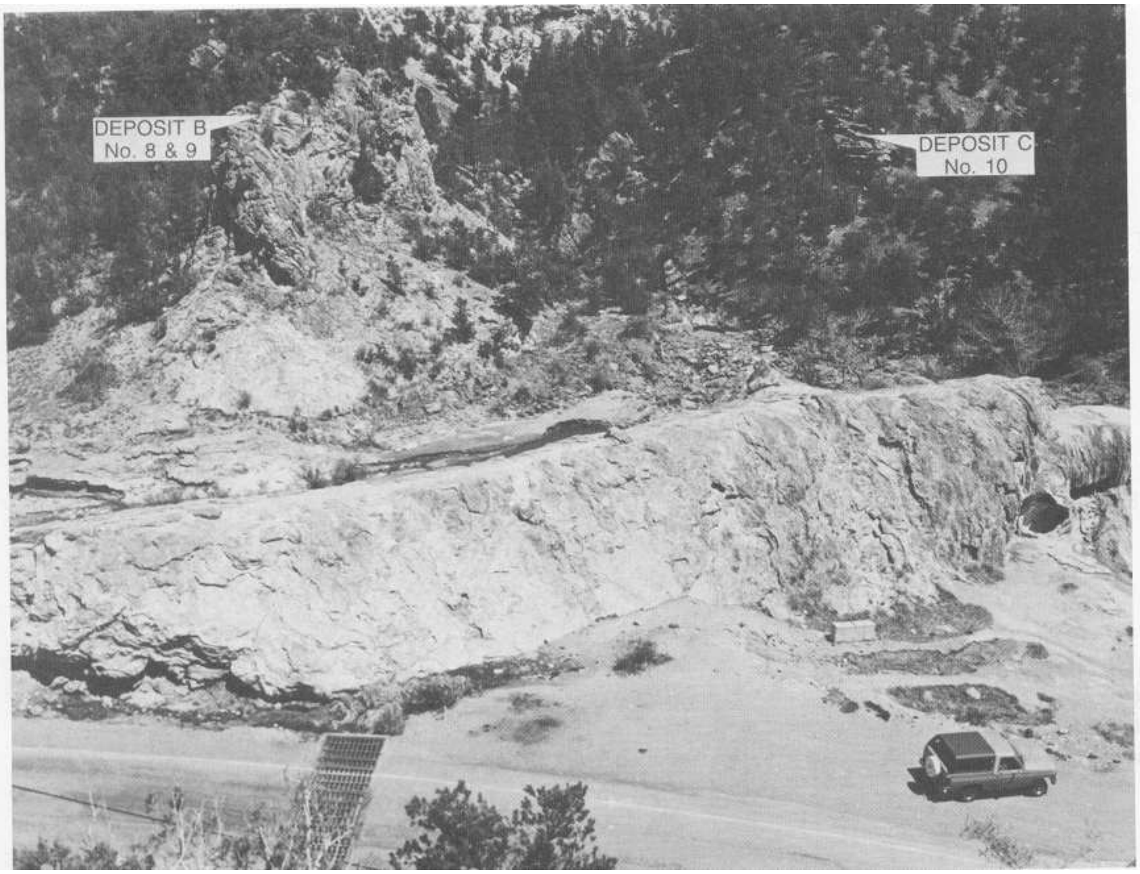
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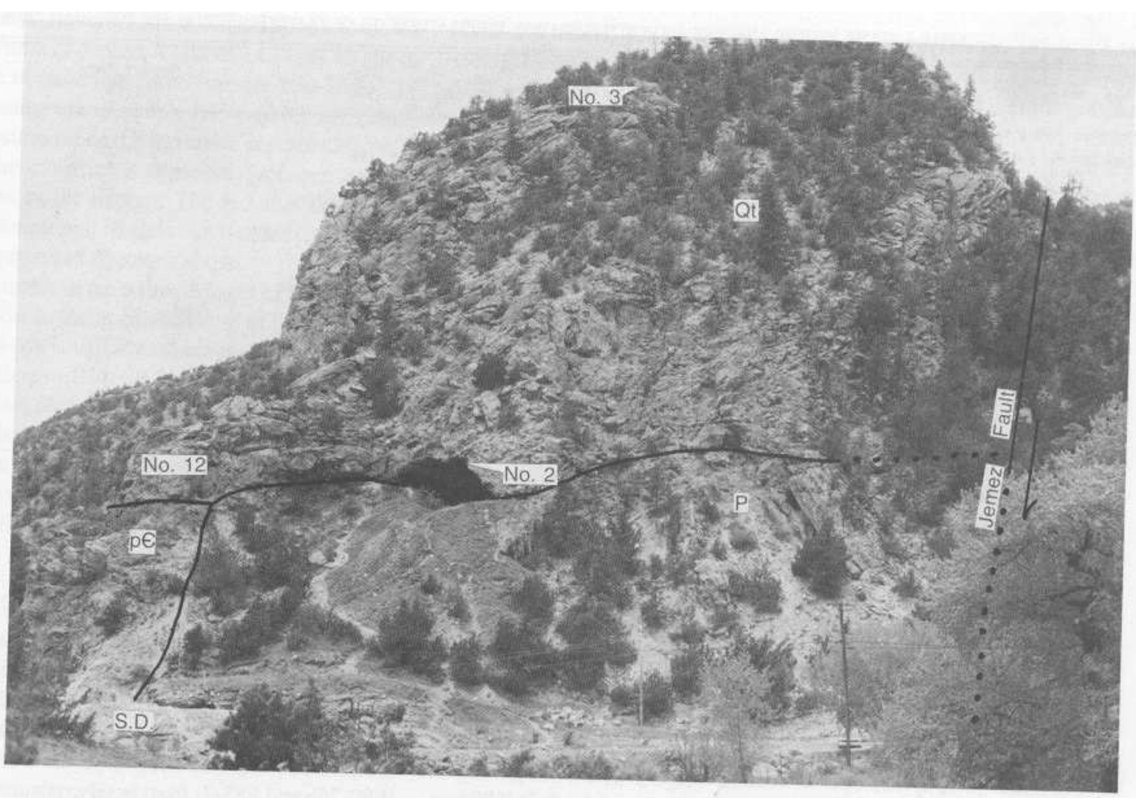
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A review of tufa and travertine deposits of the world, Ford TD, Pedley HM, EARTH-SCIENCE REVIEWS, 41: (3-4) 117-175 NOV 1996

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EVOLUTION OF A MINERALIZED GEOTHERMAL SYSTEM, VALLES CALDERA, NEW-MEXICO, GOFF F, GARDNER JN, ECONOMIC GEOLOGY AND THE BULLETIN OF THE SOCIETY OF ECONOMIC GEOLOGISTS, 89: (8) 1803-1832 DEC 1994

THE VALLES TOLEDO CALDERA COMPLEX, JEMEZ VOLCANIC FIELD, NEW-MEXICO, HEIKEN G, GOFF F, GARDNER JN, BALDRIDGE WS, HULEN JB, NIELSON DL, VANIMAN D, ANNUAL REVIEW OF EARTH AND PLANETARY SCIENCES, 18: 27-53 1990

VALLES CALDERA REGION, NEW-MEXICO, AND THE EMERGING CONTINENTAL SCIENTIFIC DRILLING PROGRAM,GOFF F, GARDNER JN, JOURNAL OF GEOPHYSICAL RESEARCH-SOLID EARTH AND PLANETS, 93: (B6) 5997-5999 JUN 10 1988 and following articles

SPECIAL SECTION ON THE VALLES CALDERA AND JEMEZ MOUNTAINS VOLCANIC FIELD – INTRODUCTION HEIKEN G JOURNAL OF GEOPHYSICAL RESEARCH-SOLID EARTH AND PLANETS 91: (B2) 1741-1741 FEB 10 1986

VALLES CALDERA GEOTHERMAL SYSTEMS, NEW-MEXICO, USA GOFF F, GRIGSBY CO JOURNAL OF HYDROLOGY 56: (1-2) 119-136 1982

GEOLOGIC CHARACTERISTICS OF VALLES CALDERA GEOTHERMAL SYSTEM IN NEW-MEXICO DONDANVILLE RF AAPG BULLETIN-AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS 63: (5) 825-826 1979

TRAVERTINE DEPOSITS OF SODA DAM, NEW-MEXICO, AND THEIR IMPLICATIONS FOR THE AGE AND EVOLUTION OF THE VALLES CALDERA HYDROTHERMAL SYSTEM GOFF F, SHEVENELL L GEOLOGICAL SOCIETY OF AMERICA BULLETIN 99: (2) 292-302 AUG 1987

J Hydro, Goff and Grigsby
Geothermal paper. 3 types of water in system, Why area is geothermally active. Geologic setting.

J Sed Pet
Chafetz and Folk

Travertines. Organic and inorganic. Controlling factors. Morphologies. Goes into detailed petrography not gross shapes. Lots of bacteria stuff. Formation of travertine and role of organics. Different formations – waterfall, lakefill, terraces. Soda dam details.

Econ Geol
Goff and Gardner
Geothermal system at ValCal. Why area is geothermal. Good geol map showing soda dam, fig 2a. Discusses the hydrothermal fluids. fig 10 how this specific geothermal system works. Evolution of hydrothermal system. Timeline in table 6. Fig 13 gives pic of evolution. Great base for talk. Summary.

ESRev
Ford and Pedley
Travertine around the world. Some descriptions of rock type. p157 has Soda Dam mention.

GSABull
Goff and Shevenell
Excellent – Travertine at Soda Dam and implications for ValCal evolution. Lots of good maps and figures. Much on Soda dam itself. Other nearby deposits. Constraints from travertine data and discussions

JGR1986 p1775 hydrothermal stuff p1847 soda dam

JGR 1988 nothing

AREPS overview of hydrothermal system

Econ Geol.
Calderas – collapse features resulting from most explosive volcanic eruptions in the terrestrial record. They are the surface expressions of shallow, subsurface plutons that can exceed 10^4 km3 in volume. High heat content and subsurface temperatures associated with shallow, crystallizing magma cause convection of hot ground waters in overlying rock. Water forms hot springs and fumaroles, leaching materials from subsurface rocks. Caldera heat flow ~ 4x usual 80 mWm-2

VC is the youngest major episode (1– 0.13 Mya) of the Jemez volcanic field (>13 – 0.13 Mya) Has been heavily drilled (40 wells) and studied. Refer to JHydro for idea of water properties. TBCont

JHydro
Springs near Soda Dam are intermediate in isotopic composition between rainwater and magmatic water. T=48C, pH=6.4, 60l/min flow rate, Ca concentration of 340 mg/litre, HCO3 1514, Cl 1503 Have dissolved lots of Palaeozoic limestone during flow to the springs.

Econ Geol cont.
fig 10 gives model of system. Analysis of water, surface geology, and 40 wells constrains model. Rainwater recharges the hydrothermal system, which equilibrates at depths of 2 to 3 km and temperatures approaching 300C in caldera fill tuffs and precaldera sedimentary and volcanic rocks. Thermal waters rise convectively to depths of roughly 500 – 600 m before flowing laterally toward the SW caldera wall. A vapour zone that contains H_2O, CO_2, H_2S, and other volatiles has formed above a liquid dominated zone whose top is at a temperature of 200C. Acid springs, mud pots, and fumaroles occur in a surface condensation zone only a few m thick. The lateral flow system (hydrothermal outflow plume) crosses the SW caldera wall above Precambrian basement though the Jemez fault zone and semipermiable Palaeozoic strata. Mixing of reservoir water and other ground waters occurs along the lateral flow path to form derivative fluids that issue as hot springs or that flow in subsurface aquifers SW of the caldera.

Table 6 for timeline. Then summarizes Goff and Shev. Have a look at the conclusions section.

GSABull
fig 3 map of soda dam area. Also get figs of travertine deposits in case we don't go there. Also fig2 geol map of soda dam
U/U and U/Th ages.
Soda Dam is a calcium carbonate travertine deposit built by presently active hot springs originating from the geothermal system in Valles Caldera. Hydrothermal features at Soda Dam discharge along the Jemez River in San Diego Canyon.
Hydrothermal system is nearly old as caldera itself. Basic hydrology virtually unchanged during this time. Soda Dam is the most recent travertine deposit of a long-lived hot-spring system that was once of great areal extent. The older travertines record the evolution of the Valles Caldera hydrothermal system. Approximately 20 hot springs and thermal seeps presently occur in the Soda Dam area. The Main Spring occurs in a dynamited notch at the northwest end of Soda Dam on the west side of NM State Highway 4 where it issues from a shear zone between Precambrian granite-gneiss and vertically standing Palaeozoic rock. Constant T=47-48C over 1973-1987. Discharge in Soda Dam system = 1000 l/min (ignore JHydro value)at present (and past century).

Chemically, the Soda Dam hot springs are Na-HCO_3-Cl waters containing 1500mg/kg HCO_3, 1500 Cl and 4600 total dissolved solids. 340 Ca and 25 Mg indicates that thermal fluids dissolve Palaeozoic limestone during underground transit from the Caldera. Mixture of hydrothermal fluid and dilute ground water during passage.

Soda dam = impressive formation of travertine 100m long, 25m wide that extends across the narrow gorge of the Jemez River and has an estimated volume of 1.5e4 m3. The dam has grown southeastward into the gorge from an upwelling source of thermal water that rises from the northeastward-trending Jemez fault zone at the northwestward end of teh deposit. The Jemez River cascades through a poorly formed tunnel of travertine underlain by Precambrian rock on the sotheast side of the dam.

Lenses of river gravel up to 0.5 m thick are incorporated into the lower part of the travertine and are exposed on the upstream side of the dam. Cobbles in these gravels are primarily rounded fragments of Bandelier Tuff, pre-caldera andesites and basalts, Permian sandstone, and Pennslyvanian limestone. All of these lithologies line the walls of San Diego Canyon for several km upstream. Thermal waters issue from various points along the base of Soda Dam, from sheared rock on the west side of the highway, and from several mounds of travertine within and adjacent to the river just downstream. A warm spring (Hidden Warm Spring, 32C) flows from a marshy flat 100m upstream on the east side of the river. A very picturesque spring issues from a 1m high mound of travertine inside a cave at the southeast end of Soda Dam (Grotto Spring, 32C).All springs presently deposit travertine.

Until about 20 years ago, thermal waters flowed from a central fissure running along the axis of Soda Dam, and State Highway 4 was ramped over the northwestern end of the formation. To remove this 6m hump in the road, the NM Highway Dept blasted a notch in the dam, forever altering the plumbing of Soda Dam. No hot springs discharge from the crest of the formation and, without fresh deposits of calcite, Soda Dam is slowly disintegrating.

Three nearby deposits of travertine (A, B, and C) are substantially older than Soda Dam. A has a volume of 1.3e7 m3 (3 orders of mag > SD), B 3e3 (5x smaller) and C <30 m3. A ~ 0.5 – 1.0 My old (234U-238U), B/C ~ 50 – 110 ky old (230Th-234U), SD samples range from 0 – 5 Ky old (230Th-234U). C and O isotope measurements suggest that the maximum temperature of the Soda Dam hot spring system has never been much greater than the current temperature and probably no greater than 60C.
A 100m above SD, B/C 20m above SD.

Three constraints:
Hydrothermal system established relatively soon after formation of the VC and hydrothermal outflow plume has operated for at least 1.0 My.
Deep circulation and buffering capacity of Pal. limestone have caused the isotopic composition of the hot springs water to vary negligibly during that time.
T probably never greater than 60C.

Episodic travertine deposition despite constant plumbing. Consistent with lake deposits in VC implying lake from 1.1 to 0.5 Mya, then breached in SW wall before 0.4 Mya, caldera lakes drained and water table drops as upper San Diego Canyon is cut. Loss of hydraulic head causes deposition of travertine to cease. 110 kya, rhyolite eruption partially fills breach in caldera, reactivates hot springs. Shaky evidence for thermal pulse then restarts system in past 10ky to form Soda Dam. Also intriguing correlation with climatic events...especially glaciation. Seems likely that outflow rates were once larger than present, hard to quantify, consistent with cooling of caldera.

Fig 10 and table 6 from econ geol, figs 2, 3 from GSA
refs econ geol, gsa, areps