U.S. Department of the Interior
U.S. Geological Survey

Open-File Report 00-037, Version 1.0
2000
Sheet 1

Abrupt Physical and Chemical Changes During 1992-1999,

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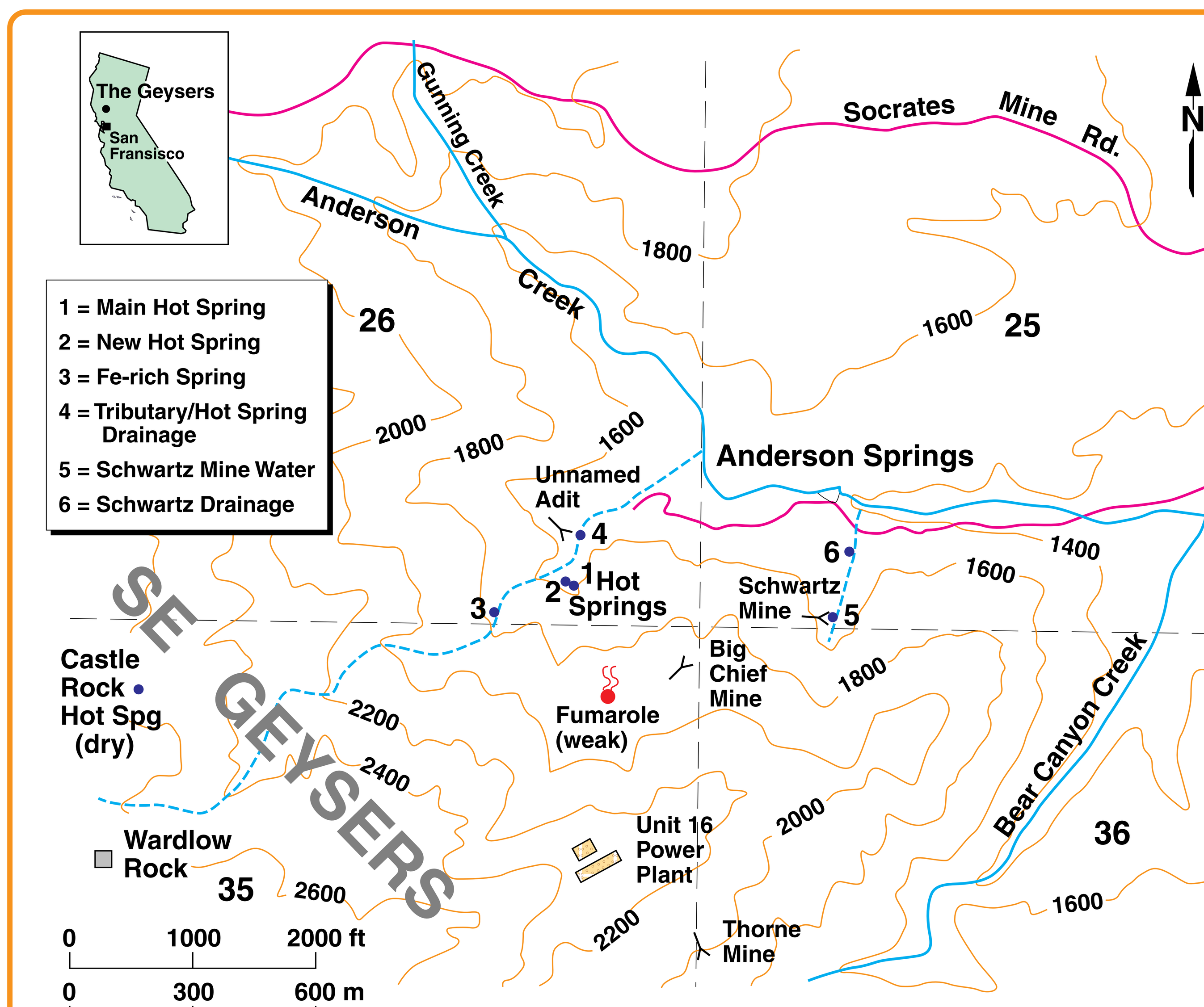
ABSTRACT

Anderson Springs (AS), located in the southwestern part of Lake County, CA, was first developed in the late 1800s as a health resort, which was active until the 1930s. Cinnabar was extracted from a few small mines (e.g. Big Chief, Thorne) in the bluffs south of the resort area, mostly from the 1870s to the 1940s. About 1260 flasks of Hg were produced from these mines. By the early 1970s, the higher ridges west and south of AS became part of the southeast sector of the greater Geysers geothermal field. Today, several electric power plants are built on these ridges, producing energy from a vapor-dominated 240°C reservoir.

Only the main hot spring at AS has maintained a recognizable identity since the 1930s. The hot spring is actually a cluster of seeps and springs (total discharge ~6 L/min) that issue from a small fault cutting Franciscan metagraywacke in a ravine SW of Anderson Creek (AC). Published and unpublished records show that the maximum temperature (Tm) of this cluster fell gradually from 63°C in 1889 to 48°C in 1992. However, Tm of the cluster climbed to 77°C in 1995 and neared boiling (98°C) in 1998. A new cluster of boiling vents and small fumaroles formed in 1998 (Tm = 99.3°C), about 30 m north of the old spring cluster. In 8/99 the new hot spring cluster was about 25 m in length and had a total discharge of about 0.5 L/min. Several evergreen trees on steep slopes immediately west of these vents apparently were killed by the new activity. Tm of the old spring cluster decreased to 78°C by 8/99, but measured 85°C in 9/99.

Thermal waters at AS are largely suface waters with added condensed steam and gases from the subjacent geothermal reservoir. The volume of steam condensate is very small compared to the volume of meteoric water. Compared to gas samples from Southeast Geysers wells, AS gases are higher in CO_2 and lower in H_2S and NH_3. The hot spring waters are low in ions of Cl and B, but are relatively high in HCO_3, SO_4 and NH_4. The waters have stable-isotope compositions that plot near the global meteoric water line, and contain a small amount of anthropogenic tritium (4.6 TU in 1991; 2.5 TU in 1999; pre-bomb background = 3 TU). Geochemical data through time reveal few consistent changes, but there were apparent maxima in the concentrations of SO_4, Ca, Fe, and Mn in 1991 to 1992, before the cluster became hotter. The black-to-gray deposits from the new spring cluster are rich in pyrite and contain anomalous metals. Fine silt and colloids filtered from a water sample in 1998 contained high metal concentrations.

As early as 1988, about 1/2 mile east of the main hot spring, an old mine adit (Schwartz Mine) in a drainage south of AC began to discharge mineralized water intermittently. In 7/98, a sudden discharge of gray, silty water flowed into AC. In 12/98, Tm of the adit water was 22°C. Flow from the adit reportedly stopped during early summer of 1999 but resumed in 8/99 (10 L/min). Compositionally, the adit water is similar to waters at AS hot spring and resembles tepid spring waters (17 to 23°C) that once discharged in the ravines surrounding the former AS resort.



Topographic map of Anderson Springs area; contours in feet.

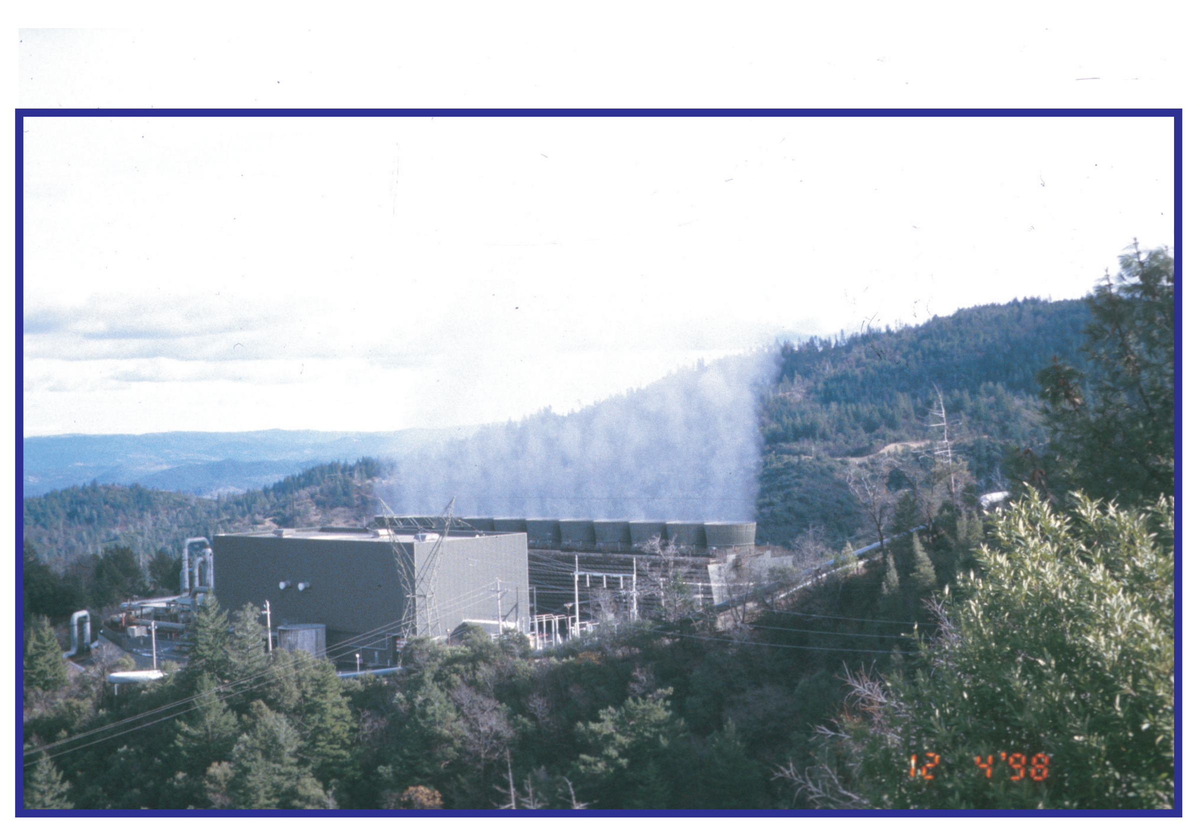


Photo looking SE of power plant (Unit 16), SE Geyers geothermal field.

Photo of gas sampling at New Hot Spring.

Anderson Hot Springs/Drainage

(values in ppm)

Map No.	Site	Date	Temp. (°C)	pH (lab)	SiO_2	Ca	Mg	Fe	Mn	Hg	NH_4	HCO_3	SO_4	Cl	B
1	Main Spg	9/98	68	7.13	73	76	32	0.70	4.83	0.0002	20.0	332	228	2.0	0.45
1	Main Spg	12/98	50	6.94	51	52	23	0.96	4.33	<0.0001	11.1	224	150	2.8	0.33
1	Main Spg	8/99	70	7.13	75	72	29	0.38	3.83	<0.00005	23.2	348	206	2.0	0.52
2	New Spg	9/98	90	7.58	66	30	11	0.18	0.82	0.0009	28.5	101	165	1.8	0.43
2	New Spg	8/99	98	8.36	75	17	3.9	0.02	0.29	0.00055	24.9	37	179	1.5	0.52
3	Fe-rich Spg	8/99	21	6.27	39	83	51	1.41	3.54	<0.00005	0.54	32	445	2.1	0.05
4	Drainage	8/99	21	5.90	41	40	25	7.12	1.78	<0.00005	2.13	0.8	261	2.4	0.21
--	Cold Spgs[a]	----	12	6.4	40	5	3	≤0.2	≤0.2	-----	----	39	1	4.2	≤0.15

[a]Average of four analyses from Thompson et al. (1981).

The thermal waters display some chemical similarities (e.g., high NH_4 and SO_4 but low Cl). They are different from typical cold spring waters in the area. See Janik et al. (1999) for complete analytical data.

Schwartz Mine Adit and Drainage

(values in ppm)

Map No.	Site	Date	Temp. (°C)	pH (lab)	SiO_2	Ca	Mg	Fe	Mn	Hg	NH_4	HCO_3	SO_4	Cl	B
5	Adit	12/98	22	6.15	69	108	54	8.2	4.8	<0.0001	10.2	62	508	1.9	0.09
5	Adit	8/99	19	6.67	69	128	60	6.5	4.5	<0.00005	14.1	175	520	1.6	0.10
6	Drainage	8/99	12	6.54	44	92	45	0.02	2.9	<0.00005	0.8	7.4	443	1.7	0.16
--	"Sulphur"	1889	17	----	42	185	117	3.9	---	----	----	455	413	11	---
--	"Belmer"	1889	23	----	72	132	43	1.0	---	----	----	175	617	6.7	tr
--	"Sour"	1889	18	----	68	10	17	6.7	1.1	----	0.7	----	220	0.8	tr

Orange precipitates of Fe-Mn hydroxides, silica and Ca-Mg carbonates and sulfates form as water flows from the adit down the natural drainage, consistent with the chemical data. Adit water is chemically similar to water from the Fe-rich Spring (see map site 3), and most closely resembles water from Belmer Spring which was used at the Anderson Springs resort until the 1930s.

Metals, Muck & Residue, New Hot Spring

(Sept., 1998; values in ppm)

	As	Cu	Hg	Pb	Sb	Se	Tl	Zn	S	Fe_2O_3 (wt-%)
Muck	14	45	30	12	23	0.51	0.79	80	21000	9.2
Residue[a]	90	350	520	470	400	<3	23	350	-----	19.9

[a]Filtered from 400 ml of spring water.

Muck at the New Hot Spring (site 2) consists of black to gray silty to colloidal solids (see photo of gas sampling), rich in pyrite and Fe-oxides. The muck is somewhat anomalous in metals, and the filter residue collected during water sampling is especially rich in metals.

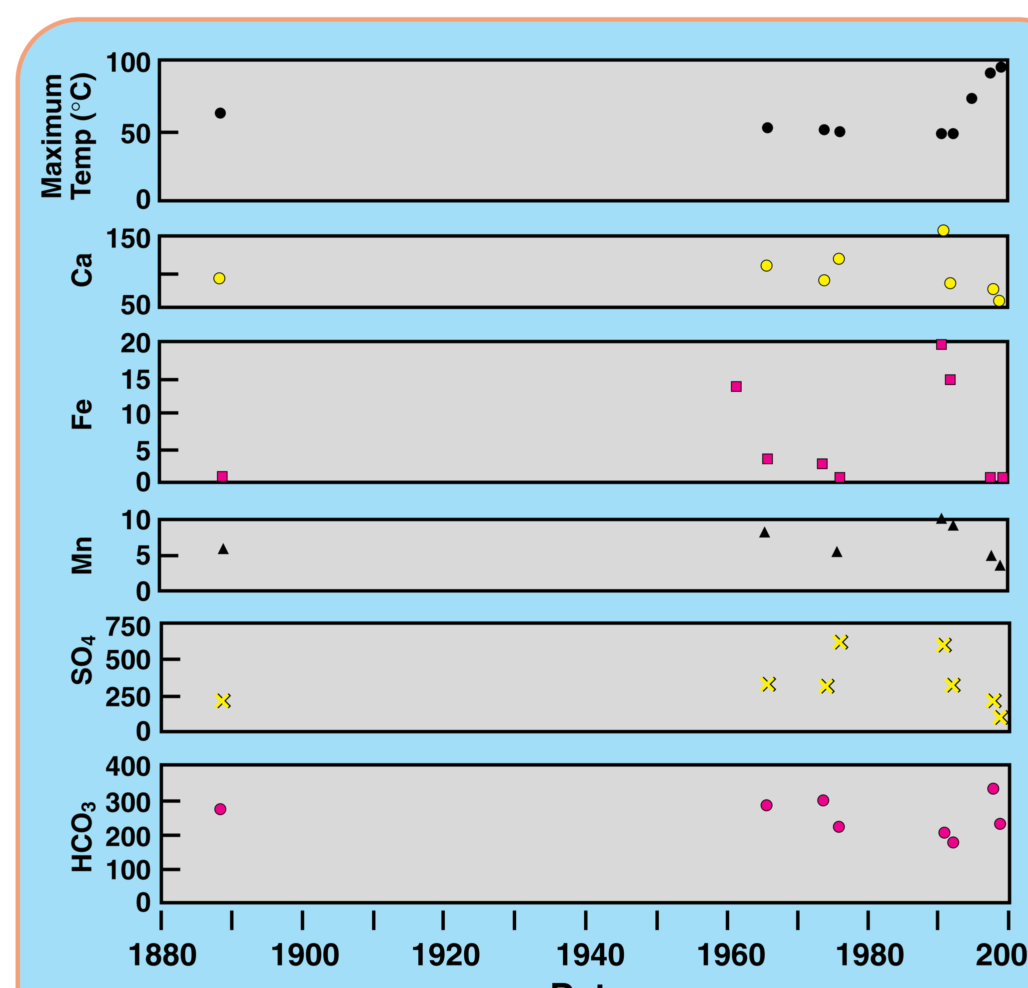
Gas Analyses, Anderson Hot Springs

(mol-% dry gas)

Map No.	Site	Date	Temp (°C)	CO_2	H_2S	H_2	CH_4	NH_3	N_2	O_2	Ar	D-P[a] (°C)
1	Main Spg	3/91	49.4	82.1	0.35	0.14	5.19	n.a.	10.1	1.76	0.12	218
1	Main Spg	3/95	76.6	90.5	2.91	0.03	3.85	0.0018	2.55	n.d.	0.04	229
2	New Spg[b]	8/99	98.4	64.5	4.85	5.50	1.15	0.29	22.5	0.78	0.31	230
--	SE Geysers Wells[c]		----	49.0	12.3	22.3	5.14	6.19	4.66	<0.01	0.06	

[a]Gas geothermometer of D'Amore and Panichi (1980).
[b]Also contains 0.00043 mol-% Hg.
[c]Mean composition of 27 gas analyses for the SE Geysers from Lowenstern et al. (1999).

As the hot spring area increased in temperature, there was a sympathetic increase in H_2S, H_2 and NH_3, and a decrease in CO_2 and CH_4, becoming more like the mean composition of steam discharges from the SE Geysers.



Time variations of temperature and selected chemical components (ppm) at Anderson Hot Springs. Temperature decreased slowly from 62 to 48°C and then rose quickly to 98°C. There are apparent maxima in Ca, Fe, Mn, and SO_4 in the early 1990s. Other components such as HCO_3 show no clear trends.

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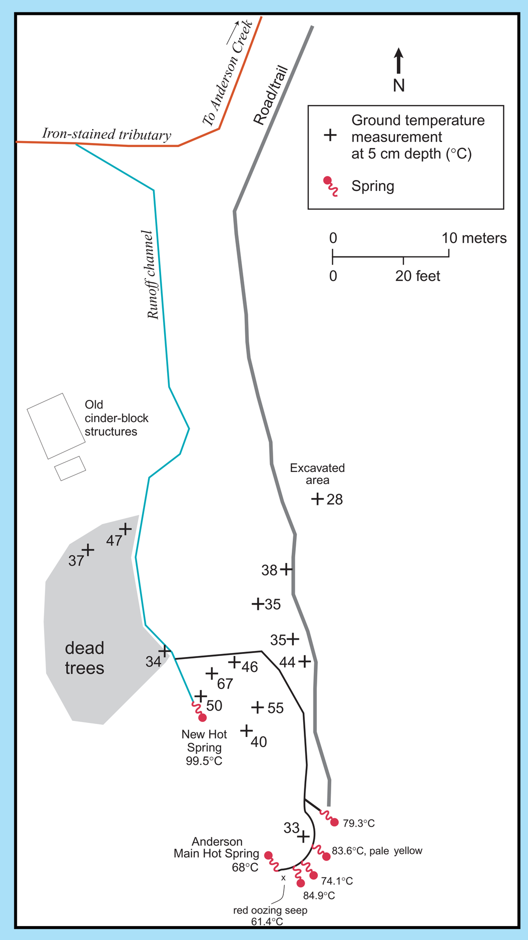
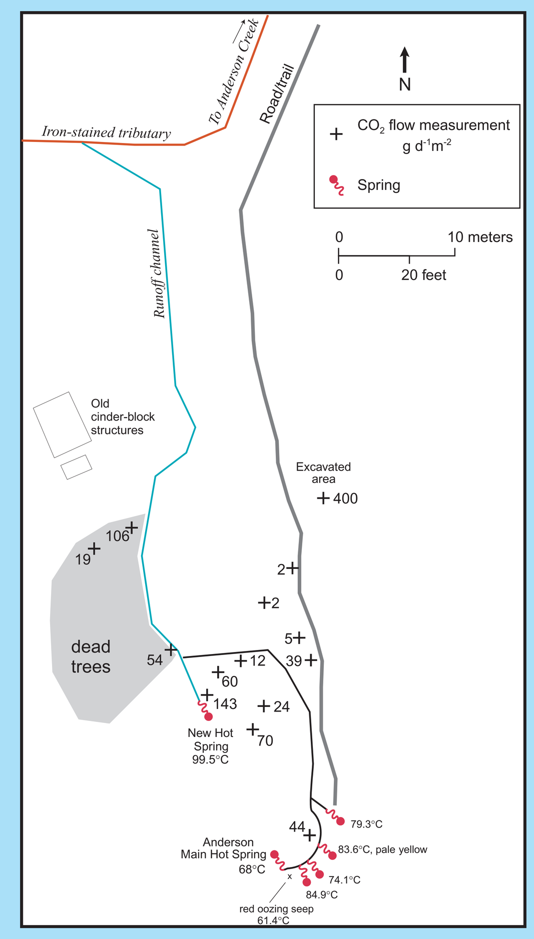
Anderson Springs, SE Geysers Geothermal Field, California

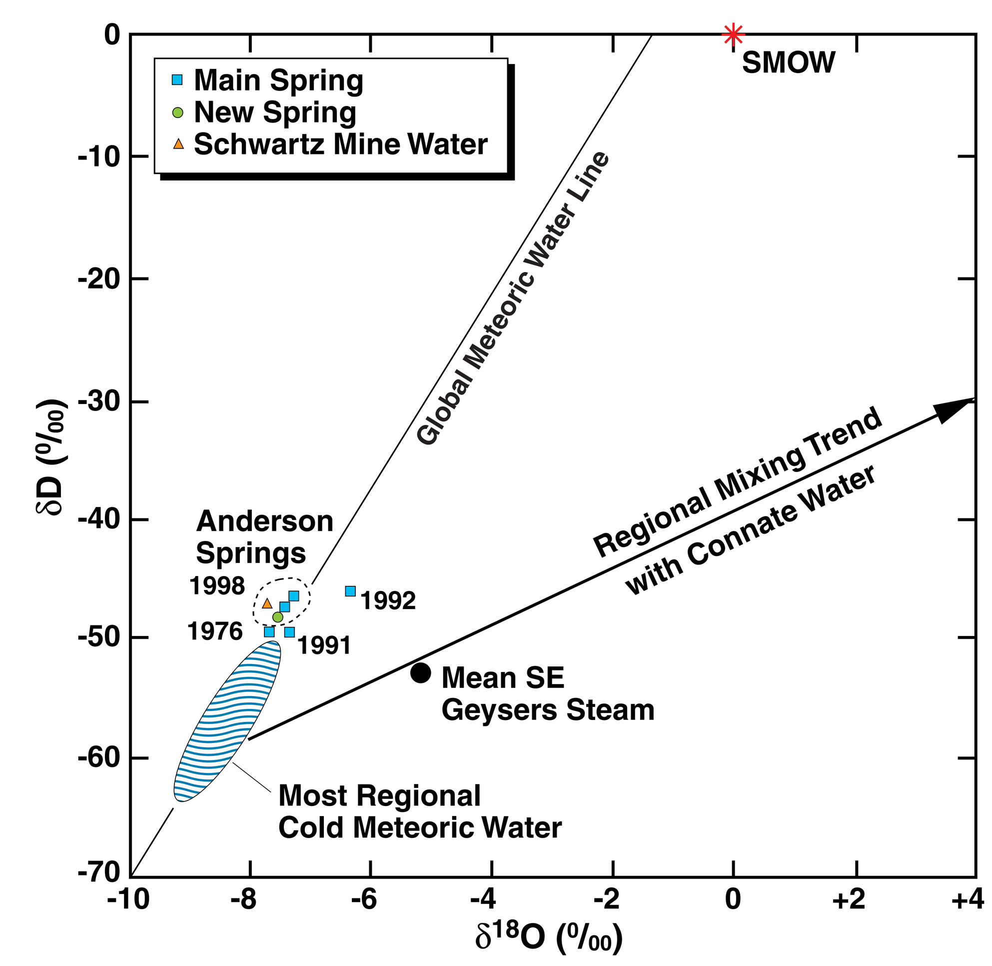
Photo of dead trees west of New Hot Spring area.



Schematic diagram of the Anderson Hot Springs showing measured temperatures (9/16/99) of the springs and the ground in the vicinity of the springs. Shaded area on the west bank of the spring-discharge channel indicates the approximate size of the dead-tree zone. The ambient air temperature for the region is approximately 13°C (Goff et al., 1977).



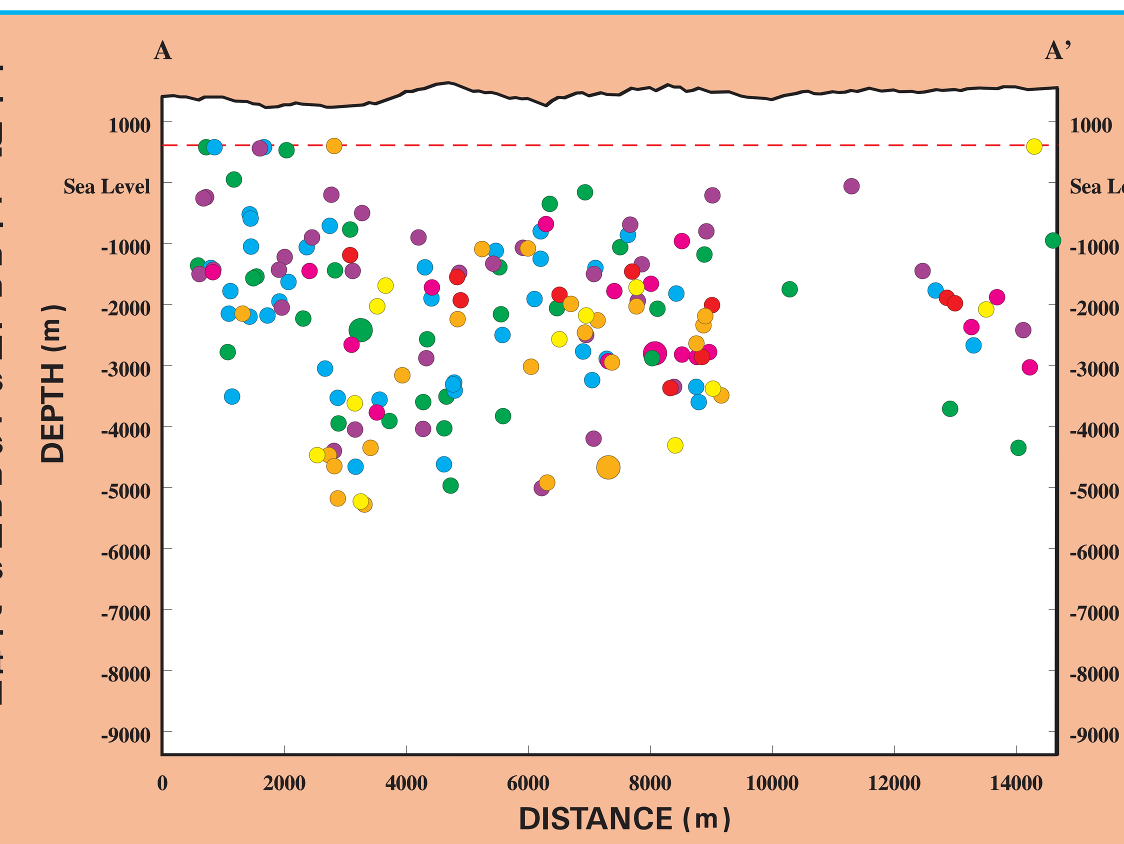
Schematic diagram of the Anderson Hot Springs showing diffuse flow of CO_2 through soil in the vicinity of the hot springs. CO_2 flow measurements were made on 9/16/99 near each site where ground temperatures were measured. These CO_2 fluxes are considered to be too low to kill the trees. The most likely cause of tree kill is heat stress in the root zone.



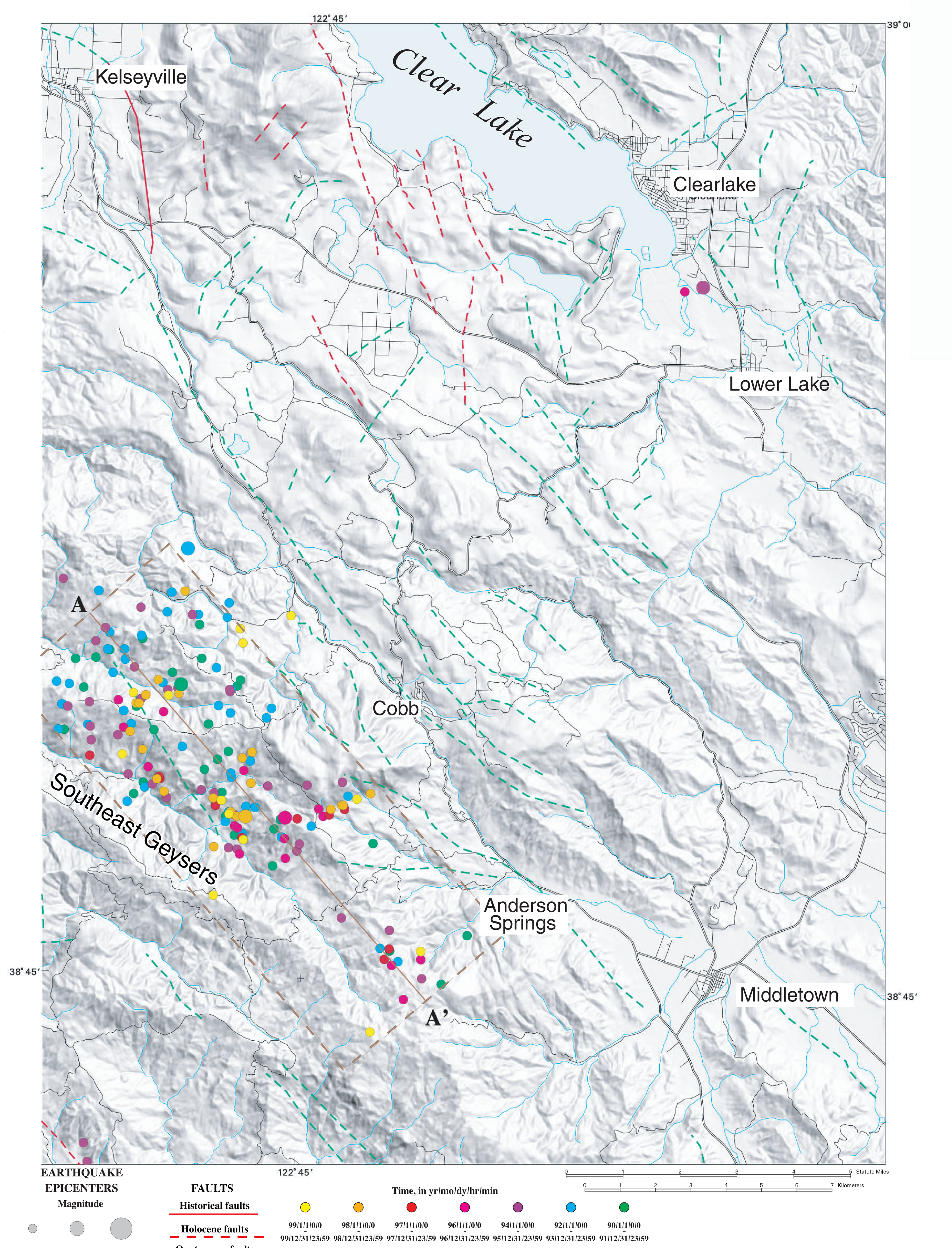
Waters at Anderson Springs are meteoric in character. They do not have enriched isotope values like most other regional thermal waters, which are mixtures of meteoric and connate fluids.

Earthquake hypocenters from 1990-1999 displayed along cross section A-A' from map at lower left. Events ±3km perpendicular to the section line are projected on to the plane A-A'. Symbol sizes and colors are the same as in the seismic map. Earthquake depths referenced to mean station elevation shown by dashed red line. Nearly all events are <5km deep, indicating the presumed vertical extent of the geothermal system.

Vertical error ±0.4 km.
Horizontal error ±0.1 km.



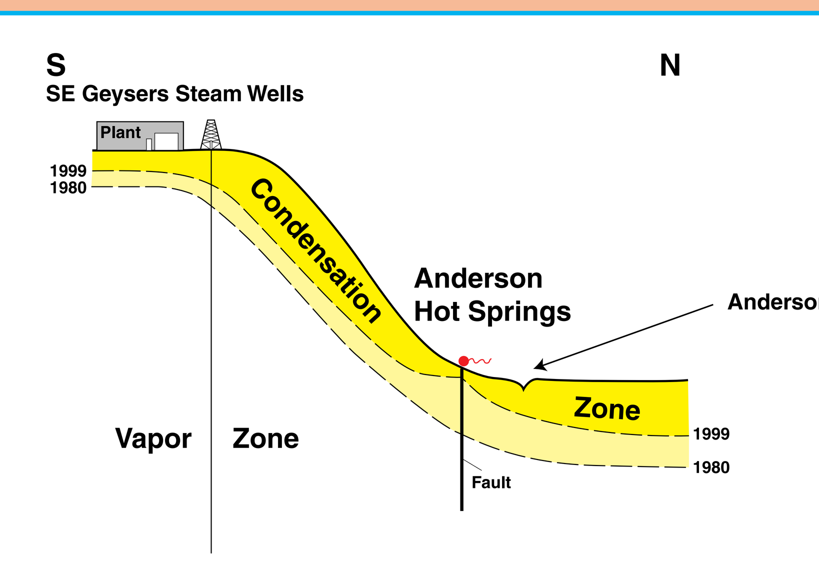
Areal Seismicity, Earthquakes of M > 3.0, 1990-1999



Fault traces were digitized from Jennings (1994: California Division of Mines and Geology State Fault Map, Scale 1:750,000) and are accurate herein to 0.8 km.
Brown dashed box displays limit for hypocenters projected in cross section at above right.

Seismic activity is correlated with the geothermal system at The Geysers. Earthquakes occuring within 3 km of Anderson Springs increased significantly after 1980 as nearby powerplants began operation. Seismicity indicates that failure occurs on small faults or fractures in regions of geothermal production and injection.

Schematic diagram (not to scale) showing possible cause of increased temperatures at Anderson Hot Springs. As steam in the reservoir is depleted, water in the condensation zone "dries out" and the condensation zone shrinks. Deep steam has a more direct pathway to the surface and shallow ground waters are heated, especially along faults.



CONCLUSIONS

The cause for the abrupt physical and chemical changes that have occurred in AS waters since 1992 is still not resolved. One obvious possibility is that 20+ years of steam withdrawal from the geothermal reservoir has caused pressure declines that have induced boiling in the condensation zone. This would cause heating and vaporization of shallow ground waters in the vicinity of AS. In addition, earthquakes in this seismically active region may have enhanced surface discharge of these thermal fluids along fractures and faults.

ACKNOWLEDGEMENTS: This work was funded by a grant from the U.S. Department of Energy, Office of Geothermal Technologies, as well as the USGS Volcano and Earthquake Hazards Programs. We thank Anthony Garcia (LANL) and Jake Lowenstern (USGS) for assistance with drafting and publication.

This poster is available on the World Wide Web at http://geopubs.wr.usgs.gov/open-file/0f00-037/

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