Paso Robles Groundwater Basin: Effects of Geothermal Waters on Water Quality and Availability

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Paso Robles Intake from Lake Nacimiento

Paso Robles City Square Hot Spring

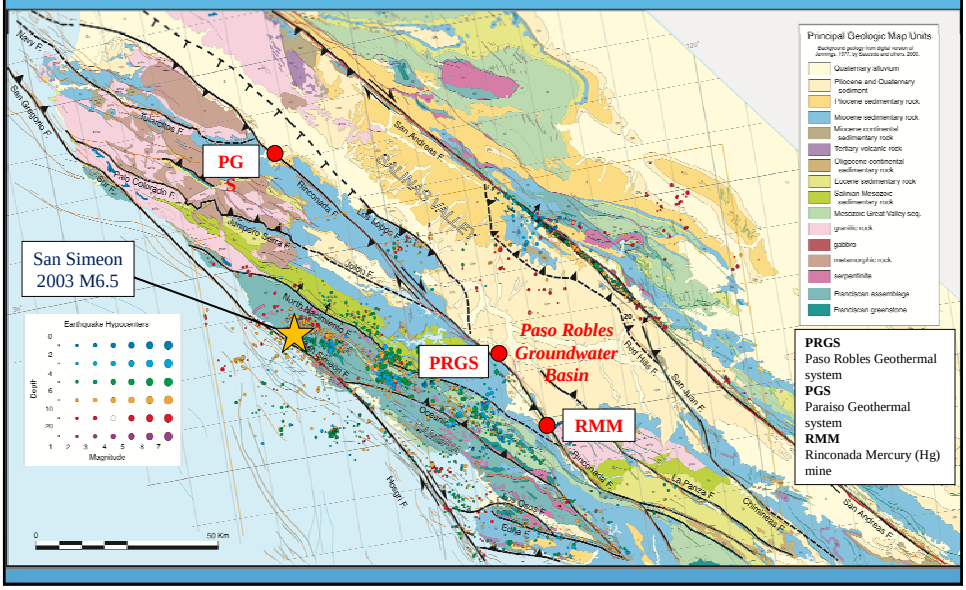
Paso Robles Groundwater Basin Study

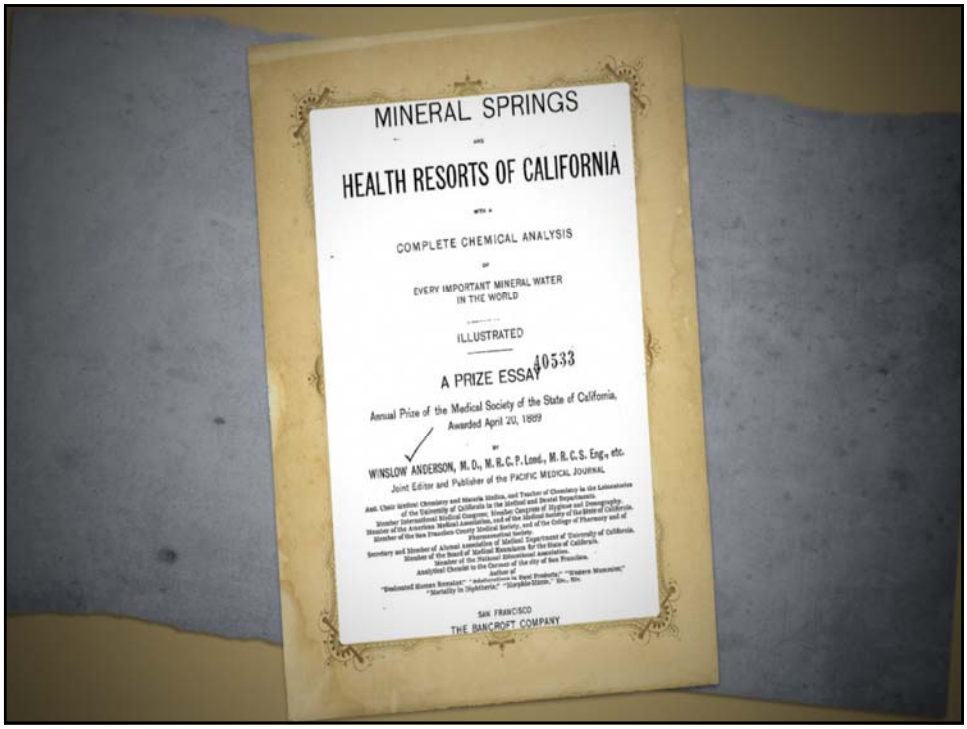
- Characterize the Paso Robles hot springs and geothermal well waters using:
  - Chemistry, light stable isotopes (^{13}C, ^{14}C, ^{32}S, ^{18}O, ^{2}H and tritium)
  - Determine age + source of water
- Characterize groundwater from Paso Robles and Templeton city water wells using:
  - Chemistry, light stable isotopes (^{13}C, ^{14}C, ^{32}S, ^{18}O, ^{2}H and tritium)
  - Determine if waters contain a component of geothermal water
- Develop a conceptual model for mixing of geothermal water with city groundwater wells → Explain water quality problems
- Determine the amount of geothermal water that can be mixed with city groundwater wells to increase available water

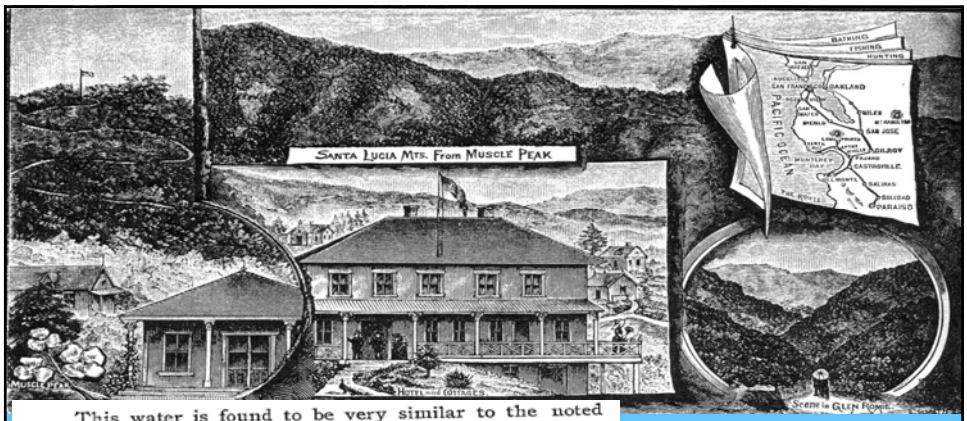
Types of Waters Present in the PRGB

- **Meteoric** (recent rainfall, snowmelt, and surface runoff)
  - Recharges aquifer
  - Known chemical and isotopic ‘signature’
- **Connate** (old waters trapped in sedimentary rocks)
  - Can retain ancient chemical and isotopic ‘signature’
- **Geothermal** (water heated by the earth – old or young)
  - Low-temp. vs. high-temp
  - Hot springs (geothermal waters rising along faults)

Geology and Earthquakes Central Coast Ranges







This water is found to be very similar to the noted Carlsbad of Austria, and of great value in rheumatism, gout, liver and kidney affections and chronic skin diseases.

The waters at Paraiso Springs have been found of great service in chronic rheumatism and arthritic affections, joint diseases, syphilitic and scrofulous contaminations and chronic skin diseases.

The soda and sulphur waters are tonic, antacid, laxative, diuretic and detergent and much prized in dyspepsia, torpidity of liver and intestines, glandular swellings, and for kidney and bladder diseases.

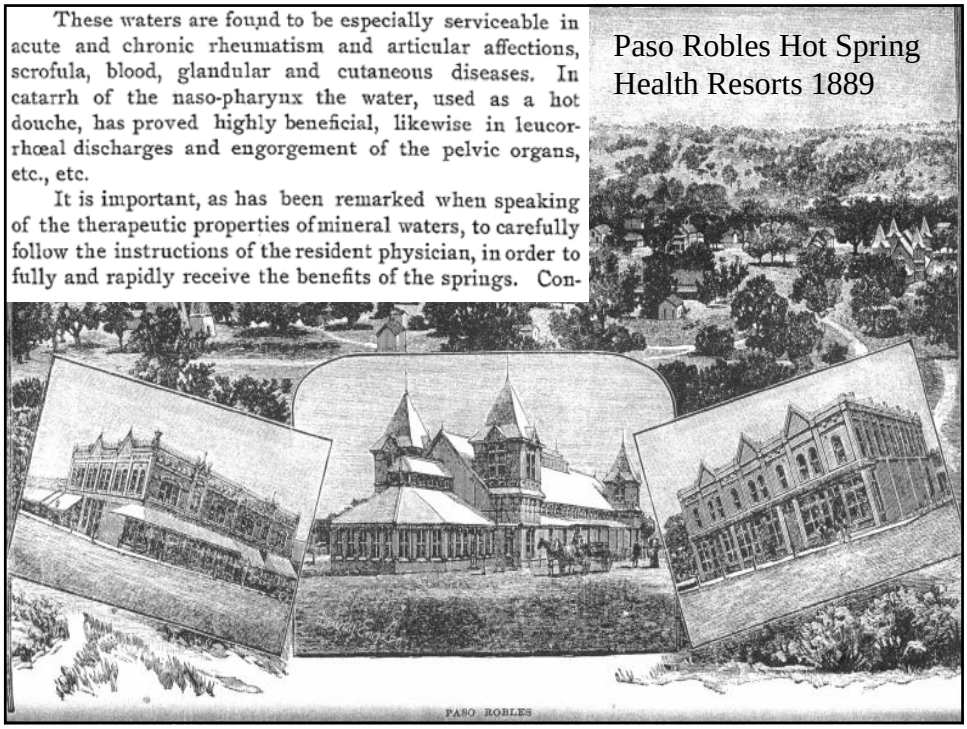
Thousands of visitors, invalids and pleasure-seekers, visit Paraiso Springs yearly and the superiority of the mineral springs, the excellence of the climate and the picturesqueness of the location bid fair to make Paraiso resort one of the most prominent mineral watering-places on the Coast.

Paraiso Hot Spring Health Resorts 1889

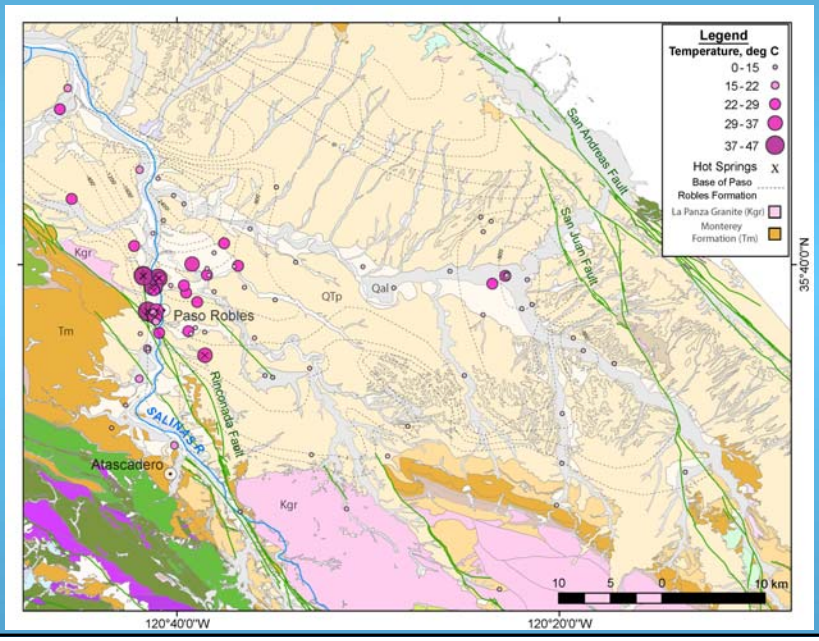
Paso Robles Hot Spring Health Resorts 1889

These waters are found to be especially serviceable in acute and chronic rheumatism and articular affections, scrofula, blood, glandular and cutaneous diseases. In catarrh of the naso-pharynx the water, used as a hot douche, has proved highly beneficial, likewise in leucorrhœal discharges and engorgement of the pelvic organs, etc., etc.

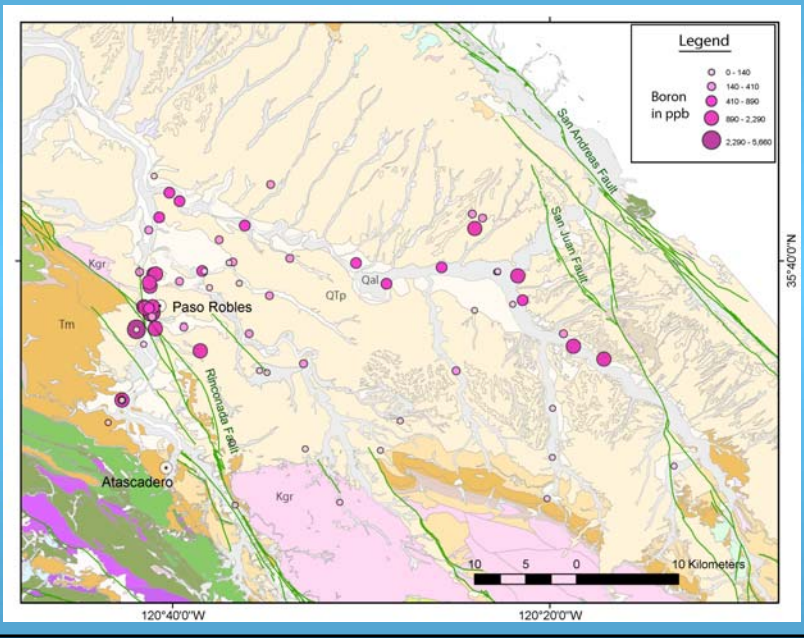
It is important, as has been remarked when speaking of the therapeutic properties of mineral waters, to carefully follow the instructions of the resident physician, in order to fully and rapidly receive the benefits of the springs. Con-



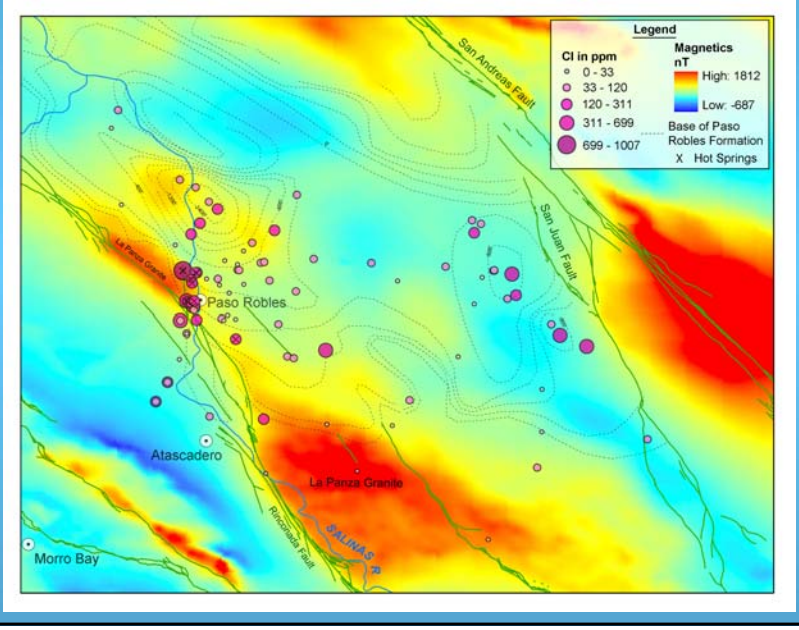
Temperature of hot springs, geothermal wells, and water wells



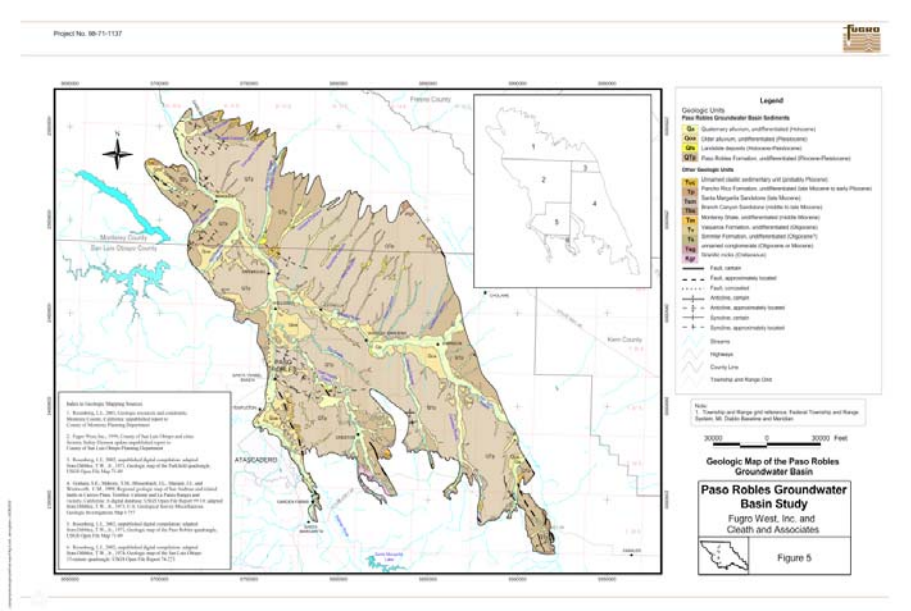
Boron concentrations in hot springs, geothermal wells, and water wells in PRGB



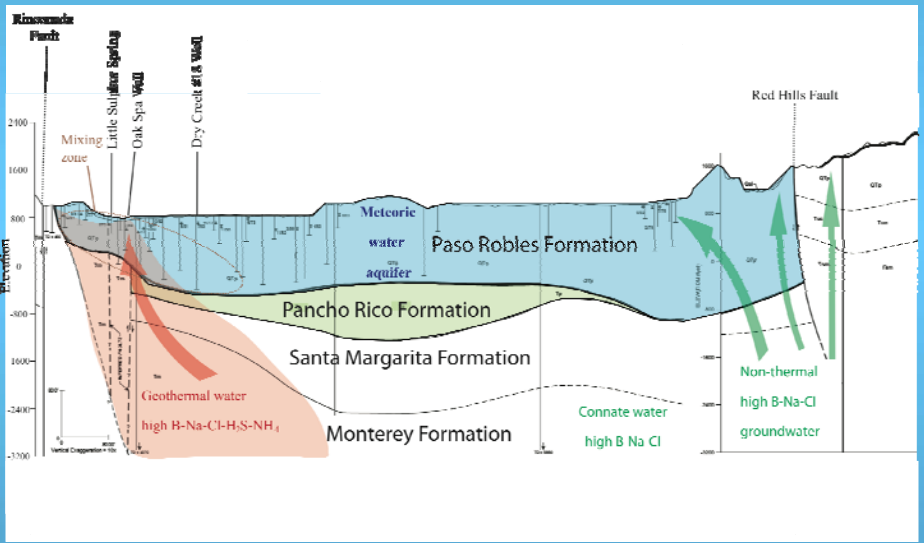
Magnetics and Chloride (Cl) in water



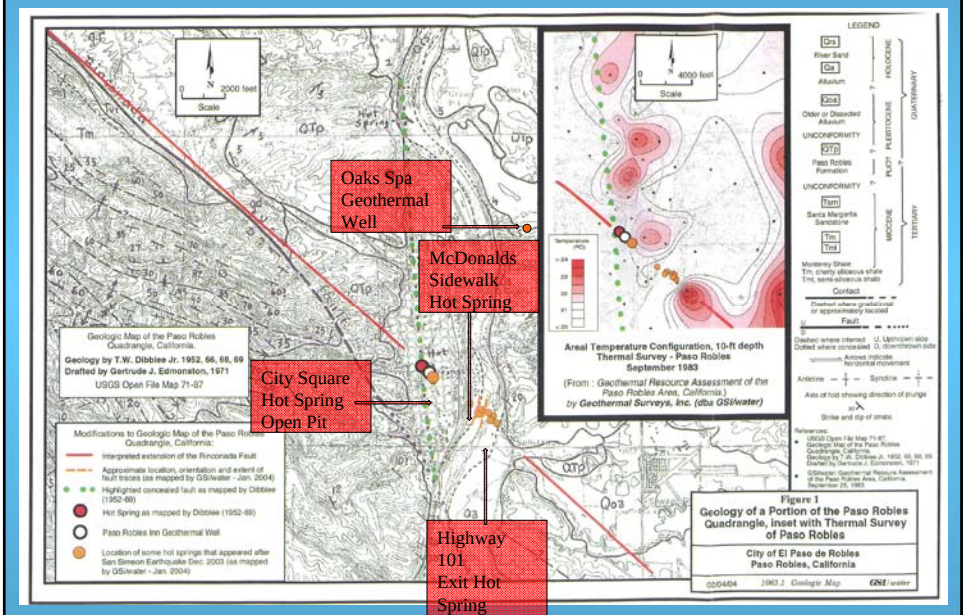
Paso Robles Groundwater Basin



West to East Cross Section of Central Paso Robles Groundwater Basin



Paso Robles Hot Springs and Geothermal Wells



Hot spring vent in city center of Paso Robles developed after 2003 M 6.5 San Simeon Earthquake

Public works initially thought it was a sewer leak so dug to fix the problem.

Hot spring water was pumped 1.5 km to the Salinas River

McDonalds Sidewalk Hot Spring Vent—26.4°C, pH 7.90

Highway 101 Off Ramp Hot Spring Vent--33.6°C, pH 6.88

Franklin Hot Spring Resort—34.3°C, pH 8.16

Geothermal well 3458 feet
produces 1000 gpm
From Monterey Formation

Mud Hot Spring Resort--44.5°C, pH 7.18

Geothermal well depth 100 feet
water from
Paso Robles Formation

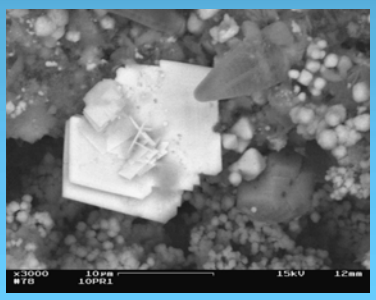
Paso Robles City Center Hot Spring

Hot spring water neutral (pH 6.85)-
Ca-Mg-carbonate-chloride water
Temperature 42.6°C

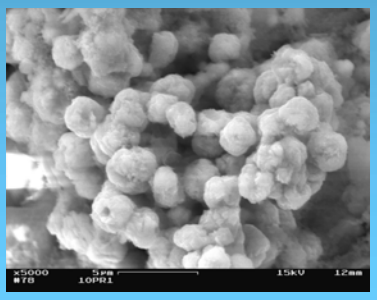
Water Board required treatment of hot spring effluent.
Water pumped to leach field on Salinas River flood plain.

Natural Gas Evasion: CH_4 (59.5%)
N_2 (33.2%)
CO_2 (7.3%)
H_2S (0.8%--lethal)
C_2H_6 (0.2%)
Precipitates consist of elemental sulfur, Iron sulfide and barite.

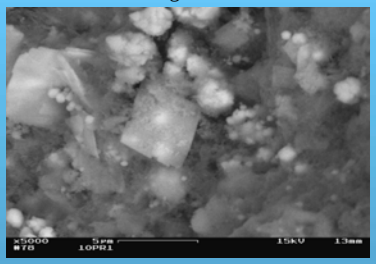
Precipitates in Paso Robles City Square Hot Spring Pool



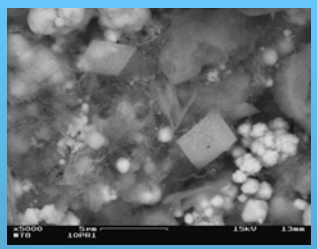
Sulfur crystals (white) and pyrite (spheres) and elongate diatoms



Pyrite (iron sulfide) Spheres



Barite crystals and pyrite (spheres)



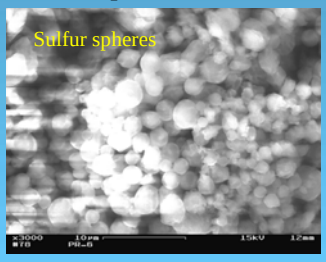
Barite crystals, pyrite (spheres) and Ca-Al-Silicate (fibrous phase)

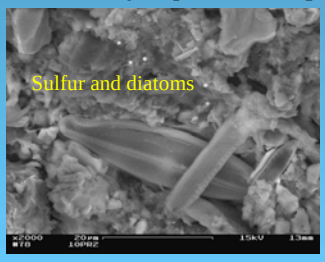
Effluent from Paso Robles City Square Hot Spring at Salinas Flood Plain

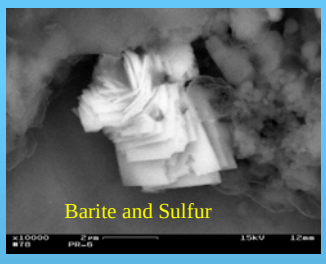
Colloidal sulfur remains in suspension in effluent

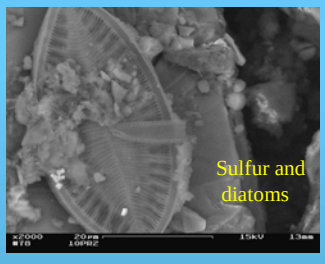
Sulfur precipitates in concrete trench constructed to divert effluent into Salinas River. Water board Required treatment in a leach field.

Sulfur Precipitate in Effluent from Paso Robles City Square Hot Spring









- Initial failure of leach field as Sulfur precipitated and plugged up flow
- Leach field reconstructed and now releases into Salinas River

Geothermal System Summary

- Geothermal water in Monterey Formation enters Paso Robles Formation aquifer along faults and fractures

  a) temperature of the geothermal water at depth is 93-106^{o}C based on Na-K-Ca geothermometer, 89-118^{o}C based on quartz geothermometer

  b) fluid saturated with respect to calcite, cements fault zones and limits flow to surface. 2003 earthquake fractured calcite cement and increased upward flow of hot water along Rinconada Fault.

  Deposition of calcite since earthquake has decreased flows to hot springs.

  c) geothermal water primarily reaches surface along basin bounding Rinconada and subsidiary faults but also upward cross formational flow along fractures

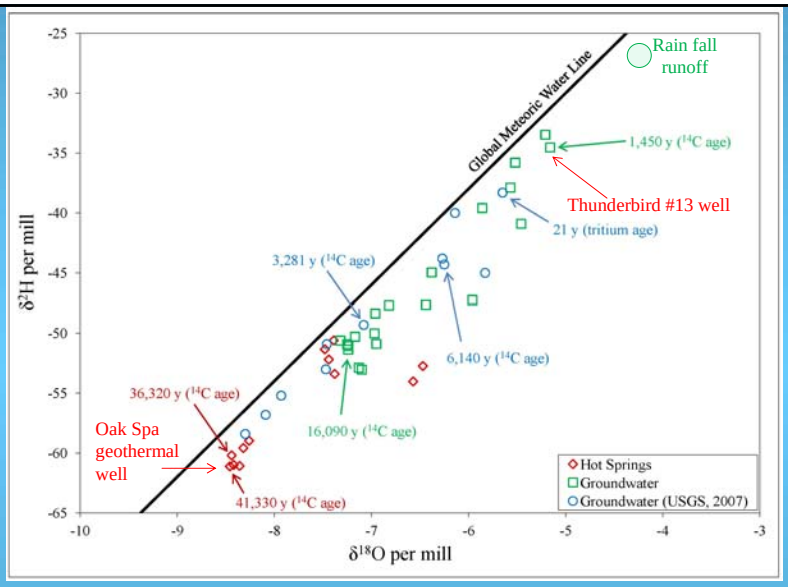
  d) geothermal water mixes with meteoric water in the Paso Robles Formation aquifer

Thunderbird #13

City Water Wells

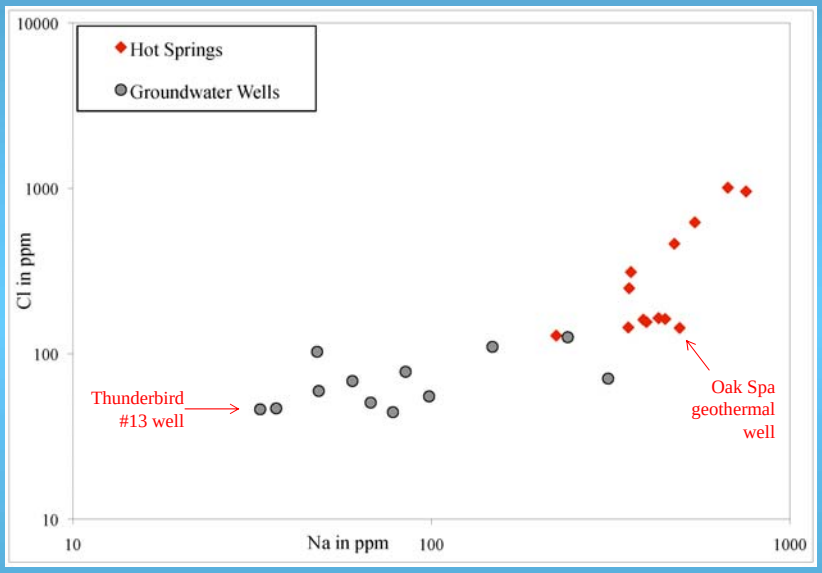
Paso Robles and Templeton City water wells sampled.
Waters analyzed for major and minor elements and isotopes of oxygen ($\delta^{18}O$), deuterium, carbon (^{13}C and ^{14}C), tritium, and sulfur.

- Low temperature, meteoric water
- Low concentrations of Boron (B), Chloride (Cl), Iron (Fe), Manganese (Mn), and ammonium (NH_4), hydrogen sulfide (H_2S)
- Relatively young water based on isotopic signature: tritium,
- ^{14}C (pmc: % modern carbon)



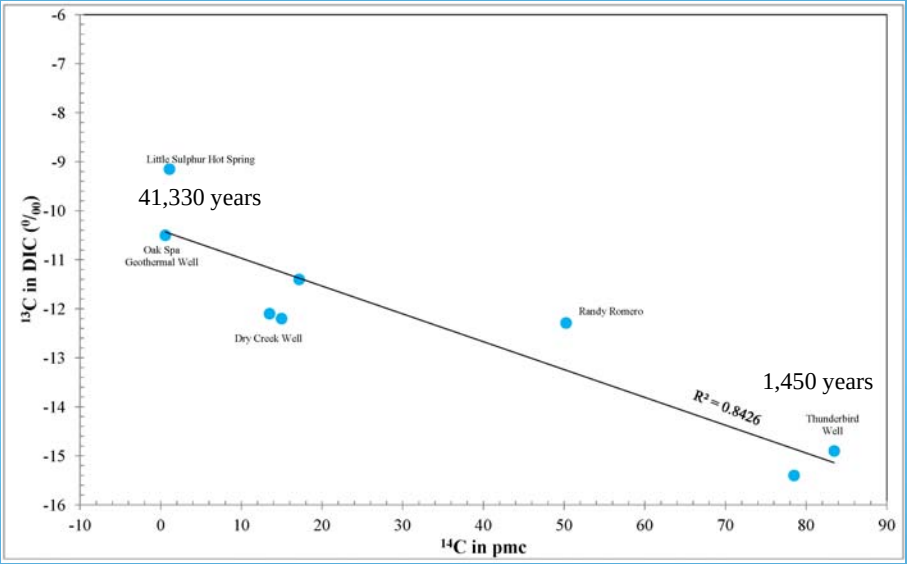
Isotopic composition of waters define a two end member mixing line:
- **End Member 1:** meteoric water in Thunderbird drinking water well, and
- **End Member 2:** geothermal water from the Oak Spa Hot Spring well
- Well and hot spring waters contain variable amounts of meteoric and geothermal water
- Poor water quality drinking water wells contain higher component of geothermal water

Sodium (Na) and Chloride (Cl) concentrations in Meteoric and Geothermal Water



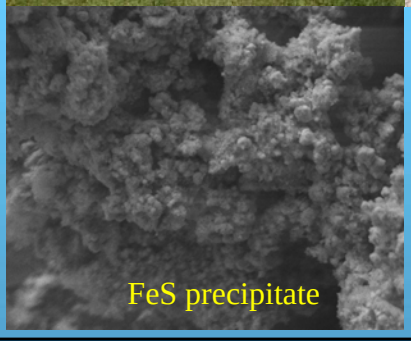
Na and Cl water chemistry define a two end member mixing line similar to isotopic data between:
- meteoric water in Thunderbird drinking water well (low Na, Cl) and
- geothermal water from the Oak Spa Hot Spring well (high Na, Cl)
- City water wells have variable Na and Cl concentration caused by mixing with geothermal water

Carbon Isotopes In Waters



Carbon isotopic data supports two end member mixing model between:
•meteoric water in Thunderbird drinking water well (younger ^{14}C age, relative depletion in DIC) and
•geothermal water from the Oak Spa Hot Spring well (older ^{14}C age, enrichment in DIC from mantle)

Geothermal End Member – Oak Spa Well



<u>Characteristics of Geothermal End Member</u>
•High temperature, saline
•High concentrations of Boron (B), Chloride (Cl), Sodium (Na), Iron (Fe), Manganese (Mn), and ammonia (NH_4)
•Relatively old water (41,000 years), enrichment in ^{13}C indicates deep (greater than 25 kms) carbon source from upper mantle

% Geothermal Fluid In Paso Robles City Water Wells Varies Seasonally with Maximum in Summer/Fall

Water Well	% Geothermal Fluid	Water Quality
Thunderbird #13	0.0%	Good
Ronconi #4	15.9%	High Fe, Mn
Sherwood #9	51.5%	High Fe, Mn, H_2S
Borchert #5	59.8%	High Fe, Mn, H_2S, NH_4(unpotable)

% Meteoric Water in Hot Springs

Hot Springs	% Meteoric Water	Geothermal Fluid Source
Oaks Spa Well #1	0.0%	Deep well, west side basin, in Monterey
Little Sulfur Springs	3.3%	Unnamed Fault
McDonalds Sidewalk	4.3%	Basin Bounding Rinconada Fault
Franklin Hot Spring Spa	7.7%	Deep well, central basin, in Monterey
Mud Springs Resort	25.6%	Shallow well,west side basin in Monterey
Highway 101 Exit Spring	28.0%	Basin Bounding Rinconada Fault
Paso Robles Inn Spa	32.3%	Basin Bounding Rinconada Fault
City Square Hot Spring	35.4%	Basin Bounding Rinconada Fault

Summary

- Ground water wells locally contaminated with geothermal water derived from the Monterey Formation,
  - a) adjacent to fault zones such as Rinconada and related faults
  - b) fractures in Paso Robles Formation permits cross formational intrusion of geothermal water into the aquifer
- Seasonal draw down of the groundwater results in increased incursion of geothermal water and associated gases (H_2S).
  - a) mixing of > 20% geothermal water results in Mn (manganese) and Fe (iron) problem
  - b) mixing of > 40% geothermal water results in hydrogen sulfide (H_2S) problem
  - c) mixing of > 40% geothermal water results in unpotable water (H_2S and ammonium, NH_4)

West to East Cross Section of Central Paso Robles Groundwater Basin