

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 , ^2H 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 , ^2H 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
- Characterize fossil water in Monterey Formation and determine mixing of fossil water with agriculture well water

Types of Waters Present in the PRGB

- **Meteoric** (recent rainfall, snowmelt, and surface runoff)
 - Recharges aquifer
 - Known chemical and isotopic ‘signature’
- **Fossil** (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)

MINERAL SPRINGS
AND
HEALTH RESORTS OF CALIFORNIA

WITH A
COMPLETE CHEMICAL ANALYSIS

OF
EVERY IMPORTANT MINERAL WATER
IN THE WORLD

ILLUSTRATED

A PRIZE ESSAY ⁴⁰⁵³³

Annual Prize of the Medical Society of the State of California,
Awarded April 20, 1889

BY
WINSLOW ANDERSON, M. D., M. R. C. P. Lond., M. R. C. S. Eng., etc.
Joint Editor and Publisher of the PACIFIC MEDICAL JOURNAL

Asst. Chair Medical Chemistry and Materia Medica, and Teacher of Chemistry in the Laboratories
of the University of California in the Medical and Dental Departments.
Member International Medical Congress; Member Congress of Hygiene and Demography.
Member of the American Medical Association, and of the Medical Society of the State of California.
Member of the San Francisco County Medical Society, and of the College of Pharmacy and of
Pharmaceutical Society.
Secretary and Member of Alumni Association of Medical Department of University of California.
Member of the Board of Medical Examiners for the State of California.
Member of the National Educational Association.
Analytical Chemist to the Coroner of the city of San Francisco.

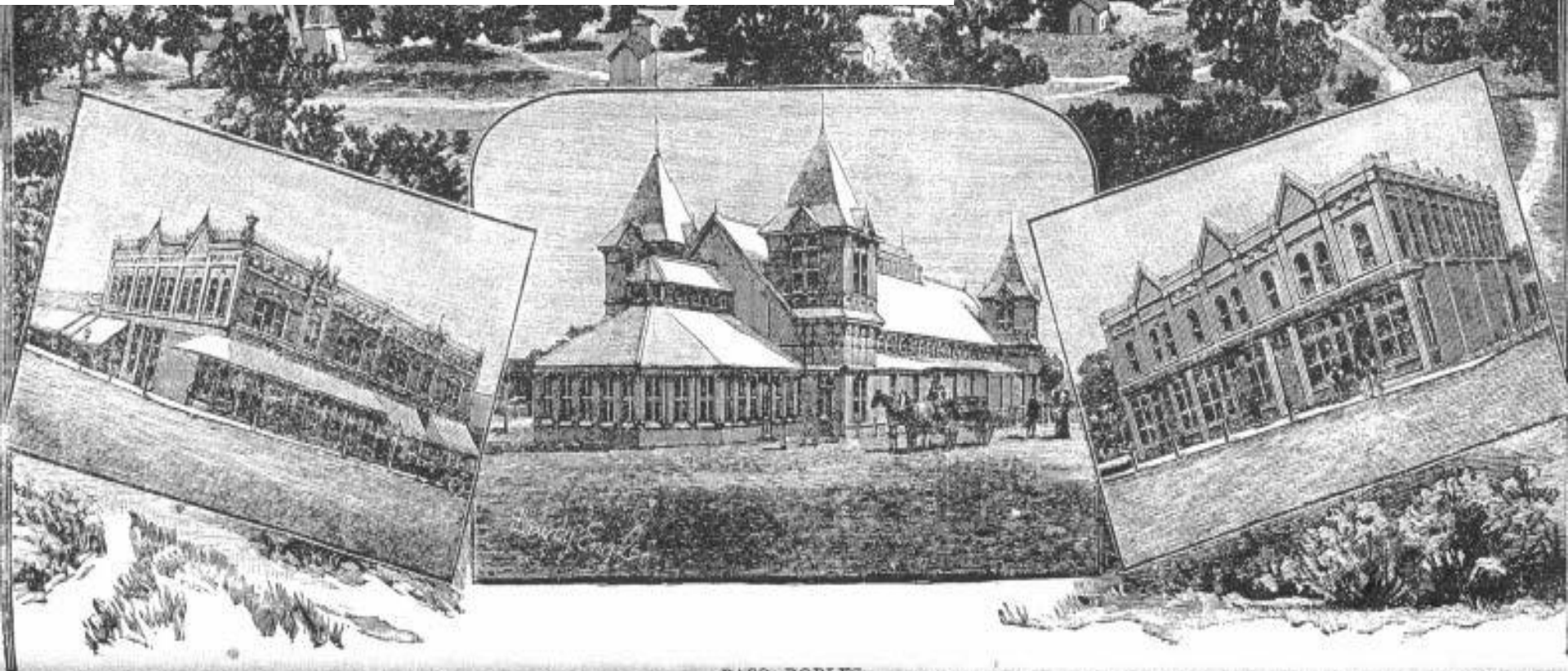
Author of
"Dedicated Human Remains;" "Adulterations in Food Products;" "Western Mummies;"
"Mortality in Diphtheria;" "Morpho-Mania," Etc., Etc.

SAN FRANCISCO
THE BANCROFT COMPANY

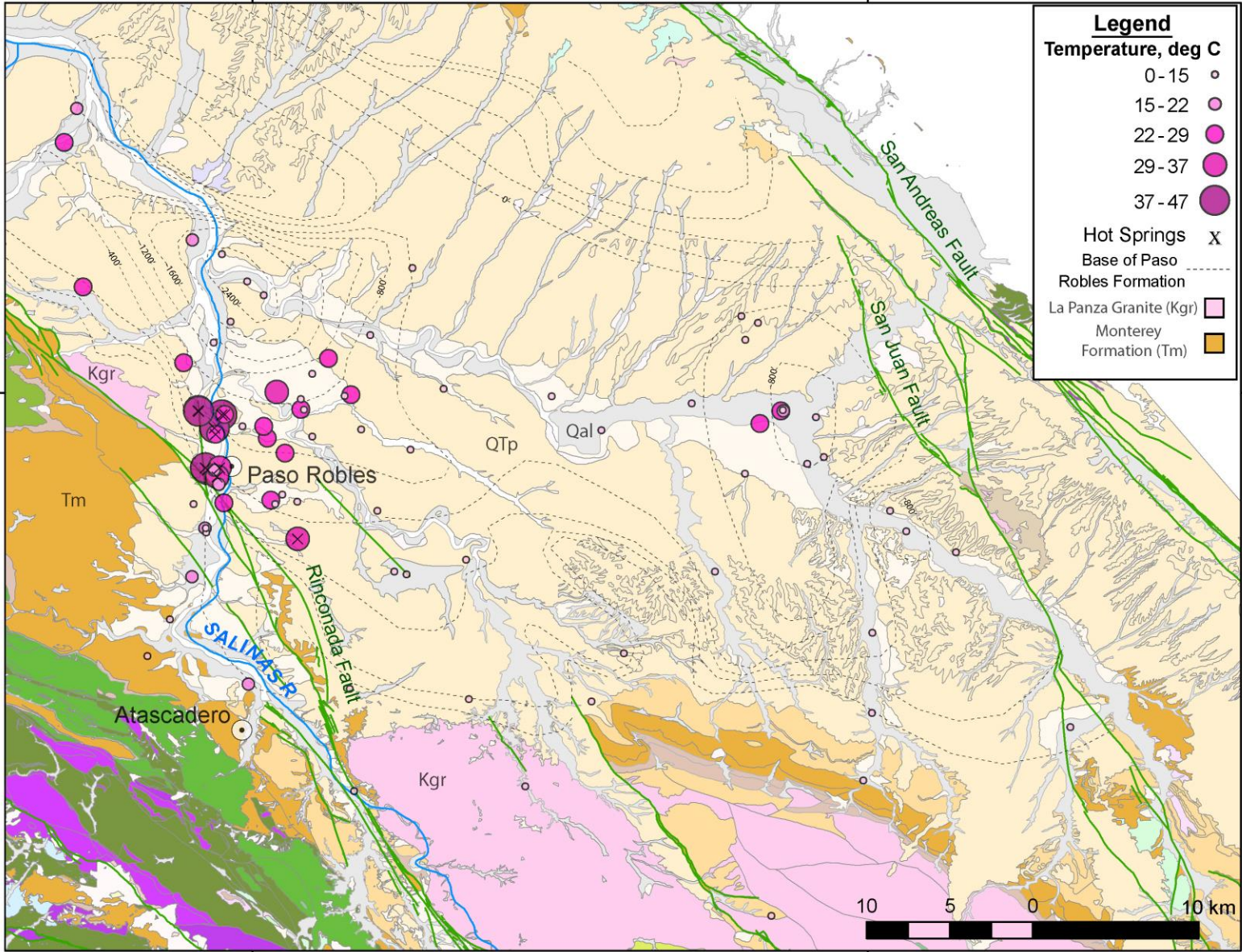
These waters are found to be especially serviceable in acute and chronic rheumatism and articular affections, scrofula, blood, glandular and cutaneous diseases. In catarrh of the naso-pharynx the water, used as a hot douche, has proved highly beneficial, likewise in leucorrhœal discharges and engorgement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

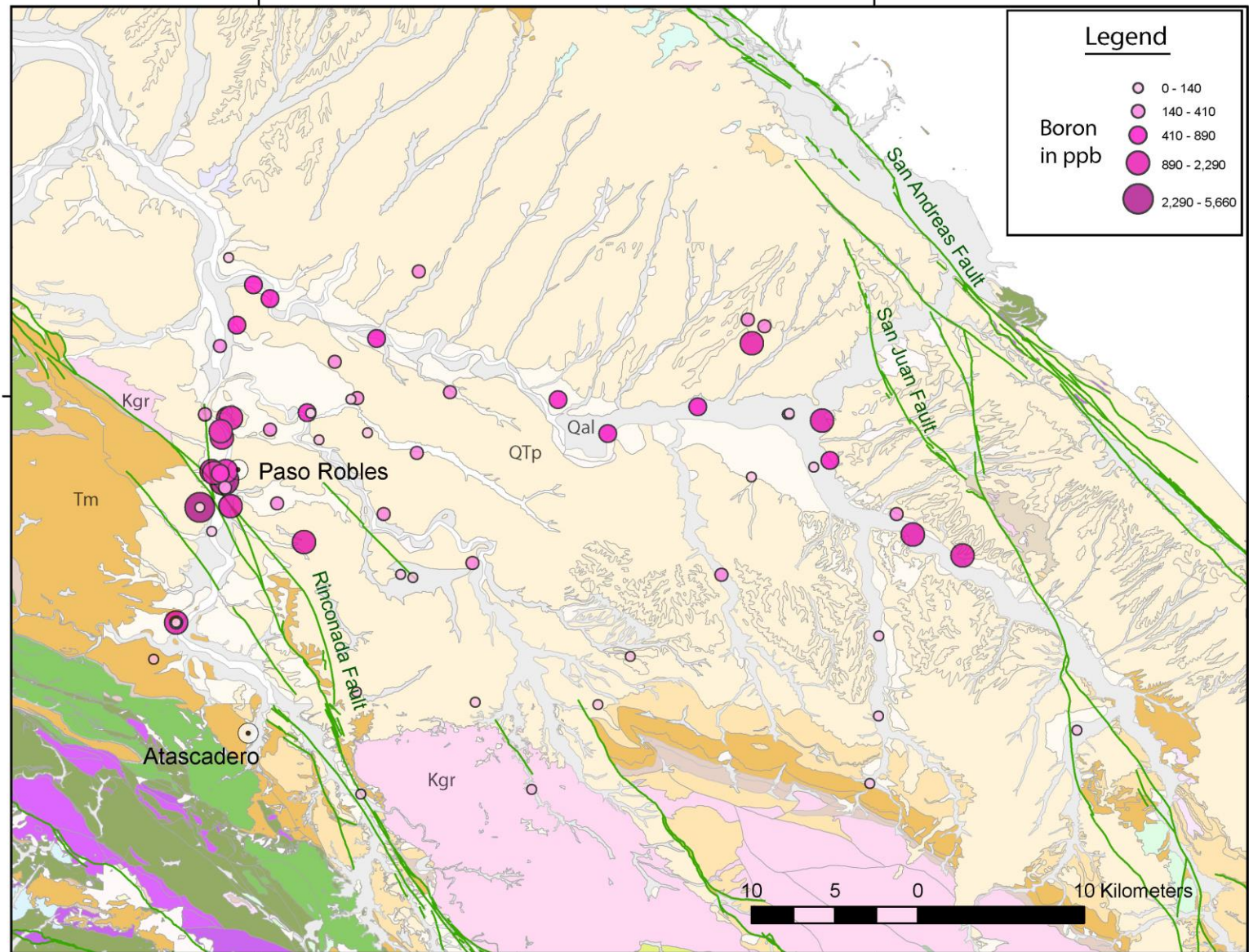
Paso Robles Hot Spring Health Resorts 1889



Temperature of hot springs, geothermal wells, and water wells



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

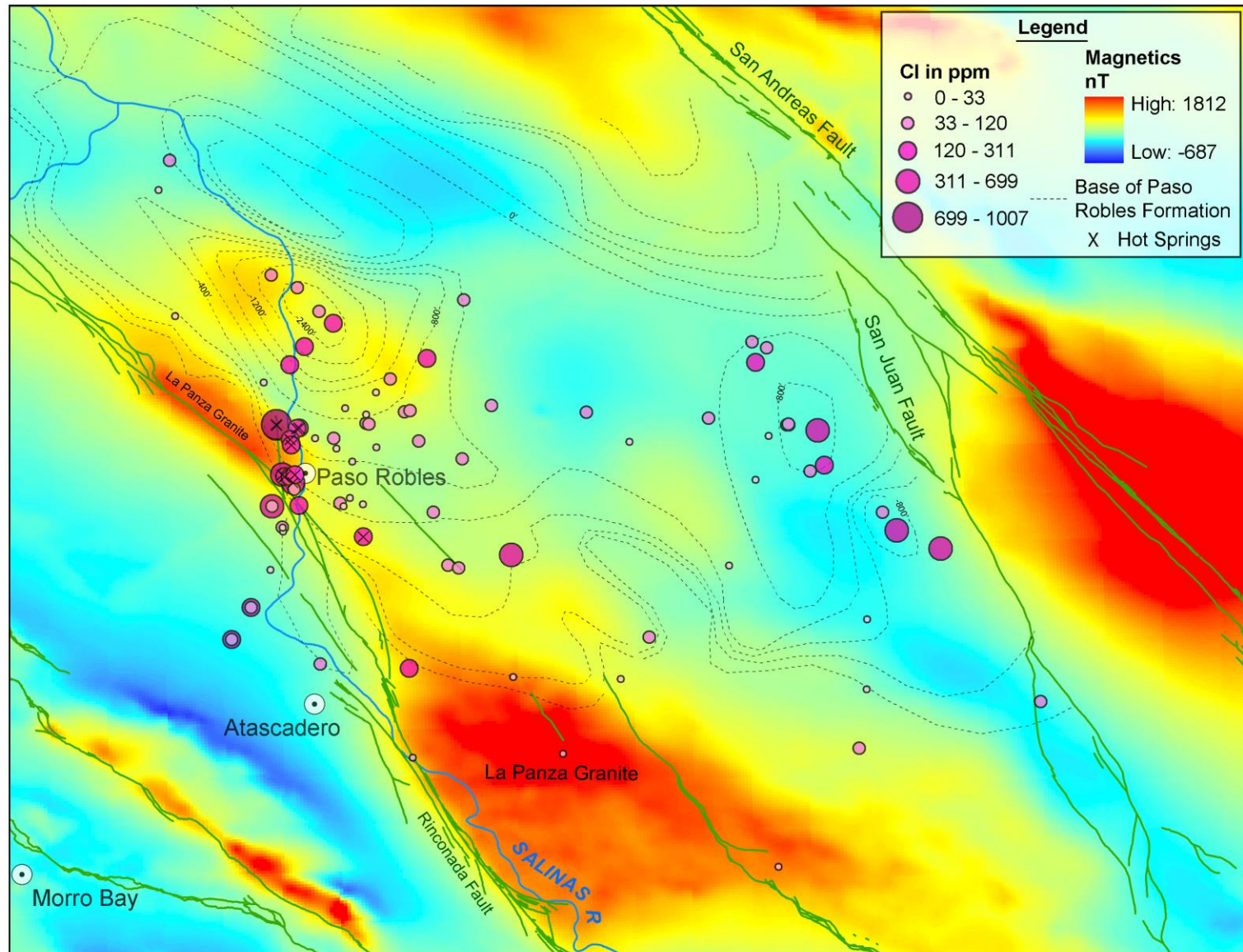


120°40'0"W

120°20'0"W

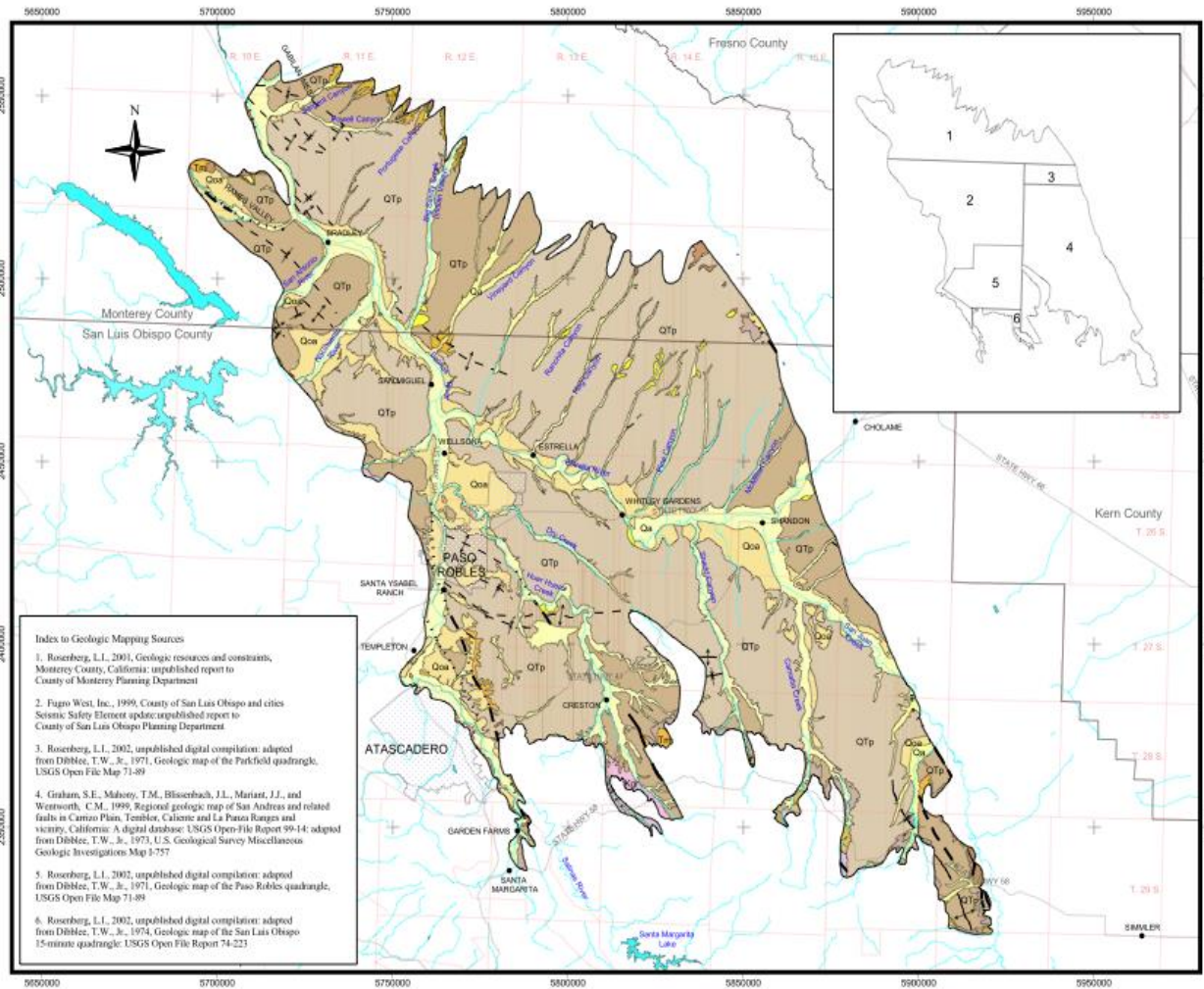
35°40'0"N

Magnetics and Chloride (Cl) in water



Paso Robles Groundwater Basin

Project No. 98-71-1137



Legend

Geologic Units
Paso Robles Groundwater Basin Sediments

- Qa** Quaternary alluvium, undifferentiated (Holocene)
- Qoa** Older alluvium, undifferentiated (Pleistocene)
- Qls** Landslide deposits (Holocene-Pleistocene)
- QTP** Paso Robles Formation, undifferentiated (Pliocene-Pleistocene)

Other Geologic Units

- Tuc** Unnamed clastic sedimentary unit (probably Pliocene)
- Tp** Pancho Rico Formation, undifferentiated (late Miocene to early Pliocene)
- Tsm** Santa Margarita Sandstone (late Miocene)
- Tbs** Branch Canyon Sandstone (middle to late Miocene)
- Tm** Monterey Shale, undifferentiated (middle Miocene)
- Tv** Vaqueros Formation, undifferentiated (Oligocene)
- Ts** Simillar Formation, undifferentiated (Oligocene?)
- Tsg** unnamed conglomerate (Oligocene or Miocene)
- Kgr** Granitic rocks (Cretaceous)

Structural Features

- Fault, certain
- - - Fault, approximately located
- Fault, concealed
- ⊥ Anticline, certain
- ⊥ Anticline, approximately located
- ⊥ Syncline, certain
- ⊥ Syncline, approximately located

Other Features

- ~ Streams
- ⚡ Highways
- ▭ County Line
- ▭ Township and Range Grid

Note:
 1. Township and Range grid reference: Federal Township and Range System, Mt. Diablo Baseline and Meridian



Geologic Map of the Paso Robles Groundwater Basin

Paso Robles Groundwater Basin Study
 Fugro West, Inc. and Cleath and Associates

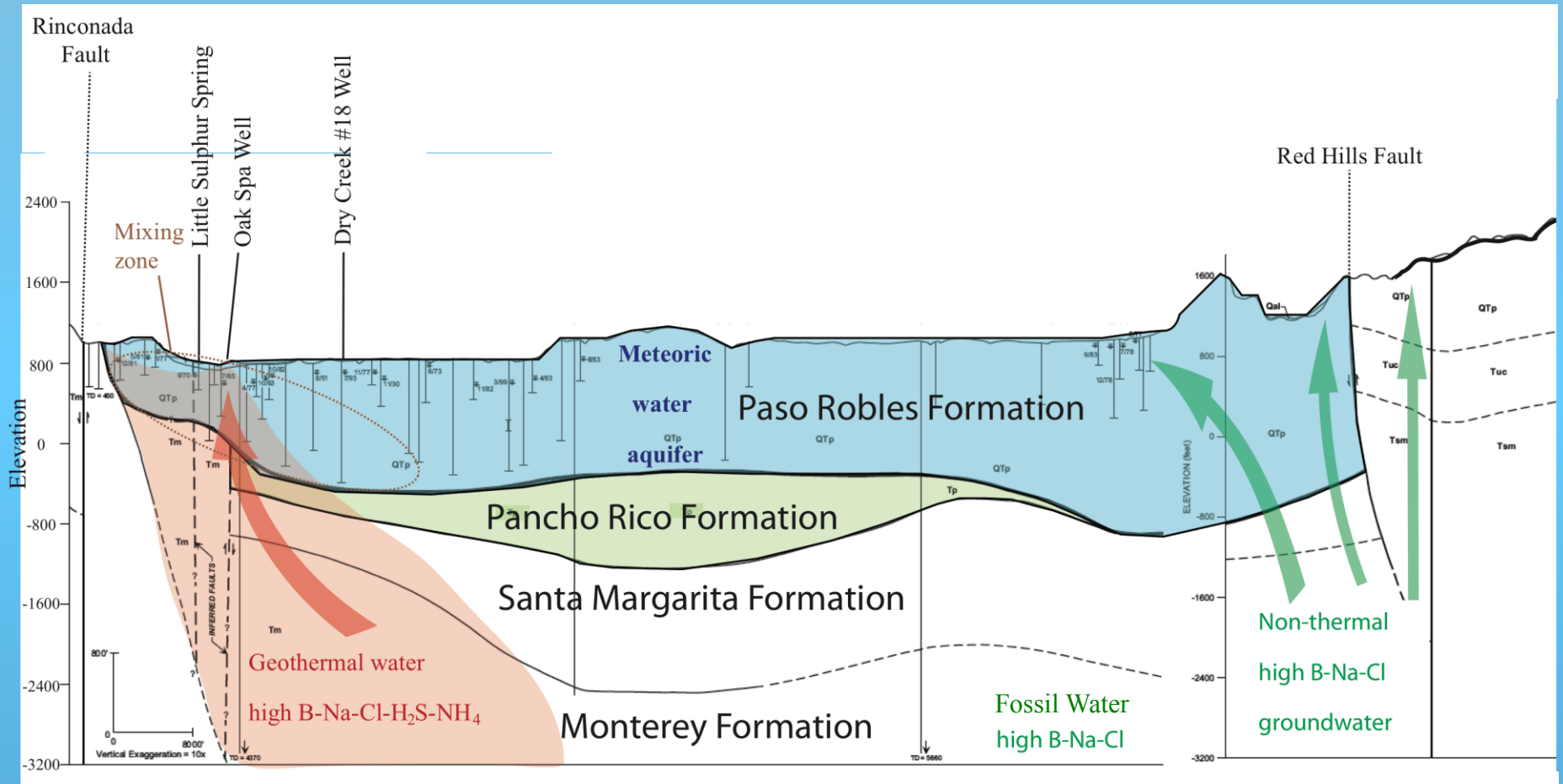


Figure 5

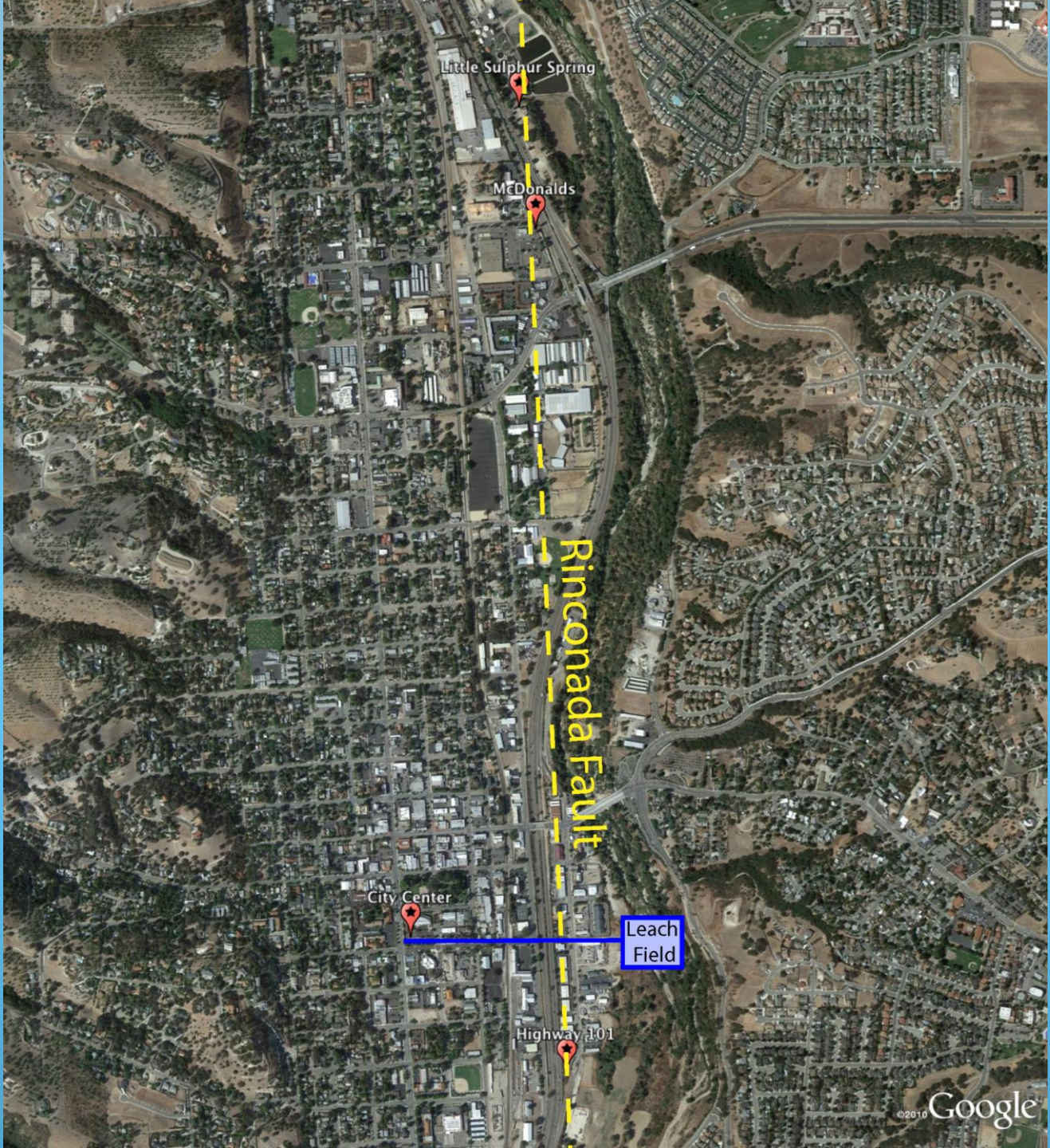
Index to Geologic Mapping Sources

1. Rosenberg, L.I., 2001, Geologic resources and constraints, Monterey County, California: unpublished report to County of Monterey Planning Department
2. Fugro West, Inc., 1999, County of San Luis Obispo and cities Seismic Safety Element update: unpublished report to County of San Luis Obispo Planning Department
3. Rosenberg, L.I., 2002, unpublished digital compilation: adapted from DBNec, T.W., Jr., 1971, Geologic map of the Parkfield quadrangle, USGS Open File Map 71-89
4. Graham, S.E., Mahony, T.M., Blissenbach, J.L., Mariani, J.J., and Westworth, C.M., 1999, Regional geologic map of San Andreas and related faults in Carmelo Plain, Temblor, Caliente and La Pasa Ranges and vicinity, California: A digital database: USGS Open-File Report 99-14; adapted from DBNec, T.W., Jr., 1973, U.S. Geological Survey Miscellaneous Geologic Investigations Map 1-757
5. Rosenberg, L.I., 2002, unpublished digital compilation: adapted from DBNec, T.W., Jr., 1971, Geologic map of the Paso Robles quadrangle, USGS Open File Map 71-89
6. Rosenberg, L.I., 2002, unpublished digital compilation: adapted from DBNec, T.W., Jr., 1974, Geologic map of the San Luis Obispo 15-minute quadrangle: USGS Open File Report 74-223

West to East Cross Section of Central Paso Robles Groundwater Basin



Hot springs formed
after the 2003
San Simeone
Earthquake



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 to
Paso Robles Formation
52% geothermal water
48% meteoric water

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

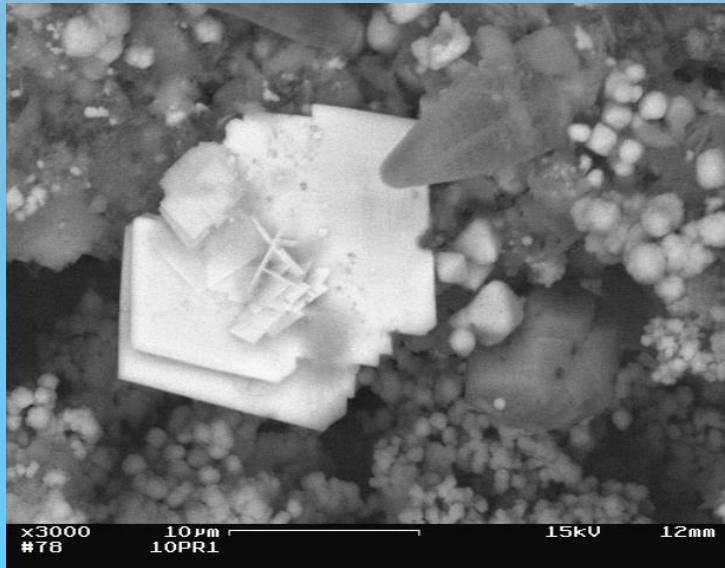
Water Board required treatment of hot spring effluent.

Water pumped to leach field on Salinas River flood plain.

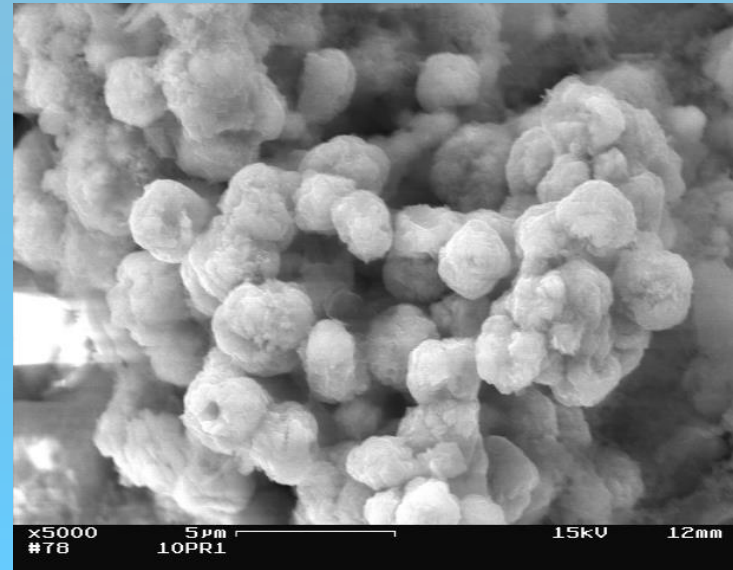
Natural Gas Evasion: CH₄ (59.5%)
N₂ (33.2%)
CO₂ (7.3%)
H₂S (0.8%--lethal)
C₂H₆ (0.2%)

Precipitates consist of elemental sulfur,
Iron sulfide and barite.

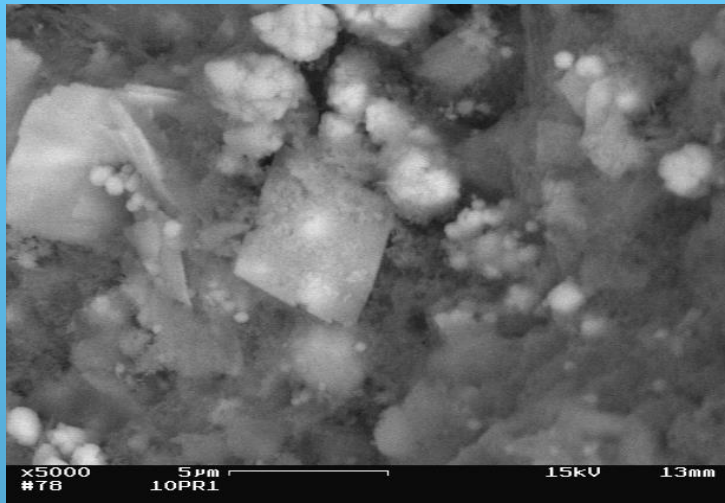
Precipitates in Paso Robles City Square Hot Spring Pool



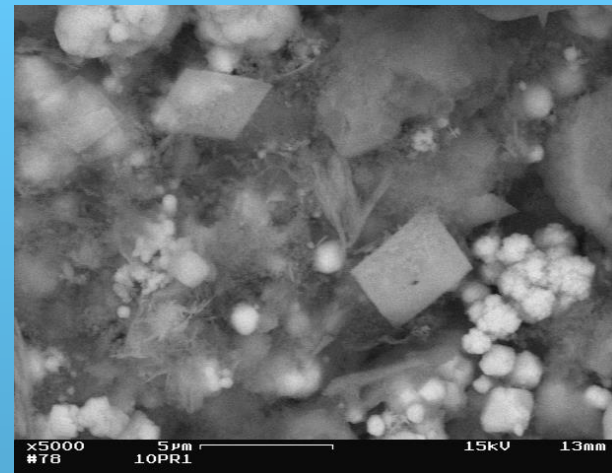
Sulfur crystals (white) and pyrite (spheres) and elongate diatoms



Pyrite (iron sulfide) Spheres



Barite crystals and pyrite (spheres)



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

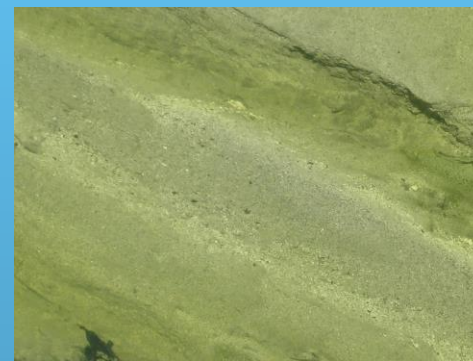
Effluent from Paso Robles City Square Hot Spring at Salinas Flood Plain



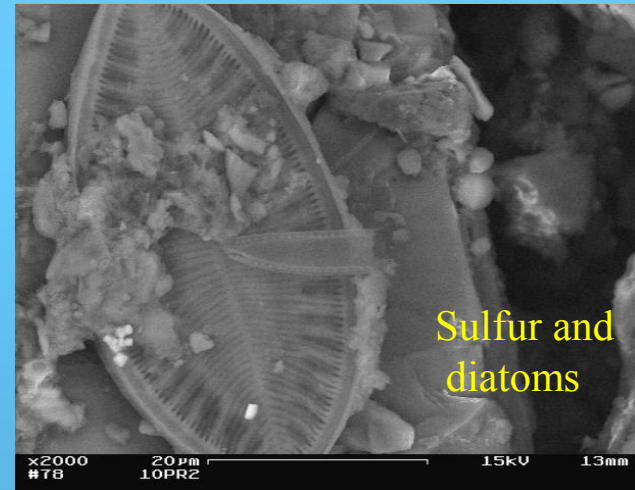
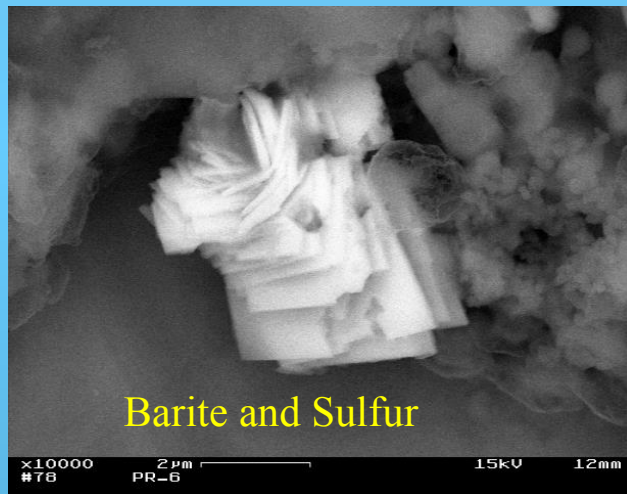
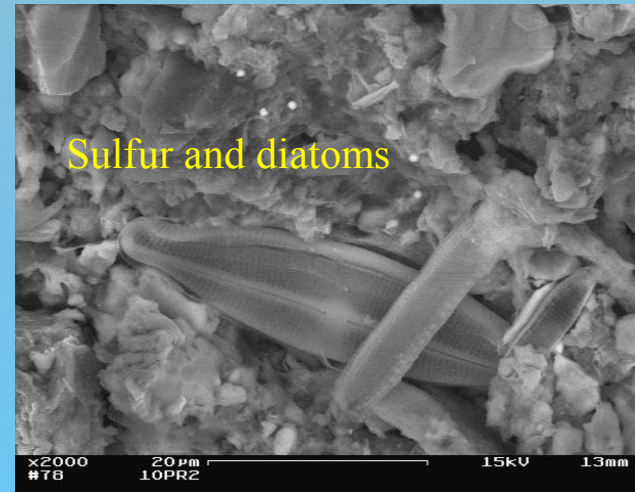
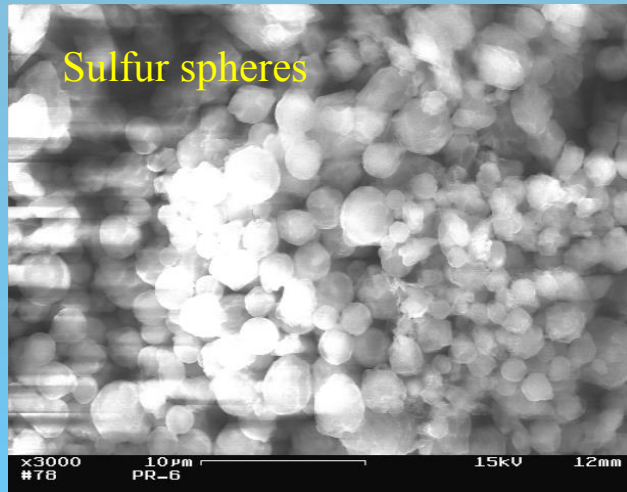
Colloidal sulfur remains in suspension in effluent



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°C based on Na-K-Ca geothermometer, 89-118°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 formation flow along fractures to the east of the Rinconada Fault
 - d) geothermal water mixes with meteoric water in the Paso Robles Formation aquifer

City Water Wells

Paso Robles and Templeton City water wells sampled.

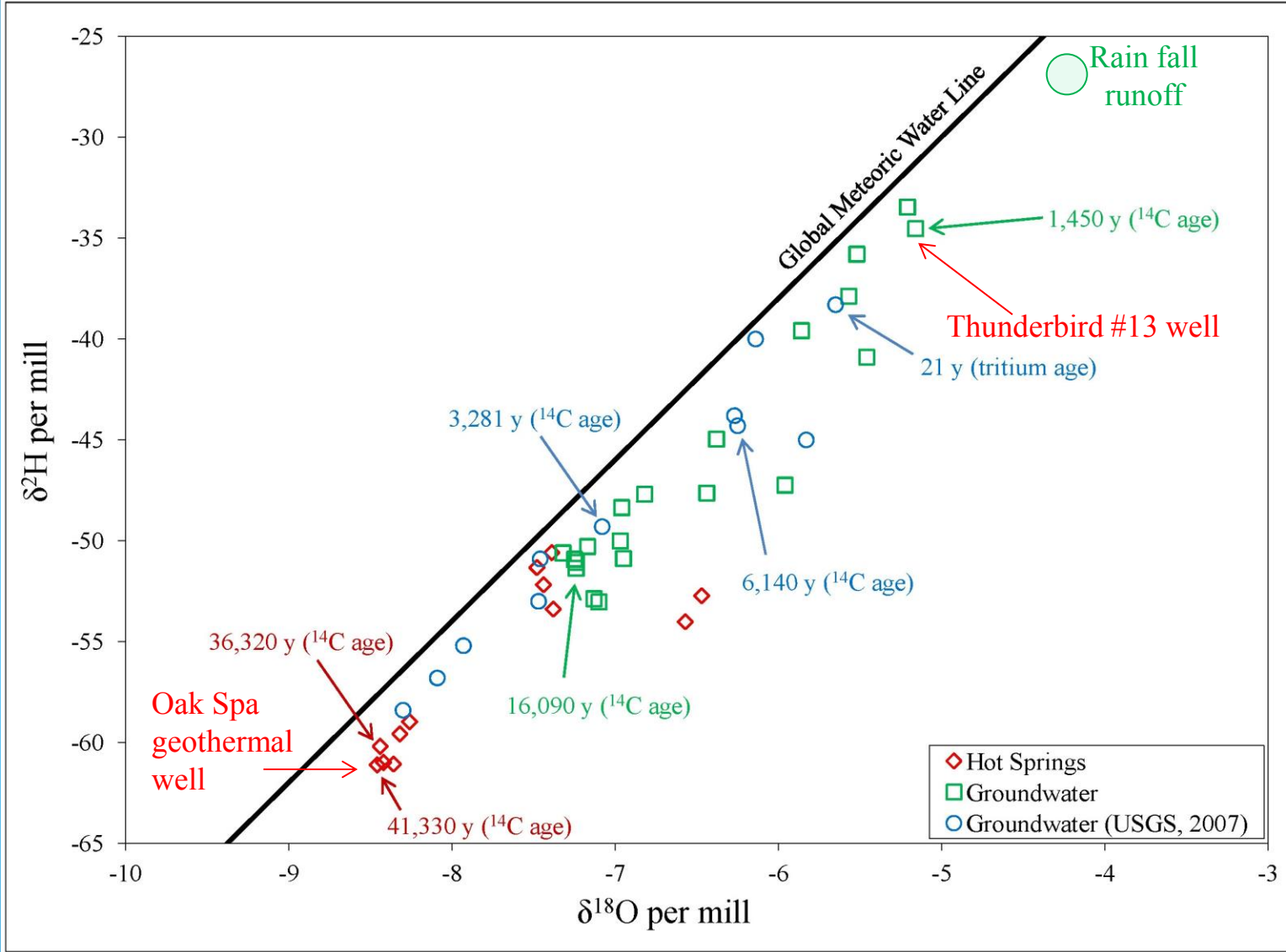
Waters analyzed for major and minor elements and isotopes of oxygen ($\delta^{18}\text{O}$), deuterium, carbon (^{13}C and ^{14}C), tritium, and sulfur.

A photograph of a white, rectangular metal pump house for a water well. The structure has a door with a warning sign and a vent on the roof. A large electric motor is mounted on a concrete base in front of the building. The well is situated outdoors with trees and a fence in the background.

Thunderbird #13

- 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)

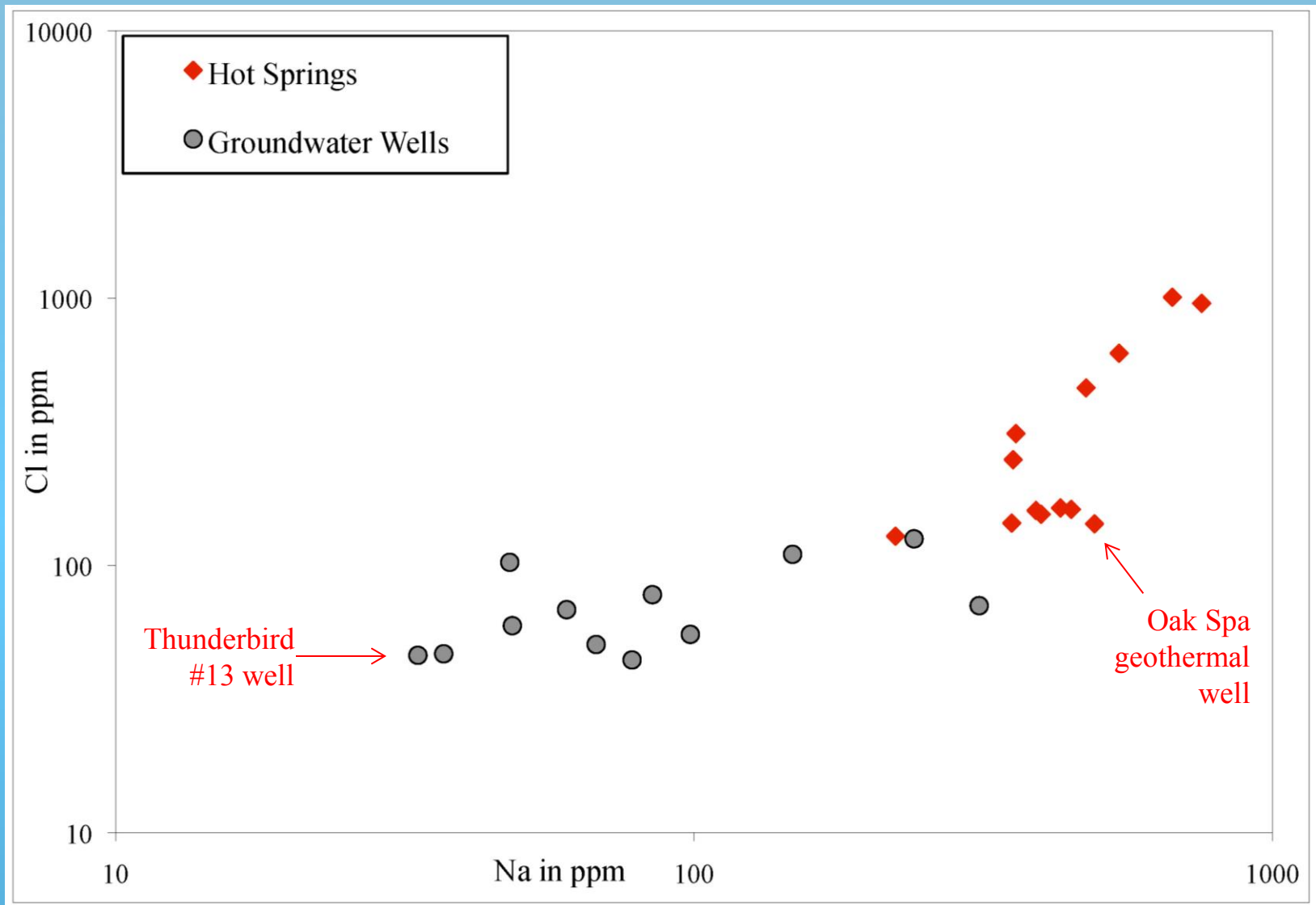




Isotopic composition of waters define a two end member mixing line:

- **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

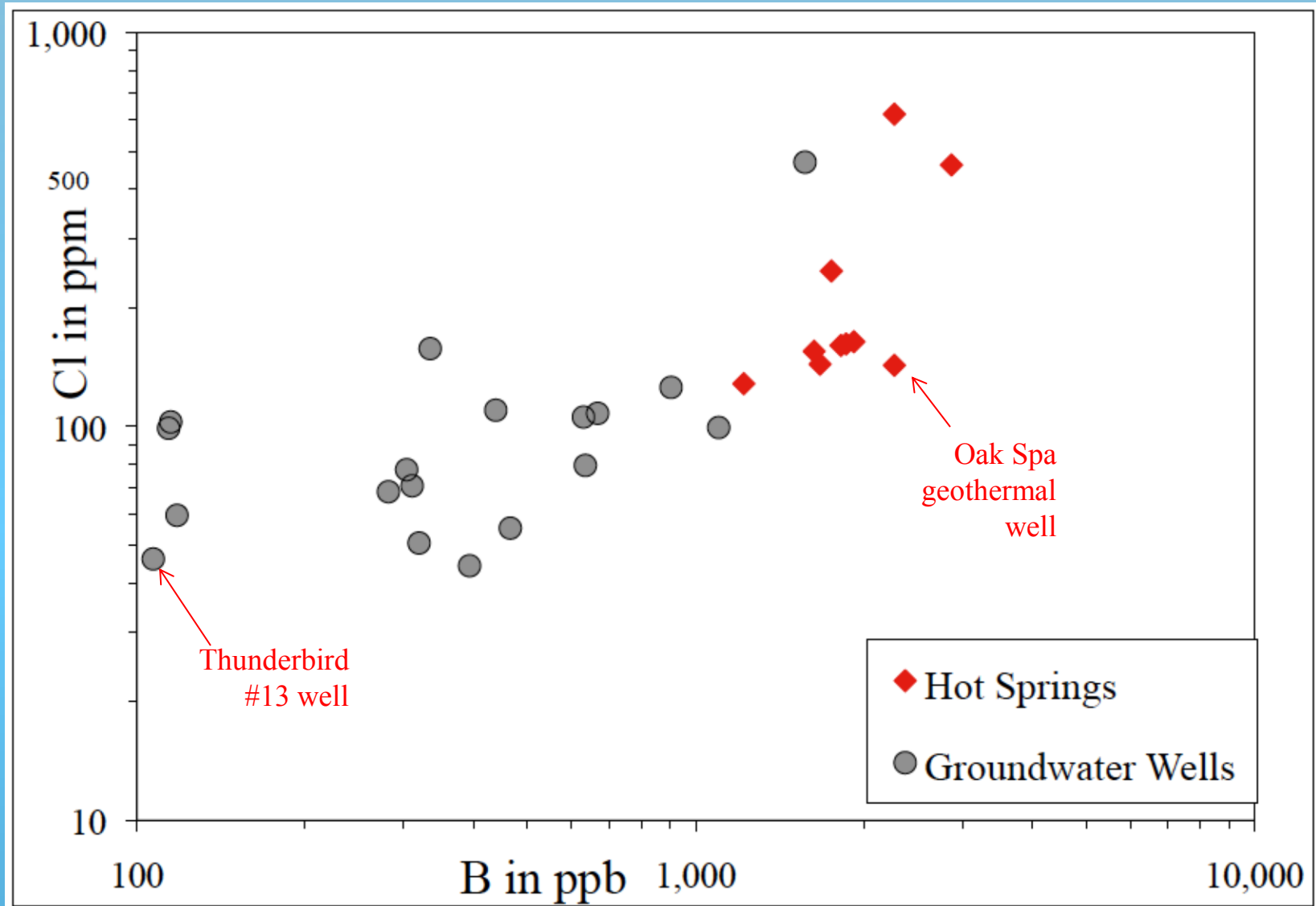
Sodium (Na) and Chloride (Cl) concentrations in Meteoric and Geothermal Water



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

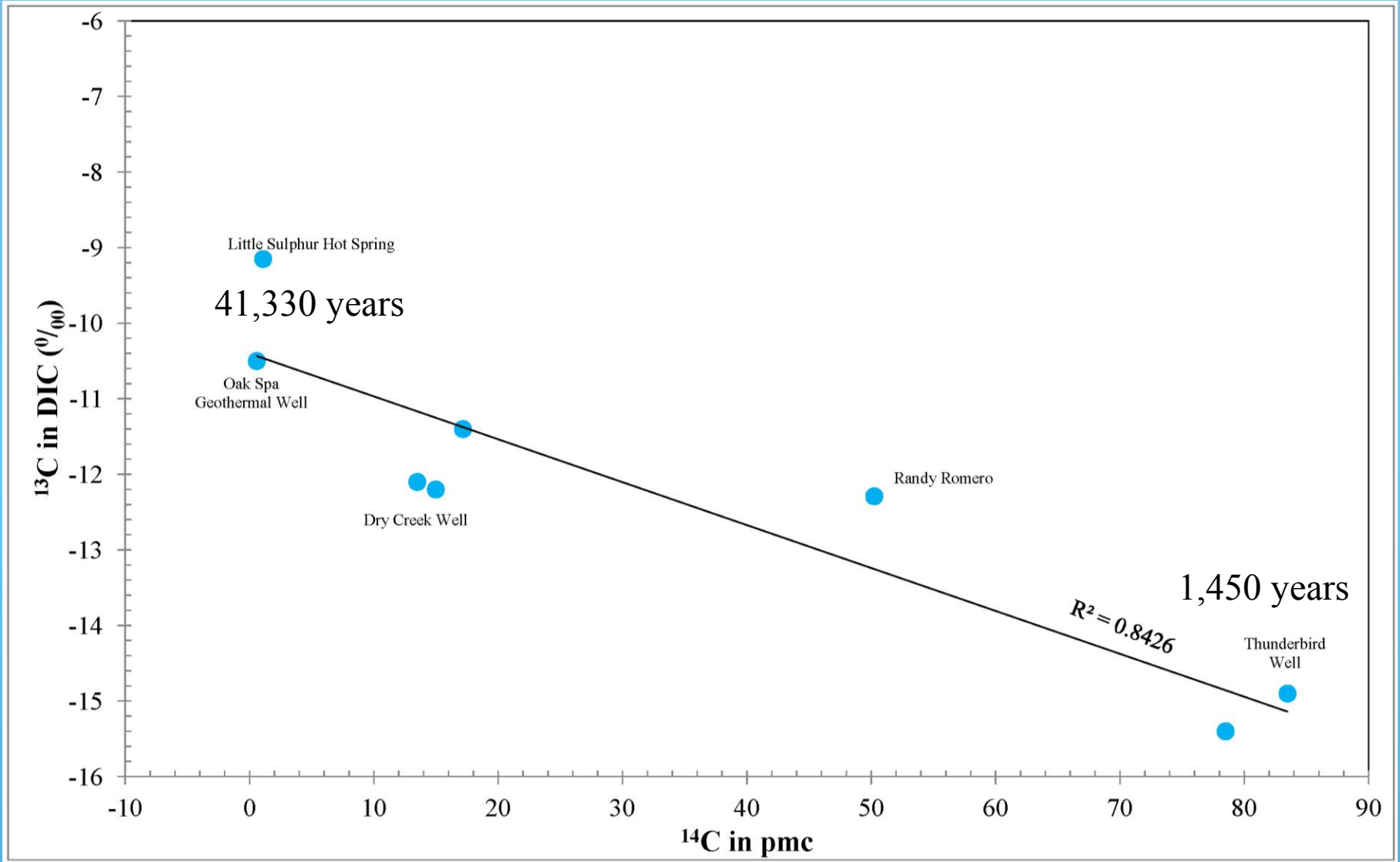
Boron (B) and Chloride (Cl) concentrations in Meteoric and Geothermal/Fossil Water



B and Cl water chemistry define a two end member mixing line:

- Meteoric water in Thunderbird drinking water well (low B, Cl);
- Geothermal/fossil water from the Oak Spa Hot Spring well (high B, Cl)
- Water wells have variable B and Cl concentration caused by mixing with geothermal/fossil water

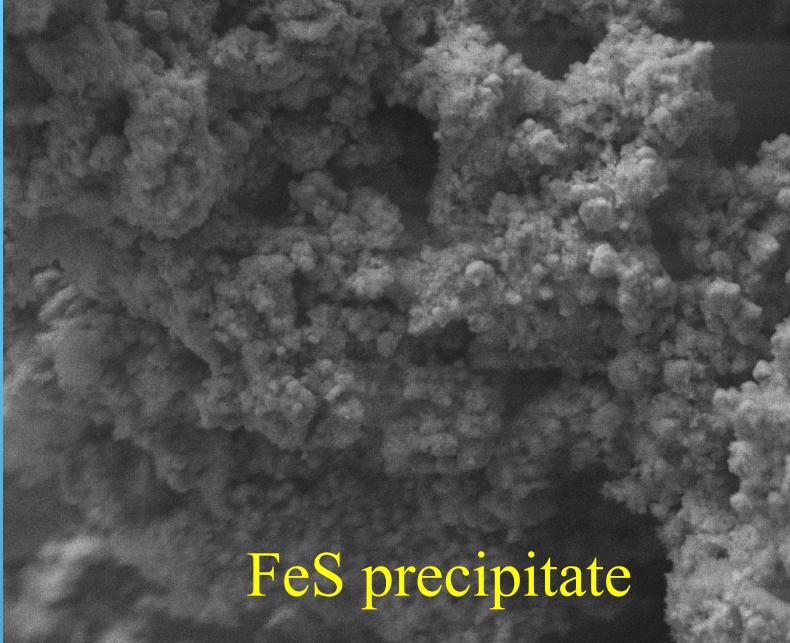
Carbon Isotopes In Waters



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



FeS precipitate

Characteristics of Geothermal End Member

- High temperature, saline
- High concentrations of Boron (B), Chloride (Cl), Sodium (Na), Iron (Fe), Manganese (Mn), and ammonia (NH₄)
- Relatively old water (41,000 years), enrichment in ¹³C indicates deep (greater than 25 kms) carbon source from upper mantle

% Meteoric Water in Hot Springs and Geothermal Wells

<u>Hot Springs</u>	<u>% Meteoric Water</u>	<u>Geothermal Fluid Source</u>
– Oaks Spa Well #1	0.0%	Deep well, west side basin, in Monterey
– Paso Robles Inn Spa	0.0%	Basin Bounding Rinconada Fault
– Little Sulfur Springs	20.7%	Unnamed Fault
– City Square Hot Spring	23.9%	Basin Bounding Rinconada
– McDonalds Sidewalk	27.5%	Basin Bounding Rinconada Fault
– Highway 101 Exit Spring	28.0%	Basin Bounding Rinconada Fault
– Franklin Hot Spring Spa	48.2%	Deep well, central basin, in Monterey

% Geothermal Water In Paso Robles and Templeton Water Wells and Vineyard and Agriculture Wells West Side of Basin

<u>Water Well</u>	<u>% Geothermal Fluid</u>	<u>Water Quality</u>
• Thunderbird #13	0.0%	Good
• Creek Side (alluvial aquifer)	0.0%	Good
• Luft vineyard well	0.0%	Boron 92 ppb
• Butterfield #12	9.7%	Good
• Ronconi #4	8.7%	High Fe, Mn
• Sherwood #9	10.1%	High Fe, Mn, H ₂ S
• Tarr #19	10.5%	Good
• Star Farm Well #1	24.7%	Boron 630 ppb
• Creek Side 300' deep	26.5%	High Fe, Mn, H ₂ S
• Borchert #5 (unpotable)	37.3%	High Fe, Mn, H ₂ S, NH ₄

% Fossil Water with High Boron Concentration In Shandon, Vineyard, and Agriculture Wells East Side of Basin

<u>Water Well</u>	<u>% Fossil water</u>	<u>Water Quality</u>
• Shandon SH-35	1.2%	Good
• Shandon SH-31	1.1%	Good
• Ranch Well, S of Shandon	11.2%	Boron 335 ppb
• Vineyard well	24.9%	Boron 635 ppb
• Ranch Well, E of Shandon	67.9%	Boron 1570 ppb

Summary

- Ground water wells locally contaminated with geothermal water derived from the Monterey Formation,
 - a) adjacent to Rinconada fault zone and related faults
 - b) fractures in Paso Robles Formation permit 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)
- East side basin wells
 - a) upwelling of fossil waters creates a potential Boron problem
 - b) No evidence of geothermal waters (high H_2S and NH_4)

West to East Cross Section of Central Paso Robles Groundwater Basin

