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

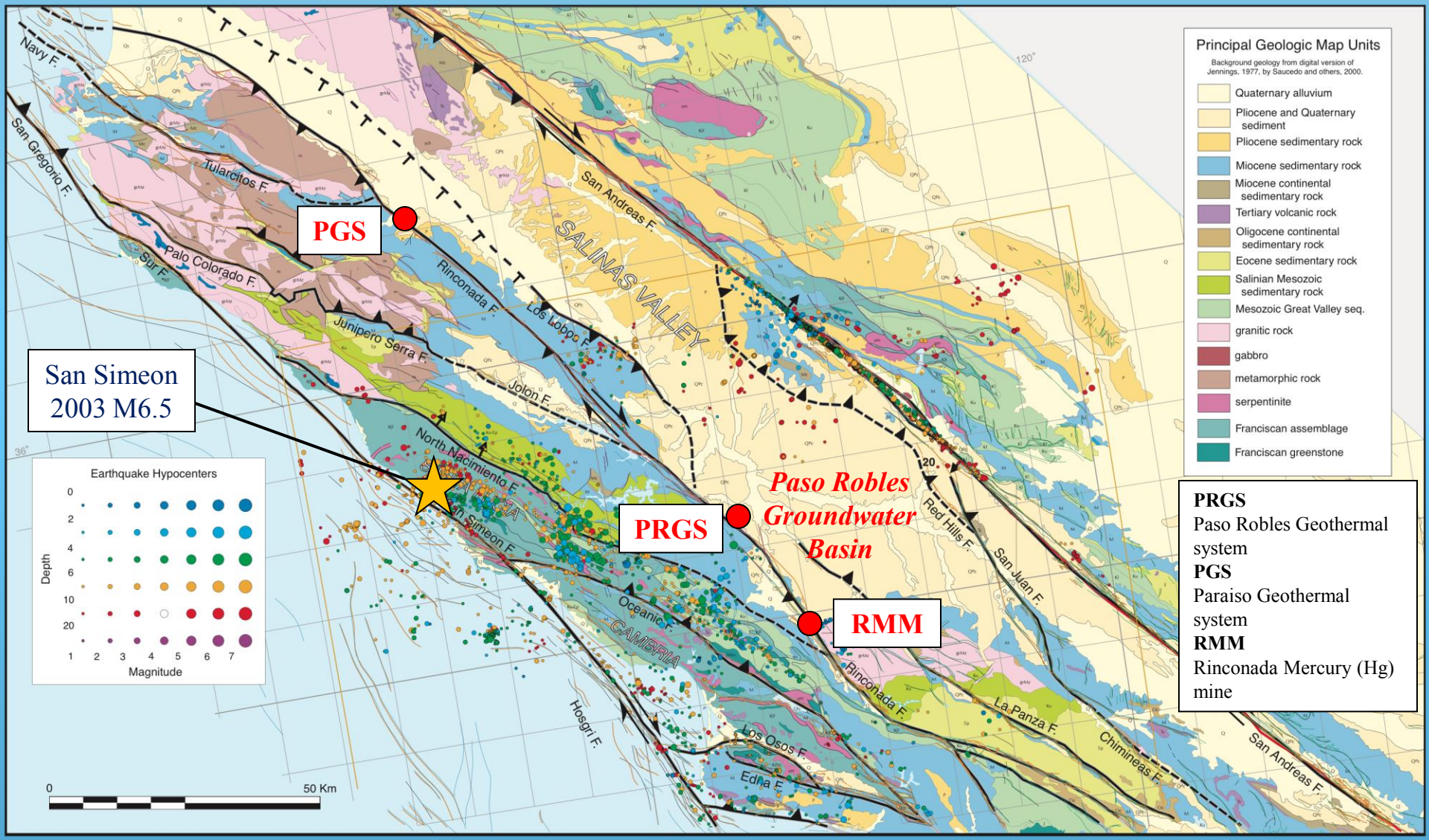
Paso Robles Groundwater Basin Study

- 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
- 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)

Geology and Earthquakes
Central Coast Ranges



MINERAL SPRINGS

AND

HEALTH RESORTS OF CALIFORNIA

WITH A

COMPLETE CHEMICAL ANALYSIS

OF

EVERY IMPORTANT MINERAL WATER
IN THE WORLD

ILLUSTRATED

A PRIZE ESSAY

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

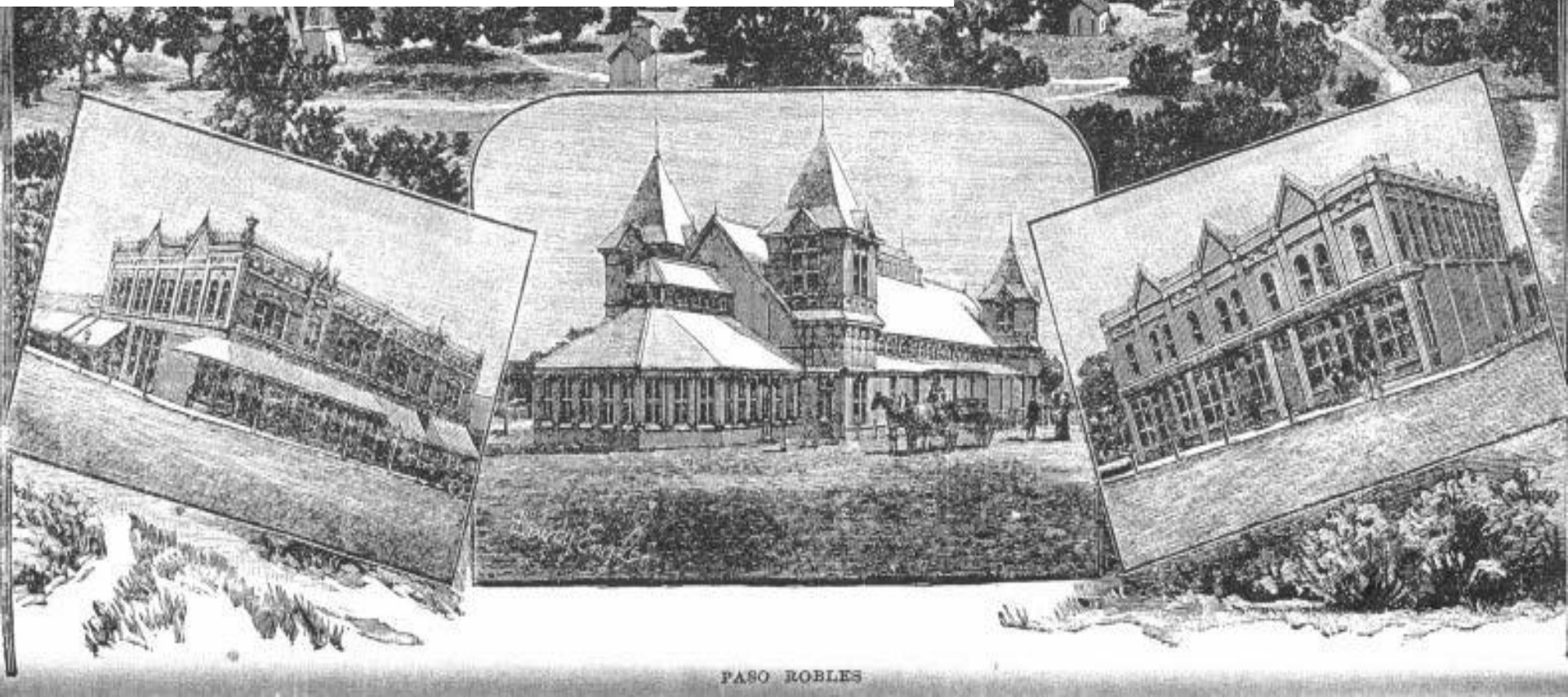
Asst. Chair Medical Chemistry and Materia Medica, and Teacher of Chemistry in the Laboratories of the University of California in the Medical and Dental Departments.
Member International Medical Congress; Member Congress of Hygiene and Demography.
Member of the American Medical Association, and of the 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
"Desiccated Human Remains;" "Adulterations in Food Products;" "Western Mummies;"
"Mortality in Diphtheria;" "Morphio-Mania," Etc., Etc.

SAN FRANCISCO
THE BANCROFT COMPANY

Paso Robles Hot Spring Health Resorts 1889

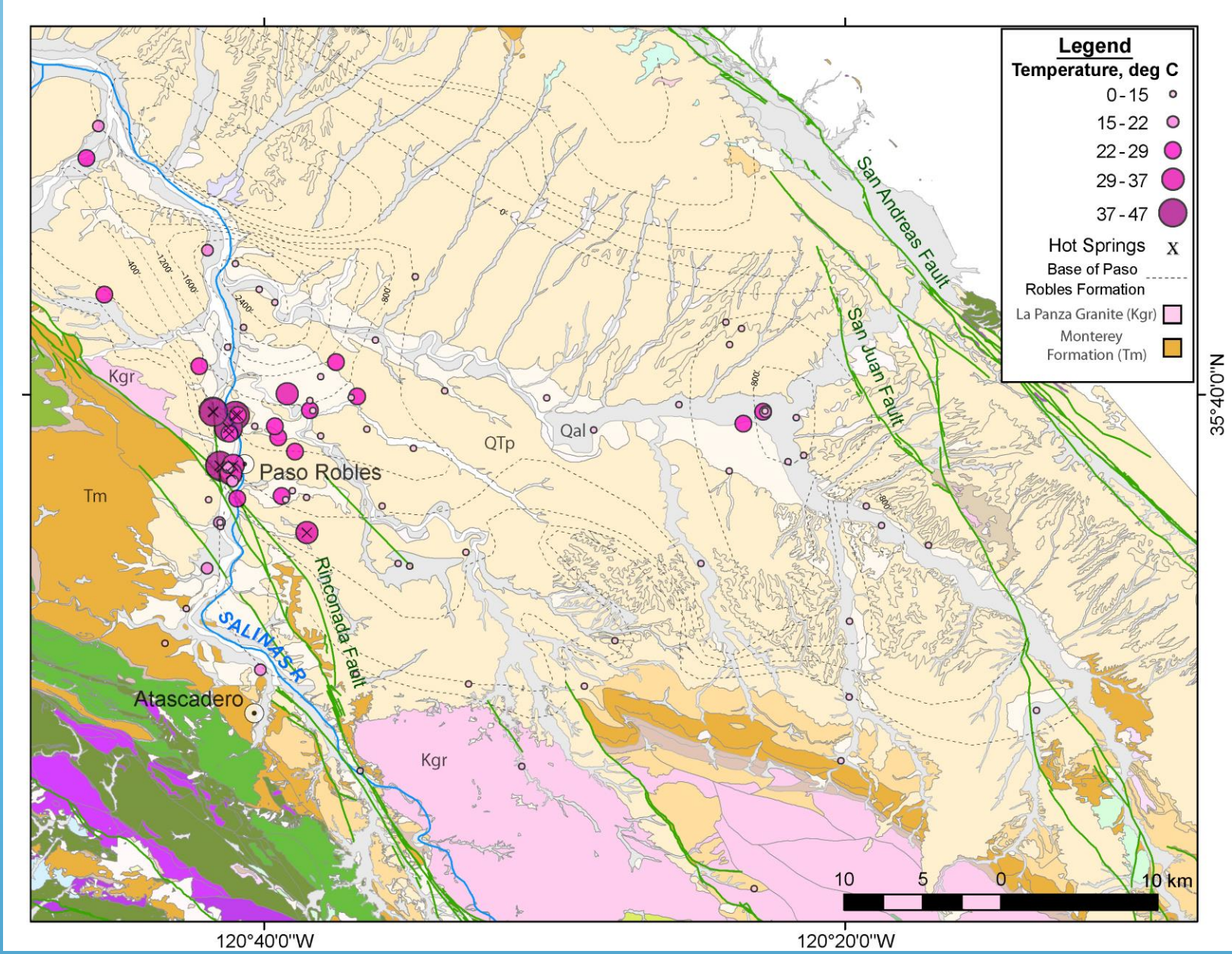
These waters are found to be especially serviceable in acute and chronic rheumatism and articular affections, scrofula, blood, glandular and cutaneous diseases. In catarrh of the naso-pharynx the water, used as a hot douche, has proved highly beneficial, likewise in leucorrhœal discharges and engorgement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

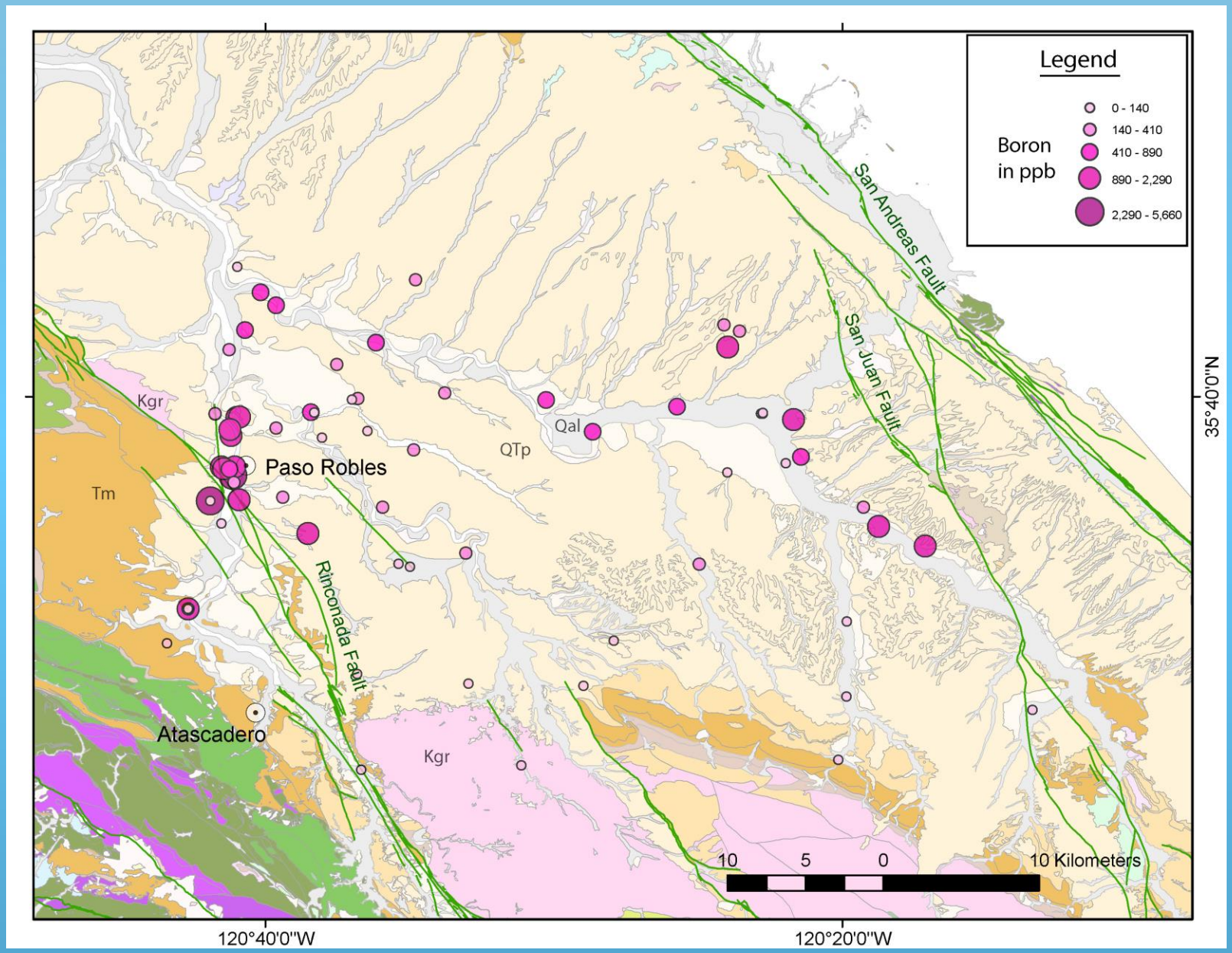


PASO ROBLES

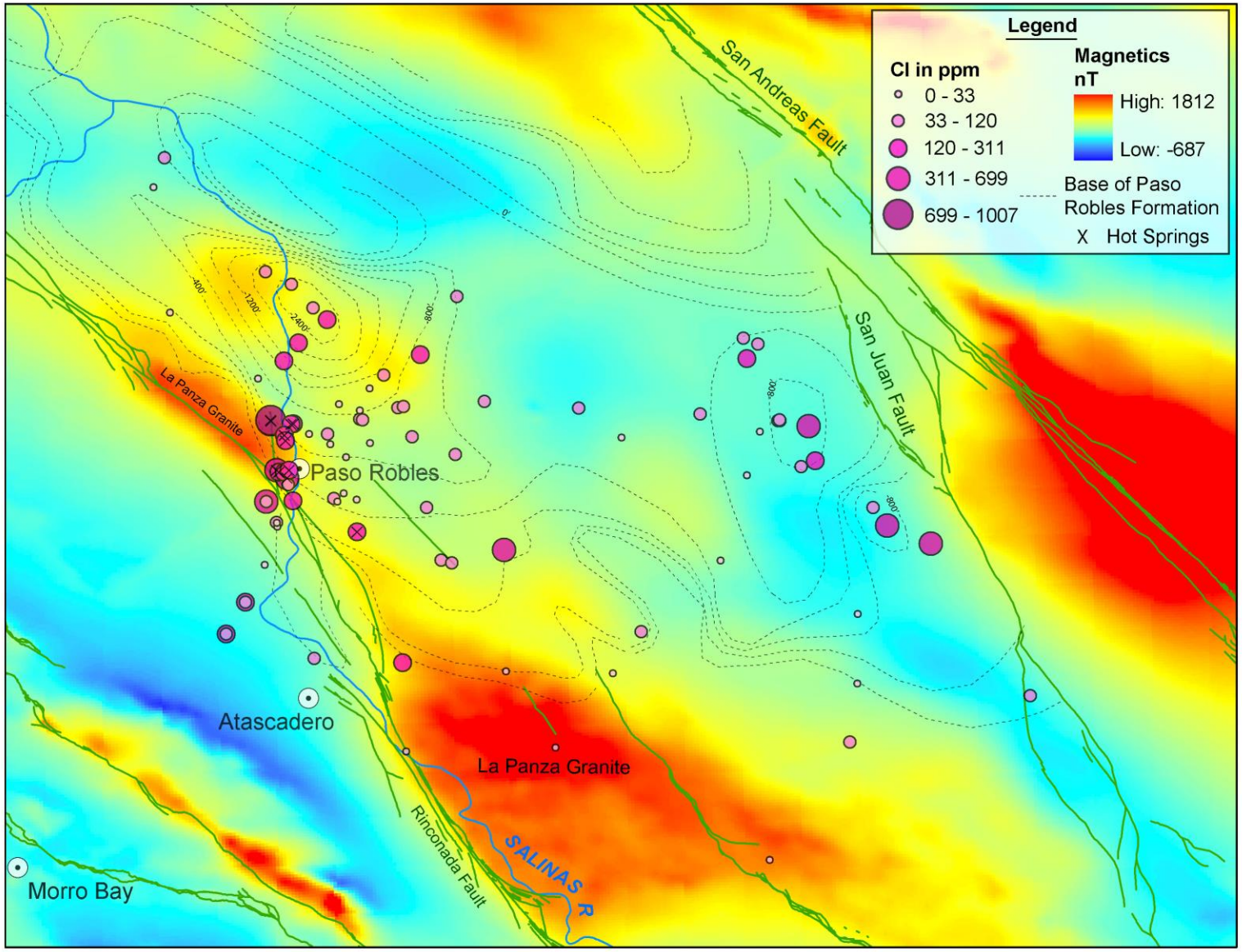
Temperature of hot springs, geothermal wells, and water wells



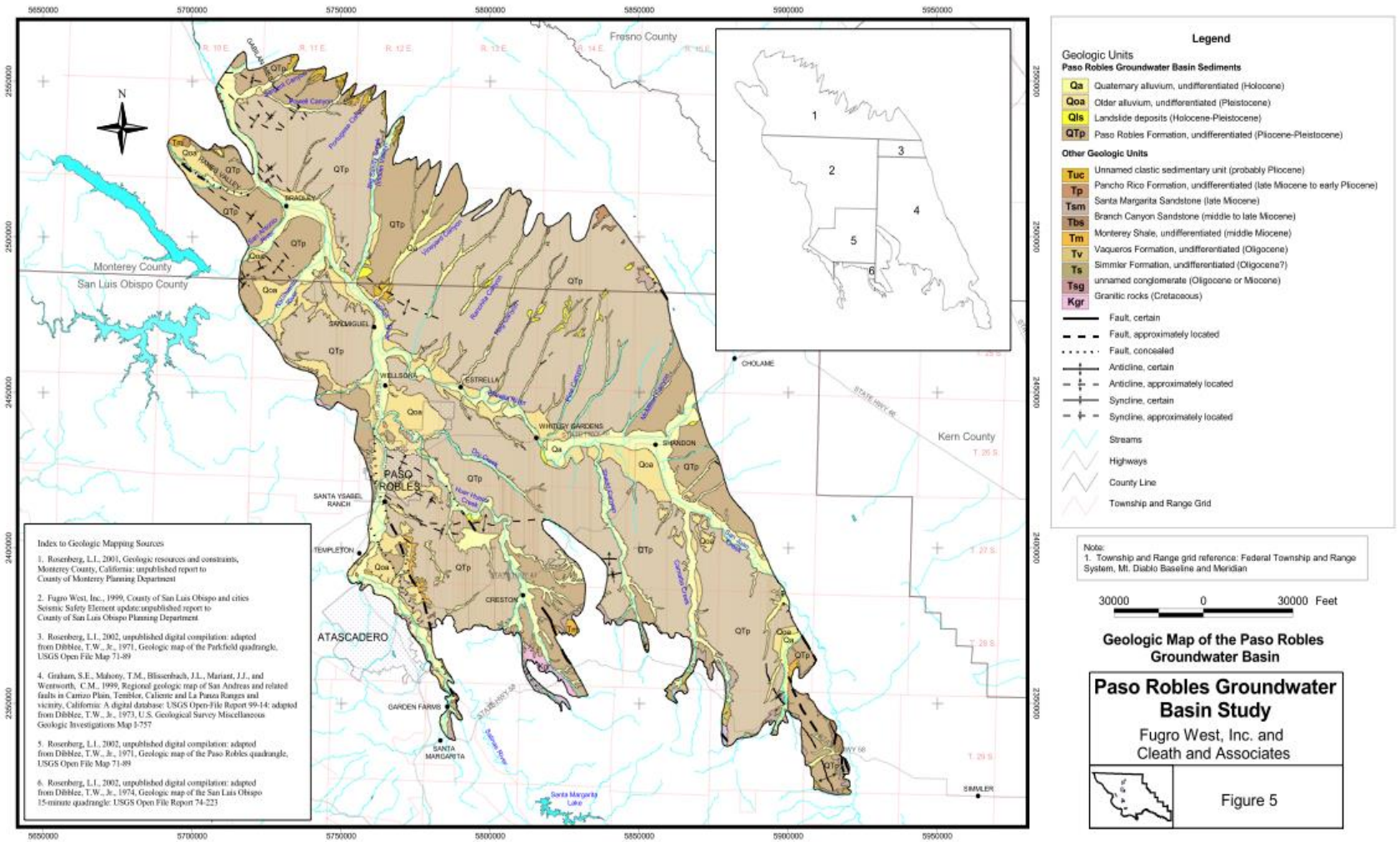
Boron concentrations in hot springs, geothermal wells, and water wells in PRGB



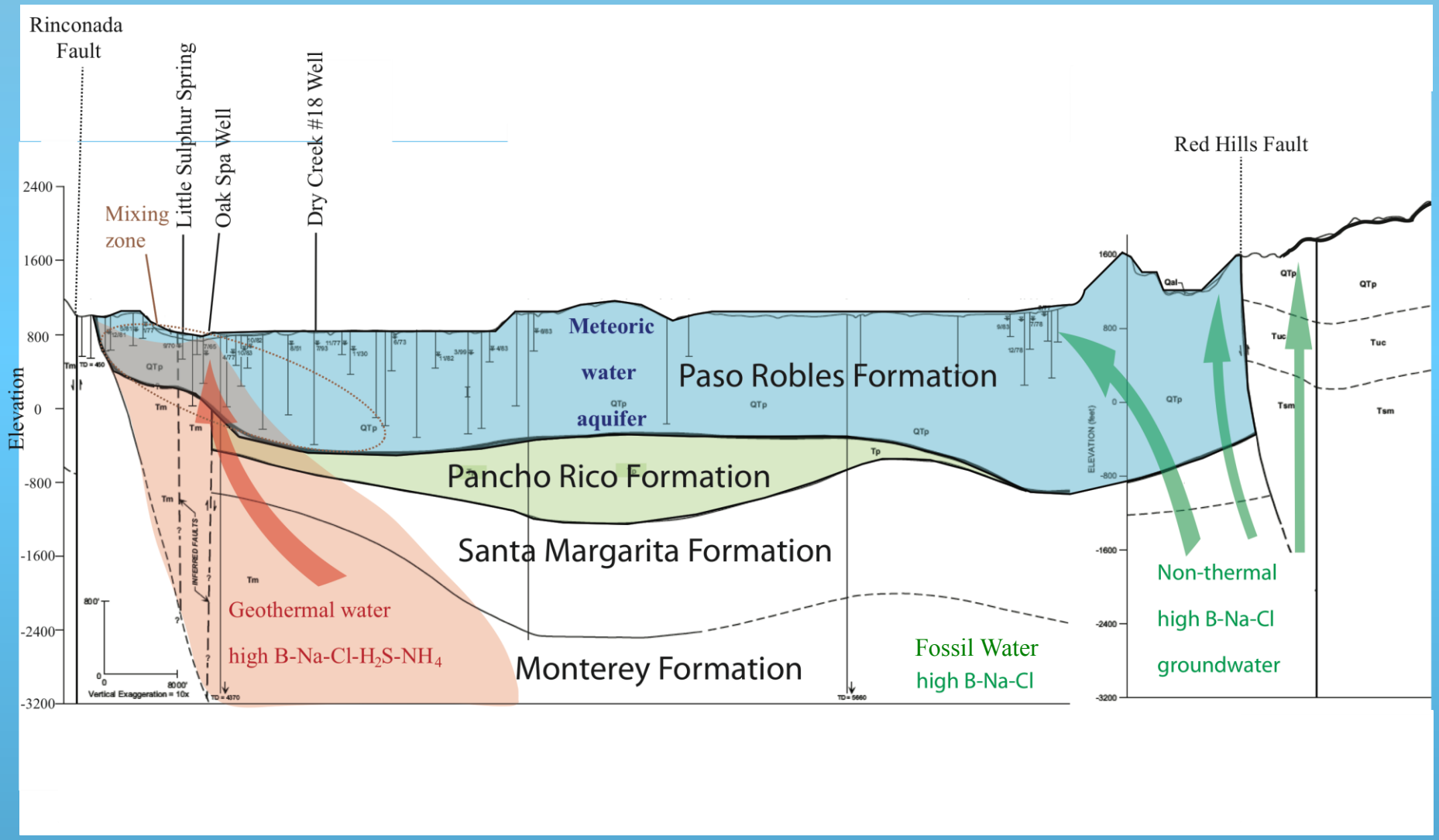
Magnetics and Chloride (Cl) in water



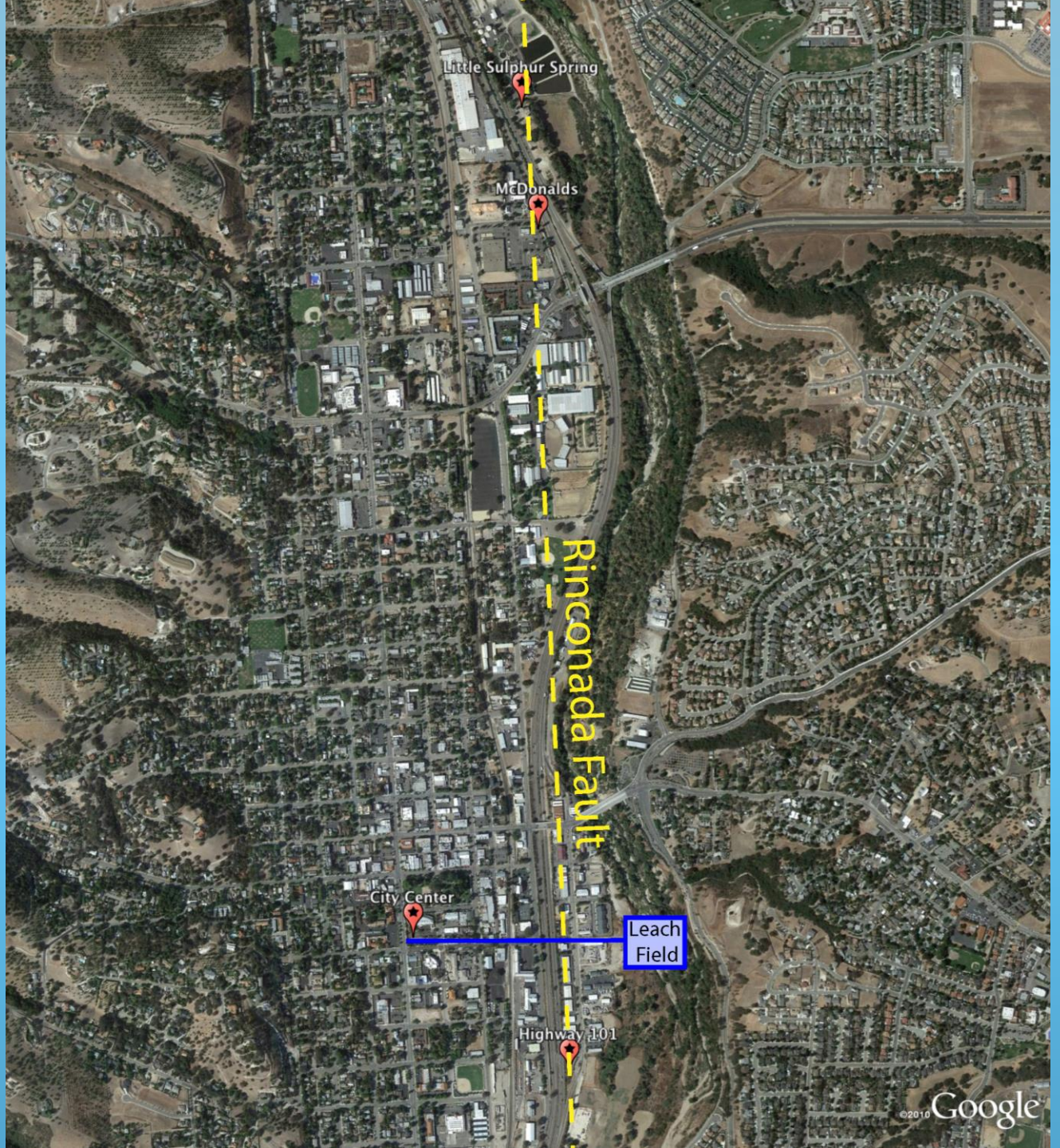
Paso Robles Groundwater Basin



West to East Cross Section of Central Paso Robles Groundwater Basin



Hot springs formed after the 2003 San Simeone Earthquake



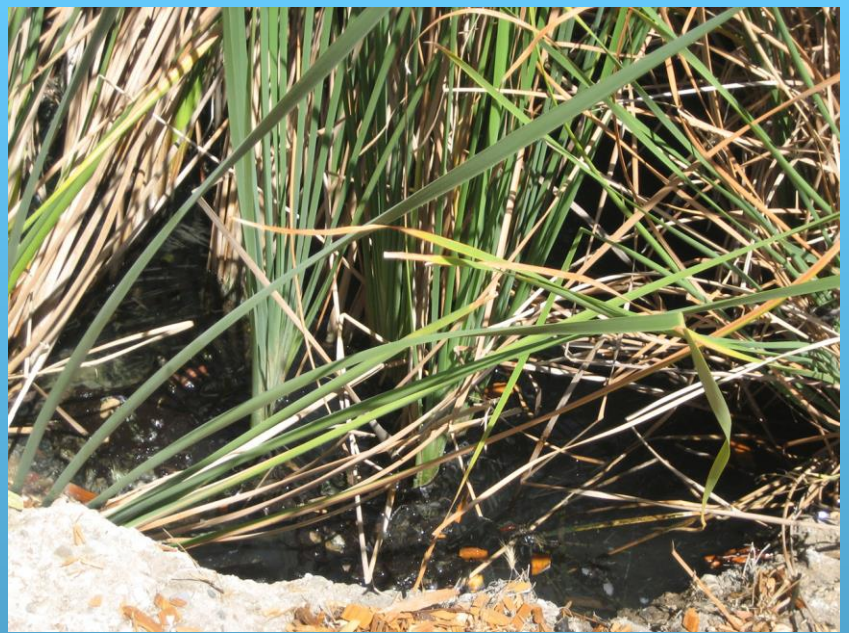
Hot spring vent in city center of Paso Robles developed after 2003 M 6.5 San Simeon Earthquake

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

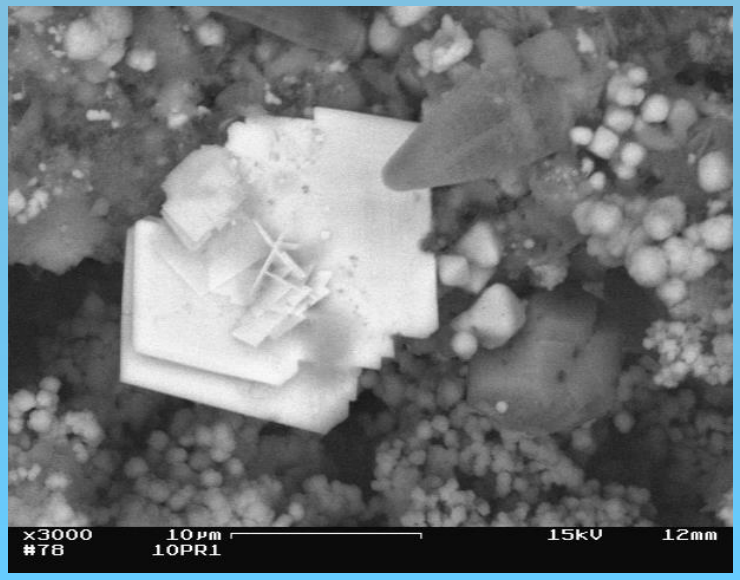
Hot spring water neutral (pH 6.85)-
Ca-Mg-carbonate-chloride water
Temperature 42.6°C

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

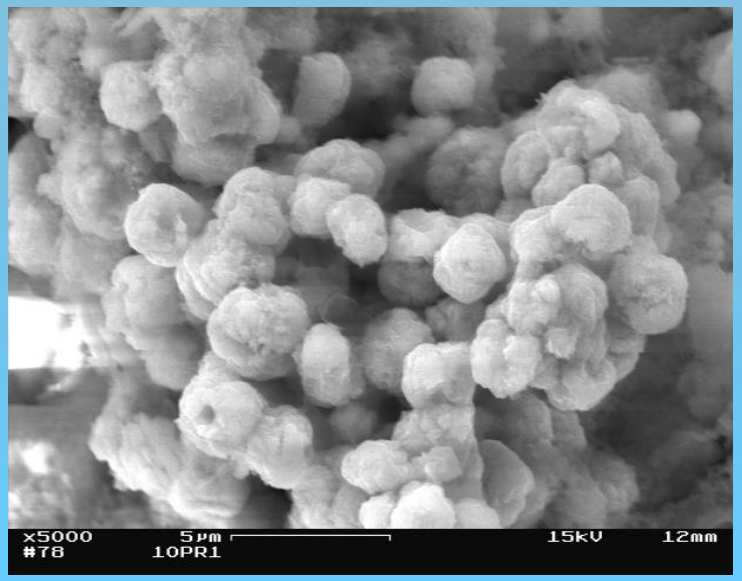
Natural Gas Evasion: CH_4 (59.5%)
N_2 (33.2%)
CO_2 (7.3%)
H_2S (0.8%--lethal)
C_2H_6 (0.2%)

Precipitates consist of elemental sulfur, Iron sulfide and barite.

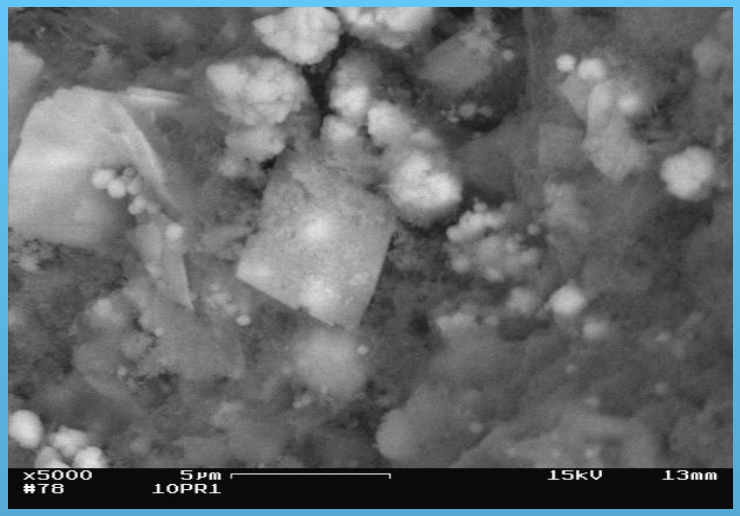
Precipitates in Paso Robles City Square Hot Spring Pool



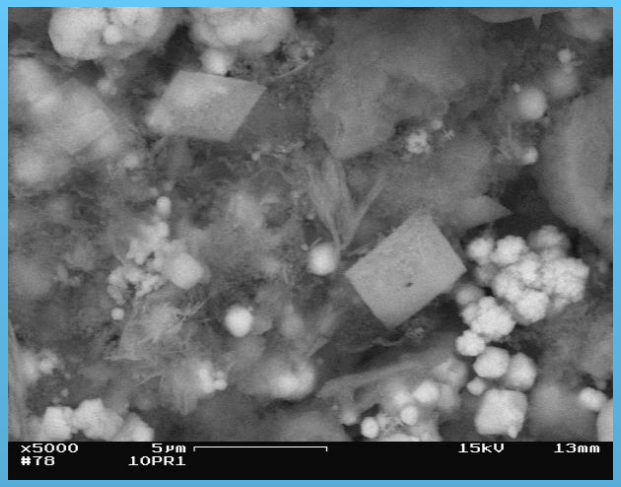
Sulfur crystals (white) and pyrite (spheres) and elongate diatoms



Pyrite (iron sulfide) Spheres



Barite crystals and pyrite (spheres)



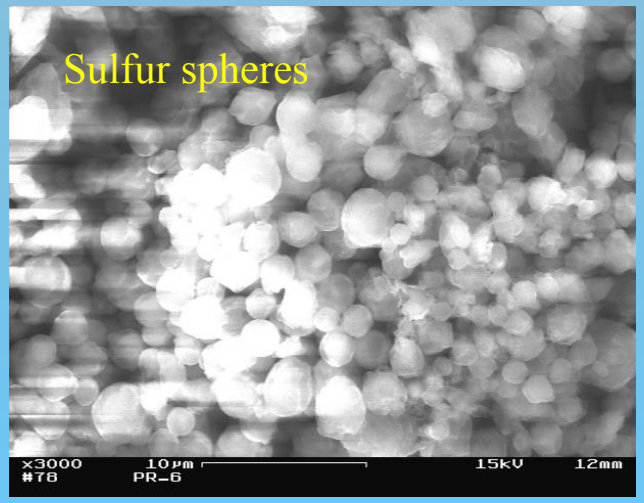
Barite crystals, pyrite (spheres) and Ca-Al-Silicate (fibrous phase)

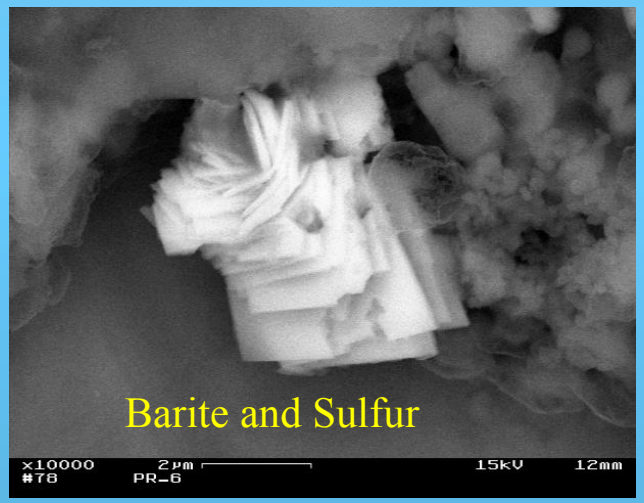
Effluent from Paso Robles City Square Hot Spring at Salinas Flood Plain

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 to the east of the Rinconada Fault

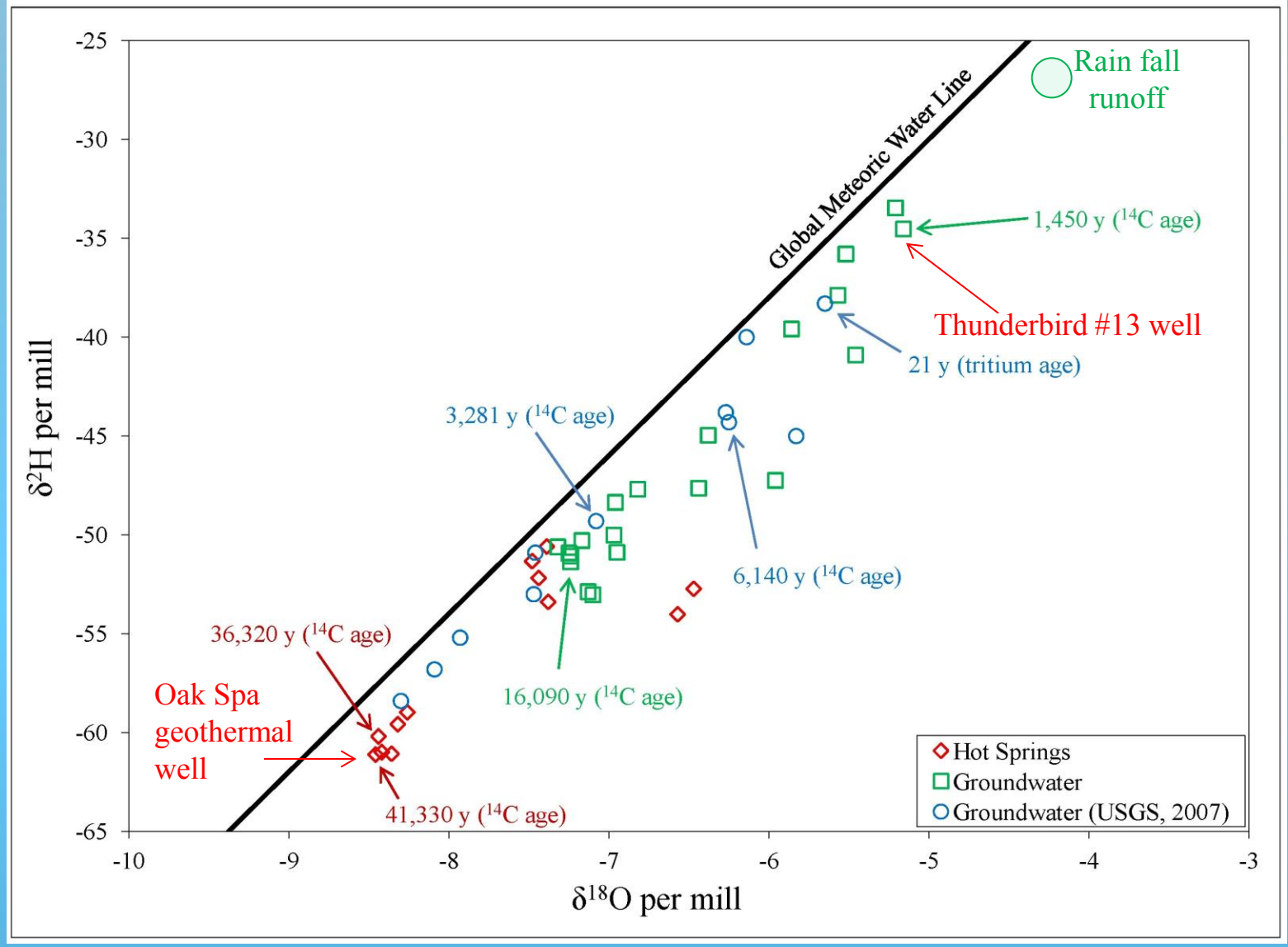
  d) geothermal water mixes with meteoric water in the Paso Robles Formation aquifer


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.

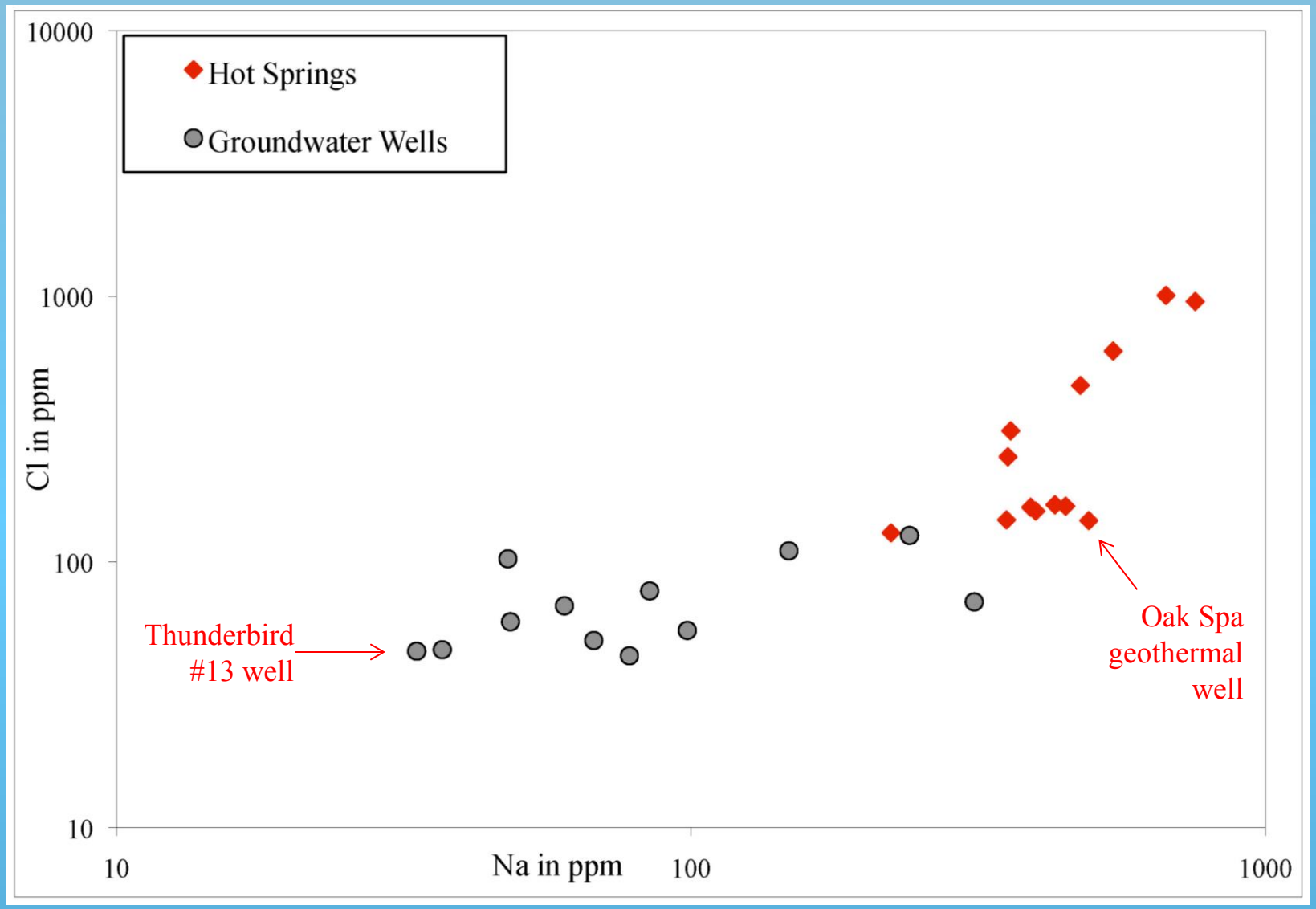
- Low temperature, meteoric water
- Low concentrations of Boron (B), Chloride (Cl), Iron (Fe), Manganese (Mn), and ammonium (NH_4), hydrogen sulfide (H_2S)
- Relatively young water based on isotopic signature: tritium,
- ^{14}C (pmc: % modern carbon)



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

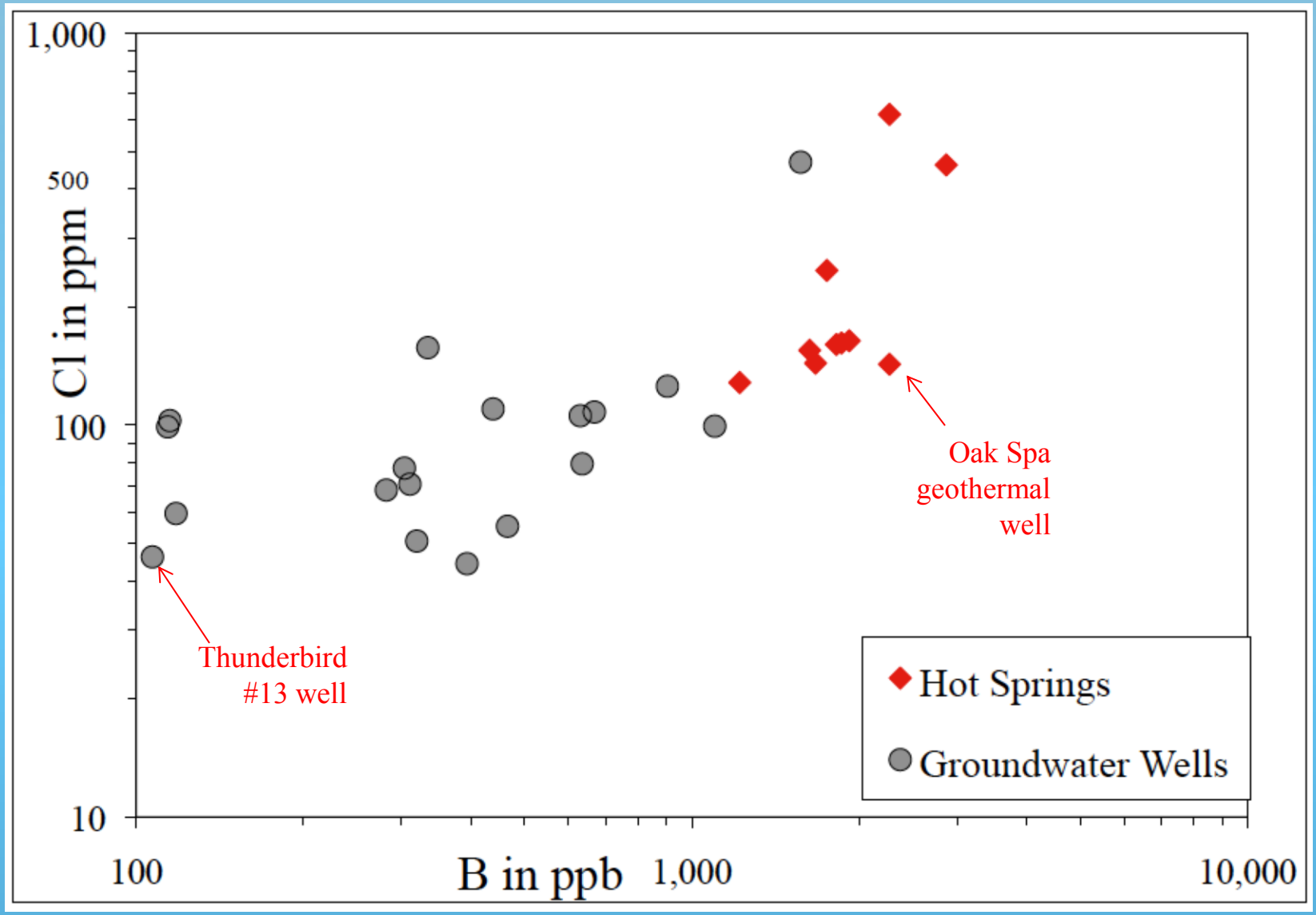
Sodium (Na) and Chloride (Cl) concentrations in Meteoric and Geothermal Water



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

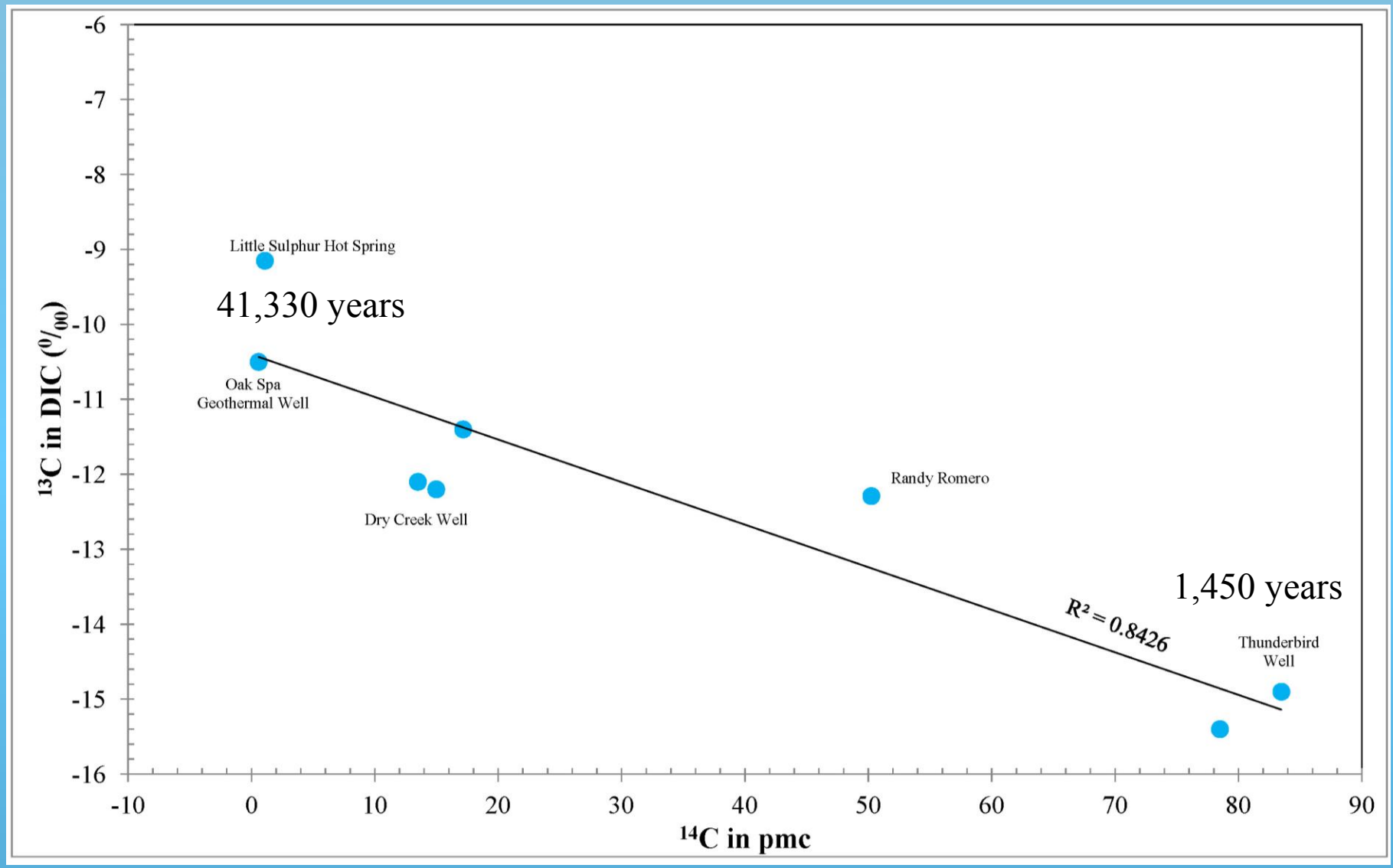
Boron (B) and Chloride (Cl) concentrations in Meteoric and Geothermal/Fossil Water



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

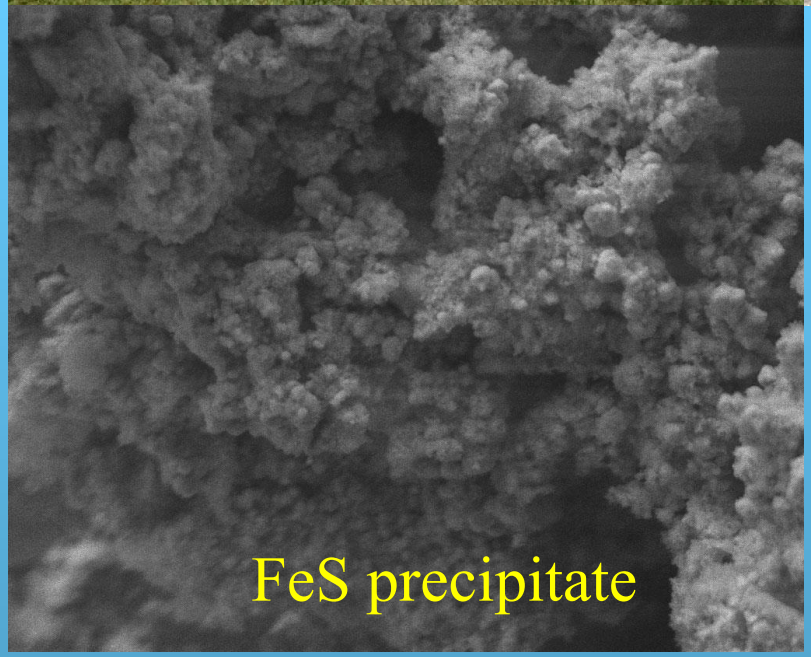
Carbon Isotopes In Waters



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



Characteristics of Geothermal End Member

- 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

% Meteoric Water in Hot Springs and Geothermal Wells

Hot Springs	% Meteoric Water	Geothermal Fluid Source
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

Water Well	% Geothermal Fluid	Water Quality
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_2S
Tarr #19	10.5%	Good
Star Farm Well #1	24.7%	Boron 630 ppb
Creek Side 300' deep	26.5%	High Fe, Mn, H_2S
Borchert #5 (unpotable)	37.3%	High Fe, Mn, H_2S, NH_4

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

Water Well	% Fossil water	Water Quality
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