Statistical and Spatial Analysis of Inorganic Anions, Cations and Radionuclides in California's Groundwater: establishing a background and analyzing spatial variability

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Andrew M. Renshaw

Lawrence Livermore National Laboratory

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Three Part Presentation

Part I: Radium & Hydraulic Fracturing

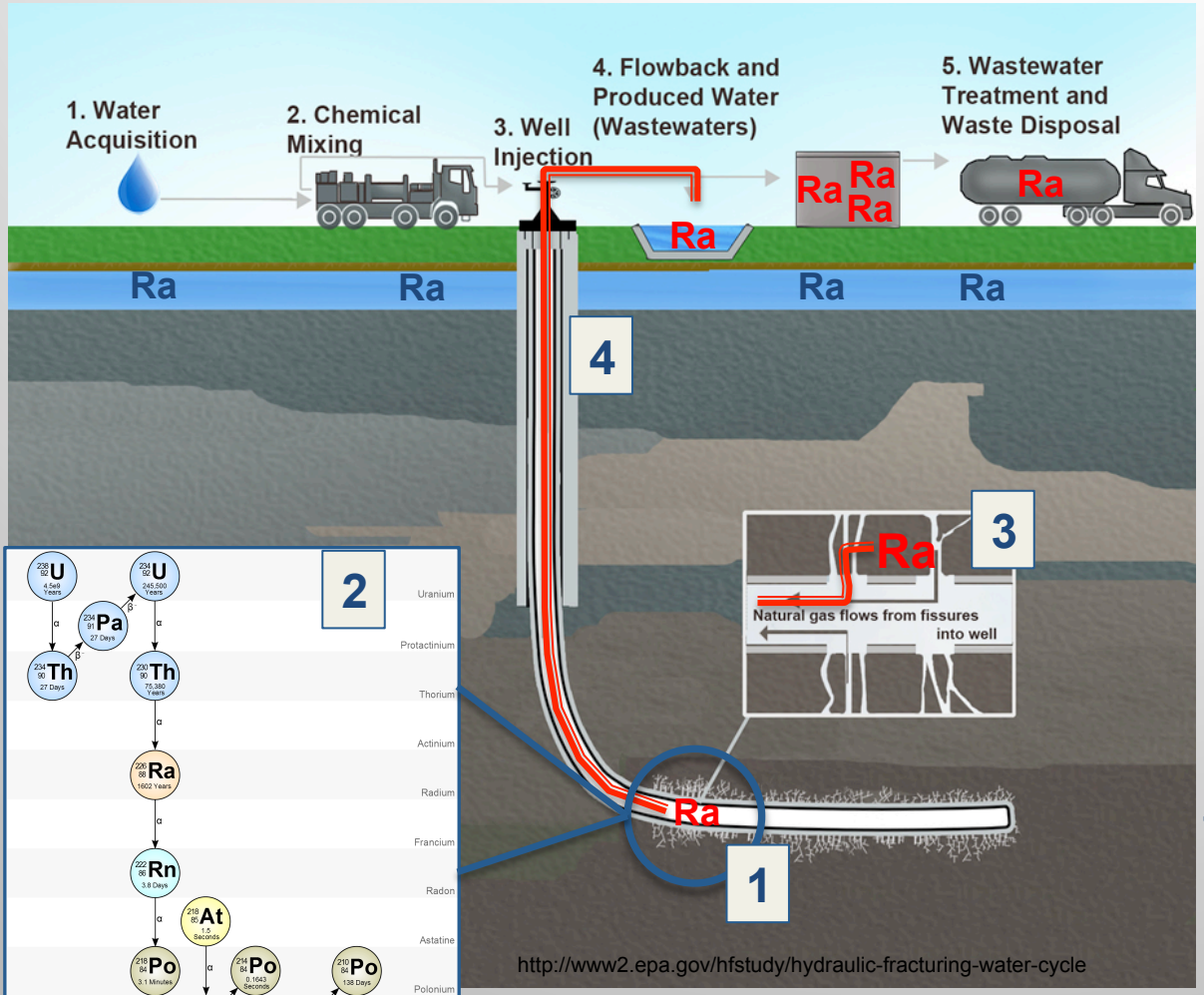
Part II: California vs. Other Oil & Gas Regions

Part III: California: Analysis of Geochemical Data Availability in Hydraulic Fracturing Areas

Radium & Hydraulic Fracturing

18,000 pCi/L	Max activity detected in Marcellus Shale produced waters[1]
30%	Of all Marcellus wastewater treated and discharged to local streams in 2011[2]
60 / 5 pCi/L	EPA Industrial Effluent Discharge Limit for Radium / EPA drinking water MCL
23,600 pCi/kg	Activity in stream sediments near Pennsylvanian treatment facility effluent discharge point.

Radium Cycle in Hydraulic Fracturing



1. Deeply seated formation water is largely anoxic
2. Radium accumulates in formation waters via ^{238}U and ^{232}Th decay
3. Fractured formation rocks release radium in solution and/or on metal carriers (i.e. Barium)
4. Radium is transported to surface in produced and flowback water

$^{238}U \rightarrow {}^{226}Ra \rightarrow$ Half Life = 1600 years; emissions = α & γ

$^{232}Th \rightarrow {}^{228}Ra \rightarrow$ Half Life = 5.75 years; emissions = β

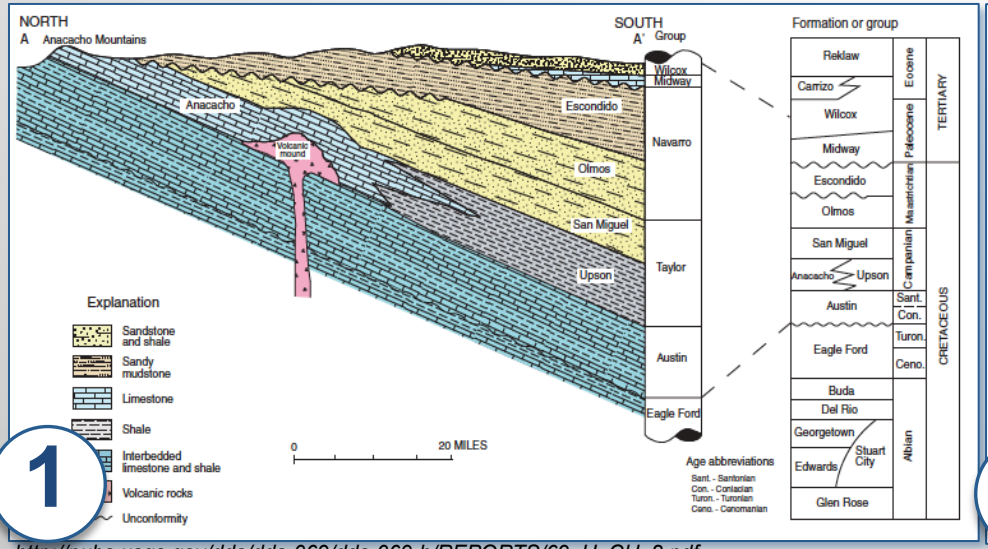
http://metadata.berkeley.edu/nuclear-forensics/Decay%20Chains.html

Produced waters

Cations and anions in Marcellus Shale Produced Water[3] with (EPA MCL) mg/L	
Chloride	146,667 (250)
Strontium	36,333 (None)
Sodium	29,333 (None)
Calcium	13,000 (None)
Barium	9,000 (2)
TDS	277,666 (500)

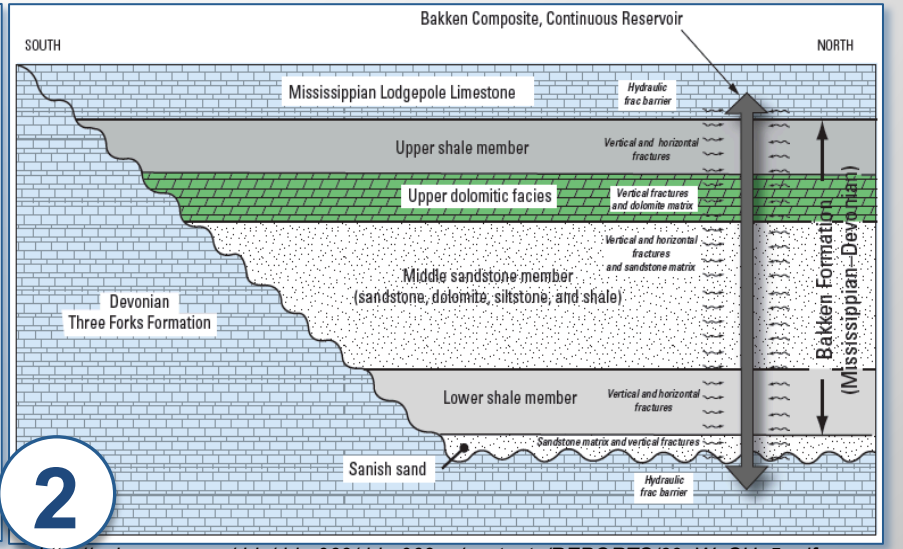
- Standard EPA method for analyzing radium in drinking water (EPA 903.0) utilizes the co-precipitation of radium with chemically similar barium.
- EPA method 903.0 produces erroneous results due to the high salinity and elevated barium concentrations in produced water.

A large amount of research and data exists for more developed oil & gas regions in the U.S.



1

http://pubs.usgs.gov/dds/dds-069/dds-069-h/REPORTS/69_H_CH_2.pdf



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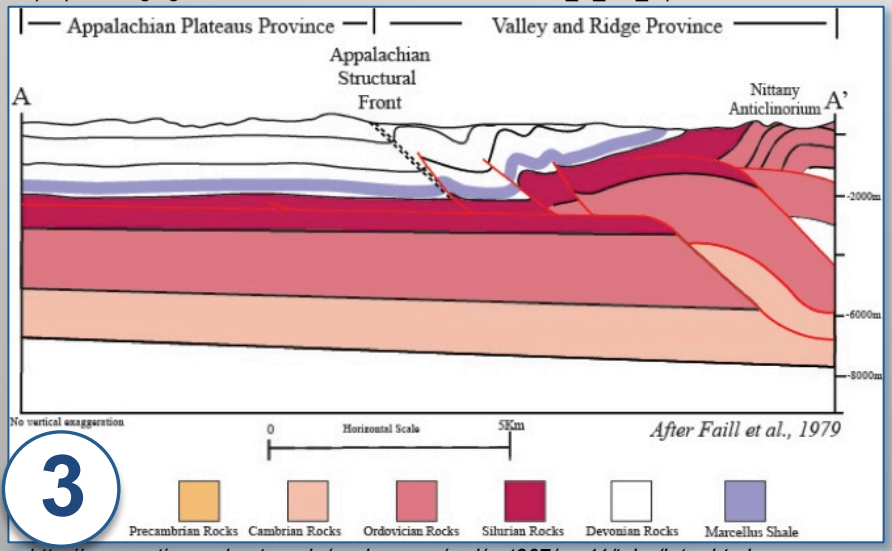
http://pubs.usgs.gov/dds/dds-069/dds-069-w/contents/REPORTS/69_W_CH_5.pdf



3

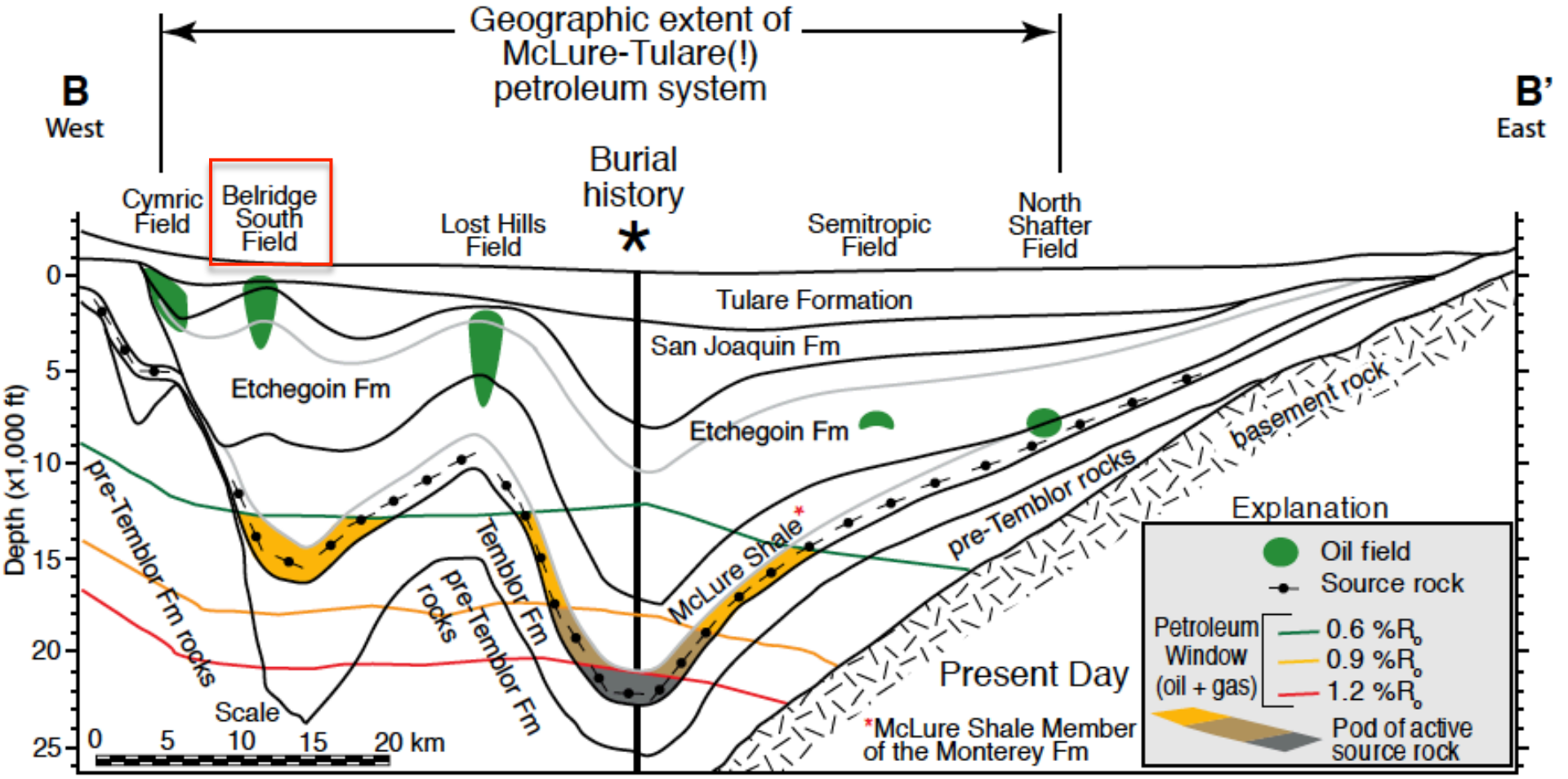
http://www.optics.rochester.edu/workgroups/cml/opt307/spr11/talor/Intro.html

1 Cretaceous Maverick Basin, Eagle Ford/Austin Group, Texas

2 Devonian-Mississippian Bakken Formation, North Dakota

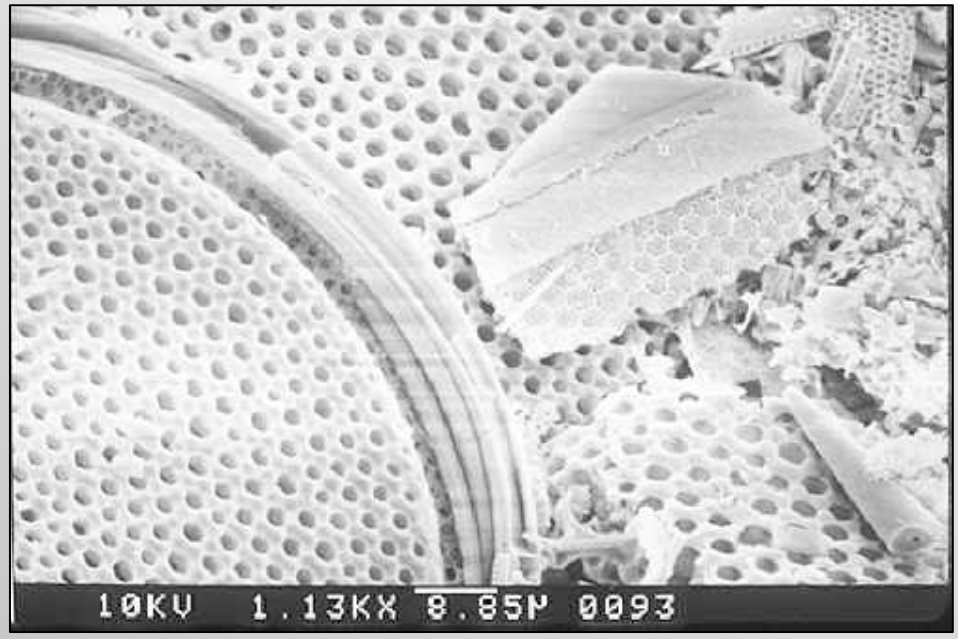
3 Middle Devonian Marcellus Shale, New York (A) & Pennsylvania (A')

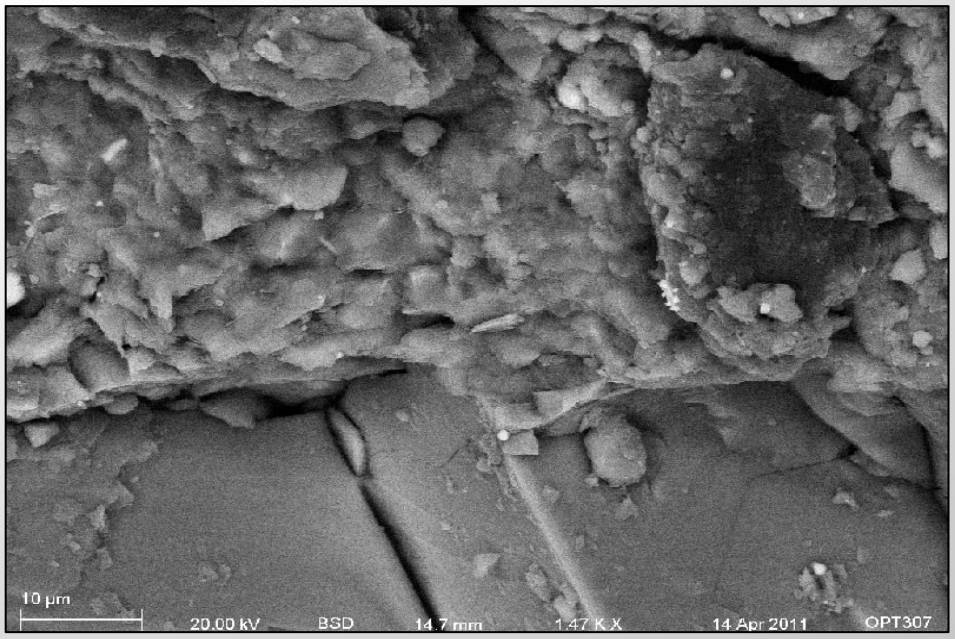
California's Miocene Monterey Formation exhibits major differences from other major oil & gas regions.



http://pubs.usgs.gov/pp/pp1713/

Diatomite vs. Black Shale





Monterey Diatomite

- Primary reservoir rock in California's primary oil field, Belridge Oil Field[4]
- Porosities up to 70%
- Gels with 10 to 1000x the viscosity of slickwater injected
- Less water demand: ~1,200 acre-feet/year

Photo: CSU Long Beach @ 1.13kx
http://geology.campus.ad.csulb.edu/people/bperry/Sedimentary%20Rocks%20Tour/sedimentary%20rocks%20images/biochemical%20sedimentary%20rocks/diatomite/diatomsspiculeSEMMontFmRick.jpg

Marcellus Black Shale

- Primary source rock in the Marcellus, Eagle Ford and Bakken oil plays
- Porosities between 1-11%
- Slickwater containing a friction reducer with 4x the viscosity of water injected
- Higher water demand: ~12.5 acre-feet/well/frac[5]

Photo: University of Rochester @ 1.47kx
http://www.optics.rochester.edu/workgroups/cml/opt307/spr11/talor/Results.html

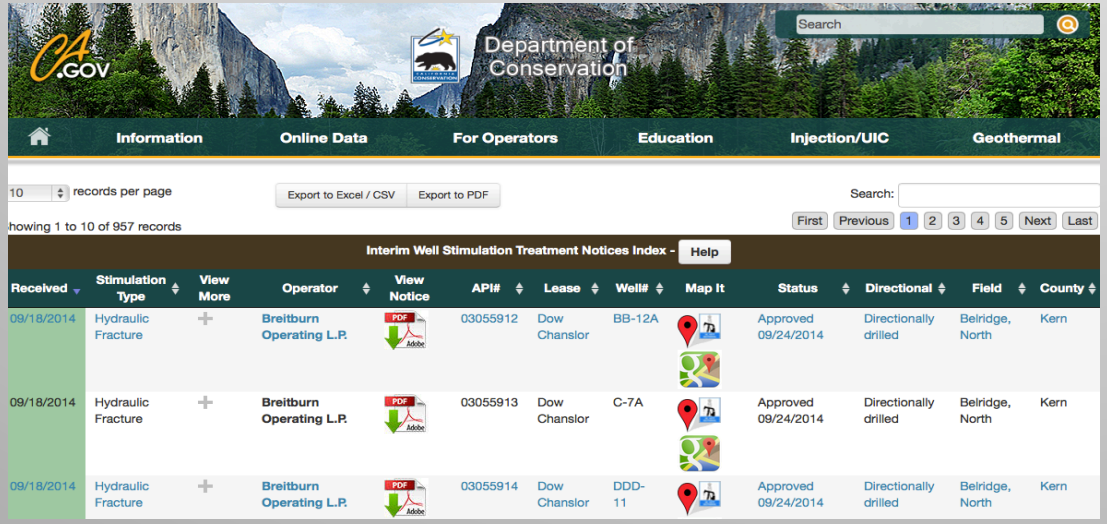
Hydraulic Fracturing has occurred in California for decades but until recently has not been regulated.

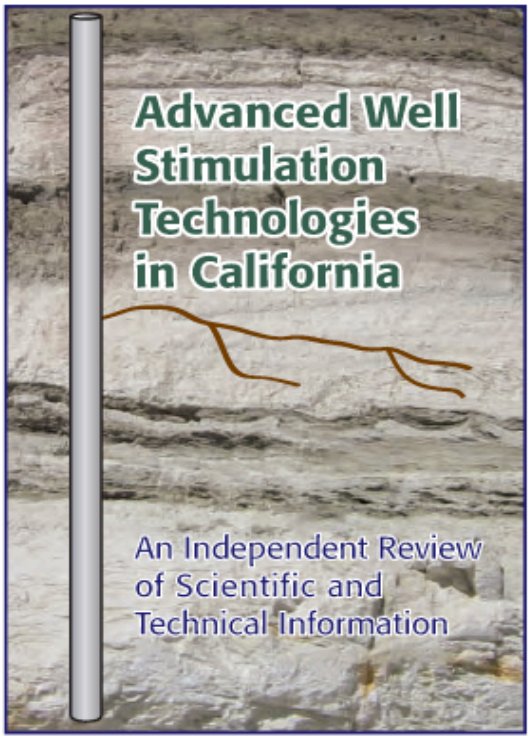
Senate Bill No. 4

CHAPTER 313

An act to amend Sections 3213, 3215, 3236.5, and 3401 of, and to add Article 3 (commencing with Section 3150) to Chapter 1 of Division 3 of, the Public Resources Code, and to add Section 10783 to the Water Code, relating to oil and gas.

[Approved by Governor September 20, 2013. Filed with Secretary of State September 20, 2013.]



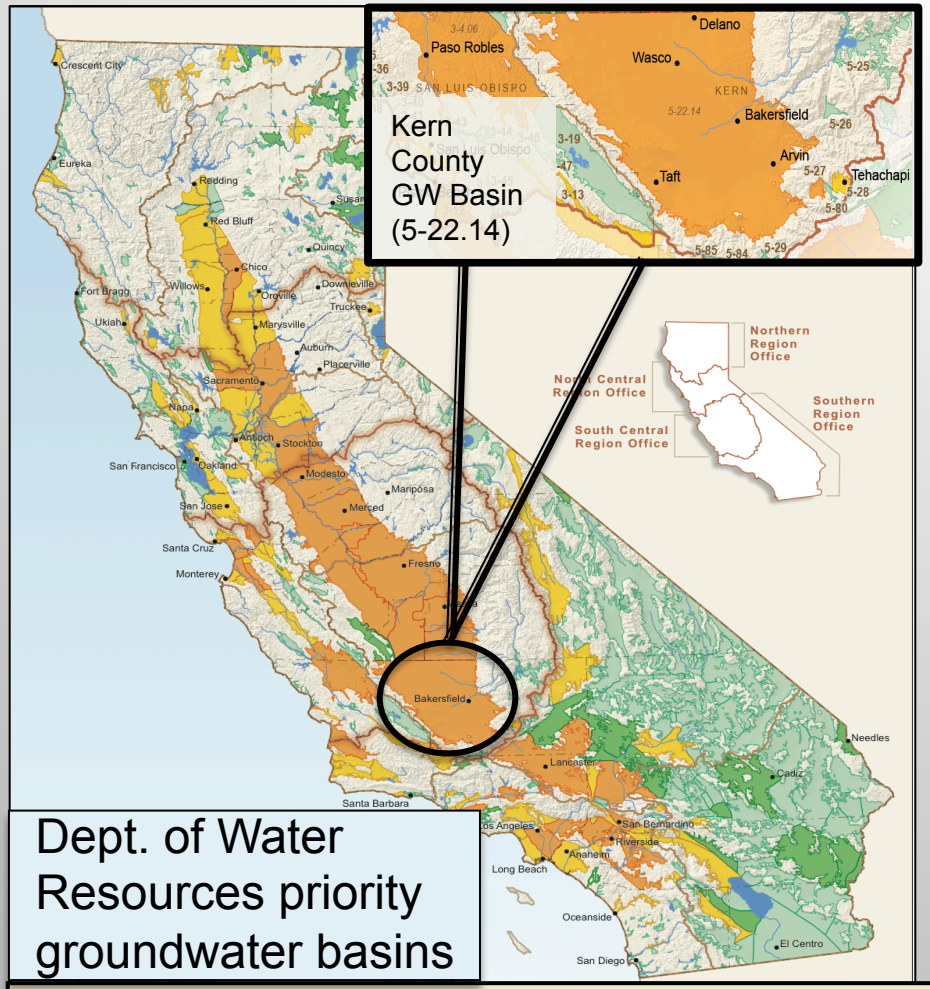


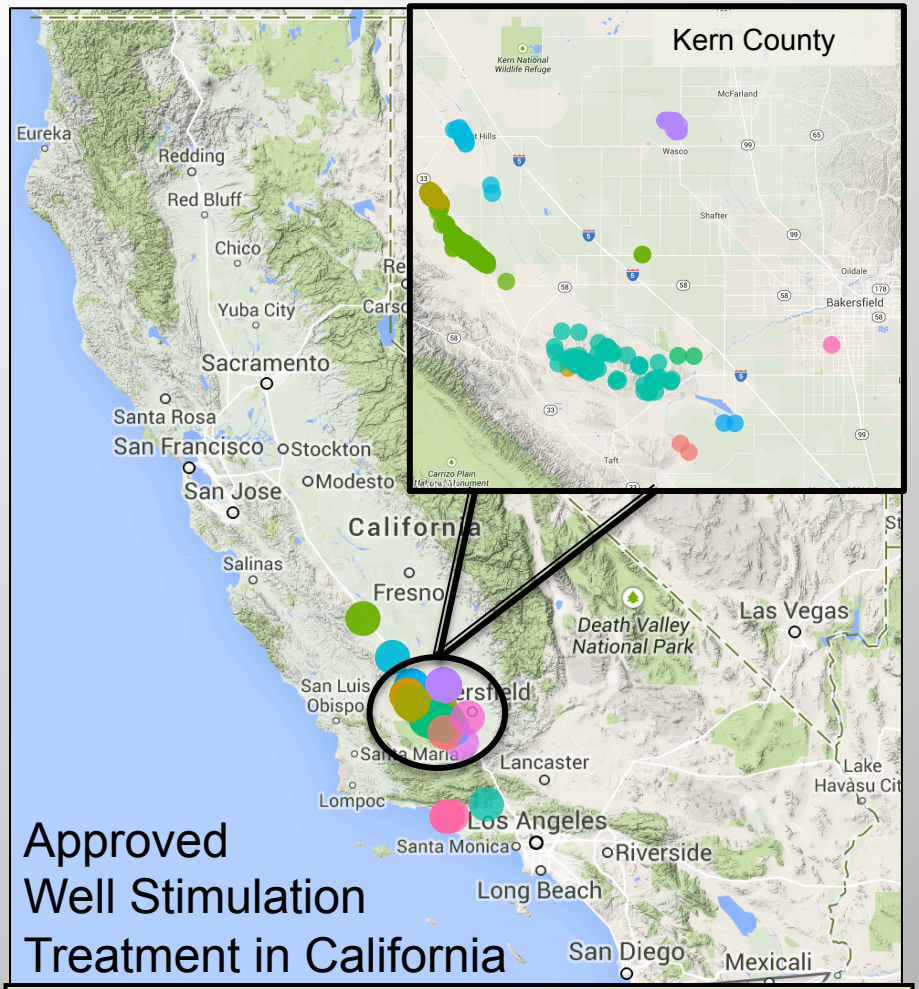
California Council on Science and Technology
Lawrence Berkeley National Laboratory
Pacific Institute

August 28, 2014

California: Hydraulic Fracturing

Data assembled from CA DOGGR and GAMA/CDPH databases utilizing R-Project Statistical Software





65% Of Bakersfield's municipal water supply is from GW[6]

6.8 Billion dollars in agriculture revenue (2013)[7]

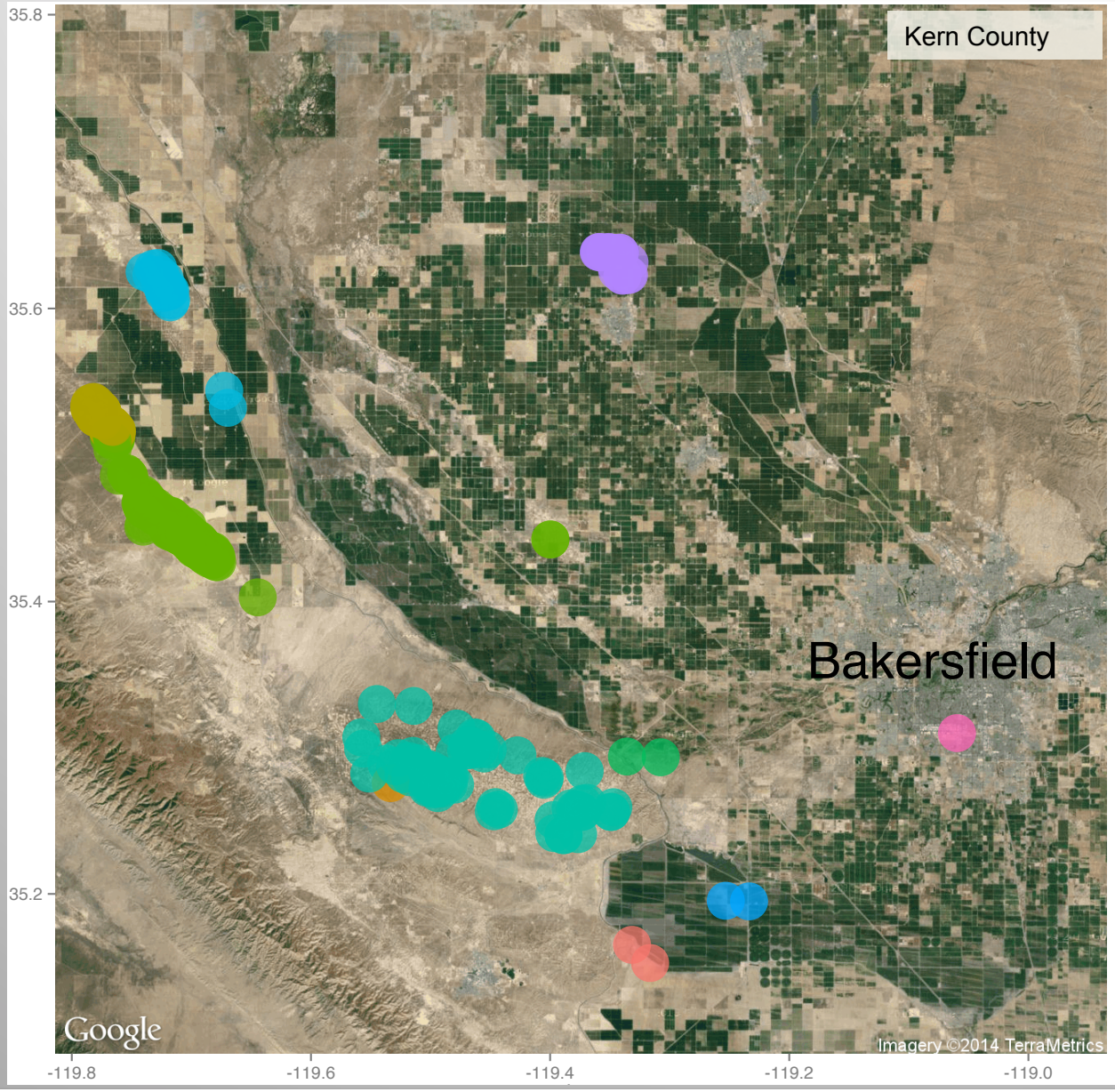
21 DWR's priority basin ranking out of 515 GW basins

99% Of all approved WST occurs in Kern County

94% Kern County WST in Belridge and Elk Hills fields

96% WST as "Hydraulic Fracture" in Kern County

California: Hydraulic Fracturing



California
Wells = 978
Kern County = 970

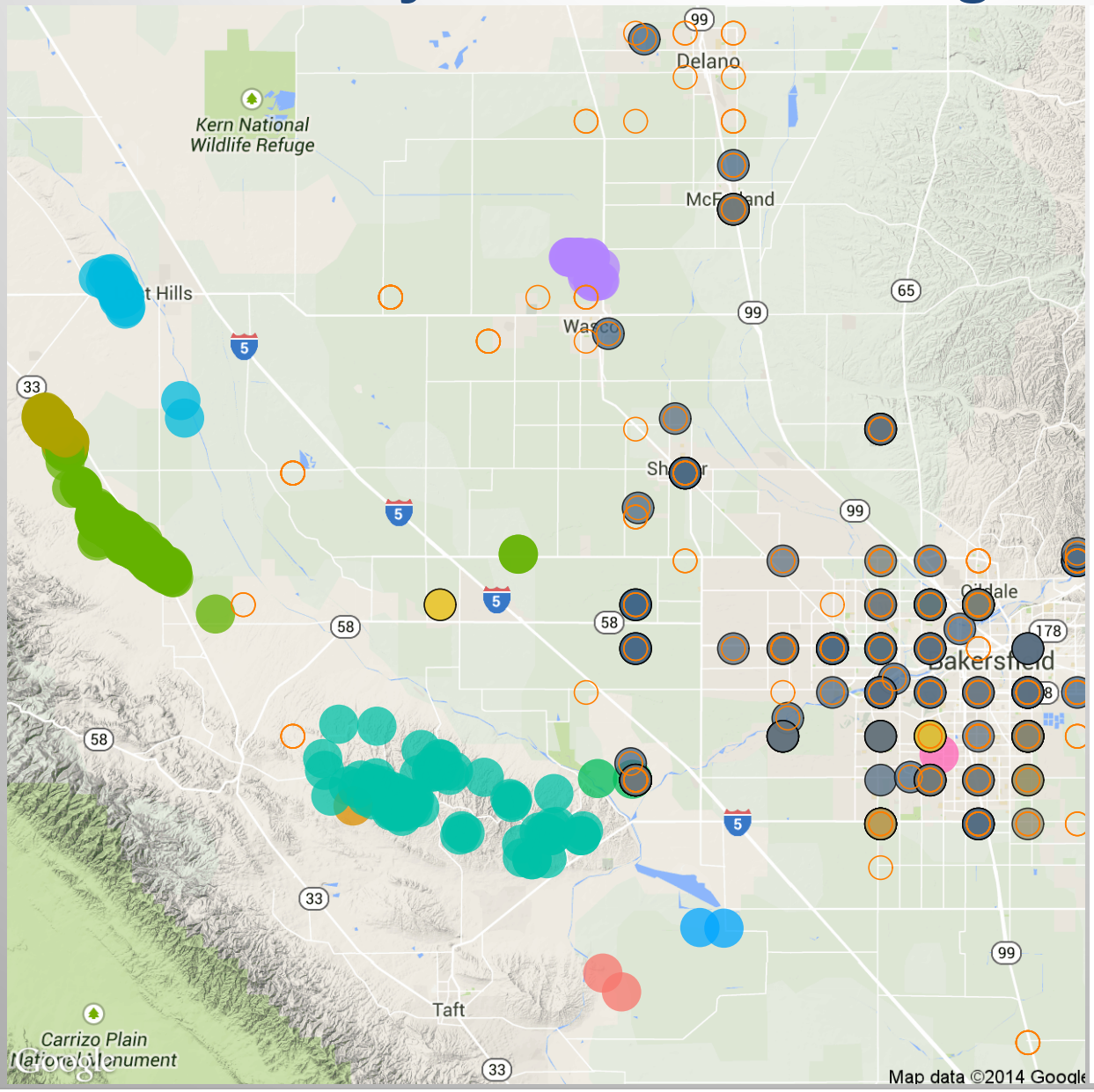
Belridge Oil Field
Wells = 827
Of Total = 85%

Elk Hills Oil Field
Wells = 88
Of Total = 9%

Other Kern County Oil Fields
Wells = 55
Of Total = 5%

Data from CA Division of Oil, Gas and Geothermal Resources (DOGGR)

California: Hydraulic Fracturing & Radium



Field

- Any Field
- Asphalto
- Belridge, North
- Belridge, South
- Coles Levee, North
- Elk Hills
- Lost Hills
- Paloma
- Rose
- San Emidio Nose
- Stockdale

RA226 pCi/L

4
3
2
1
0

RA228 data pt.

Radium-226

Data pts. = 164
CDPH pts. = 93%

Mean = 0.321
Median = 0.180

Data pts. near WST = 0-1

Radium-228

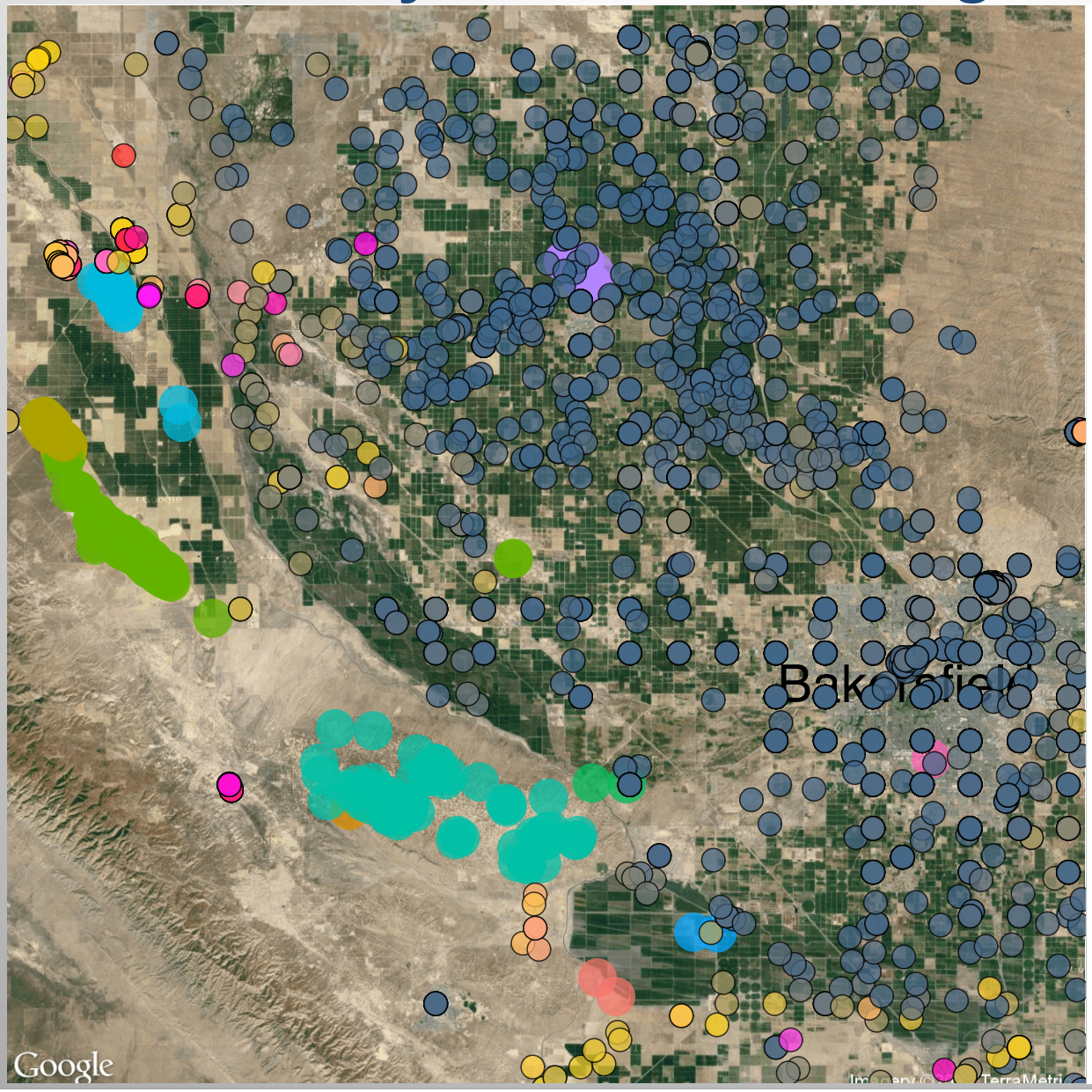
Data pts. = 275
CDPH pts. = 96%

Mean = 0.703
Median = 0.440

Data pts. near WST = 3-4

Data from CA Groundwater Ambient Monitoring & Assessment Program (GAMA)

California: Hydraulic Fracturing & Total Diss. Soilids



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- Stockdale

TDS mg/L

10000
7500
5000
2500

TDS (mg/L)
Data pts. = 5074
CDPH = 64%

Mean = 1461
Median = 285

EPA Drinking Water MCL = 500 mg/L

Protected Water <10,000 ppm

Conclusions and Further Research

- Produced waters contain elevated radium activity and high concentrations of other anions and cations, including TDS.
- The Monterey Formation presents a very different geologic setting and geochemical indicators will likely be different from previously studied WST areas.
- Too little data are available to interpret the relationship between ambient groundwater conditions and WST in Kern County.
- In order to use geochemical data to examine effects of WST on shallower groundwater, data from oil field shallow groundwater and WST wastewater, produced and flowback are needed.

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Lawrence Livermore National Laboratory
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