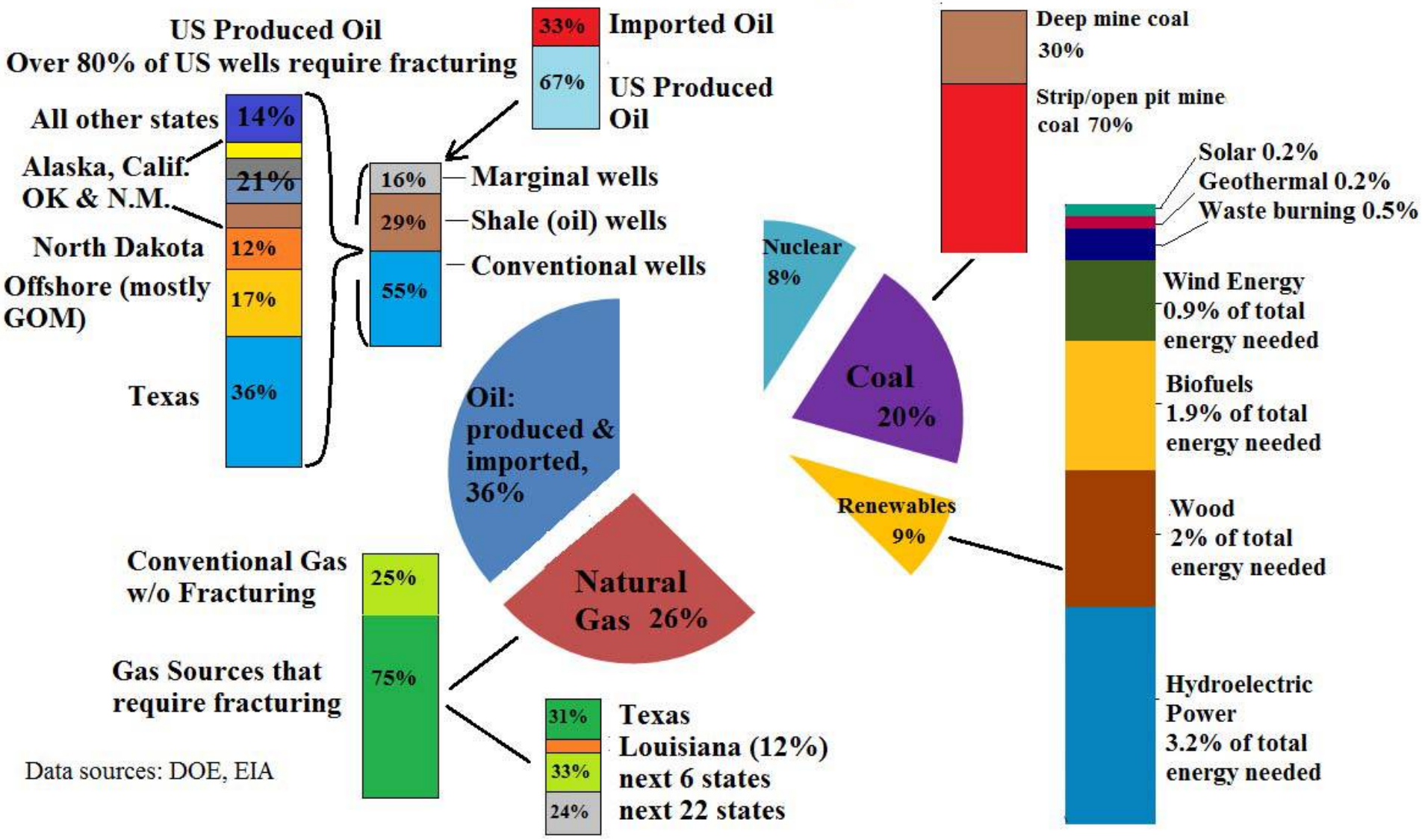
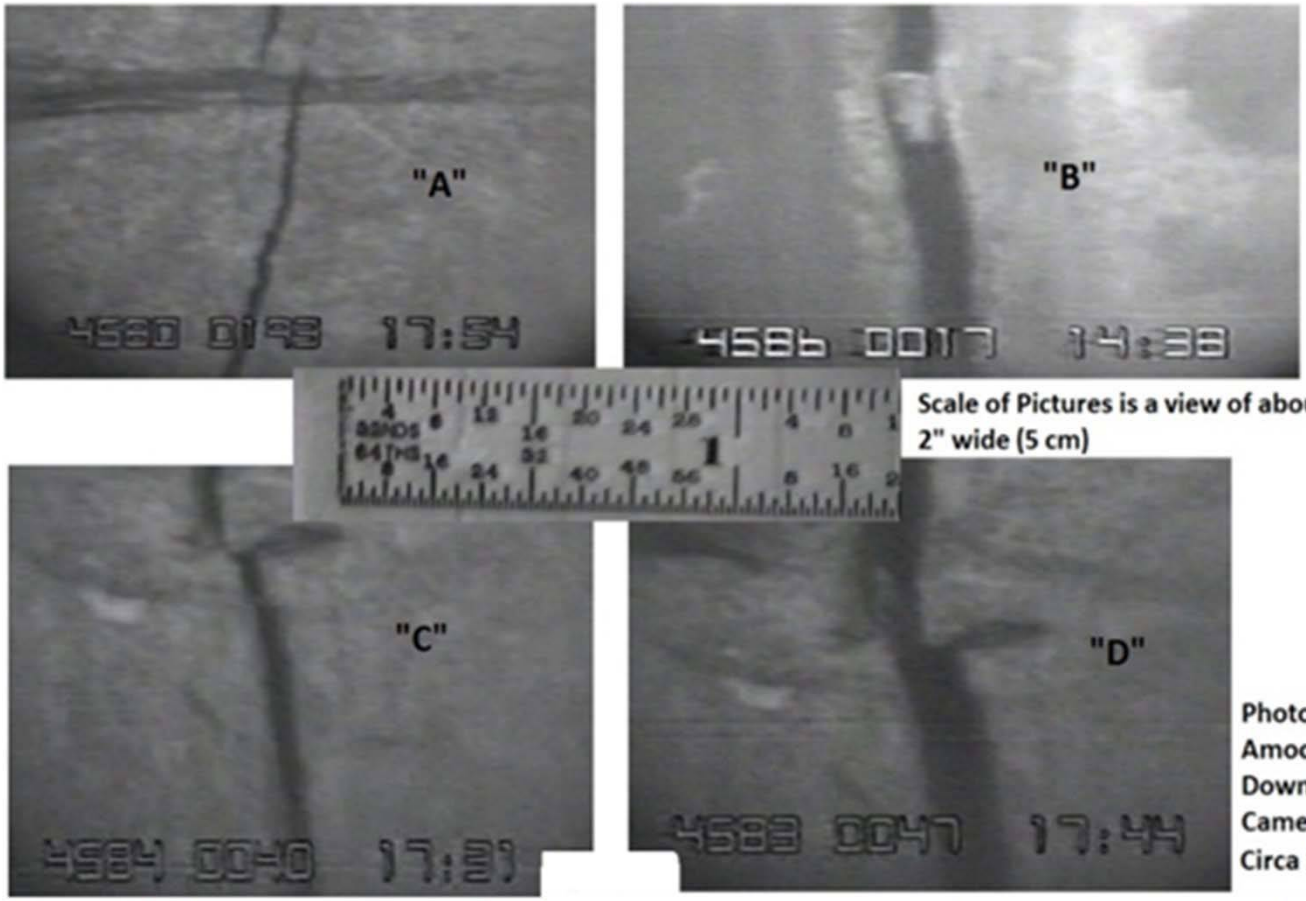
HYDRAULIC FRACTURING OVERVIEW – THE WHAT, WHERE AND HOW.

GEORGE E. KING, P.E.

Sources Contributing to Total US Energy Usage



WHAT DO FRACTURES LOOK LIKE DOWNHOLE?

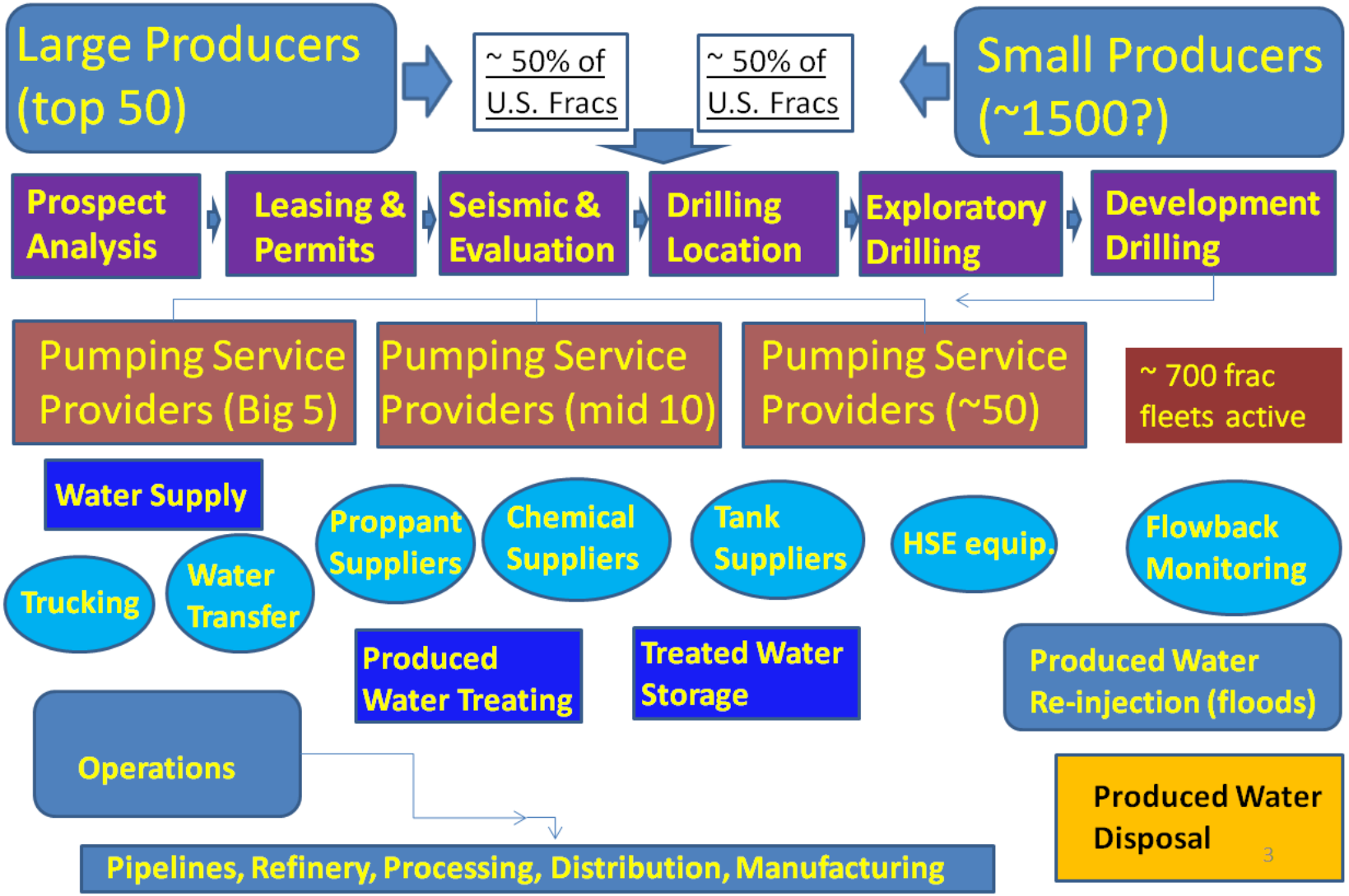


Scale of Pictures is a view of about 2" wide (5 cm)

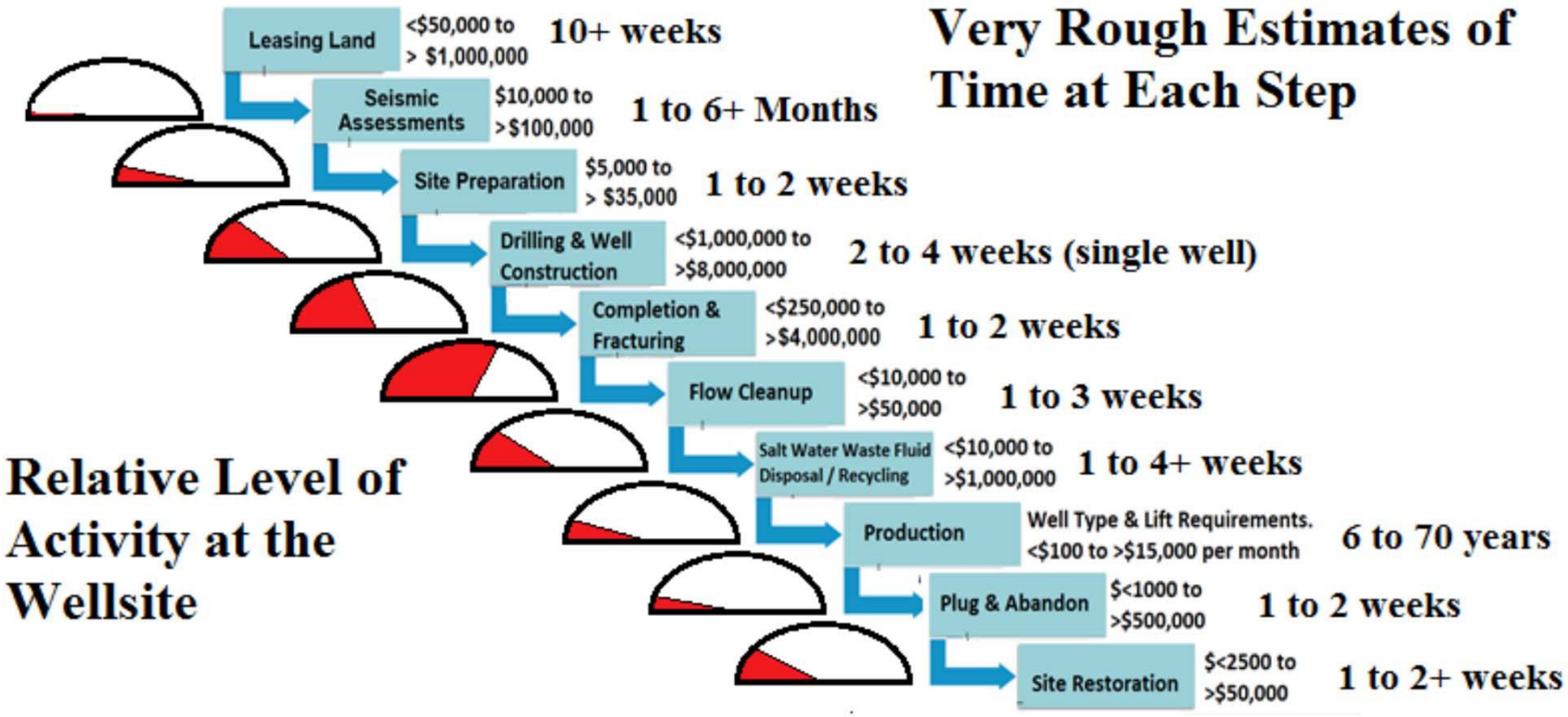
Photos from Amoco Downhole Camera Circa 1970.

Downhole Camera Pictures of Hydraulic Fractures, Open Hole Completions, Vertical Wells

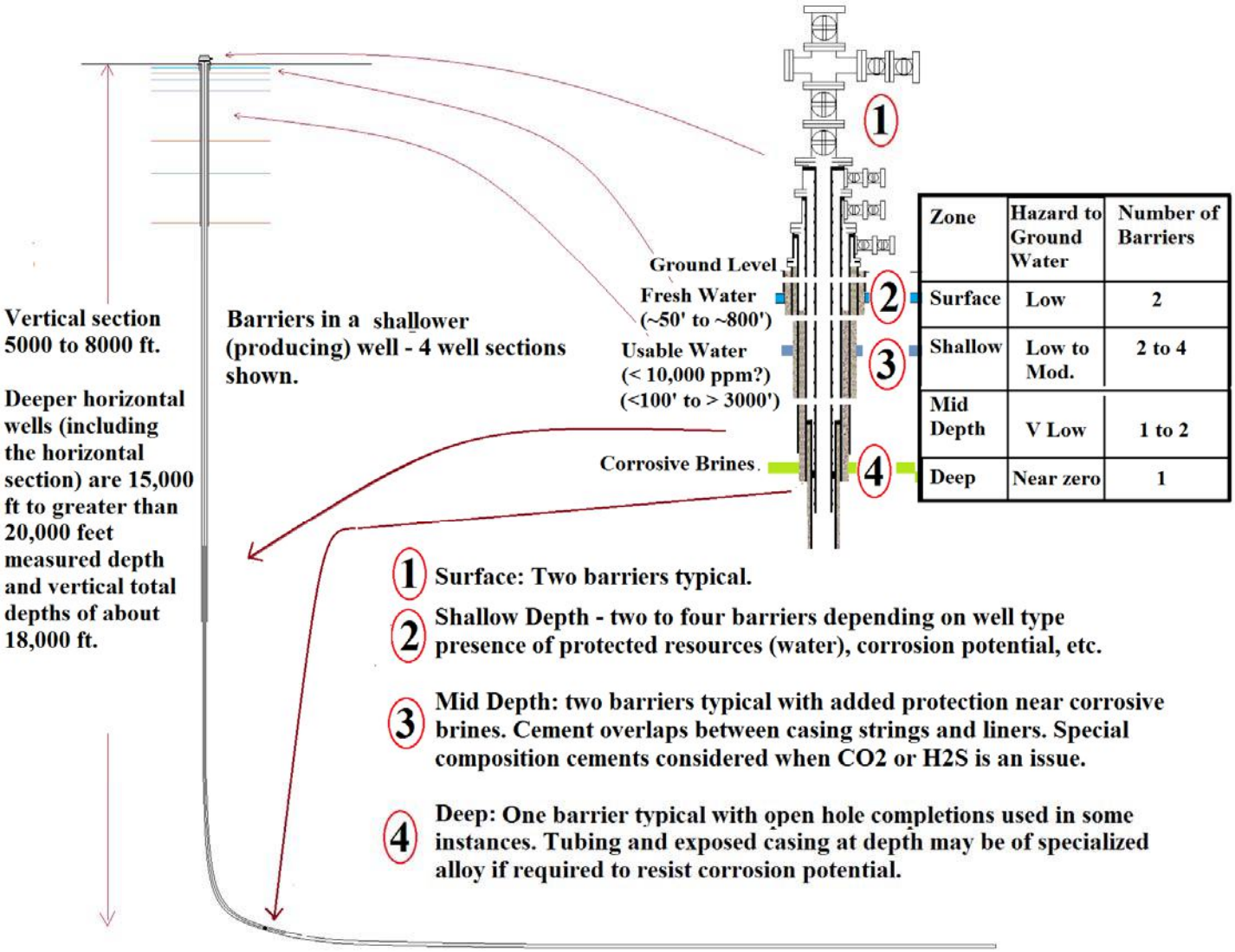
Who Does Fracturing?



HOW MUCH TIME DOES A WELL OR A DEVELOPMENT TAKE?



Completed Well - How Many Barriers are Typical?



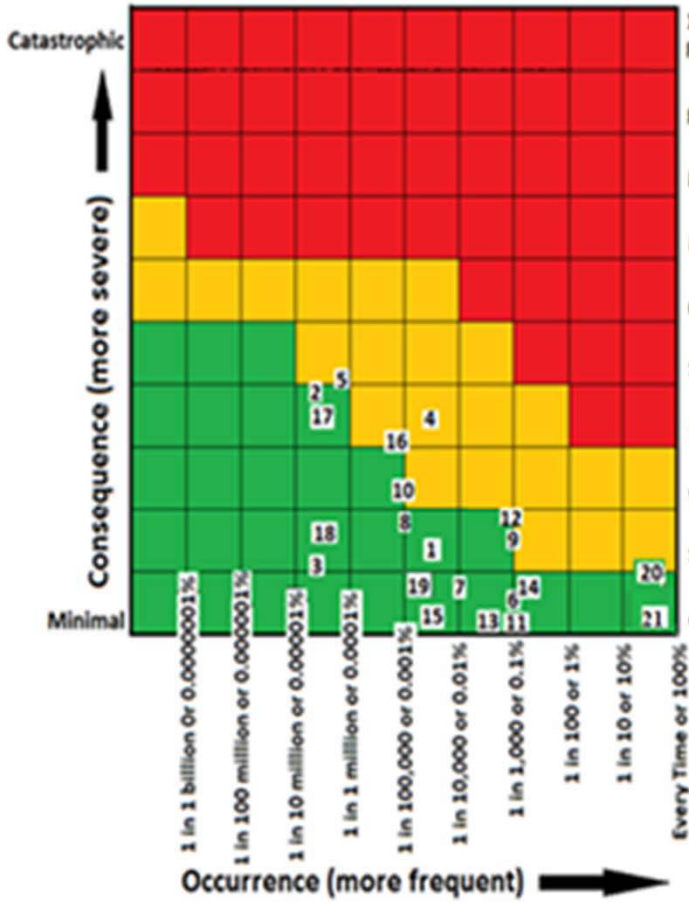
Zone	Hazard to Ground Water	Number of Barriers
Surface	Low	2
Shallow	Low to Mod.	2 to 4
Mid Depth	V Low	1 to 2
Deep	Near zero	1

1. Surface: Two barriers typical.
2. Shallow Depth - two to four barriers depending on well type presence of protected resources (water), corrosion potential, etc.
3. Mid Depth: two barriers typical with added protection near corrosive brines. Cement overlaps between casing strings and liners. Special composition cements considered when CO_2 or H_2S is an issue.
4. Deep: One barrier typical with open hole completions used in some instances. Tubing and exposed casing at depth may be of specialized alloy if required to resist corrosion potential.

Fracturing Risk Evaluation => Very Small Risks To Groundwater

Frac to Surface?	Less than 1 chance in a million
Frac Ruptures Surf Csg?	Less than 1 chance in 100,000
Earthquake > 5.0 mag.	Less than 1 chance in a million
Spills Diesel at surface	About 1 chance in 10,000?

Highest Risks are Transport, Some from Well Construction



10 - > 1 Mile Diam. Subsurface Pollution, Toxic, Not Recoverable. Similar to acid mine drainage.

9 - 100 ft to 1 Mile Diam. Pollution, Toxic, Not Recoverable. Similar to acid mine drainage.

8 - > 1 Mile Diam., Surface Pollution Toxic, Slow or No Biodegradation. Less toxic than acid mine drainage.

7 - 100 ft to 1 Mile Diam., Surface Pollution Toxic, Slow or No Biodegradation. Less toxic than acid mine drainage.

6 - <100 ft. Subsurface Pollution, Toxic but dispersible or recoverable. Similar to storage tank leak of oil or gasoline.

5 - < 100 ft. Diam. Surface Pollution, Toxic but dispersible. Similar to spill of fertilizer, ammonia or small diesel spill

4 - Spill or Leak of 50 to 500 gal (1.94M3) Non Toxic but persistent chemical, Similar to salt spredding on icy roads.

3 - Large volume (<5,000 gal) spill of raw fresh or salt water with low conc. chemicals, similar to partly treated sewage.

2 - Spill (<25,000 gal) of raw fresh water with no chemicals. Similar to a swimming pool draining on the ground.

1 - Small spills (<5 gal or 20 liter) of diluted, non toxic, quickly biodegradable, household or food grade chemical.

1. Spill clean fresh or salt water
2. Spill biocide
3. Spill dry additives
4. Spill of diesel from truck wreck
5. Spill of diesel -wrecked re-fueler
6. Spill frac tank water, no adds
7. Spill frac tank water w/adds
8. Spill diesel fuel while re-fueling
9. Spill of frac tank -flowback water
10. Frac press ruptures surface casing
11. Cooling pulls tubing out of packer (casing maintains integrity)
12. Mud channel, well < 2000 ft
13. Mud channel, well > 2000 ft
14. Intersects well in the pay zone
15. Intersect properly abandoned well
16. Intersects improper abandoned well
17. Frac to surface through rock, well greater than 2000 ft deep.
18. Earthquake, mag. >5.0
19. Frac intersects a natural seep
20. Emissions > background
21. Normal frac operation – no problems.

Full Details in SPE 152596

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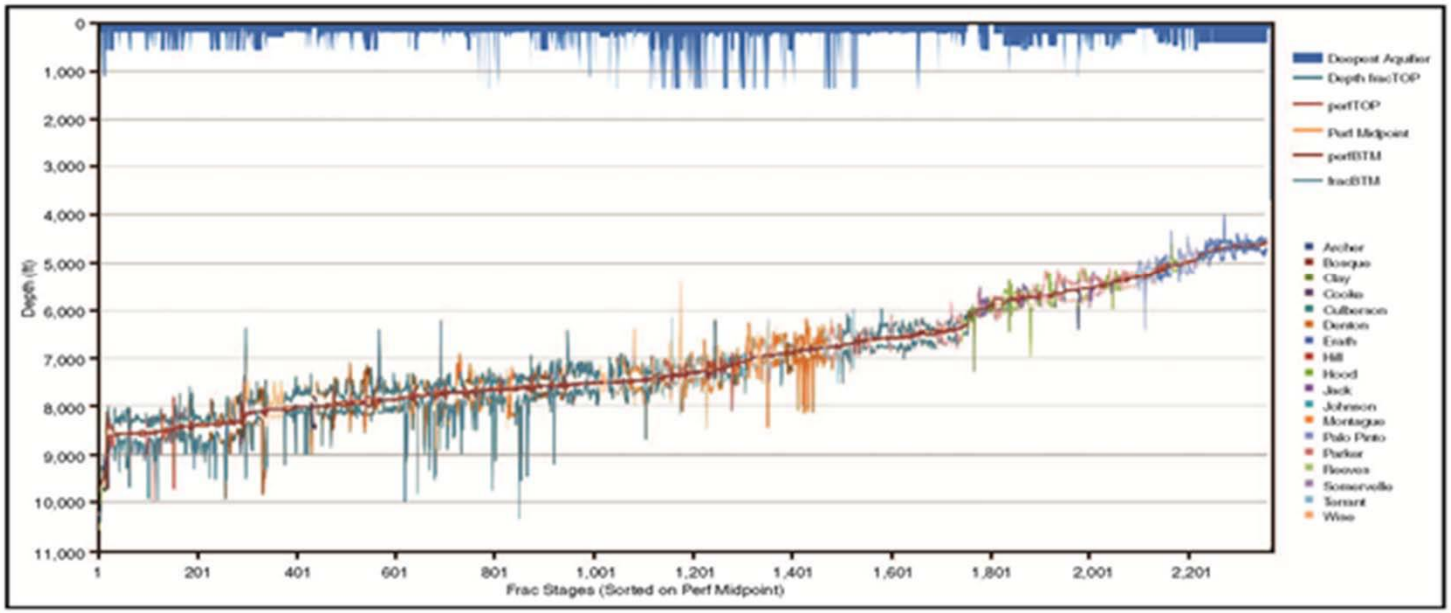
Microseismic monitoring maps the highest possible extent of shear fracturing growth.

Fracture height growth and approach to deepest fresh water					
Shale	Number of fracs with micro-seismic data	Primary Pay Zone Depth Range	**Fresh water depth in area (ft)**	**Distance from top of fracture to base of deepest fresh water**	**Closest approach of fracture in shallowest pay to deepest fresh water**
Barnett (TX)	3000+	4700' to 8000'	500' (1200')	4800'	2800'
Eagle Ford (TX)	300+	8000' – 13,000'	200' (400')	7000'	6000'
Woodford (OK)	200+	4400' – 10,000'	200 (600)	7500'	4000'

Data from Fisher and Warpinski, American Oil & Gas Reporter, 2011, Used by permission.

Barnett Shale Mapped Fracture Treatments (TVD)



WHAT CHEMICALS ARE USED?

Most Common Additives	Composition	CAS Number	Total amt. in avg frac (10k bbl)	Used in recycled water?	Alternate Use
Friction Reducer	Polyacrylamide	9003-05-8	1200 to 2500 gallons.	Yes – must formulate to fit	baby diapers, floc for drink water – food grade
Biocide	Glutaraldehyde	111-30-8	50 to 100 gallons.	yes	Medical disinfectant
Scale Inhibitor (if needed)	Phosphonate & polymers	6419-19-8 & others	10 to 100+ gallons – local need	Specific ions are a problem.	Cleaners & med. treatment
Gellants (hybrid / gel)	Guar & Cellulose	9000-30-0 9004-62-0	Depends on frac type ~1000 to 2000 lb.	Ca^{++} , Fe^{x} & TDS are a problem.	Thickening ice cream / soup
Acid	5% TO 15% hydrochloric	7647-01-0	~0 to 2000 gals total (if acid is used)		food prep, mfg, swim pools,
Acid Corrosion inhib.	Quat. Ammonium salts, etc.	Various	2 to 40 gals total if acid is used		Industrial applications for corrosion reduction

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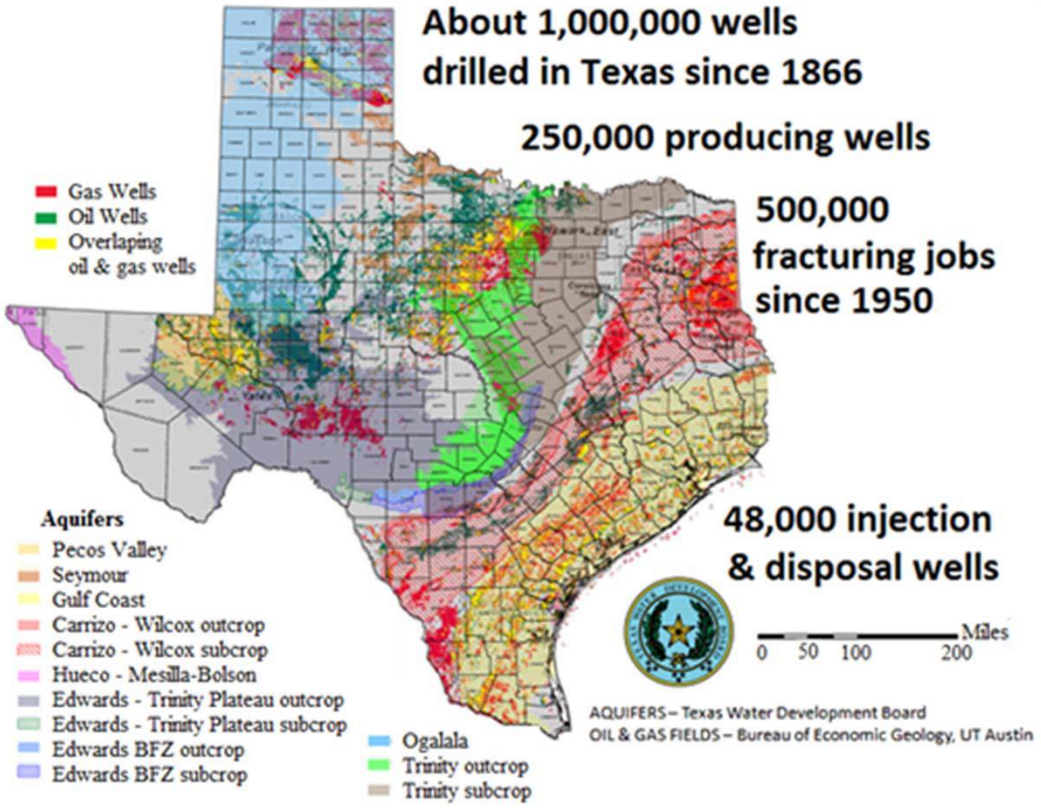
What are Groundwater Pollutants Today & Where Do Oil & Gas Wells Fit in this Picture?

Used Texas as a Study Case.

Over a million penetrations through the 29 major & minor aquifers in Texas.

Texas is #2 in total Groundwater withdrawals with ~ 80% going to Agriculture & Municipalities.

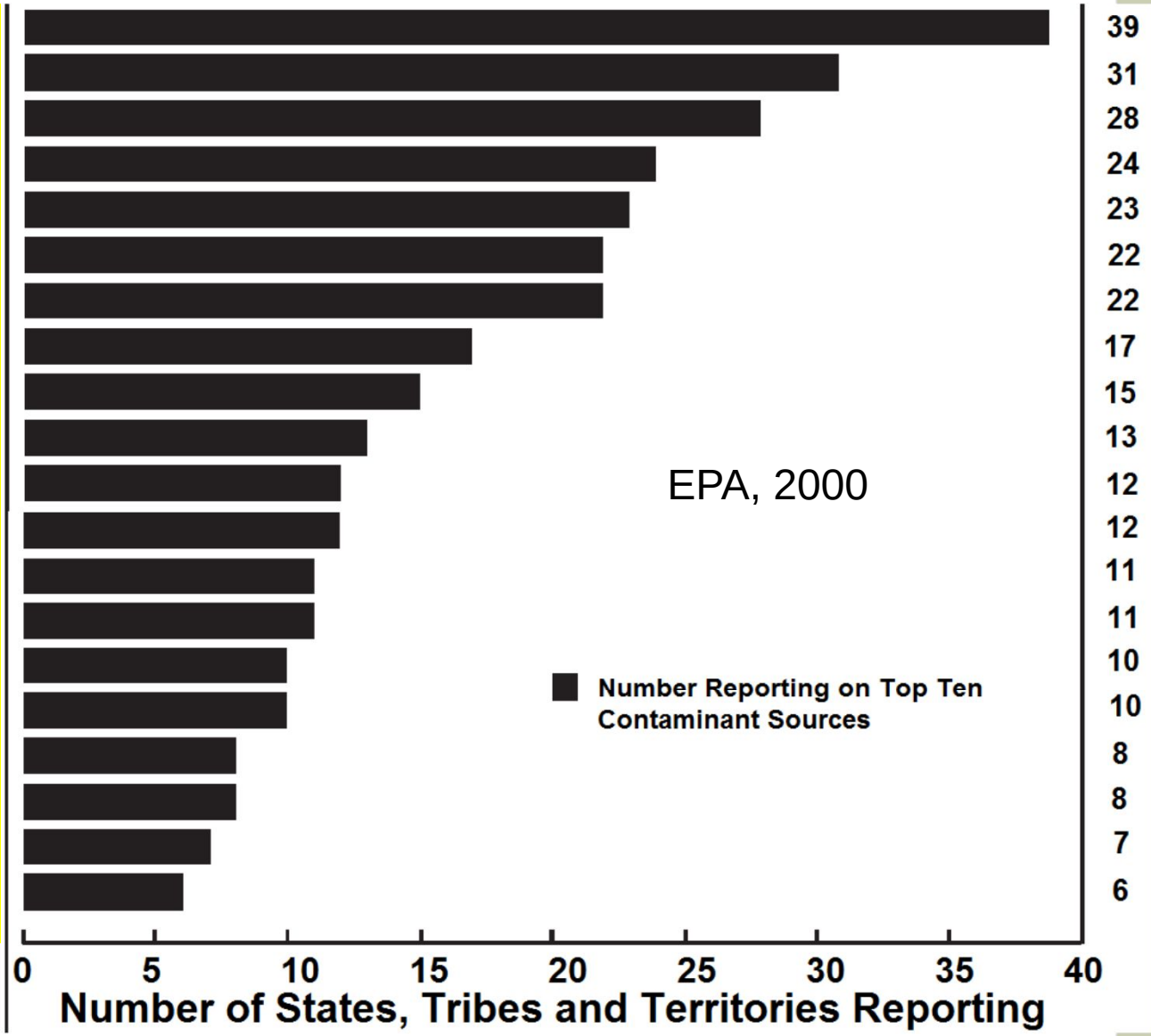
If the water was really polluted by O&G wells, we'd see it quickly in Municipal & Ag.



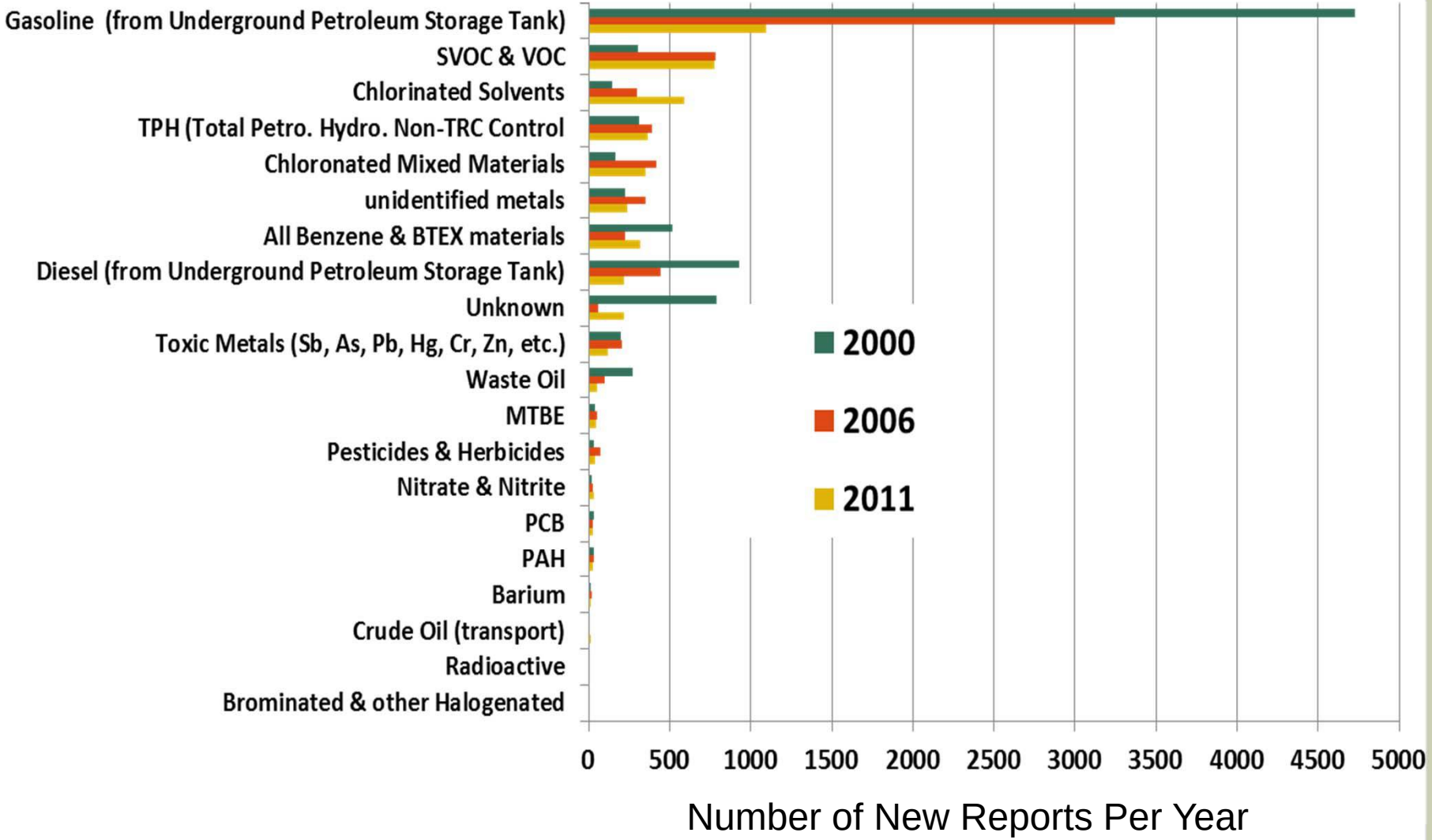
SPE 166142, Barrier vs. Well Failure, King

What are Actual Groundwater Pollutants?

UST – Gas & Diesel
Septic Systems
Landfills
Spills
Fertilizer
Large Industrial Facilities
Hazardous Waste Sites
Animal Feedlots
Pesticides
Surface Impoundments
Storage Tanks – surface
Urban Runoff
Salt Water Intrusion
Mine Drainage
Agriculture Chem. Facilities
Pipelines & Sewer
Shallow Inj. Wells
Salt Storage & Road Salting
Land application of Waste
Irrigation Practices



Last 12 years of Pollution Reports in Texas – Top 20 Listed - TCEQ & TGPC Database



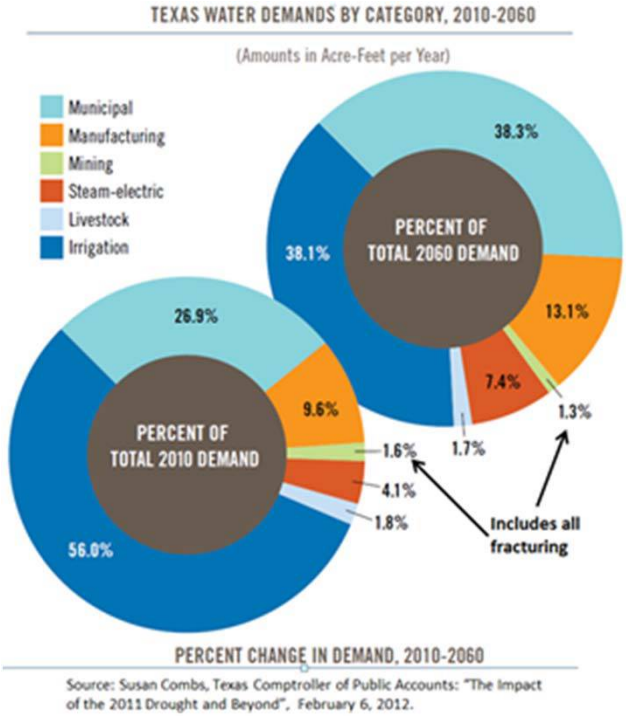
SPE 166142, Barrier vs. Well Failure, King

HOW MUCH WATER DOES FRACTURING USE?

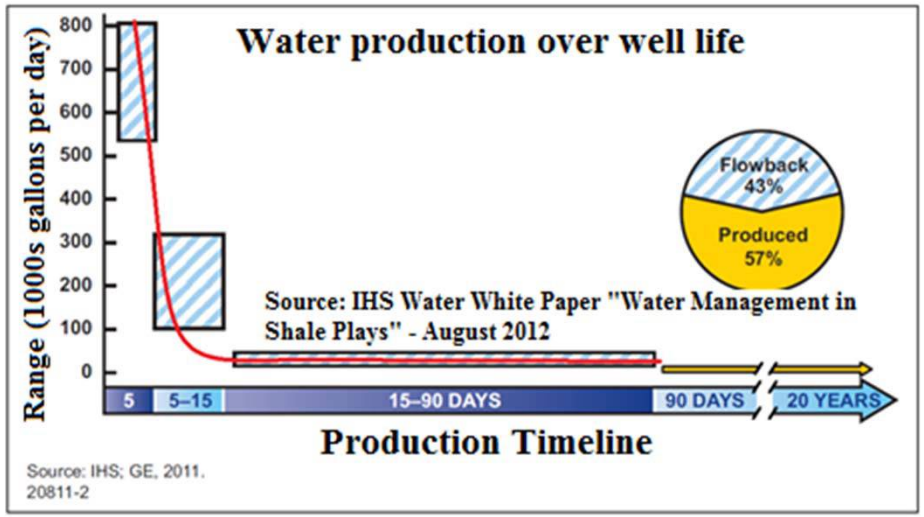
Depending on the well and the formation, the operations in one well might use 5 million gallons.
10,000 such wells in a year in Texas would use 50 billion gallons.
1000 wells in this area might use 5 billion gallons

To put this in context:

- Houston loses 20 billion gallons of water per year in leaks.
- Irrigation in Texas uses 2.8 trillion gallons per year
- Average yearly flow of the Brazos is 2 trillion gallons.



Source: Susan Combs, Texas Comptroller of Public Accounts: "The Impact of the 2011 Drought and Beyond", February 6, 2012.



About 40% of water after fracturing returns in first 2 weeks

CAN PRODUCED WATER BE RECYCLED?

=>

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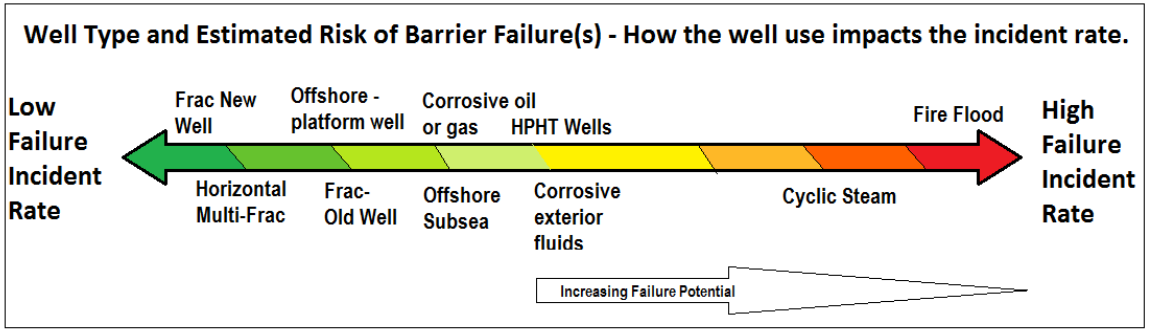
Do Wells Leak? A Review of Well Studies: >330,000 wells

Area	# Wells	Type Wells	Barrier Failure Freq. Range (w/contain)	Well Integ Freq. w/ leak path	Leaks to GW by sampling
Ohio	64,830	D&C shoe test fail (74)* Take worst case - Prod. 39	0.035% in (34,000 wells 1983-2007), 0.1% old wells worst	~0.06% (total)	
Texas	253,090	D&C Failures, shoe test fail* (10) **Prod (56) fail assumed	0.02%	0.02% old era wells, 0.004% new era wells	Producer 0.005% to 0.01% Injector 0.03% - 0.07%
Texas	16,000	Horizontal Multi-frac wells	0	0	

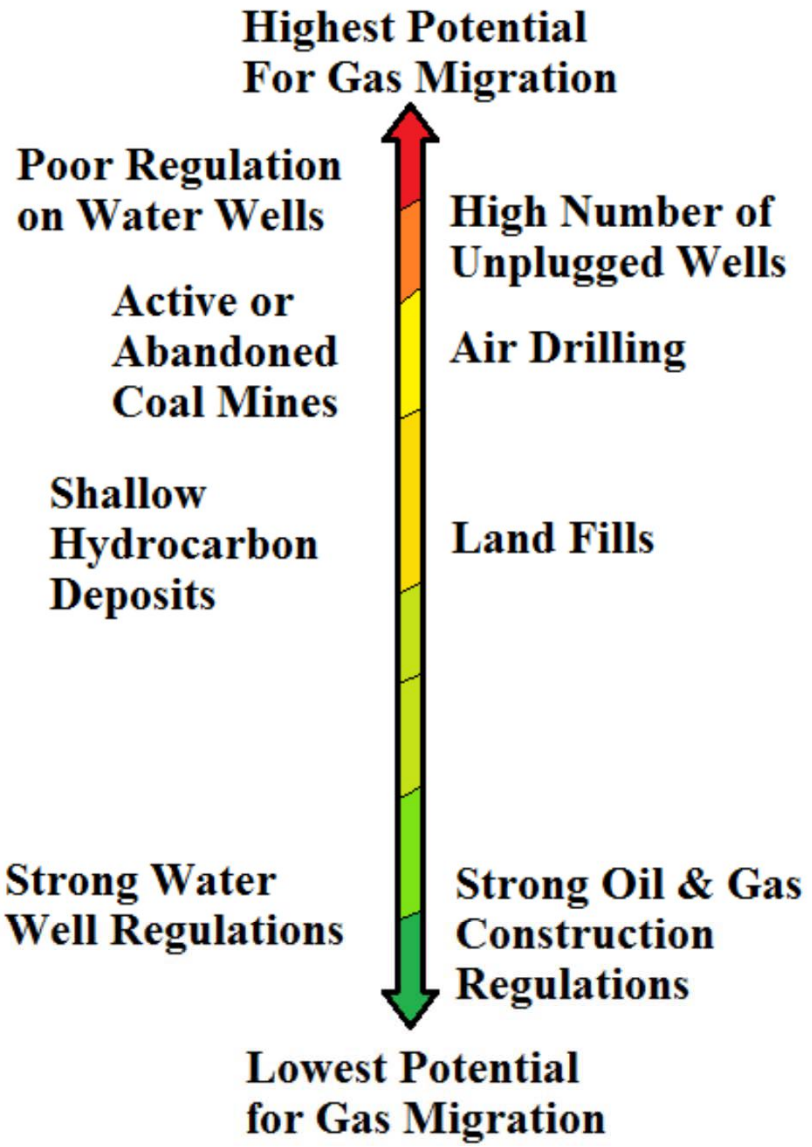


(Sources of data in SPE 166142)

SPE 166142, Barrier vs. Well Failure, King & King

WHAT IS THE POTENTIAL FOR GAS MIGRATION INTO A WATER WELL?

The potential for gas migration into water wells is high in some parts of the country and low in others.



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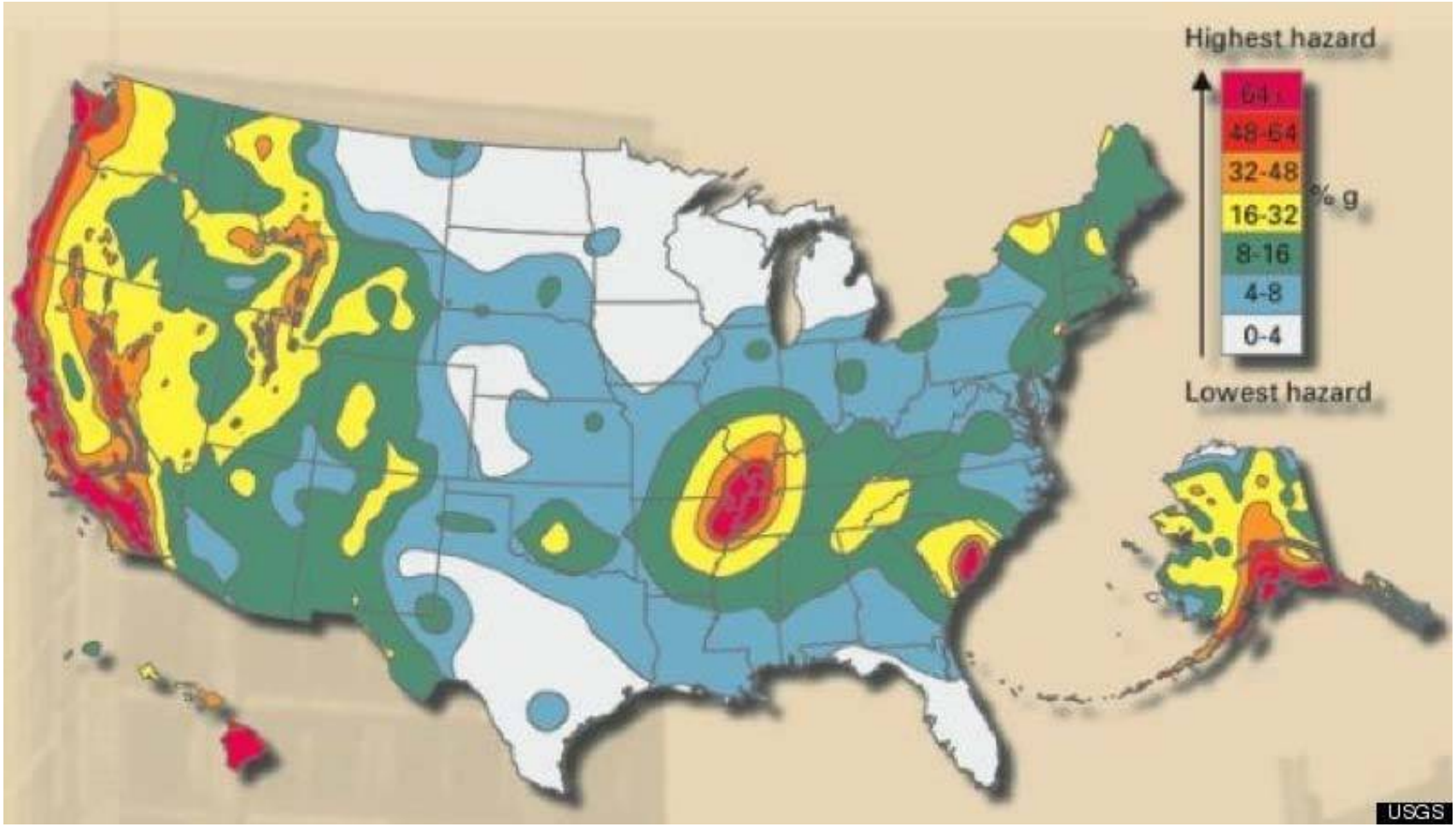
CAN A LARGE EARTHQUAKE HAPPEN HERE?

- The magnitude of an earthquake is related to the length of the fault on which it occurs -- the longer the fault, the larger the earthquake.
- The San Andreas Fault is 800 miles long – max quake in in the 7's.
- The largest earthquake ever recorded was a magnitude 9.5 on May 22, 1960 in Chile on a fault that is almost 1,000 miles long.

WILL FRACTURING CAUSE EARTHQUAKES?



Earthquakes are more influenced by plate and fault movement than any other factor.
Dams, Mines and Injection wells are the largest man-made drivers.

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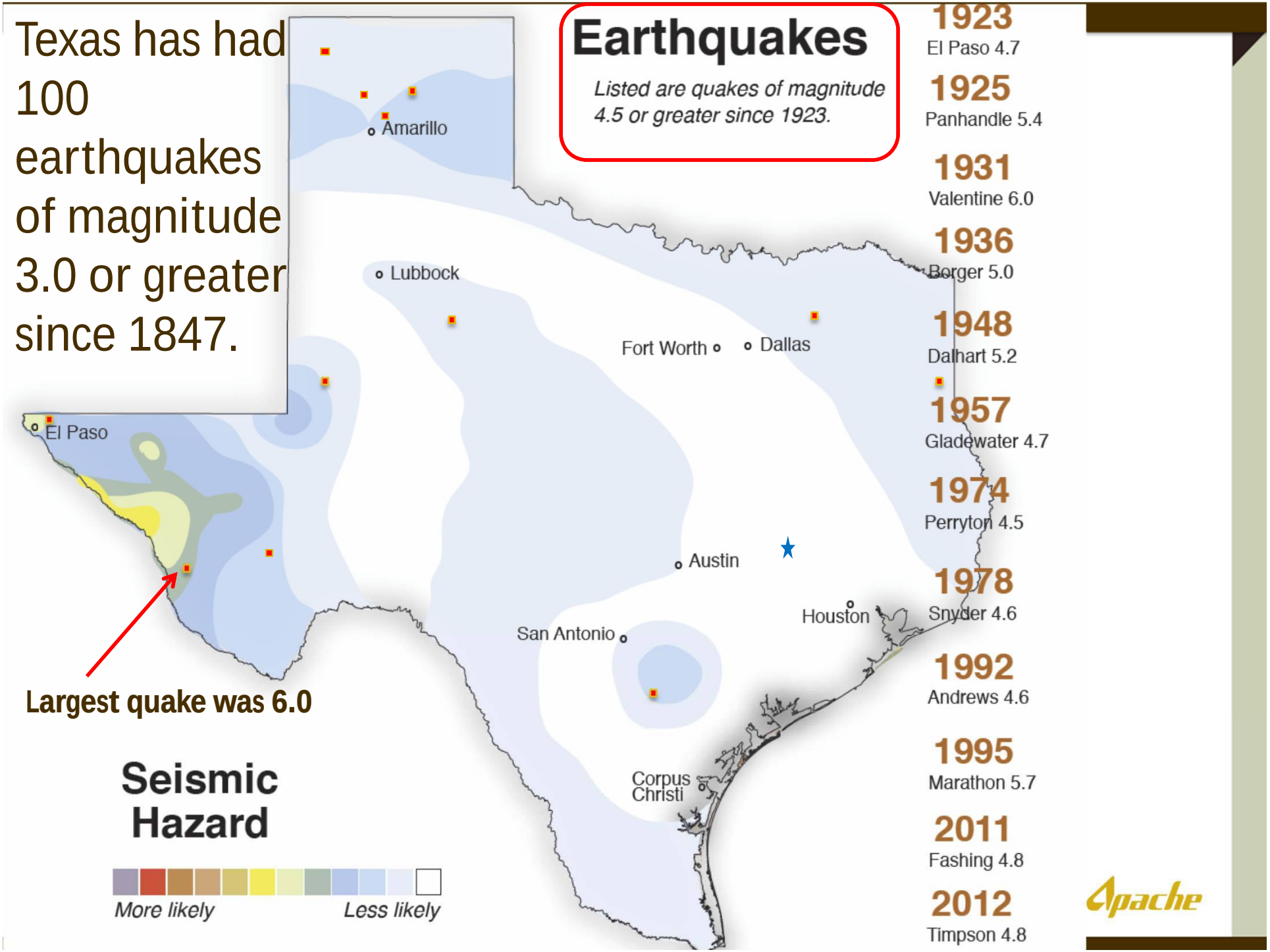
Texas has had 100 earthquakes of magnitude 3.0 or greater since 1847.



THANK YOU!

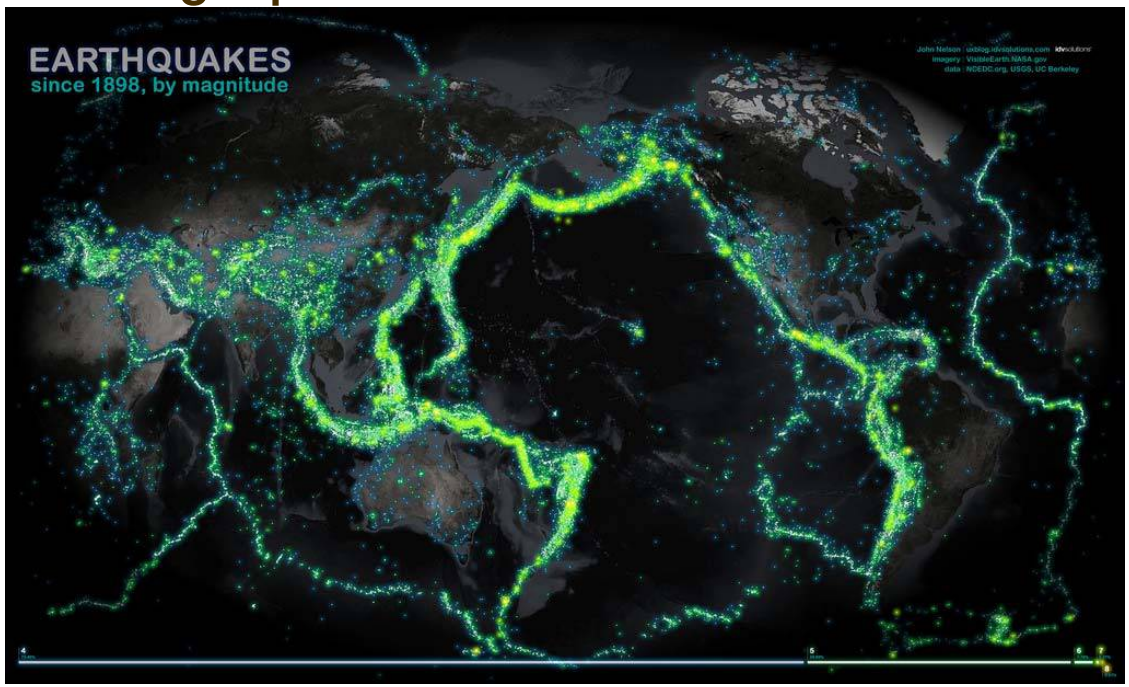
- I am happy to address technical questions about the concepts of well construction and fracturing.
- George.King@apachecorp.com

Other information is at www.GEKengineering.com

=> free downloads tab.

WHY THE INCREASE IN EARTHQUAKES? THE RING OF FIRE MAY BE THE MAJOR CAUSE

- Over 90% of earthquakes and 75% of volcanic eruptions occur in the pacific rim area known as the ring of fire.
- Started waking up in mid to late 2012.



More than 100 years of earthquakes glow on a world map.
Credit: John Nelson, IDV Solutions.

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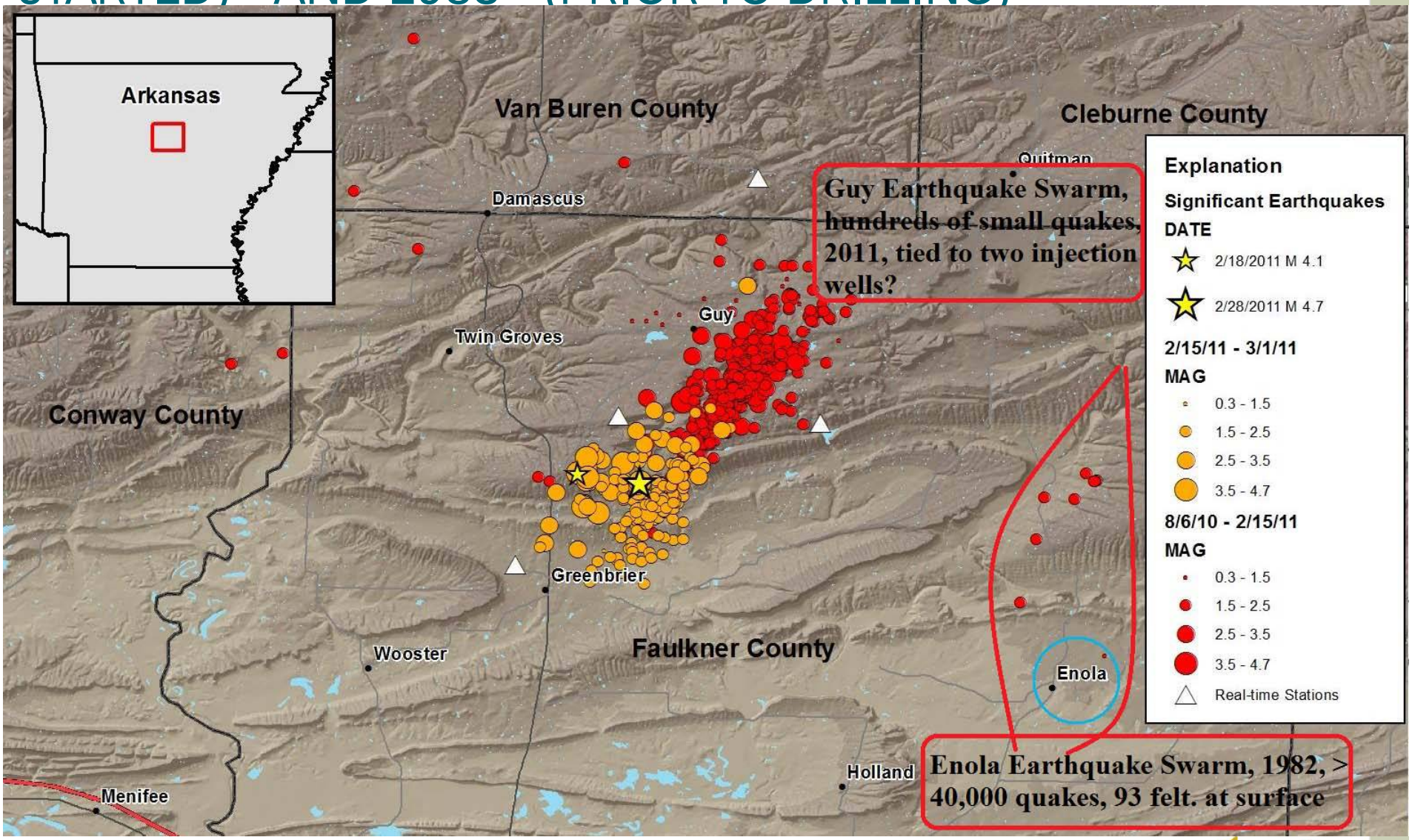
CAN MAN-MADE ACTIVITY CAUSE SMALL EARTHQUAKES?

- Earthquakes induced by human activity have been documented in a few locations in the United States, Japan, and Canada.
- Some limited power causes:
  - injection of fluids into deep wells for waste disposal
  - filling of large reservoirs for water supplies.
  - Deep mining can cause small to moderate quakes
  - Nuclear testing has caused small earthquakes in the immediate area surrounding the test site,
  - but other human activities have not been shown to trigger subsequent earthquakes.
- Earthquakes are part of a global tectonic process that generally occurs well beyond the influence or control of humans. The focus (point of origin) of an earthquake is typically tens to hundreds of miles underground, and the scale and force necessary to produce earthquakes are well beyond our daily lives.

EARTHQUAKES IN ARKANSAS – 2011 (AFTER DEVELOPMENT STARTED) - AND 1983 - (PRIOR TO DRILLING)



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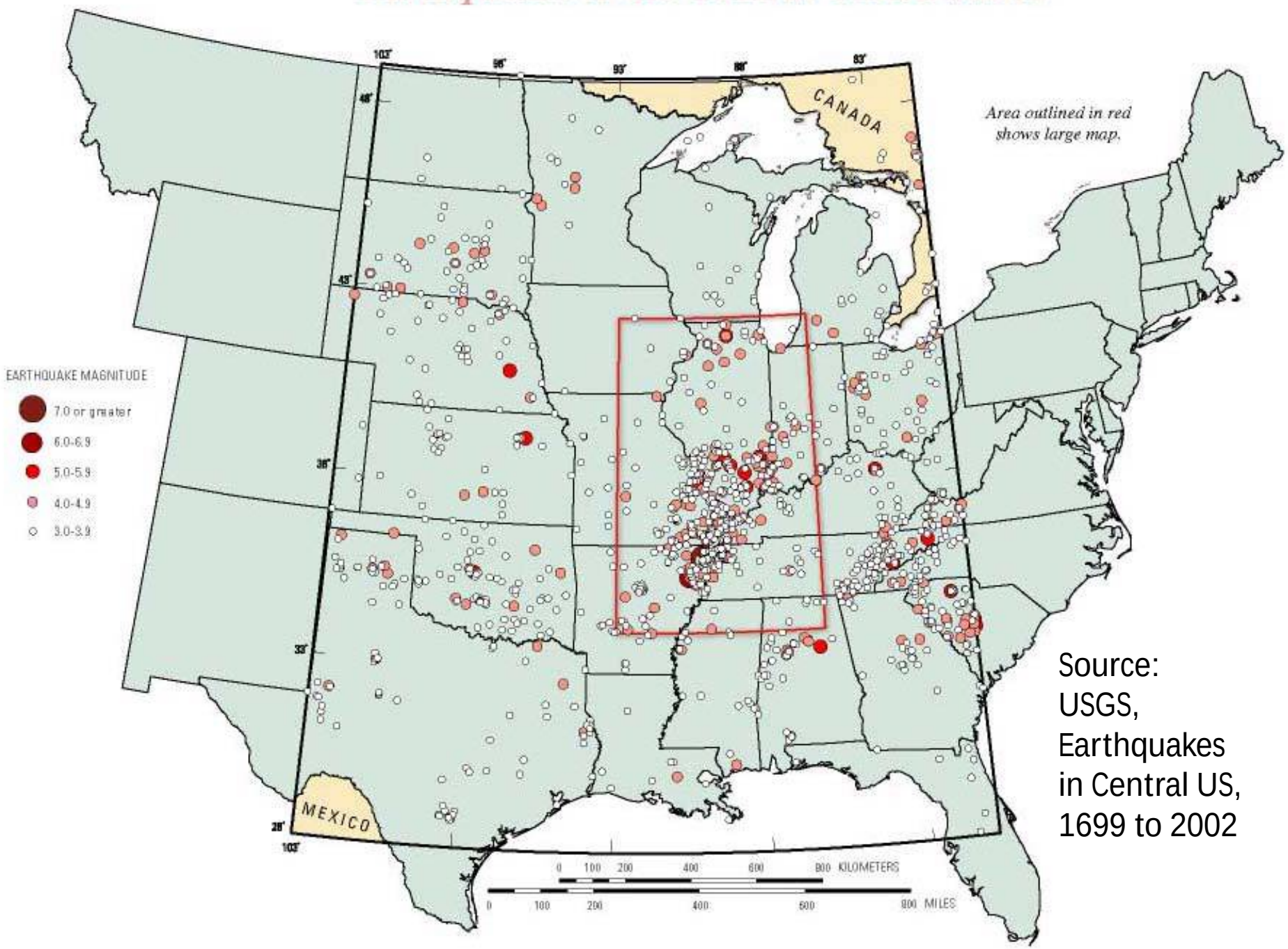
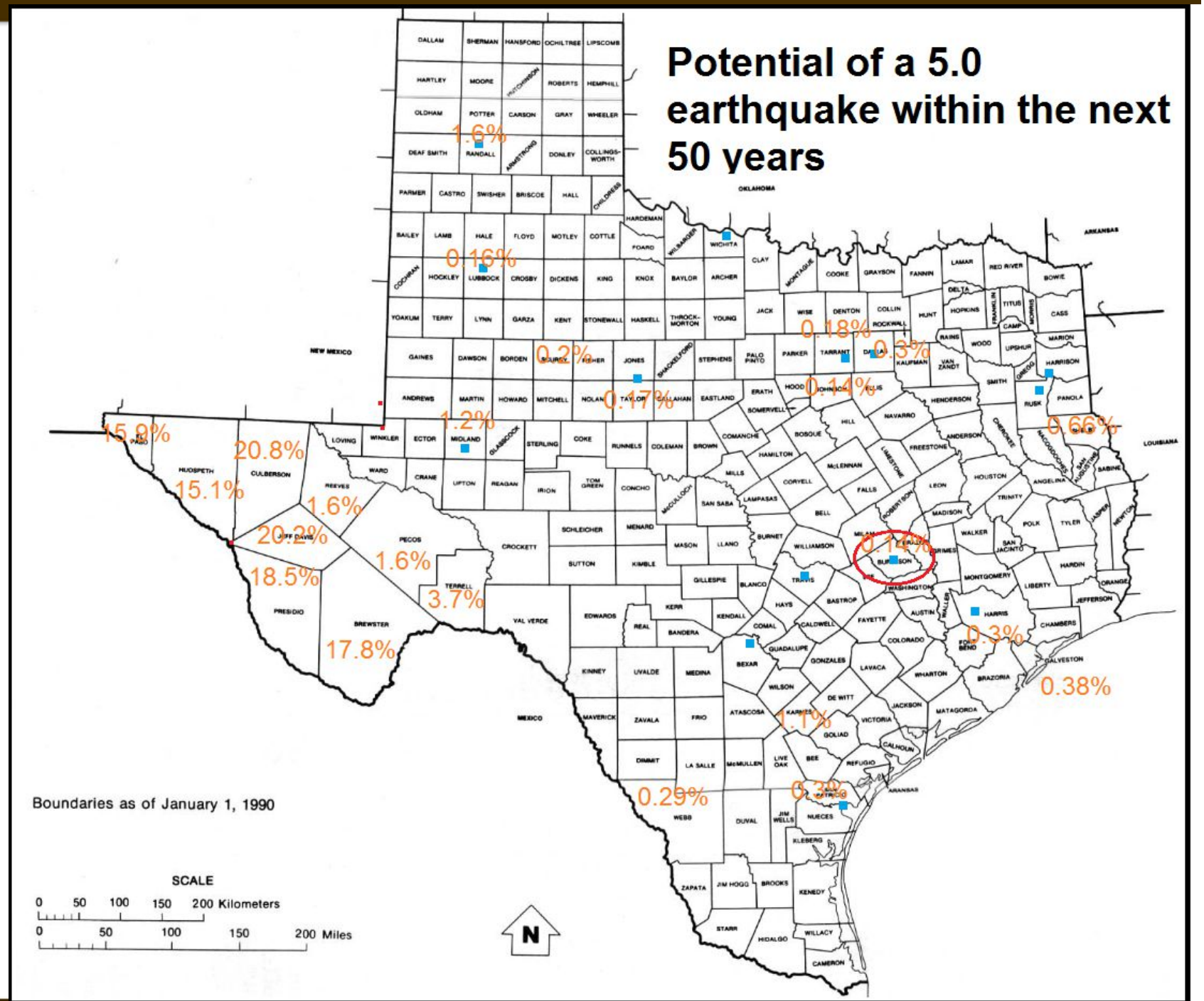
Earthquakes in the Central United States



Source: USGS, Earthquakes in Central US, 1699 to 2002


Potential of a 5.0 earthquake within the next 50 years
1.6%
0.16%
0.2%
0.17%
1.2%
0.18%
0.3%
0.14%
0.66%
15.9%
20.8%
15.1%
1.6%
20.2%
1.6%
18.5%
3.7%
17.8%
0.1%
0.3%
0.38%
1.1%
0.29%
0.2%
Boundaries as of January 1, 1990
SCALE
0 50 100 150 200 Kilometers
0 50 100 150 200 Miles
N

How Much Cement is Needed for Isolation?
Every inch of cement is NOT required to be perfect.

Quality of cement is more important than the volume.

Isolation can only be measured with a pressure test.

Bond logs are not always best tool

- ~10% channels missed.
- Instances of false negatives.

Over 10,000 psi can be held with less than 50 ft of cement, but 200 to 300 ft is routinely used.