GROUND-WATER LEVEL CHANGES IN U.S. AQUIFERS AS POTENTIAL TRIGGERS FOR EARTHQUAKES

JUNE 2013

Jean Antonides

NOTE:

Outside sources of information cited or shown in this material will be referenced and given credit at the end of this presentation.

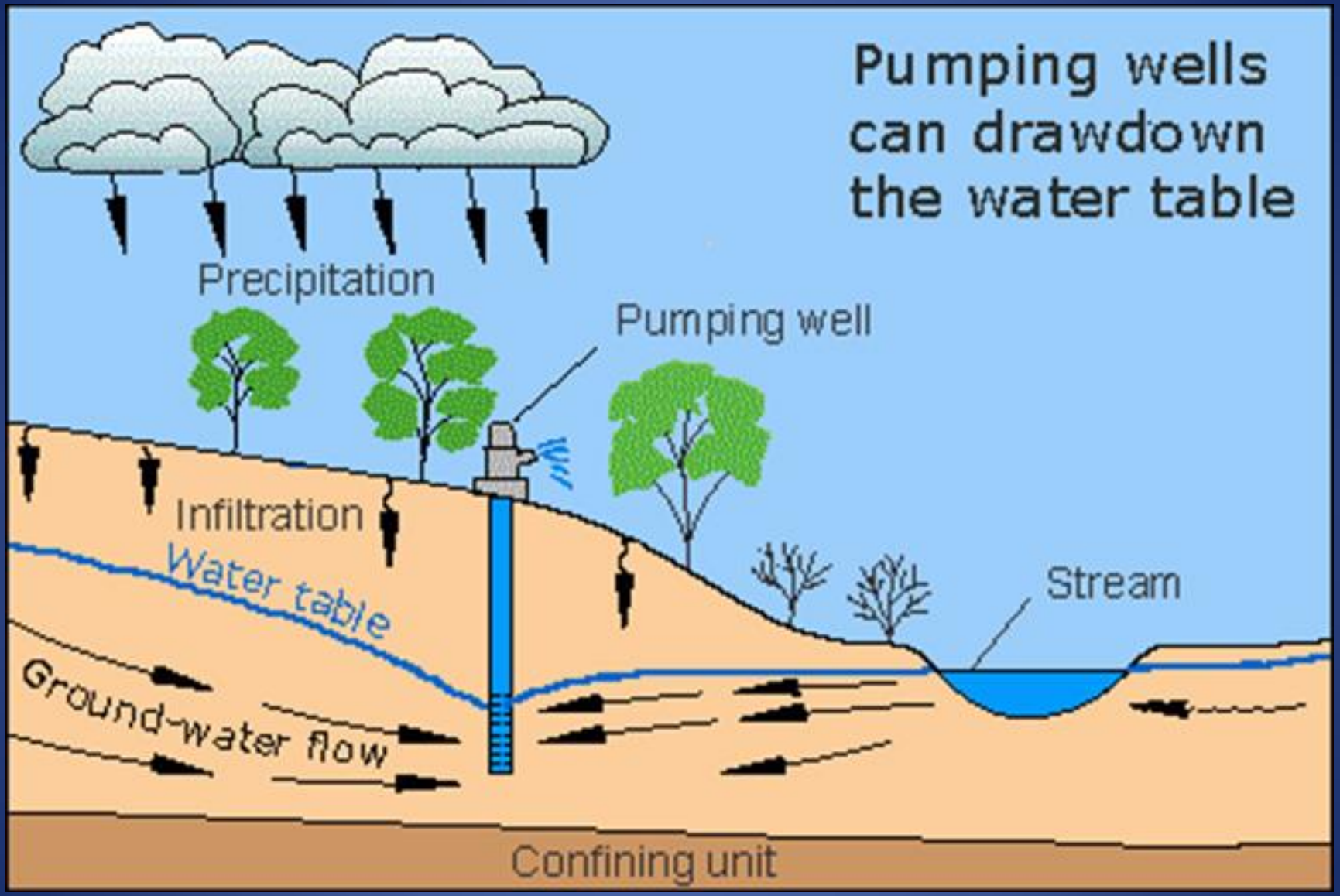


Figure 1: Methods that water enters a groundwater aquifer.

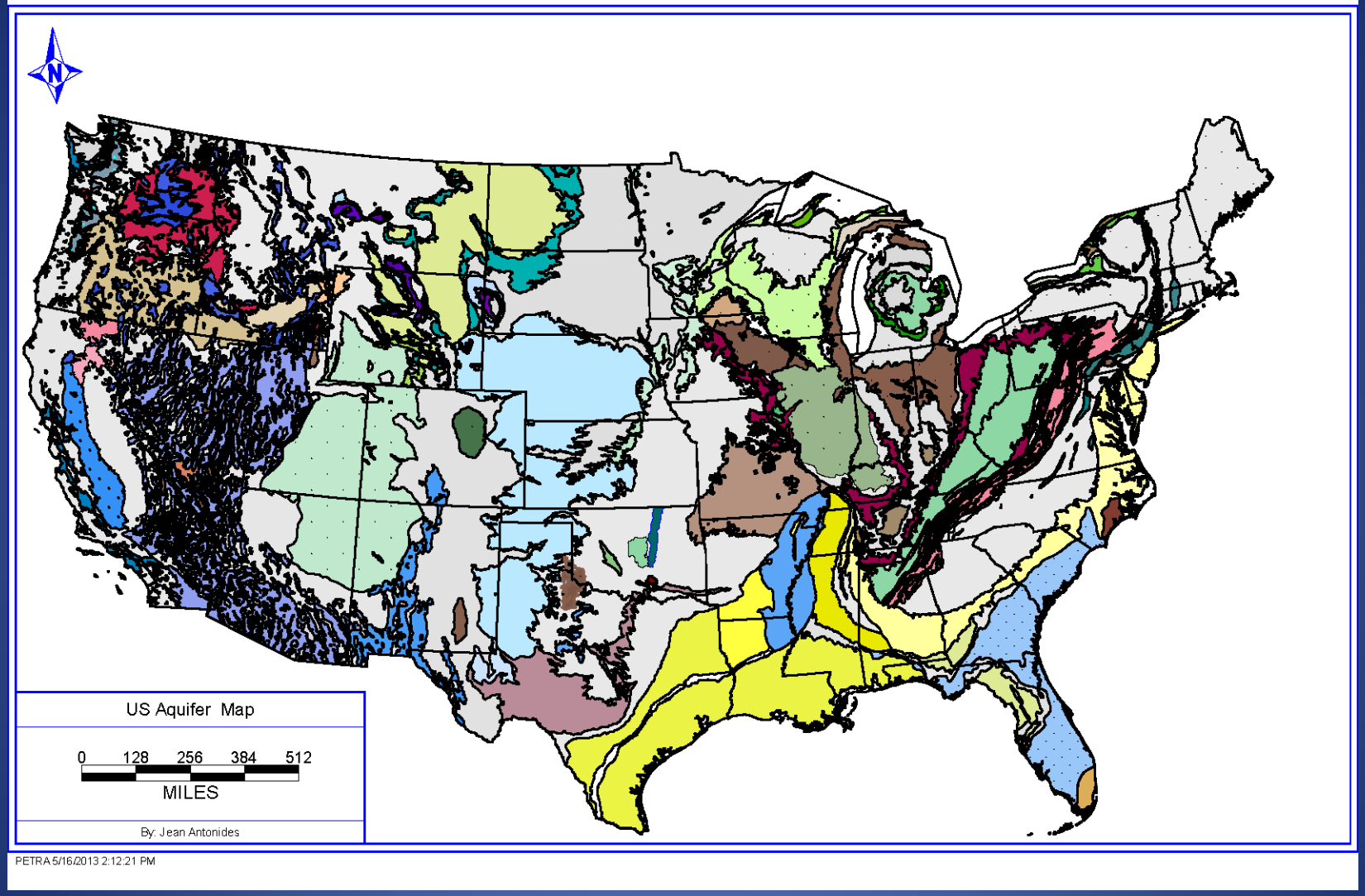


Figure 2: Amended USGS map of major aquifers of the U.S.

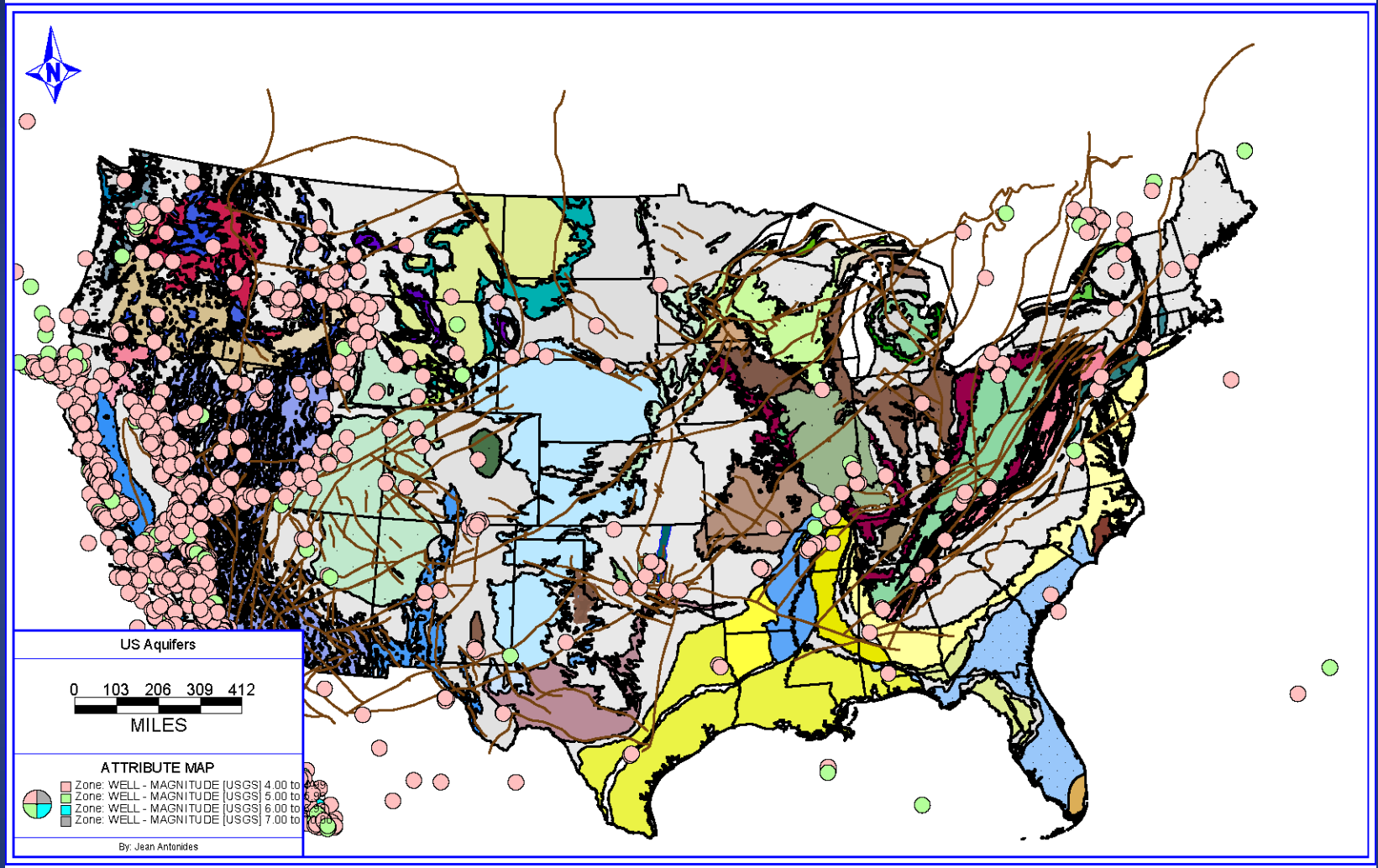


Figure 3: USGS aquifer map with 1980 – April 2013 earthquakes > M 4.0. along with the location of the sub-plates of the North American plate.

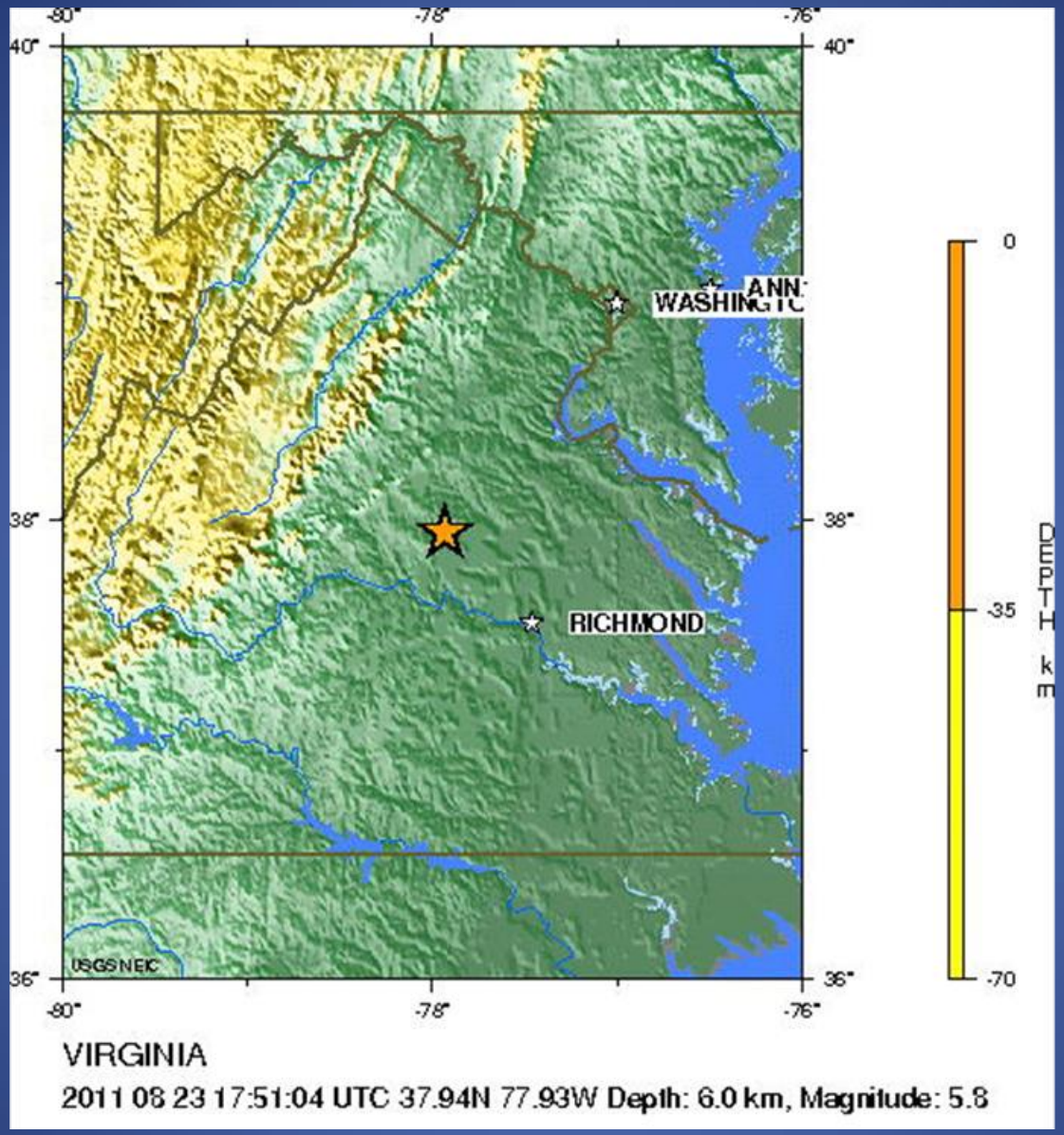


Figure 4: Location of the epicenter of the 2011 Virginia quake, from the USGS.

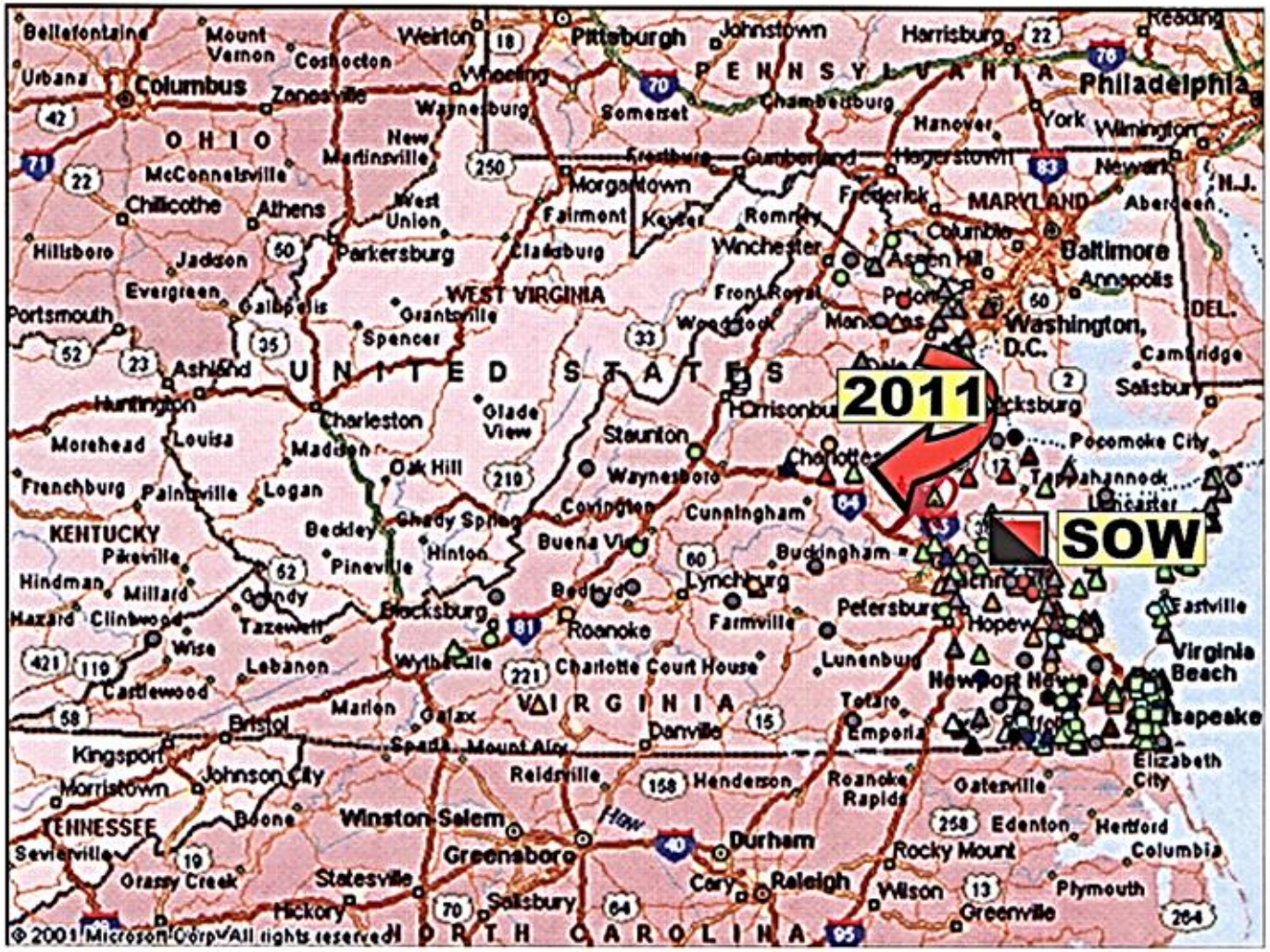


Figure 5: Virginia groundwater monitoring system, from the USGS.

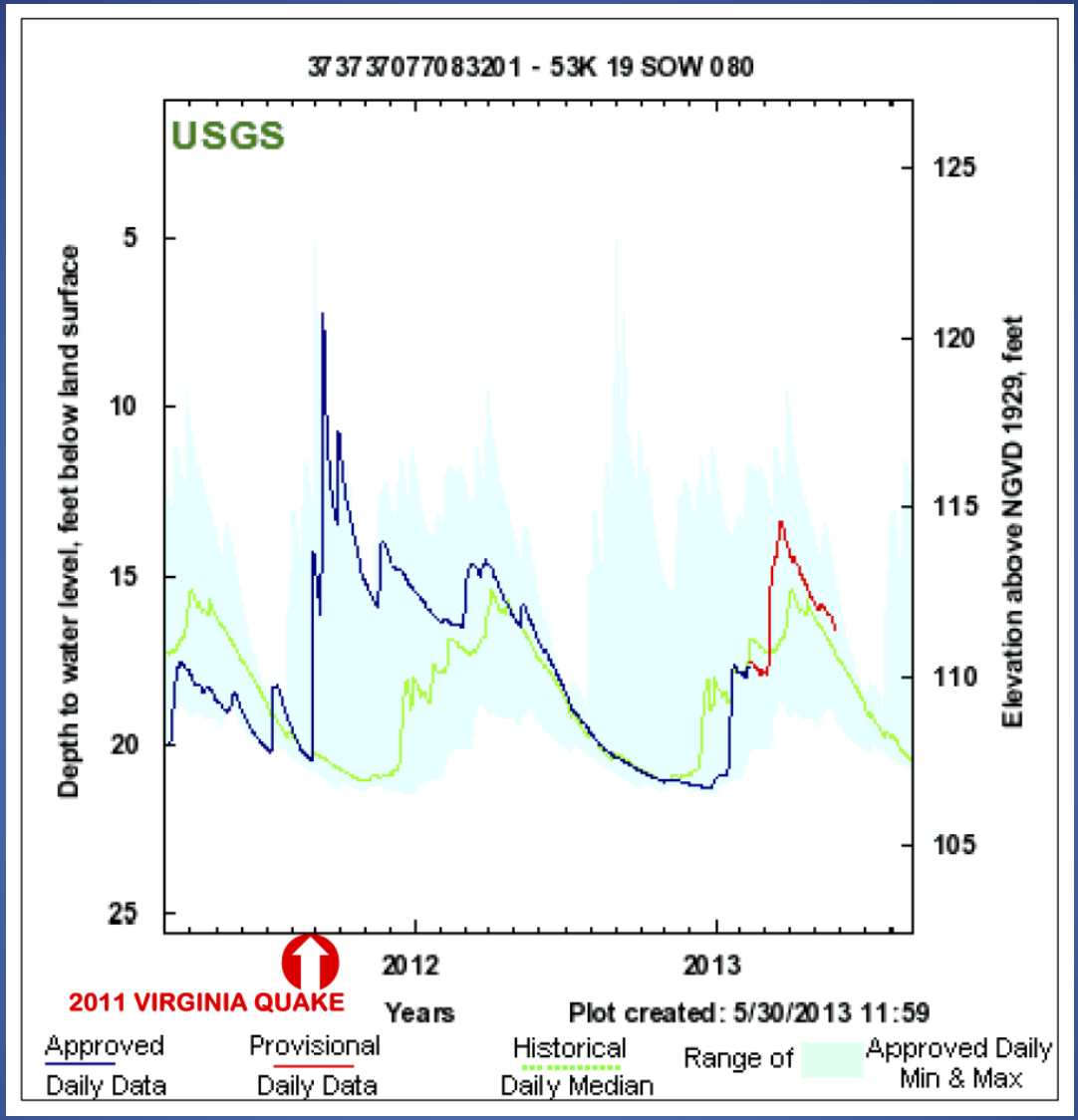


Figure 6: SOW 080 Virginia monitoring well, which is Located east of Richmond, Virginia.

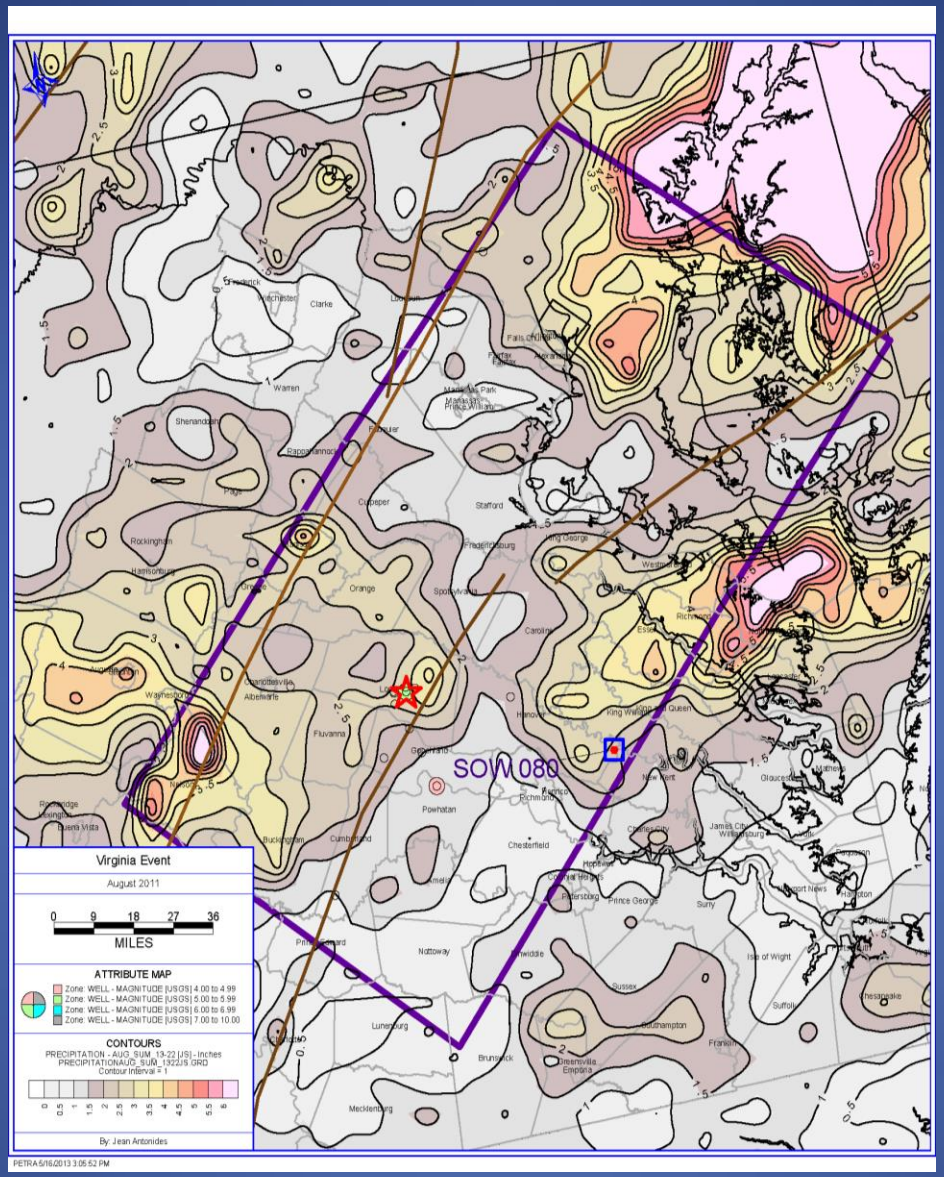


Figure 7: Cumulative rainfall map of 2011 Virginia quake area from August (13 - 22) 2011.

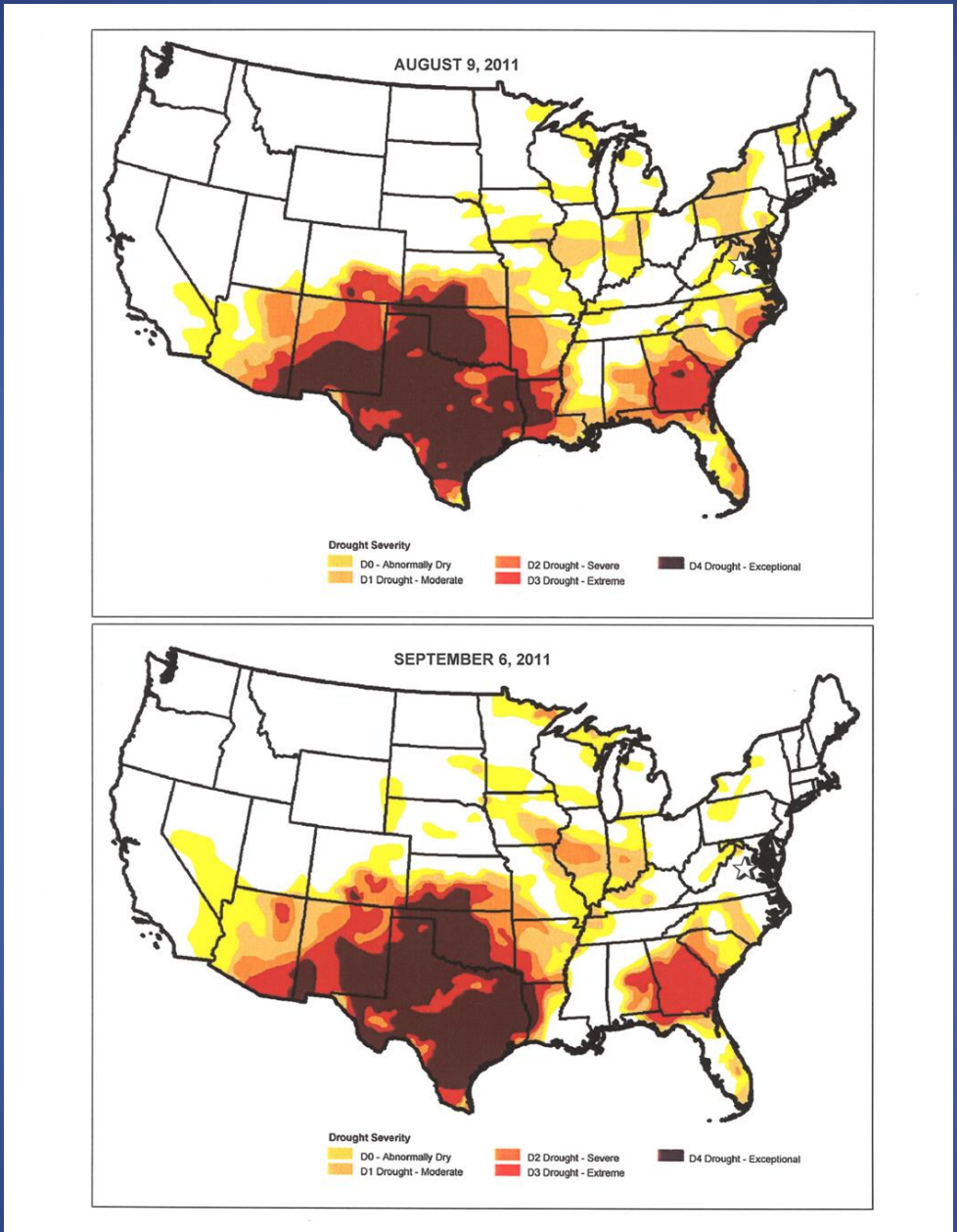


Figure 8: Drought maps before and after 2011 Virginia quake.

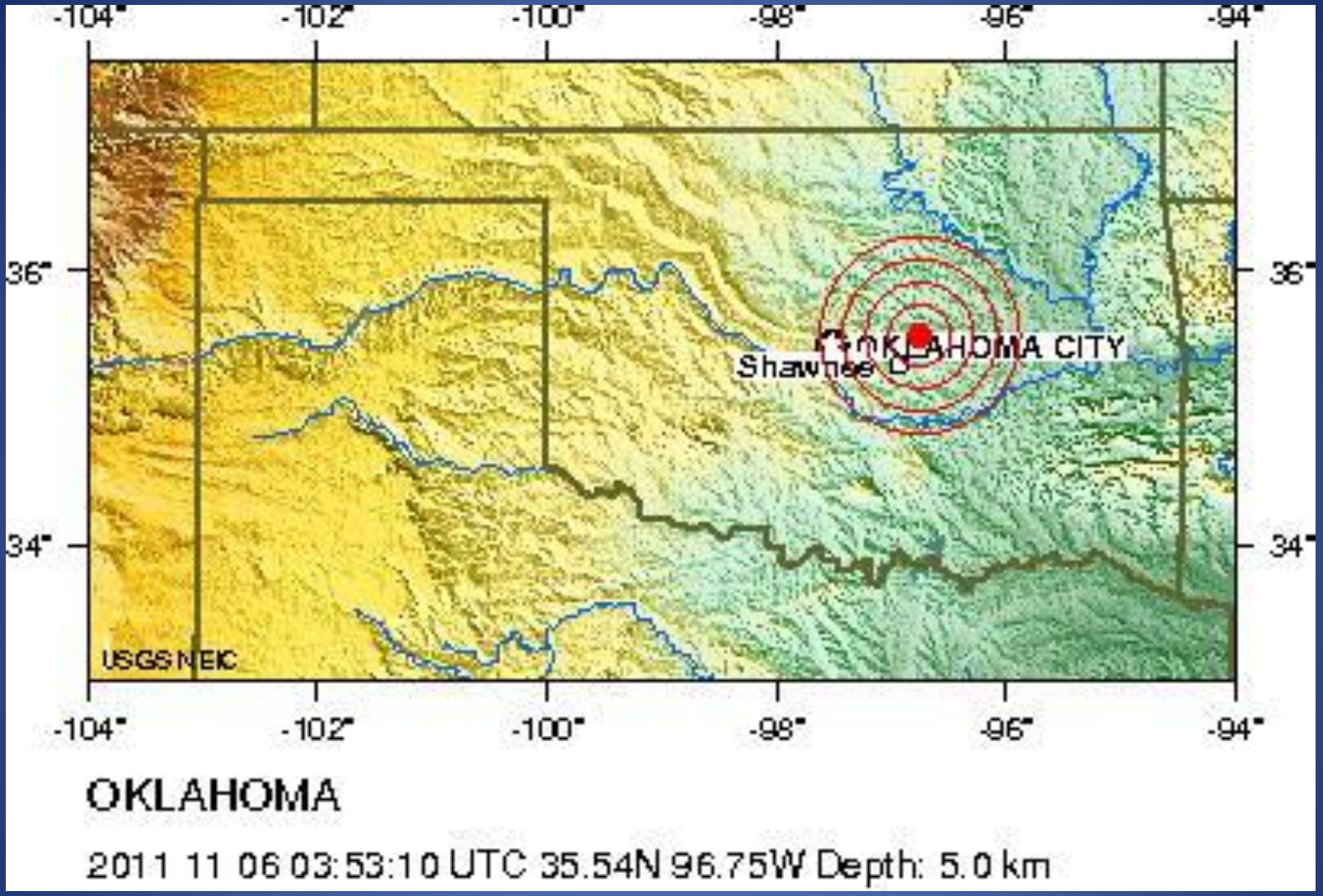


Figure 9: Location of 2011 Oklahoma quake, from the USGS.

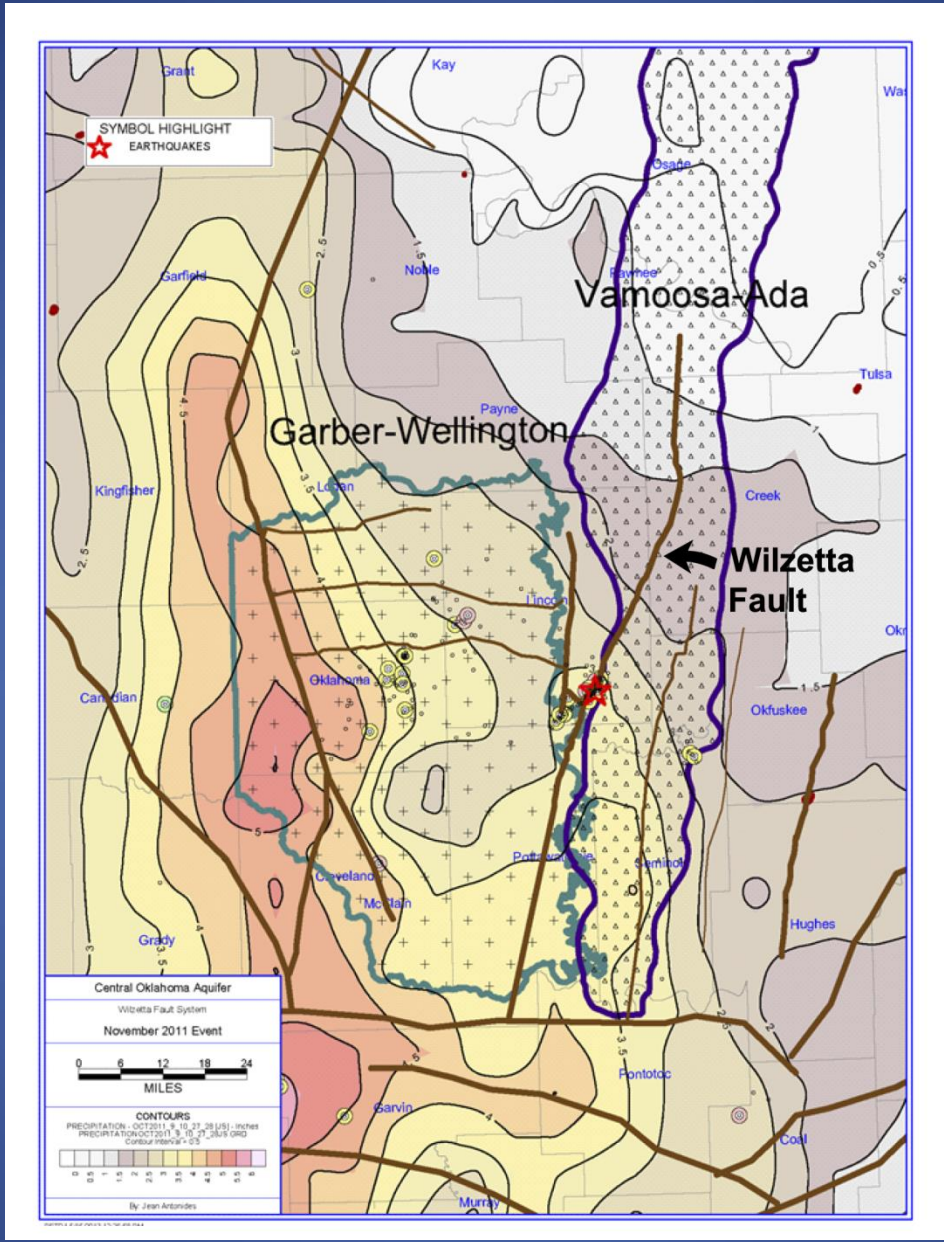


Figure 10: Cumulative rainfall map from October (9, 10, 27,28) 2011.

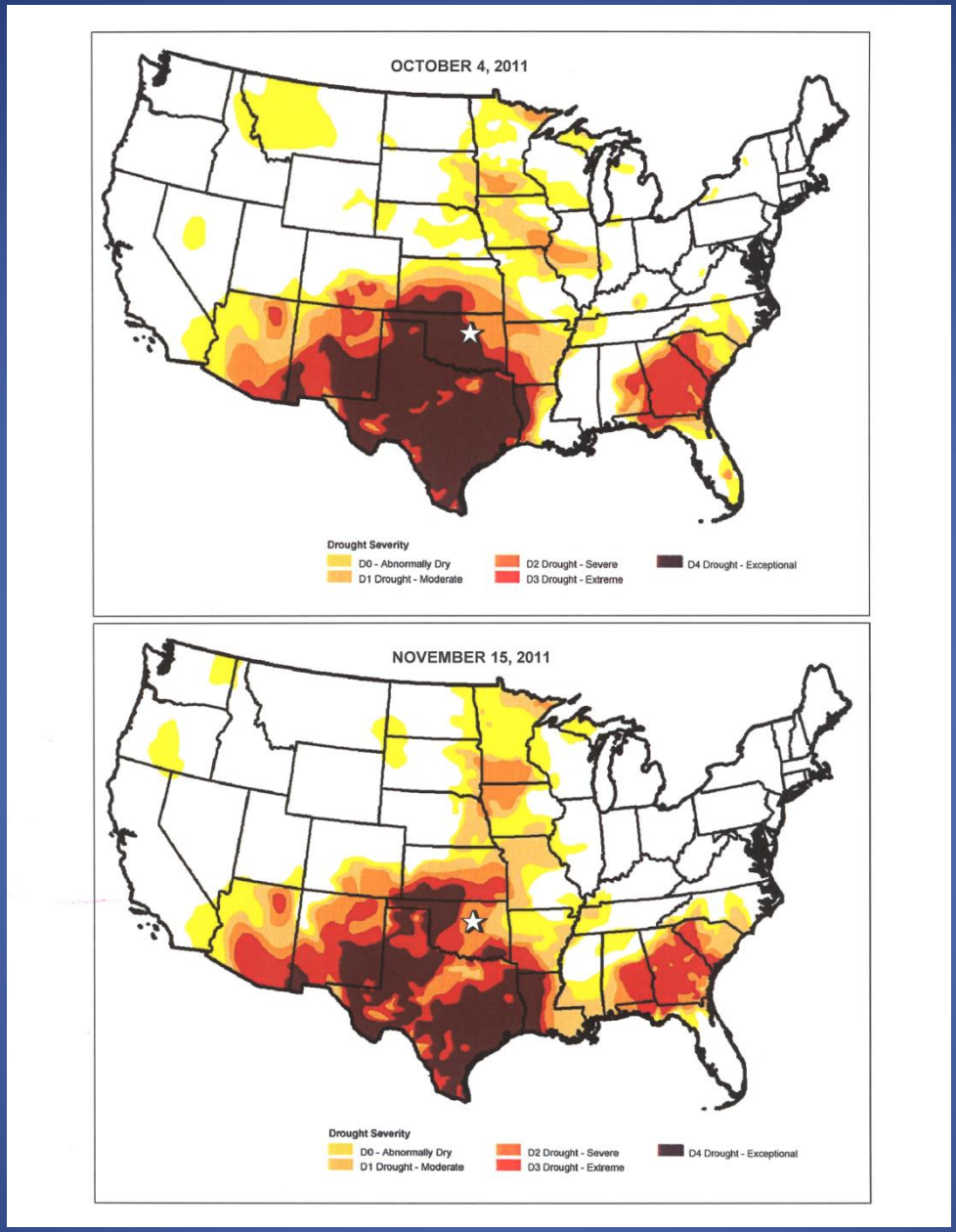


Figure 11: Drought maps before and after 2011 Oklahoma quake.

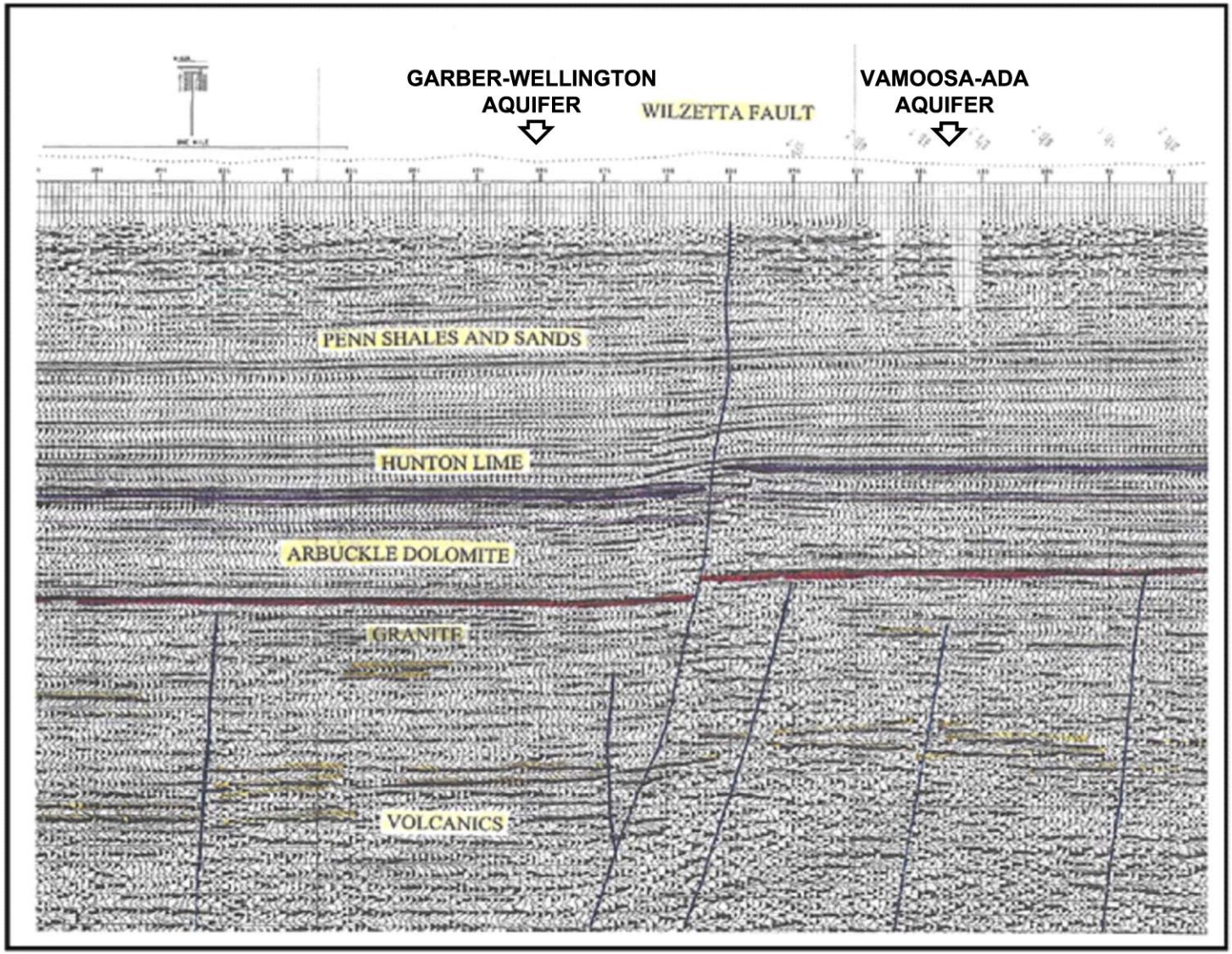


Figure 12: E - W - seismic profile across Wilzetta Fault Complex.

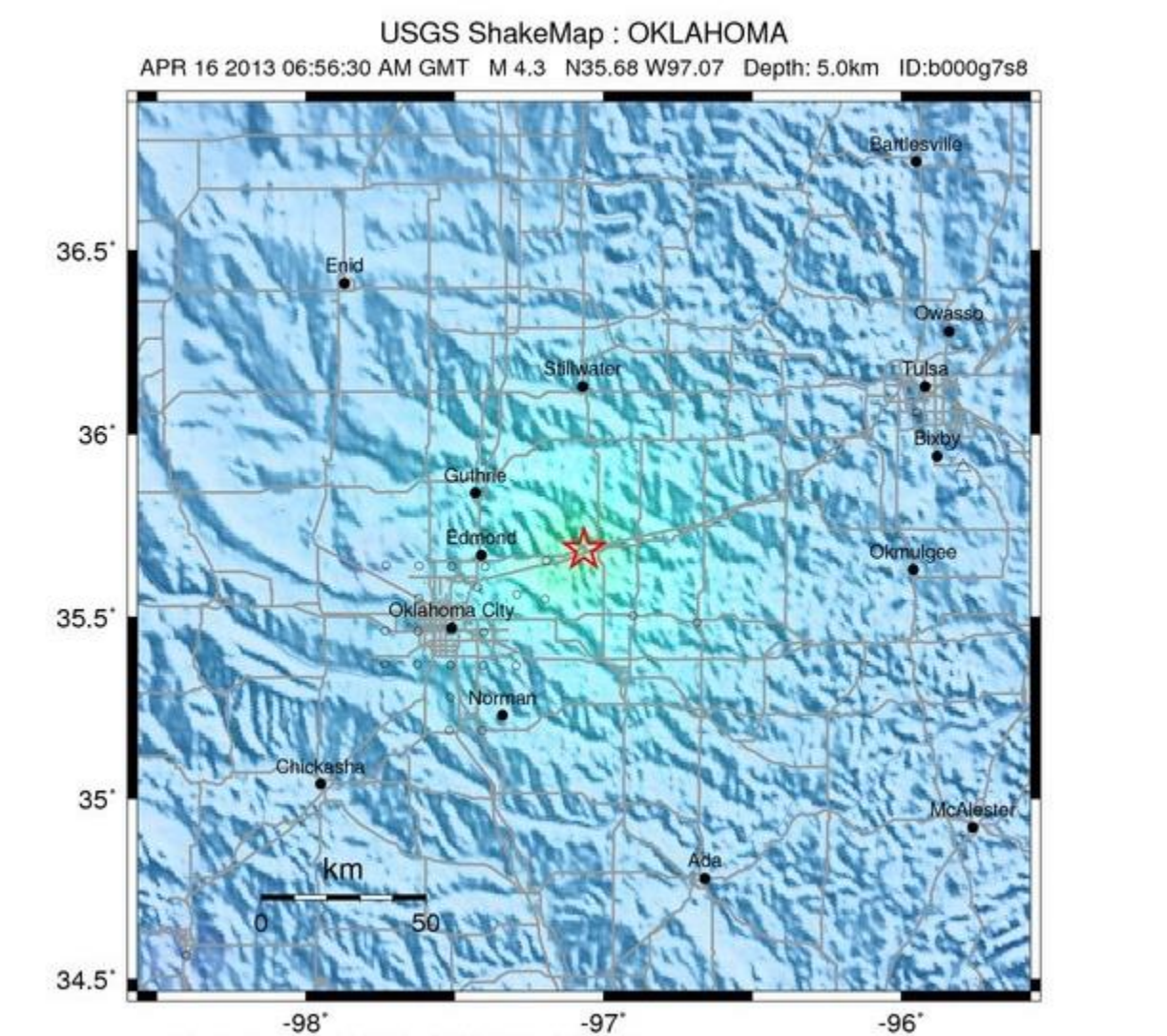


Figure 13: Location of 2013 Oklahoma quake, from the USGS.

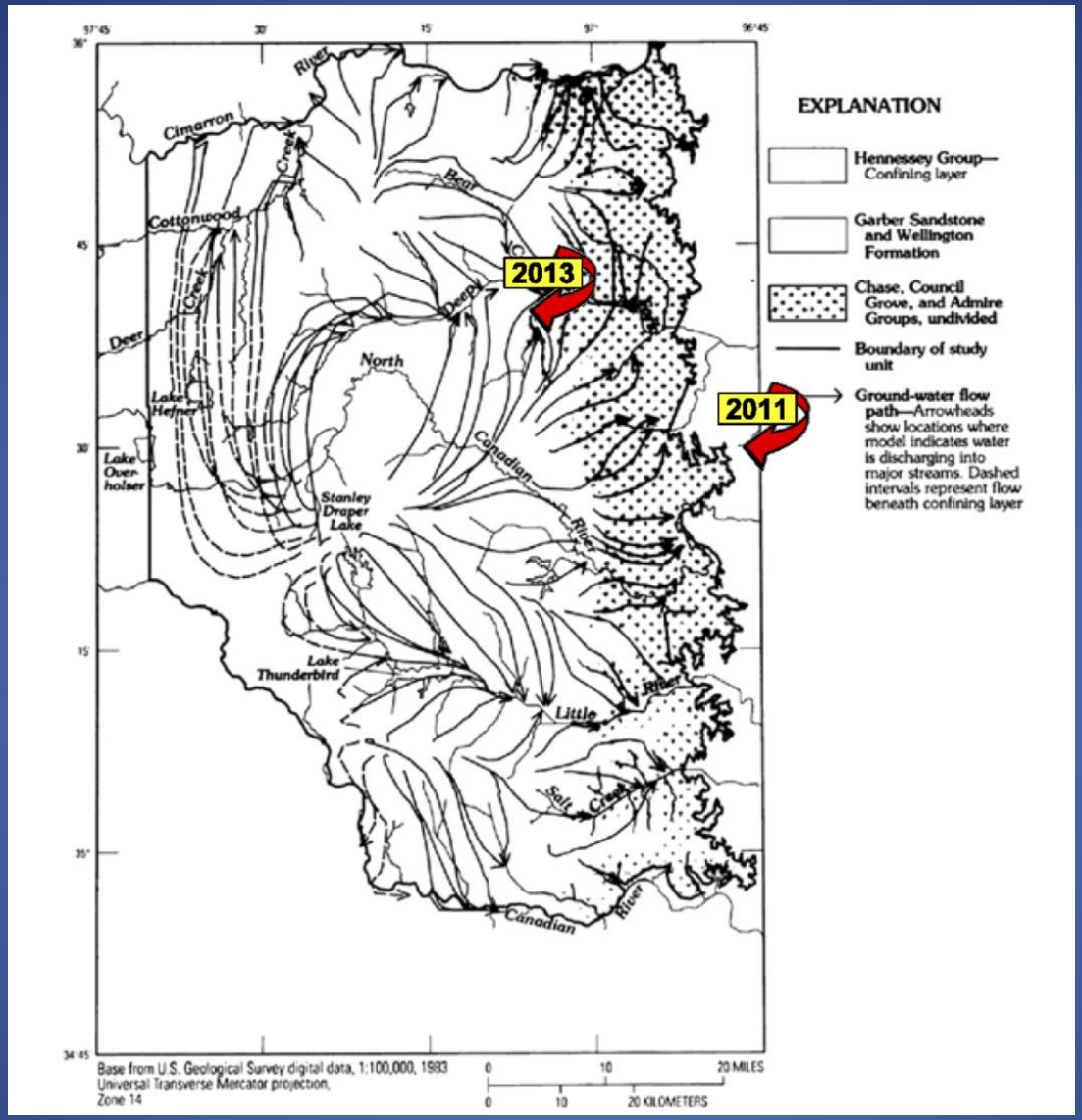


Figure 14: Groundwater recharge pattern of the Central Oklahoma Garber Wellington aquifer.

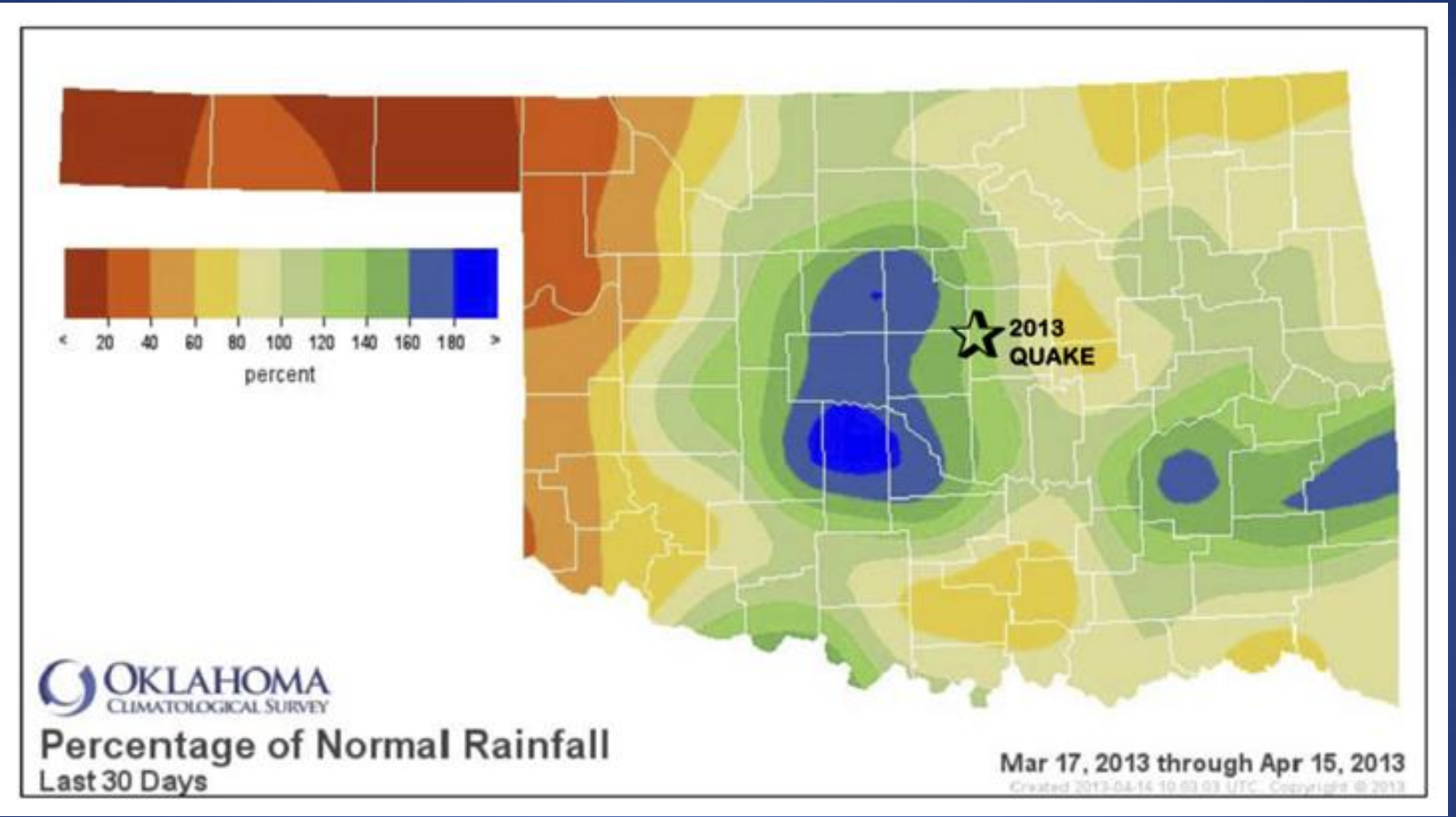


Figure 15: Rainfall percentage map for the month preceding 2013 Oklahoma earthquakes.

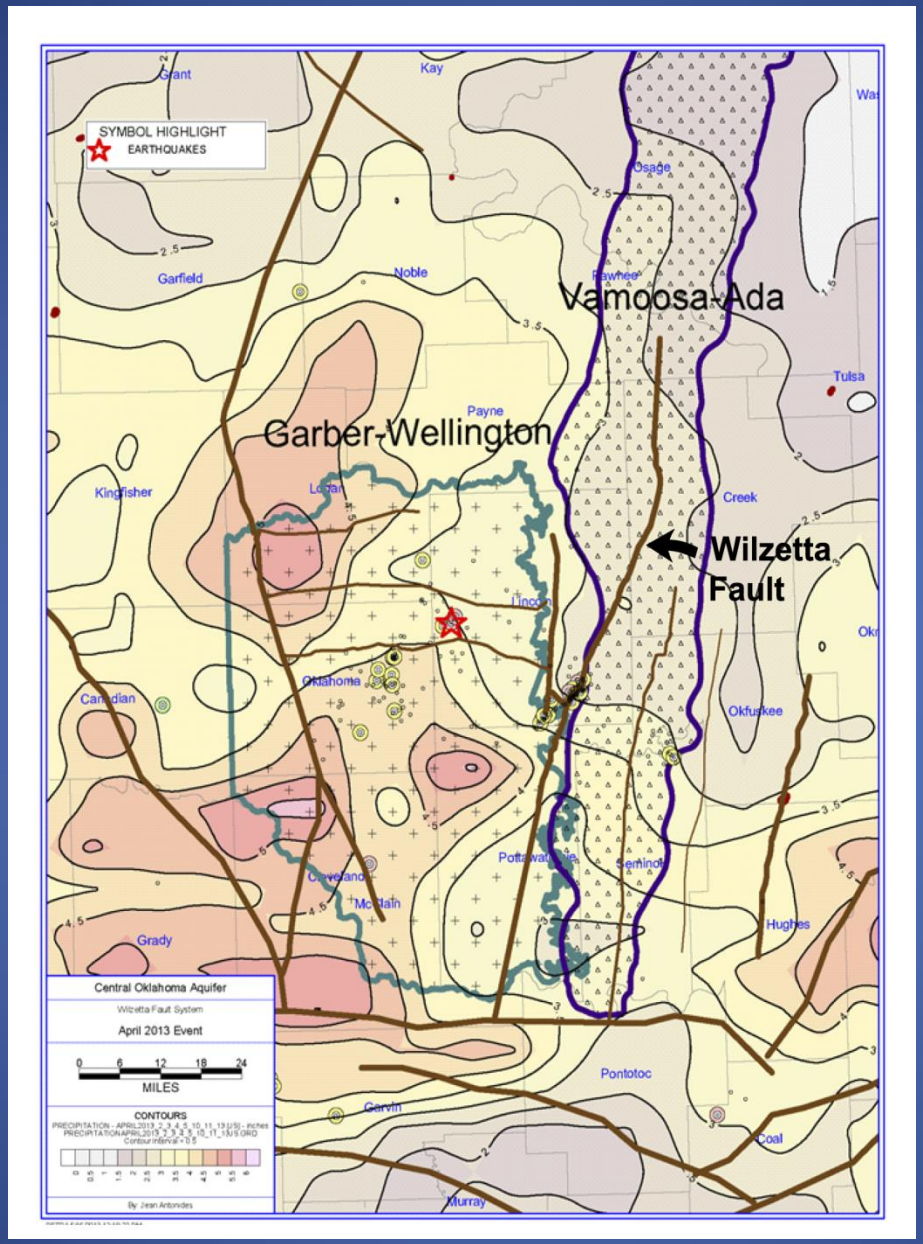


Figure 16: Cumulative rainfall map from April (2-5, 10, 11, 13) 2013.

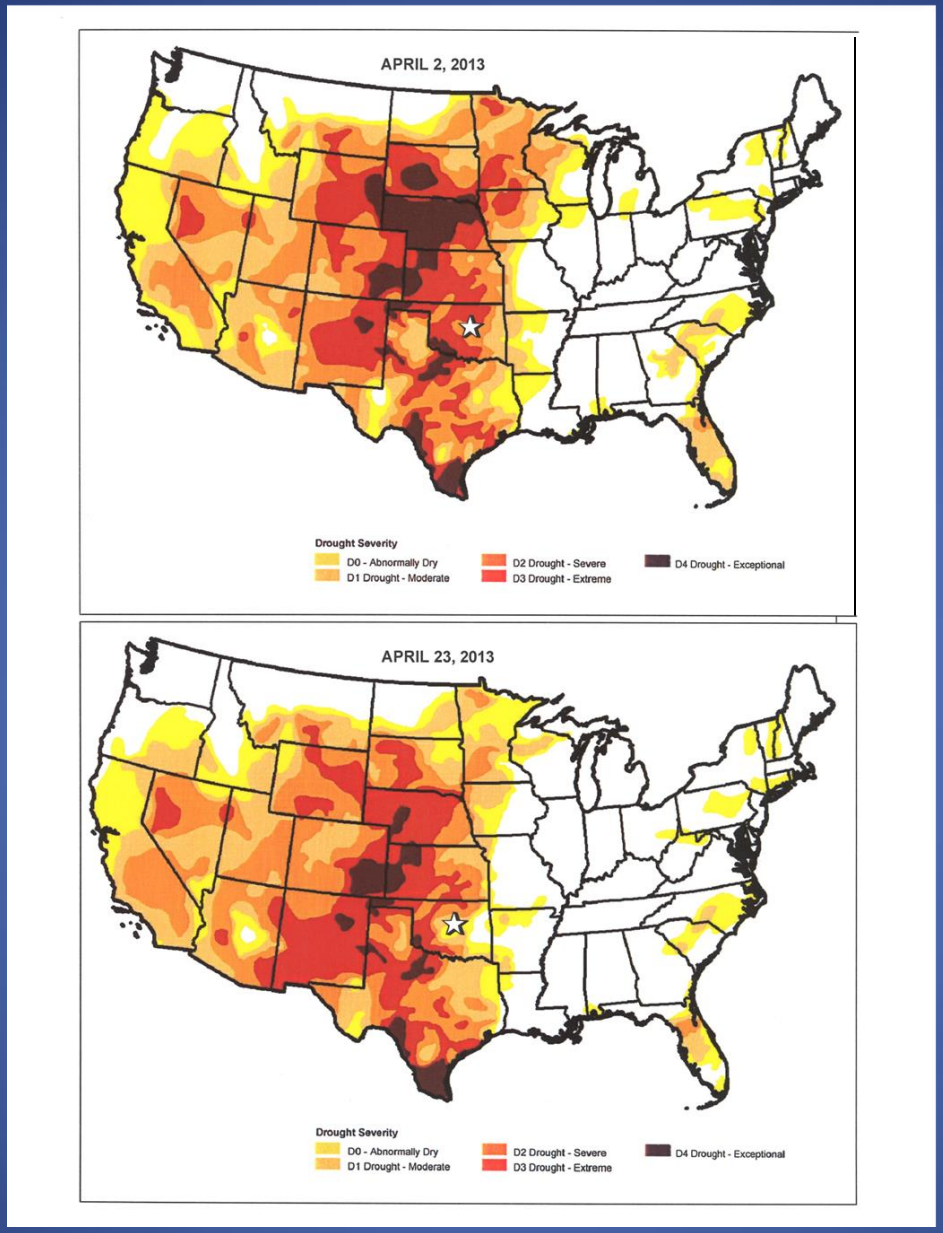


Figure 17: Drought maps from before and after the 2013 Oklahoma quake.

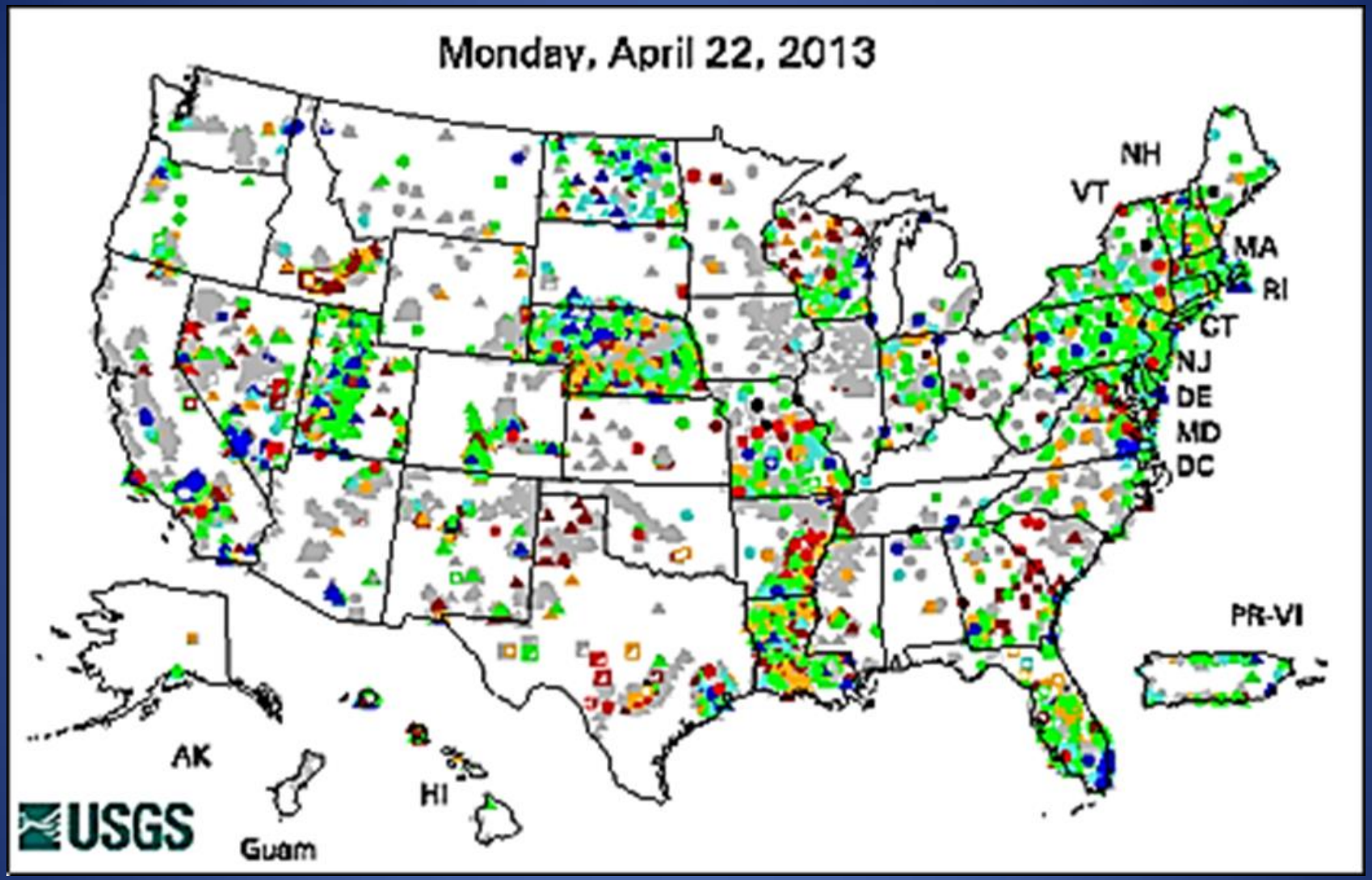


Figure 18: USGS monitoring system for groundwater aquifers (March 2013).

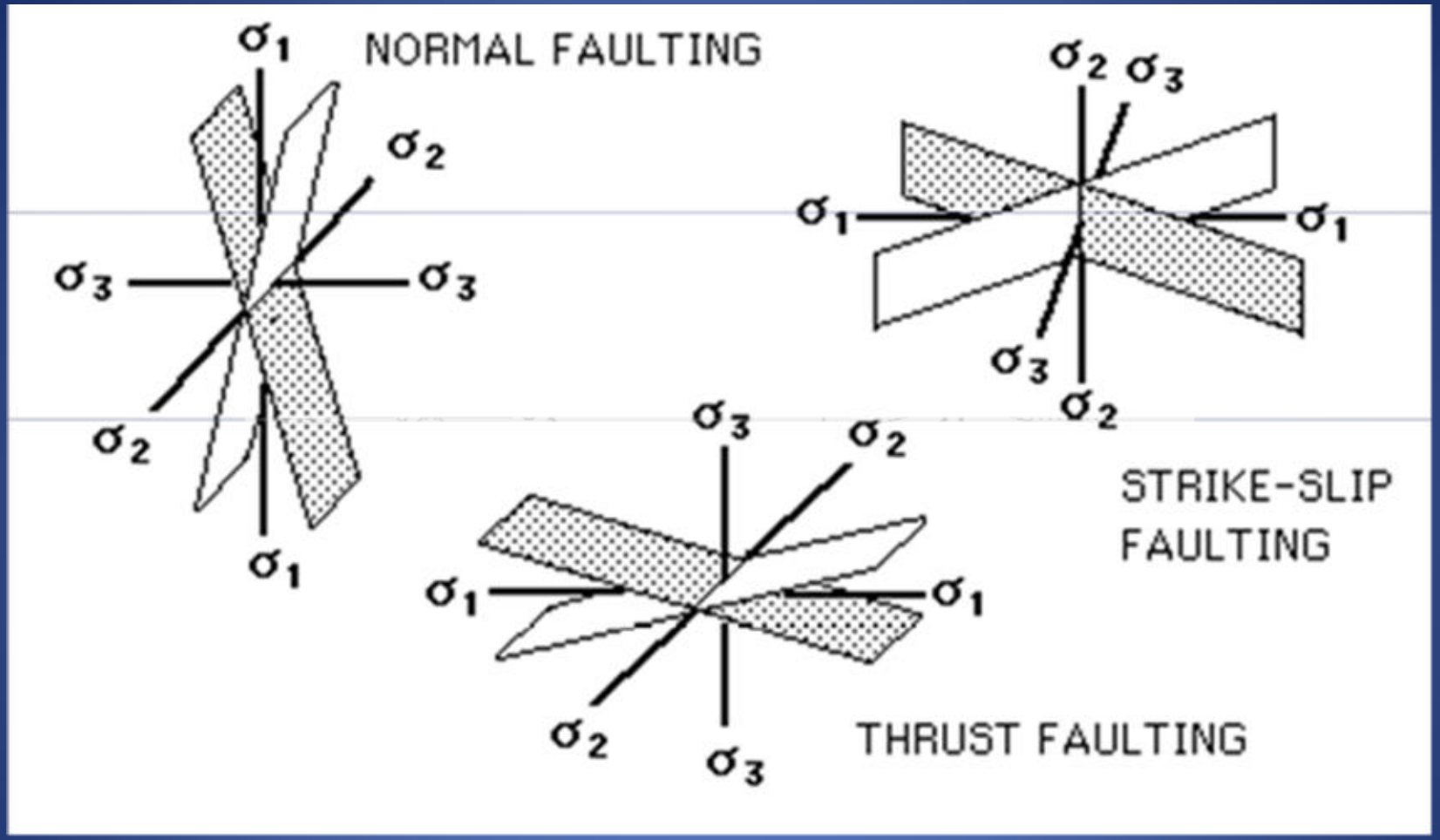


Figure 19: Buoyancy affects the sigma 2 stress in compression strike slip fault systems.

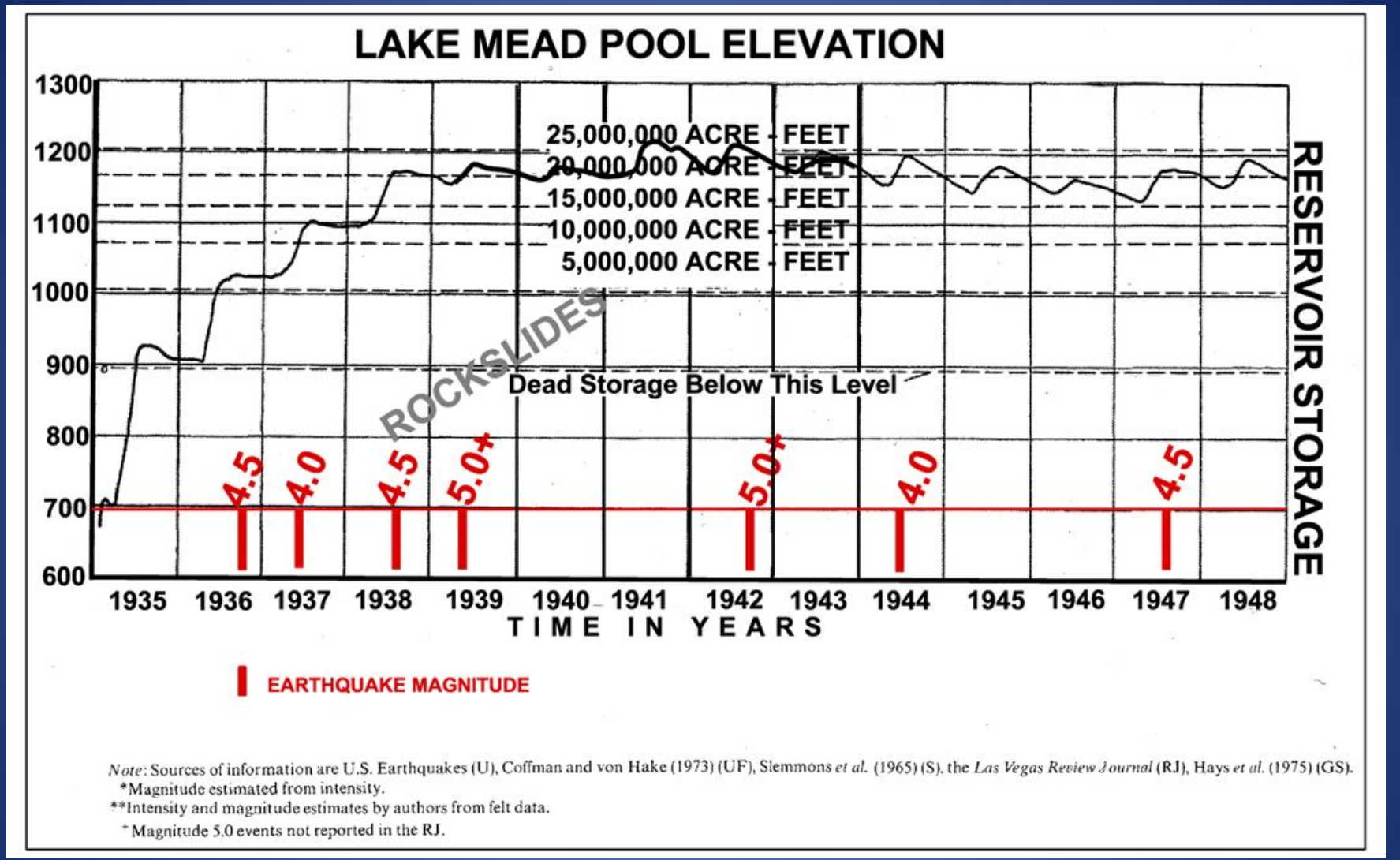


Figure 20: Water level and storage volumes of Lake Mead from 1935 - 1948. Date and estimate of earthquakes size from 1975 study of seismicity of the region. Notice the correlation between the filling of the reservoir and timing of earthquakes in the area.

Figure 21: Taipei 101 was completed in 2004, it weighed 780,000 tons when completed. It has been associated with an increase in seismic activity during its construction.

Table 1: Mass transfer events along with respective weight change to the system.

Event	Water (acre/ft)	Number of rain events (Day)	Total number of Days	Total Weight (Tons)	Weight/Day (Tons)	Weight for each 10% of Absorption (Tons)
Virginia 2011	1,839,580	8	10	2.5 Trillion	250 Millions	250 Millions
Oklahoma 2011		4	19			
Garber Welllington	559,361			760 Million	40 Millions	76 Millions
Vamoosa-Ada	251,361			342 Million	18 Millions	34 Millions
Oklahoma 2013		7	12			
Garber Welllington	617,386			839 Million	70 Million	84 Million
Vamoosa-Ada	355,545			483 Million	40.3 Millions	48 Millions
SWD Well (5000bbl/day)	21	-	30	28,773	959	-
Lake Mead (1936)	5,000,000	-	60	6.8 Trillion	113 million	-
Buri Khalifa Tower		-	3 Years	960,000	877	-

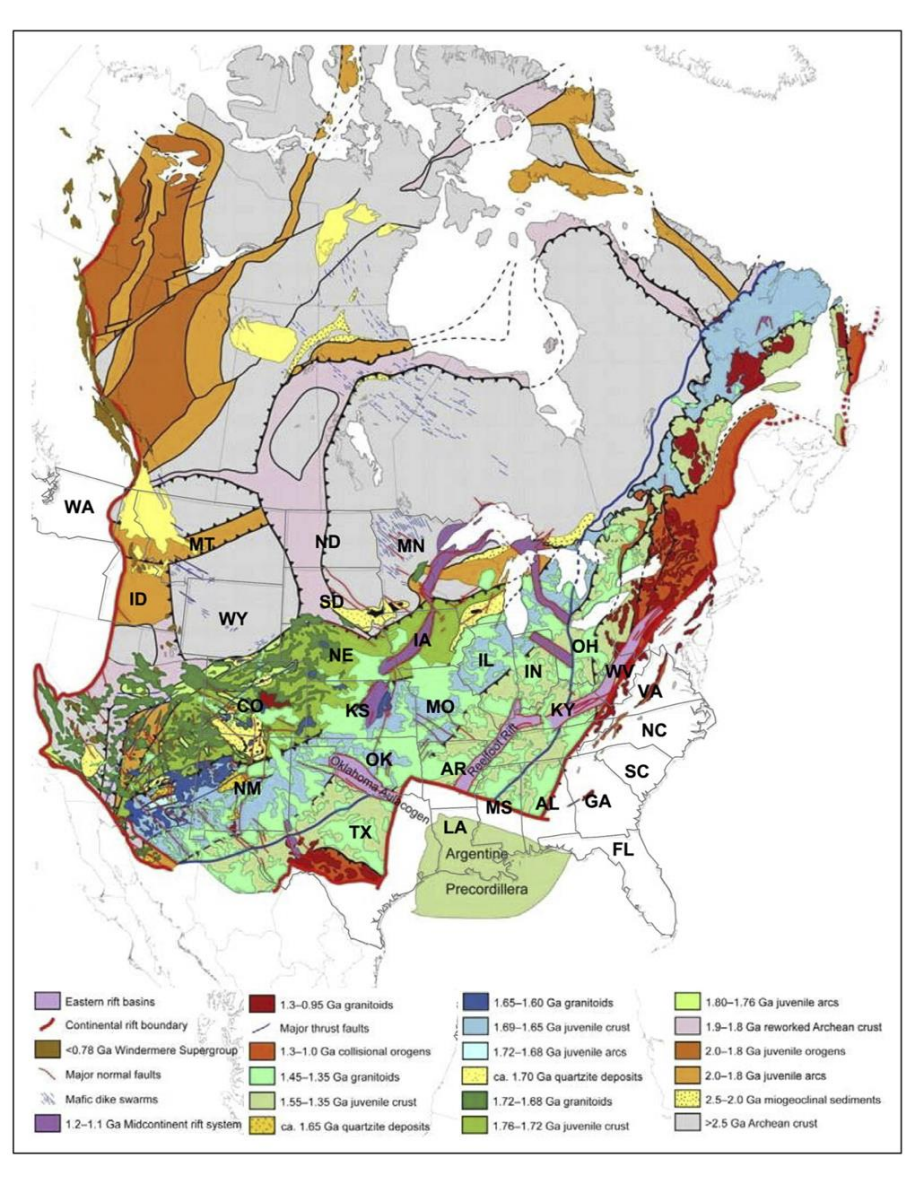


Figure 22: Proterozoic plate map of North American plate.

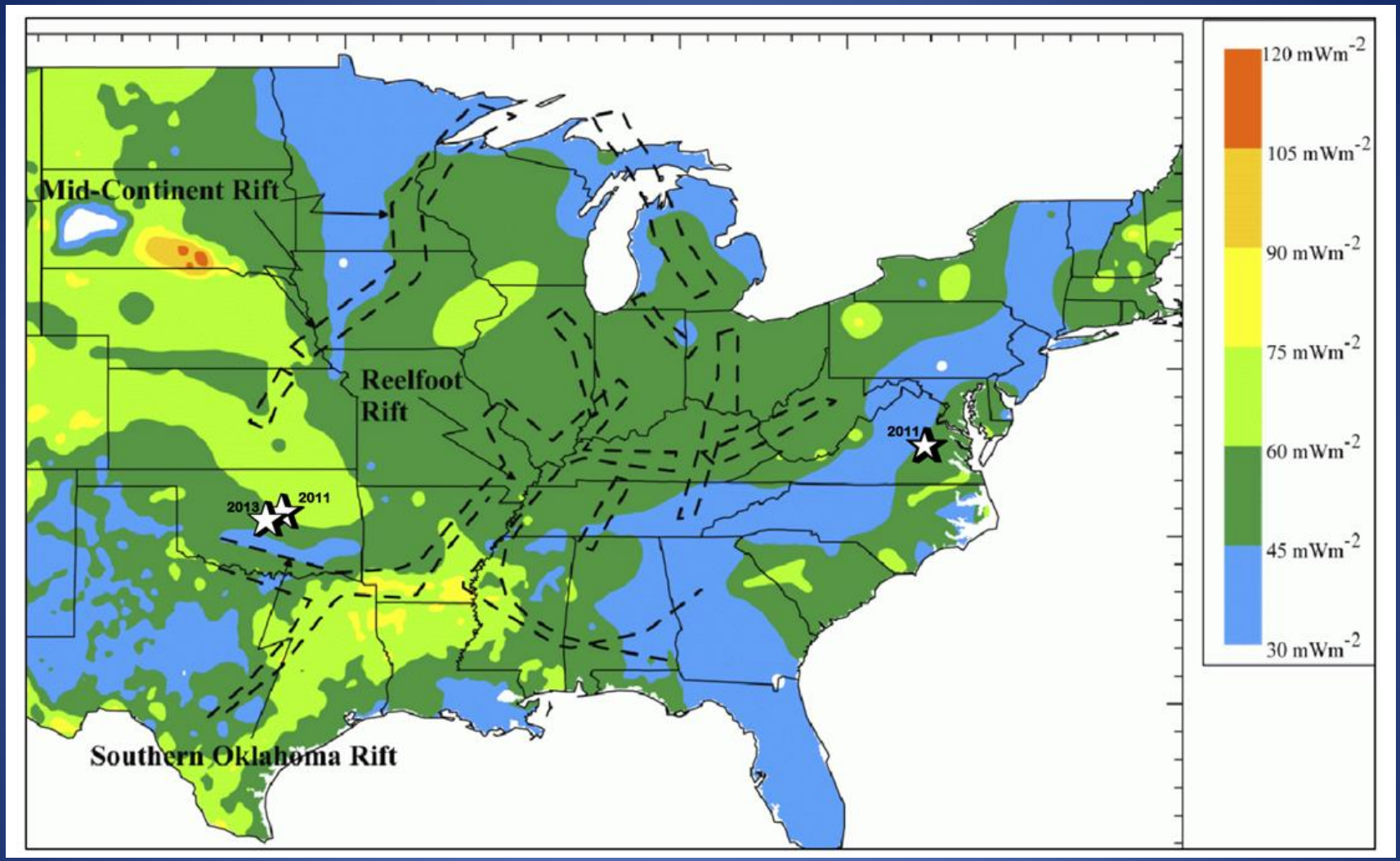


Figure 23: Heat source map of the U.S. Though the system of sub-plate boundaries are thought to be cooling, they are still active and generating heat. Some of heat signature is affected by the apparent thinning of zones within the crust.

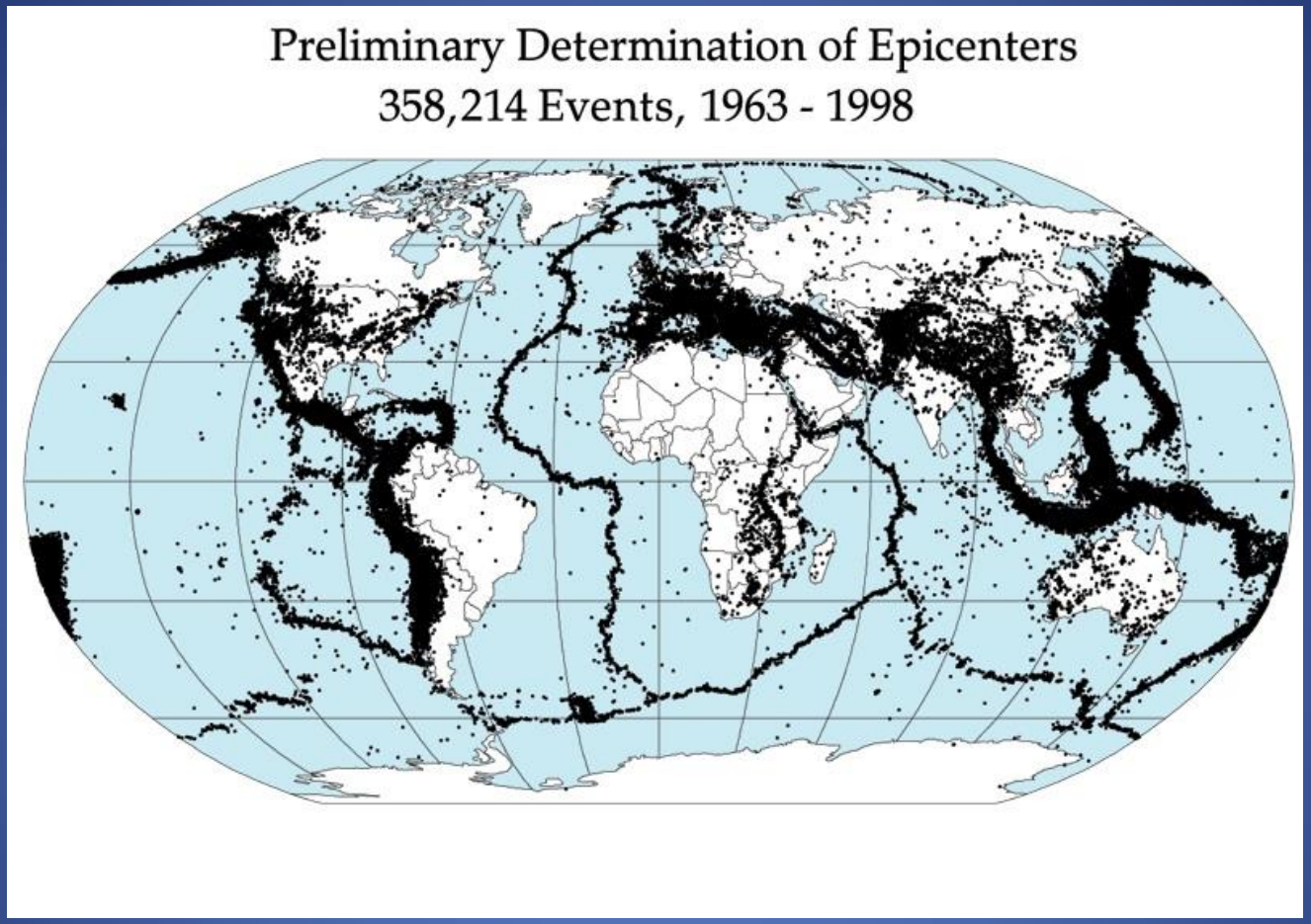


Figure 24: Locations of earthquakes from 1963 – 1998 outline the major active plate boundaries, along with some of the less active sub-plate boundaries.

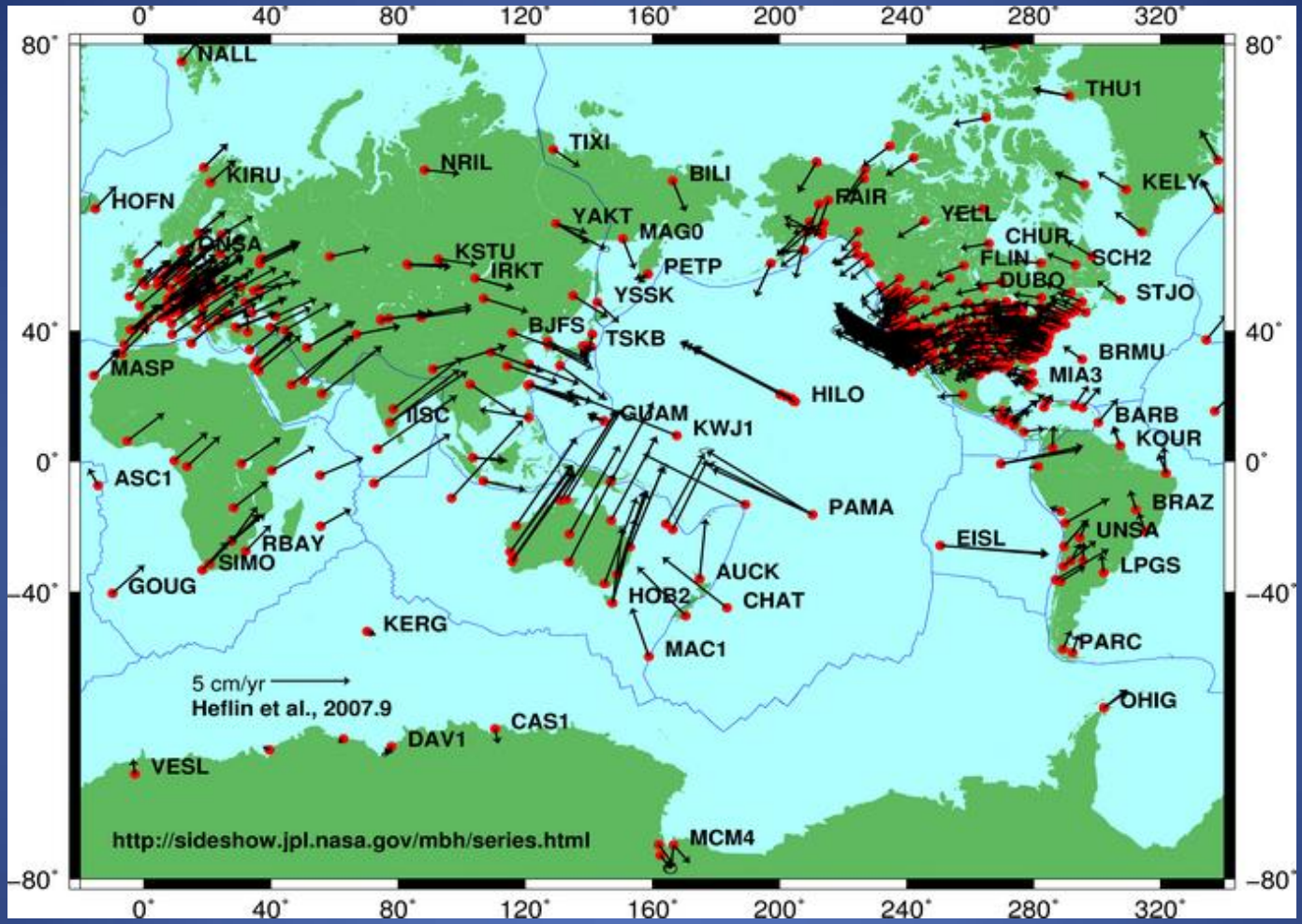


Figure 25: Shows the active steering current forces on the crustal plates due to plate tectonics. Compressional forces from southeast currently act upon the U.S. portion of the North American plate.

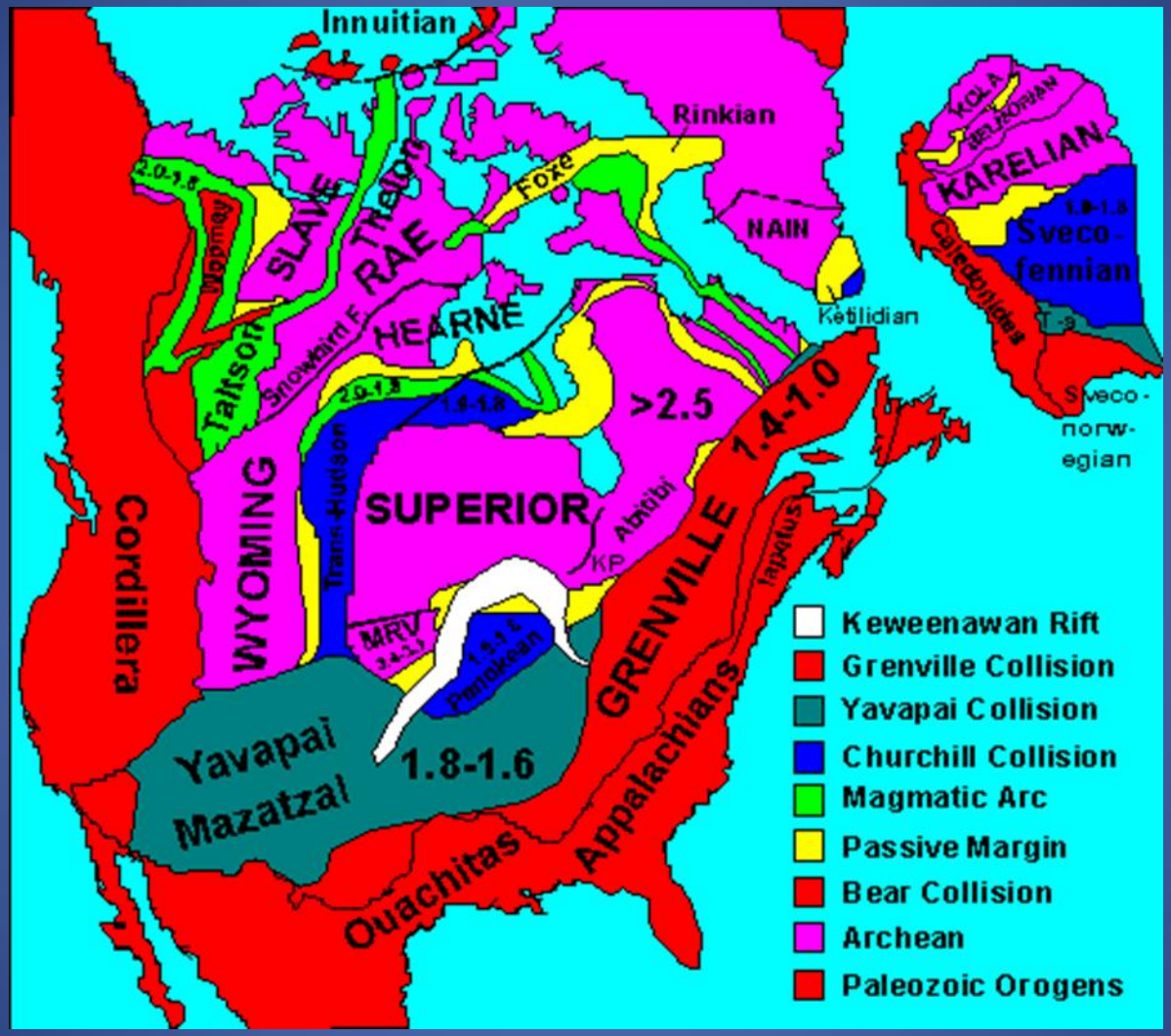


Figure 26: North American plate and its major sub-plates.

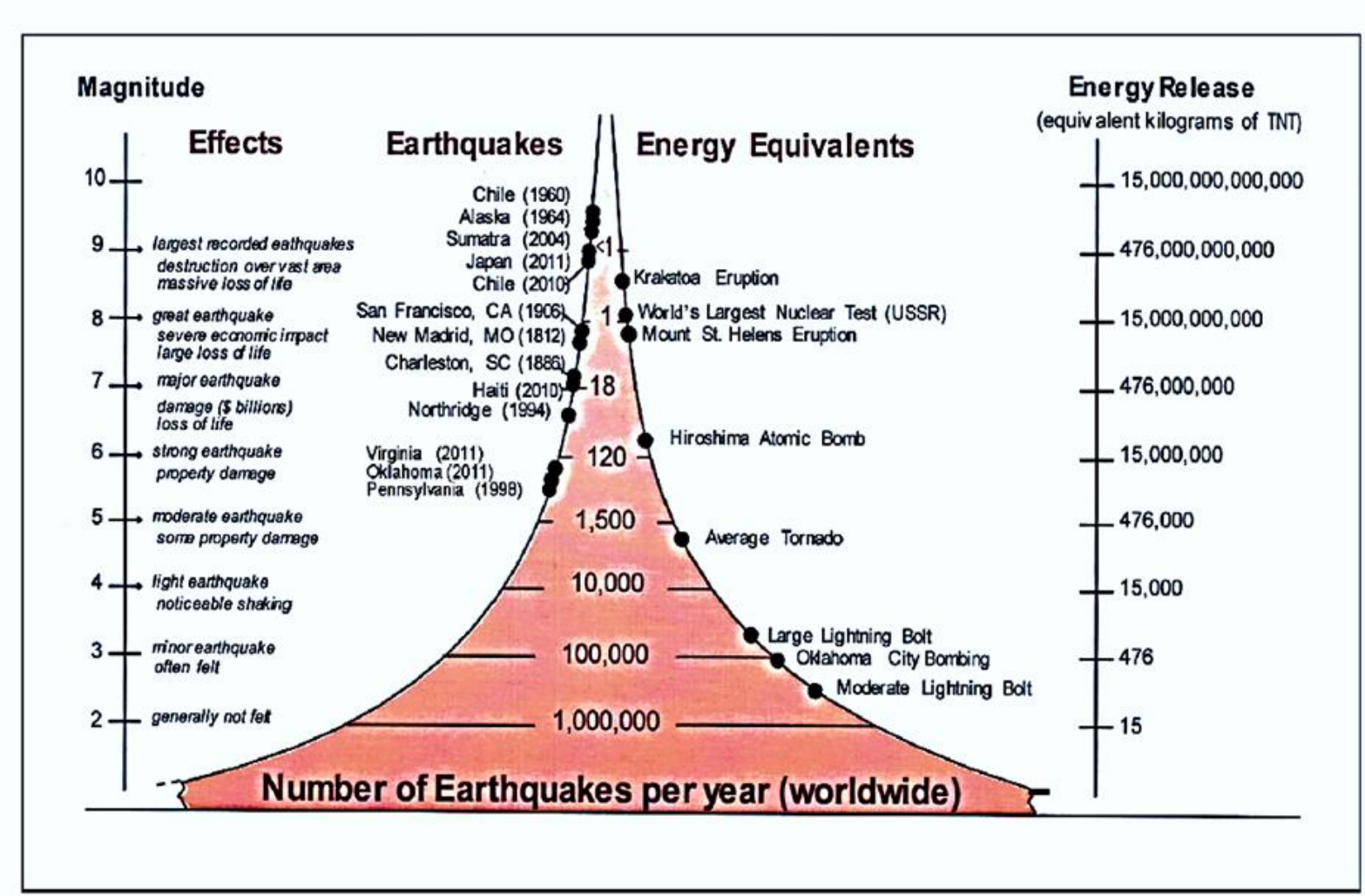
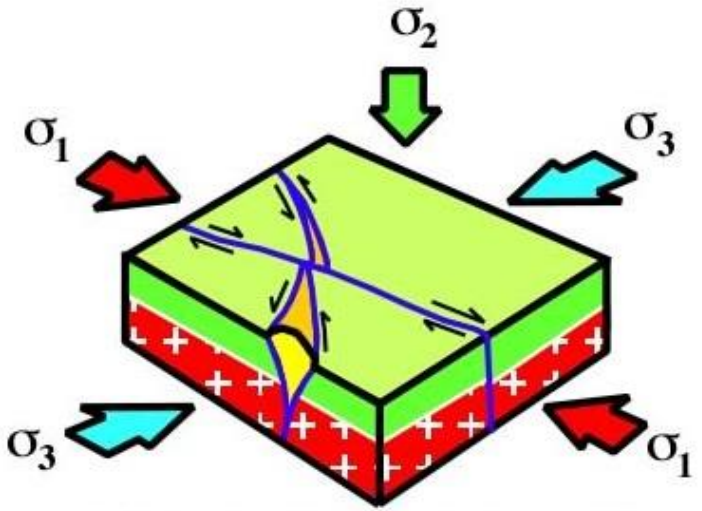


Figure 27: IRIS scale comparing energy release of earthquakes to other events.

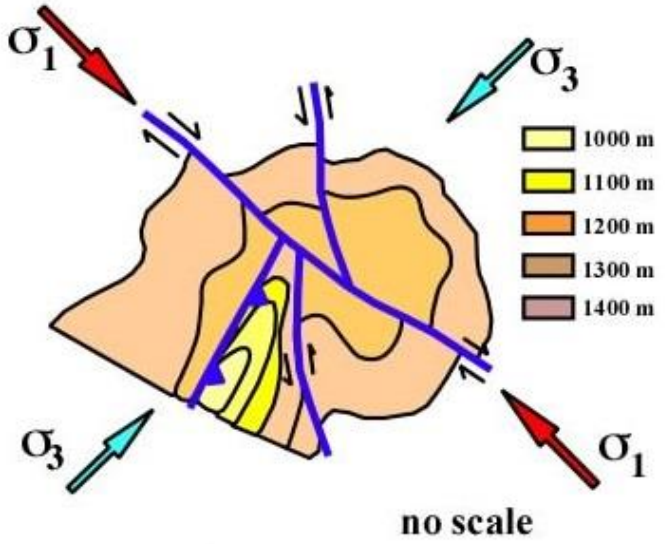
Compressive Strike Slip

Tectonic Sketch



The throw is not constant along strike slip faults

Time Contour Map

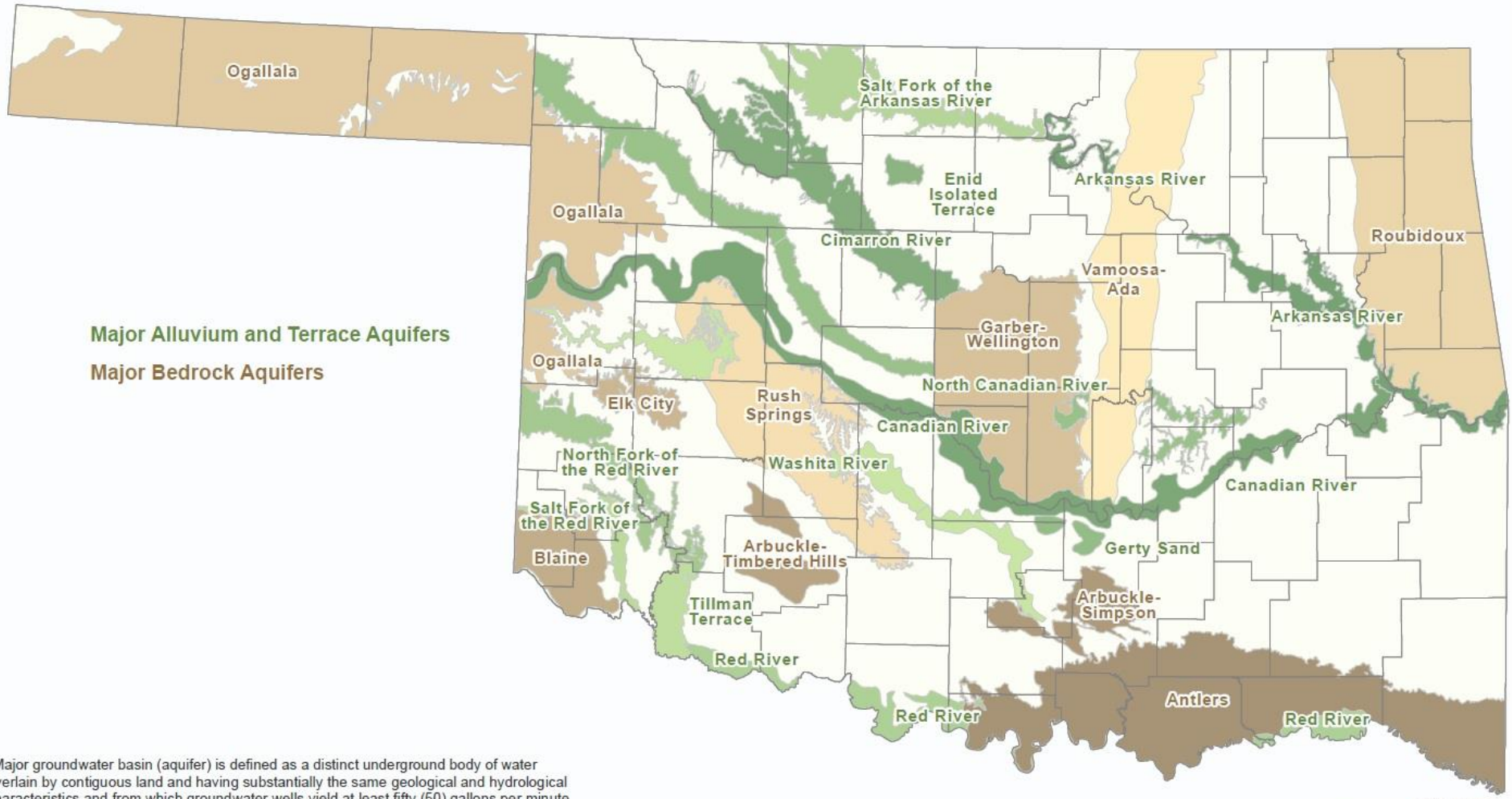


no scale

$\sigma_t > 0$ σ_1 horizontal σ_2 vertical

Oklahoma Groundwater Resources

Major Aquifers of Oklahoma



*Major groundwater basin (aquifer) is defined as a distinct underground body of water overlain by contiguous land and having substantially the same geological and hydrological characteristics and from which groundwater wells yield at least fifty (50) gallons per minute on the average basinwide if from a bedrock aquifer and at least one hundred fifty (150) gallons per minute on the average basinwide if from an alluvium and terrace aquifer, or as otherwise designated by the Board.

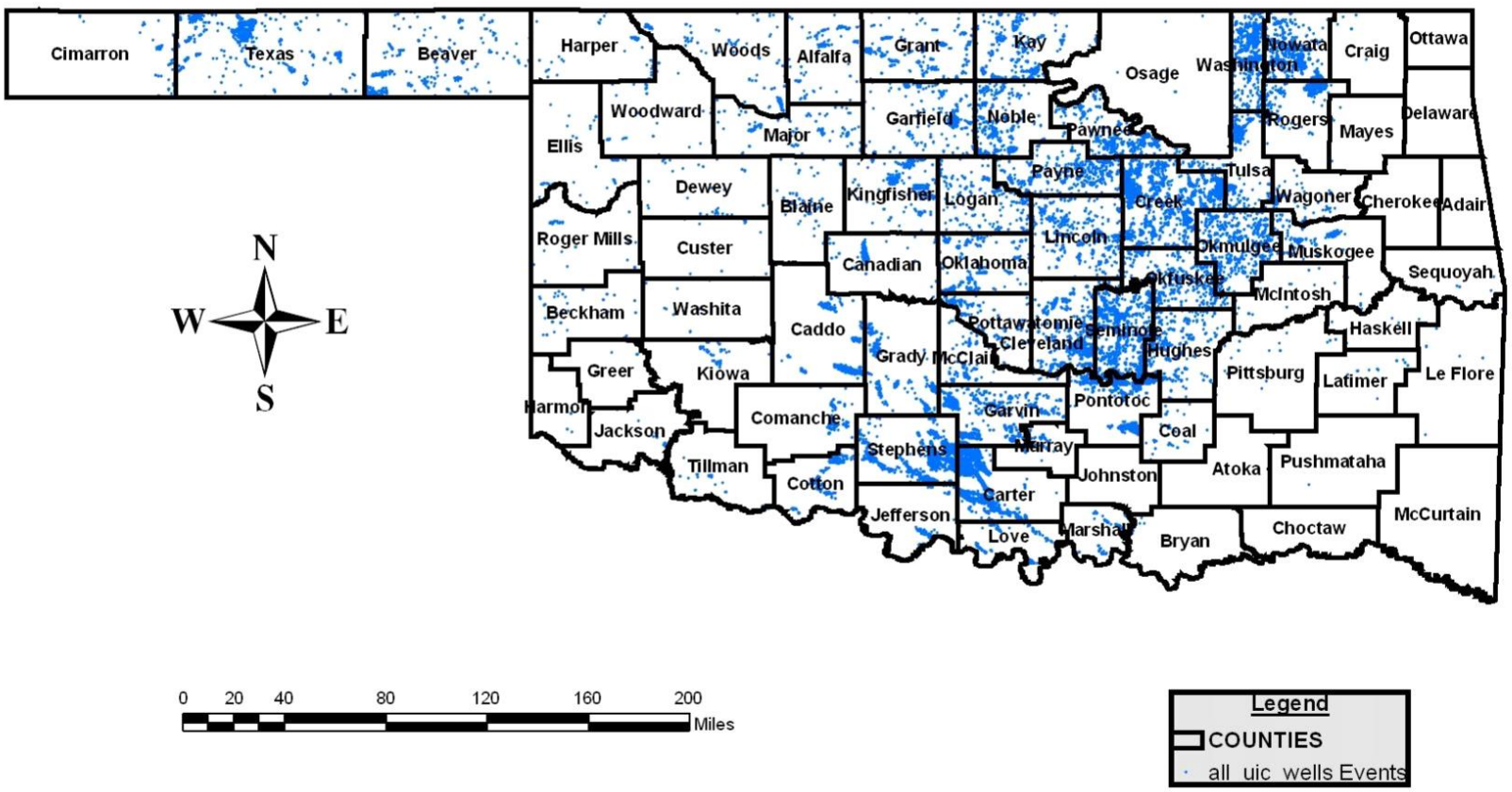
For more information please visit the OWRB's web site at: (http://www.owrb.ok.gov)

N W E S

0 50 Miles

State of Oklahoma
OWRB
Water Resources Board
the water agency

All Oklahoma Class II UIC Wells
(SW Disposal and Injection)



Oklahoma
Active Commercial Class II Wells
March 1, 2010

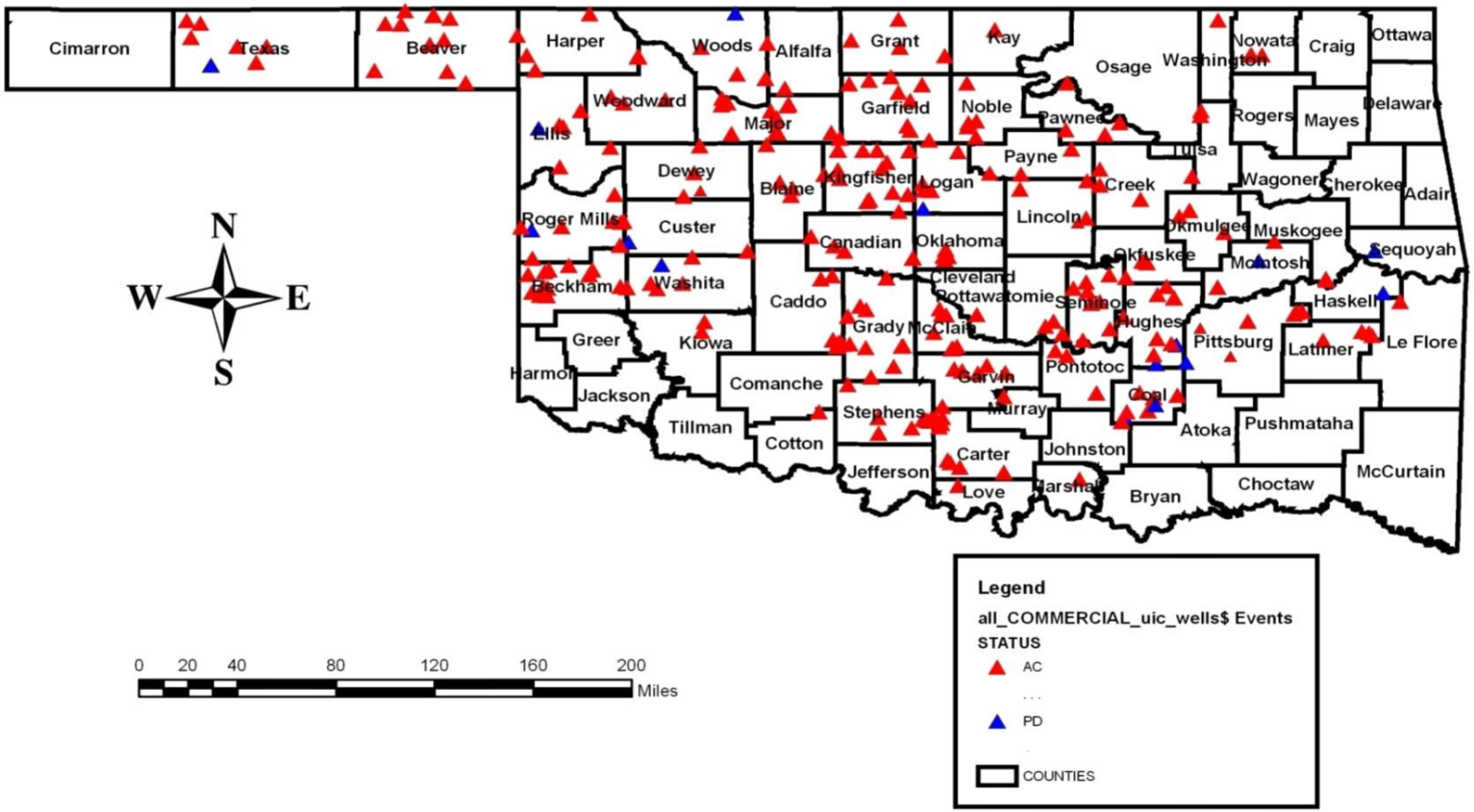


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Figure 1 *Aquifers and groundwater, from USGS water-science school*. (2013, JUNE 04). Retrieved from http://ga.water.usgs.gov/edu/earthgwaquifer.html

Figure 2 http://water.usgs.gov/ogw/pubs.html

Figure 3 http://water.usgs.gov/ogw/pubs.html

Figure 4 http://earthquake.usgs.gov/

Figure 5 Virginia Department of Environmental Quality, Status of Virginia's Water Resources, A Report on Virginia's Water Resources Management Activities. (2012). *A report to the Honorable Robert F. McDonnell, Governor and the General Assembly of Virginia.* http://va.water.usgs.gov

Figure 6 *USGS--Water Resources of the United States, Groundwater Watch.* (n.d.). Retrieved from http://groundwaterwatch.usgs.gov/AWISites.asp?S=373737077083201

Figure 7 http://water.weather.gov/precip/download.php

Figure 8 *U.S. drought monitor.* (2013, MAY 28). Retrieved from http://droughtmonitor.unl.edu/

Figure 9 http://earthquake.usgs.gov/

Figure 10 http://water.weather.gov/precip/download.php

Figure 11 *U.S. drought monitor.* (2013, MAY 28). Retrieved from http://droughtmonitor.unl.edu/

Figure 12 Representative sample of seismic data over the Wilzetta Fault Area

Figure 13 http://earthquake.usgs.gov/

Figure 14 Parkhurst, D. L.; Christenson, S. C.; Breit, G. N., 1993. *Ground-water-quality assessment of the Central Oklahoma Aquifer, Oklahoma; geochemical and geohydrologic investigations.* U.S.Geological Survey; Books and Open-File Reports Section [distributor], Open-File Report 92-642,viii, 113 p. :., maps ;28 cm.

Figure 15 (n.d.). Retrieved from http://climate.ok.gov/

Figure 16 http://water.weather.gov/precip/download.php

Figure 17 *U.S. drought monitor.* (2013, MAY 28). Retrieved from http://droughtmonitor.unl.edu/

Figure 18 (n.d.). Retrieved from http://groundwaterwatch.usgs.gov/

Figure 19 *Structural geology lecture 22, the mechanics of faulting (the strength of the earth's crust).* (n.d.). Retrieved from http://www3.geosc.psu.edu/~jte2/geosc465/lect22.rtf

Figure 20 Thomas, H. (1954). *First fourteen years of Lake Mead.* Retrieved from http://pubs.usgs.gov/circ/1954/0346/report.pdf and Rogers, A. M., & Lee, W. H. K. (1976,OCTOBER). *Seismic study of earthquakes in the Lake Mead, Nevada-Arizona region*. Retrieved from http://usgsprojects.org/lee/Rogers_Lee_BSSA1976.pdf

Figure 21 *Skyscraper that may cause earthquakes.* (n.d.). Retrieved from http://www.guardian.co.uk/environment/2005/dec/02/naturaldisasters.climatechange

Figure 22 Whitmeyer, S., & Karlstrom, K. (2007, August).*Tectonic model for the Proterozoic growth of North America*. Retrieved from http://geosphere.gsapubs.org

Figure 23 *New Madrid seismic zone: a cold, dying fault?* (n.d.). Retrieved from http://www.earth.northwestern.edu/people/seth/research/nmsz.html

Figure 24 http://en.wikipedia.org/wiki/Plate_tectonics

Figure 25 Plate tectonics from wikipedia, the free encyclopedia. (n.d.). Retrieved from http://en.wikipedia.org/wiki/Plate_tectonics

Figure 26 *File: North America basement rocks.png from wikimedia commons.* (n.d.). Retrieved from http://commons.wikimedia.org/wiki/File:North_america_basement_rocks.png

Figure 27 *How often do earthquakes occur?.* (2011,June). http://www.iris.edu/hq/files/publications/brochures_onepagers/doc/EN_OnePager3.pdf (Our figure was taken from this page and modified)

COMPRESSIVE STRIKE SLIP SLIDE

http://homepage.ufp.pt/biblioteca/WebBasPrinTectonics/BasPrincTectonics/Page6.htm

OKLAHOMA GROUNDWATER RESOURCES SLIDE

http://www.owrb.ok.gov/maps/pdf_map/major_aquifers.pdf

ALL OKLAHOMA CLASS II UIC WELLS (SW DISPOSAL AND INJECTION) SLIDE

http://itec.cherokee.org/Portals/24/OCC%20UIC%2020210.pdf

OKLAHOMA ACTIVE COMMERCIAL CLASS II WELLS MARCH 1, 2010 SLIDE

http://itec.cherokee.org/Portals/24/OCC%20UIC%2020210.pdf