A Detailed Oklahoma Stress Map for Induced Seismicity Mitigation*

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Abstract

We report progress on a project to create a detailed map of in situ stress orientations and relative magnitudes throughout the state of Oklahoma. Over the past 5 years, seismicity has increased remarkably in much of the state, apparently related to significant increases in waste-water injection. The purpose of this project is to develop detailed knowledge of the stress field in the state to identify which pre-existing faults could be potentially active in response to injection-related pore-pressure increases. Over 50 new stress orientations have been obtained, utilizing wellbore image data and shear-velocity-anisotropy measurements from sonic dipole data provided by the oil and gas industry. These data reveal a very uniform ENE direction of maximum compressive stress through much of the state. As earthquake focal plane mechanisms generally indicate strike-slip faulting, the stress orientation data identify which pre-existing faults are potentially active. The data are consistent with slip on the near-vertical, NE-trending fault associated with at least one of the M 5+ earthquakes in the Prague, OK, sequence in 2011. If successful, it would demonstrate that combining detailed information about pre-existing faults and the current stress field could be used to guide the siting of injection wells so as to decrease the potential for injection-related seismicity.

Selected References

Boness, N.L., and M.D. Zoback, 2005, Shear velocity anisotropy in and near the San Andreas fault: Implications for mapping stress orientations: EOS (Transactions, American Geophysical Union), fall meeting supplement, abstract, T23E-03, v. 86, p. 52.

Boness, N.L., and M.D. Zoback, 2005, Mapping stress and structurally controlled shear velocity anisotropy in California : Geology, v. 34/10, p. 825-828.

McNamara, D.E., H.M. Benz, R.B. Herrmann, E.A. Bergman, P.Earle, A. Holland, R. Baldwin, and A. Gassner, 2015, Earthquake hypocenters and focal mechanisms in central Oklahoma reveal a complex system of reactivated subsurface strike-slip faulting, Geophysical Research Letters, v. 42, p. 2742–2749.

McNamara, D.E. et al., 2015**,** Efforts to monitor and characterize the recent increasing seismicity in central Oklahoma: The Leading Edge, v. 34/6, p. 628-639.

McNamara, D.E., et al., 2015, Reactivated faulting near Cushing, Oklahoma: Increased potential for a triggered earthquake in an area of United States strategic infrastructure, Geophysical Research Letters, v. 42, doi:10.1002/ 2015GL064669.

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AAPG ACE 2015

Structure and Tectonics of Unconventionals

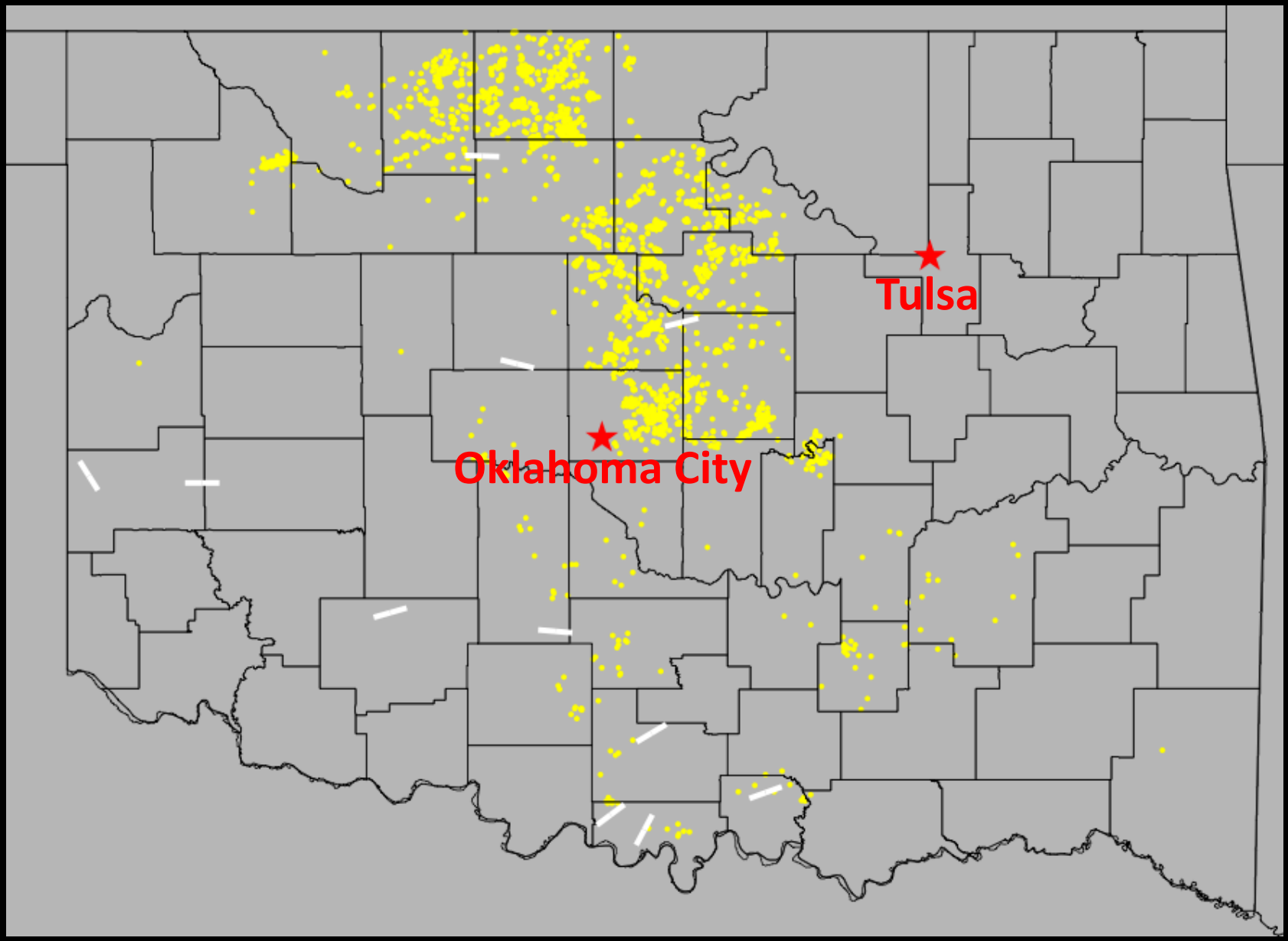
Abstract #2098740

06/02/2015

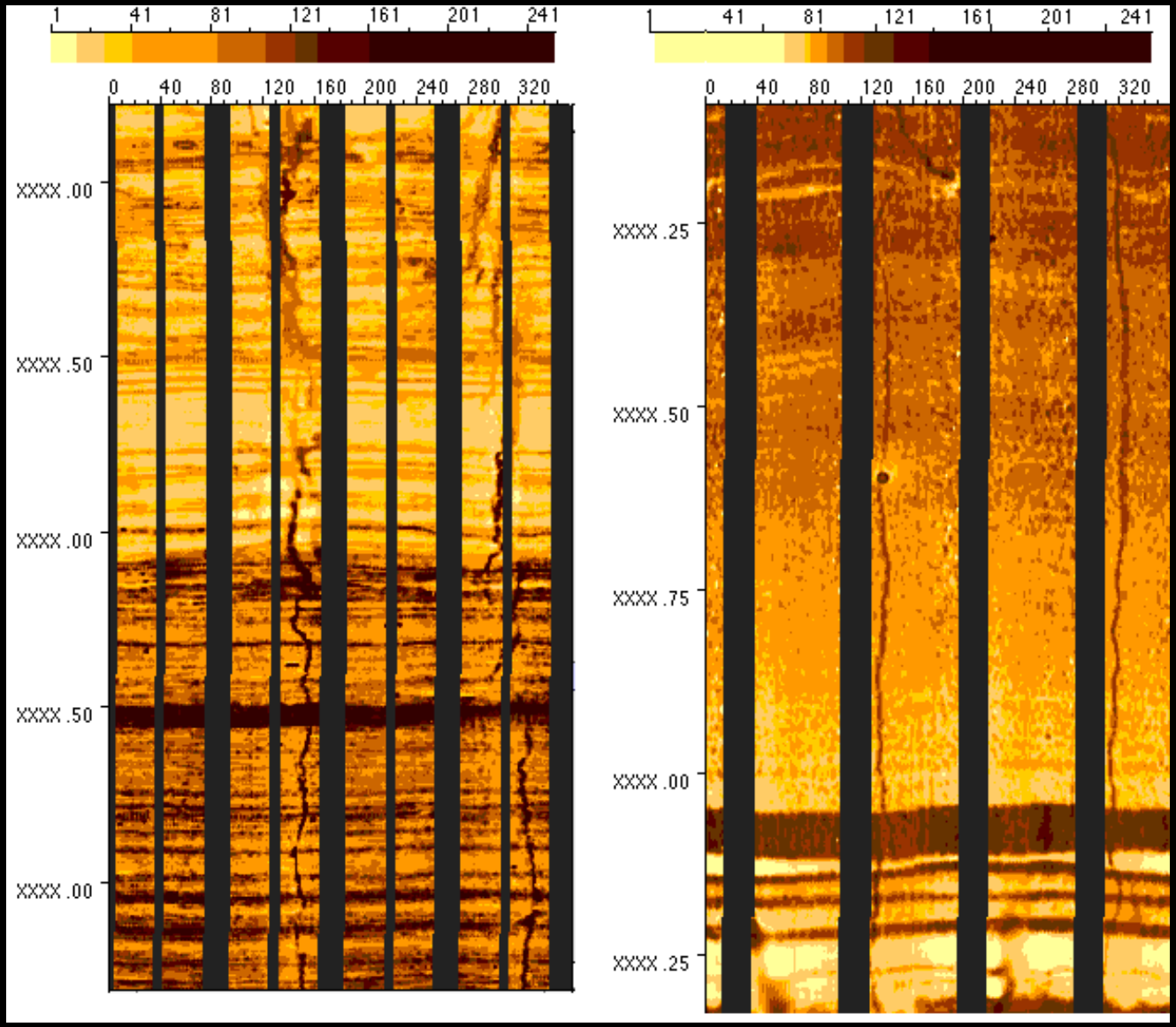
Roadmap

1. Recent Earthquakes and WSM Data
2. Data Collection
3. Statewide Stress Map
4. Oklahoma City Hazard Case Study
5. Preliminary Fault Analysis Results

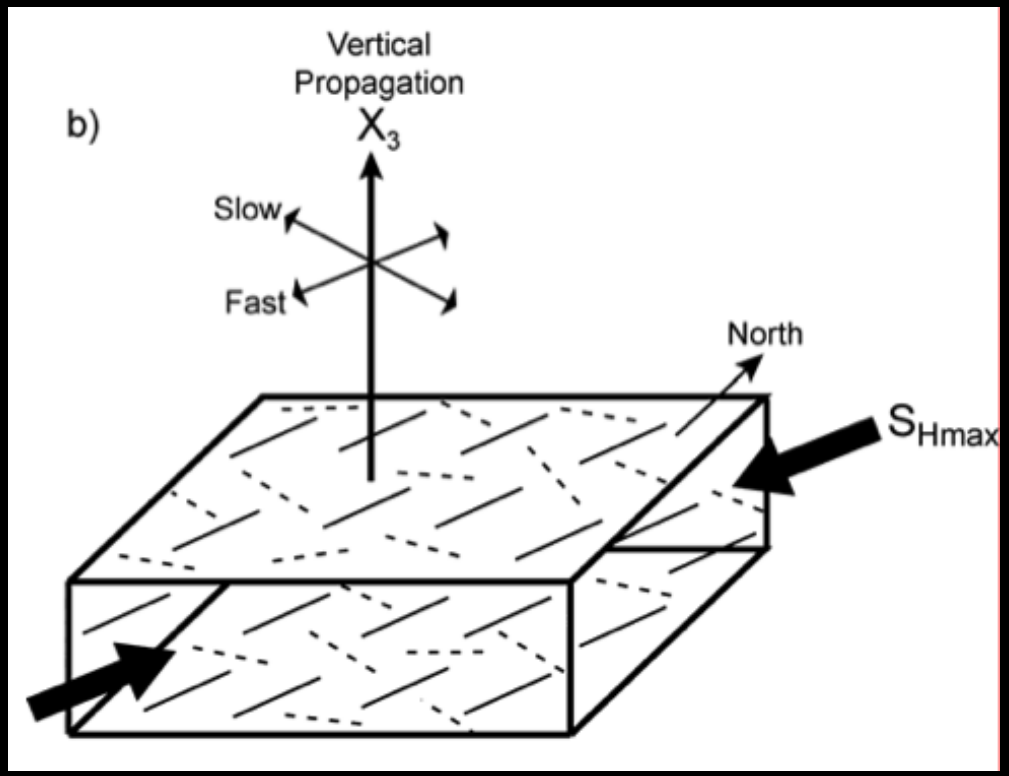
Recent Oklahoma Earthquakes and WSM

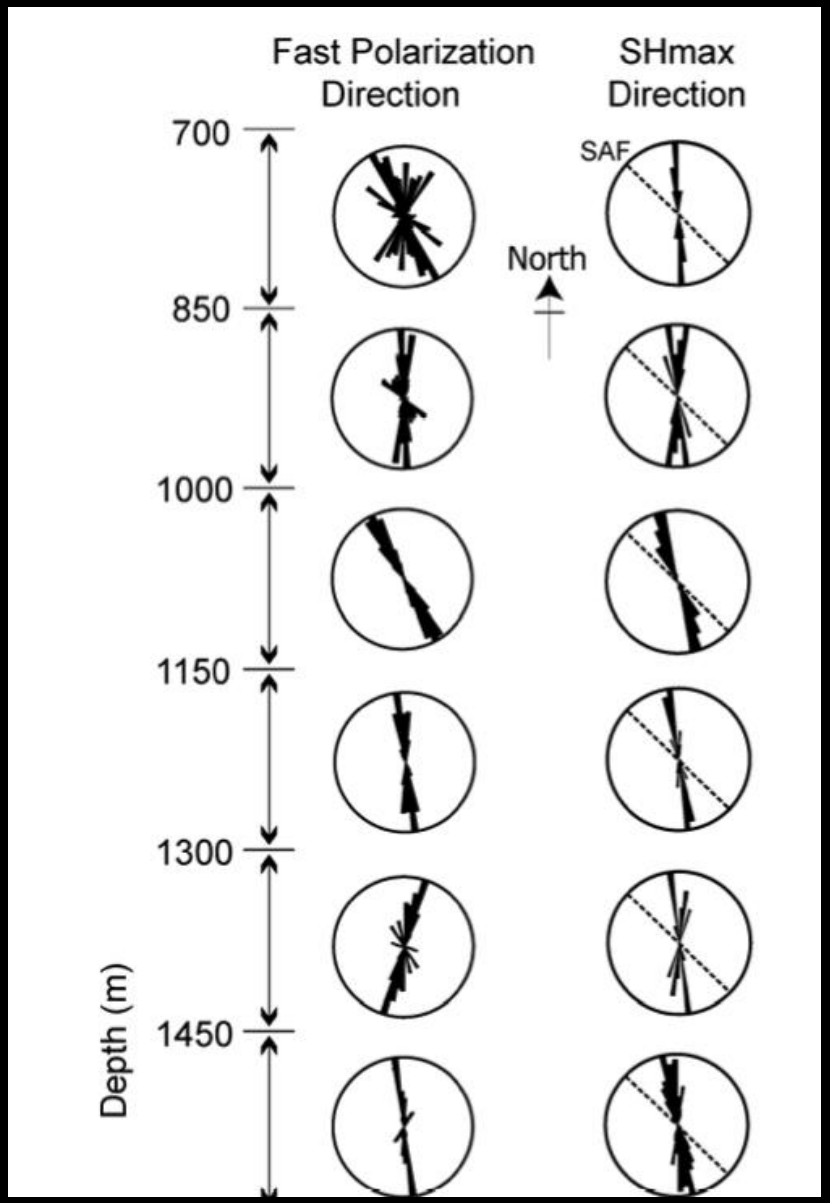


Data: Drilling-Induced Tensile Fractures in FMI Logs



Fast V_s Azimuth for S_{Hmax}

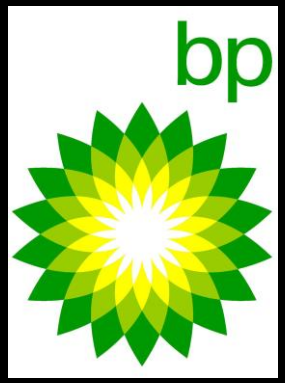




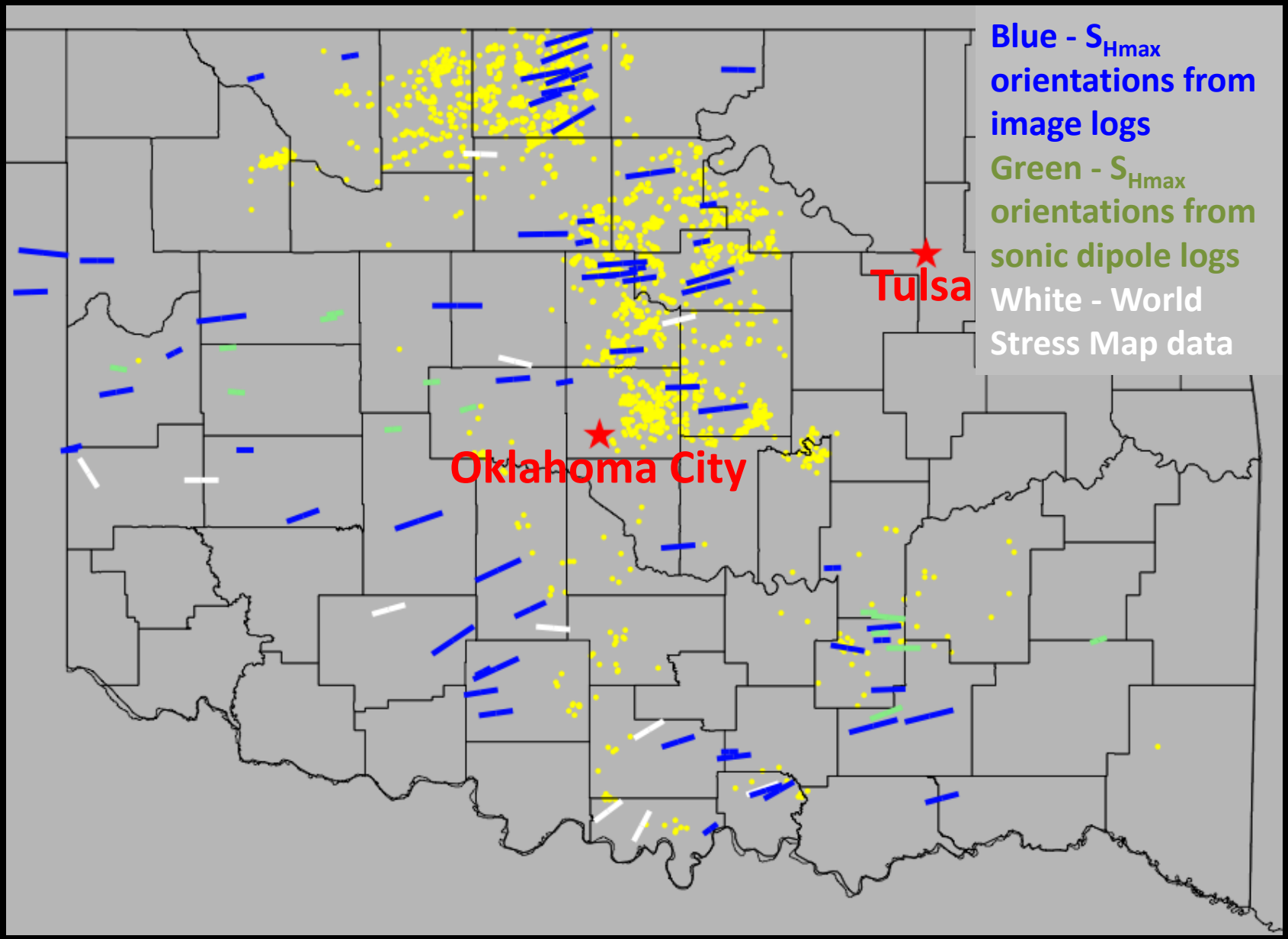
After Boness and Zoback, 2005

77 New Oklahoma Stress Points

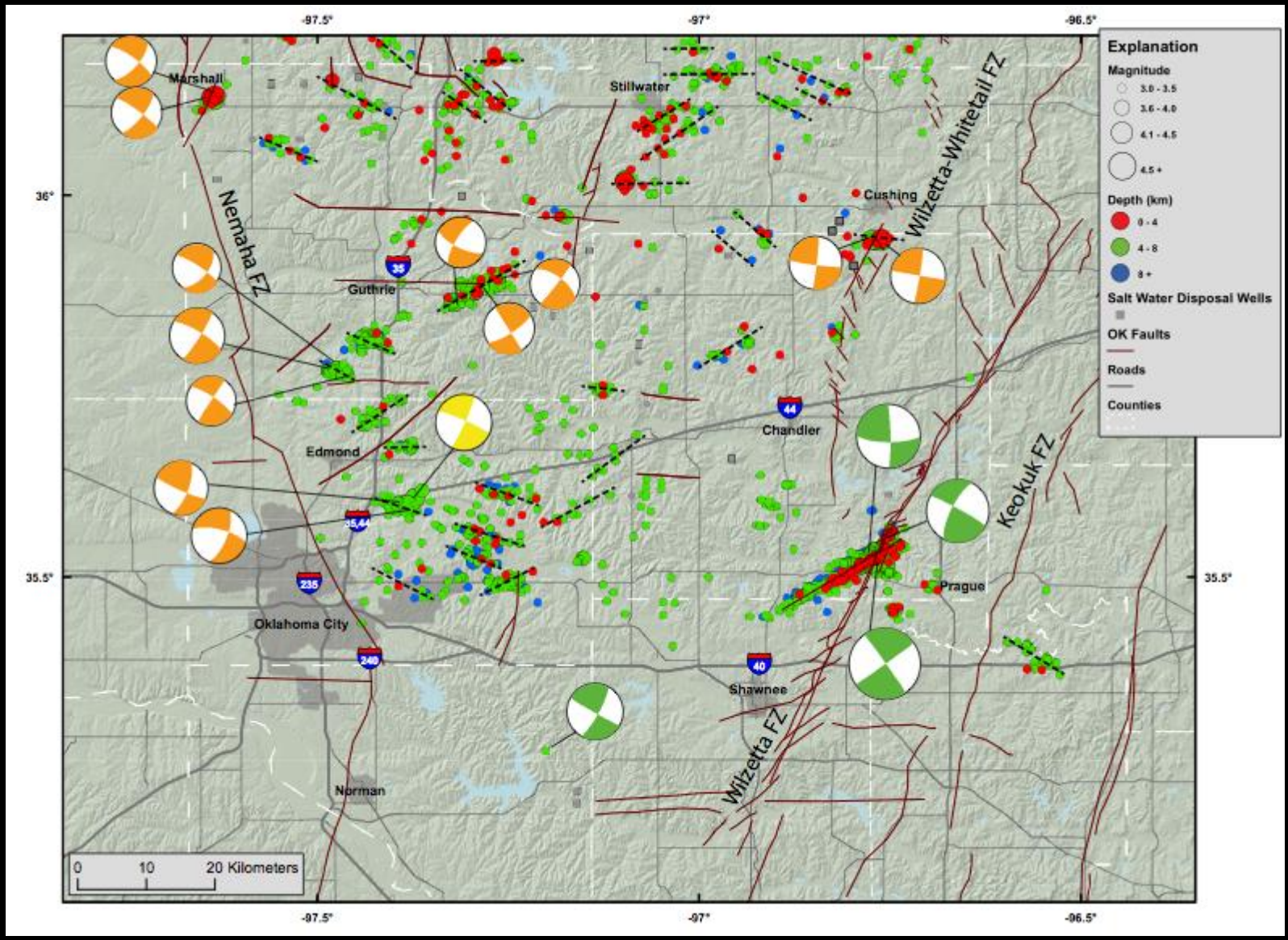
- Image Logs (FMI, UBI, STAR): 63 wells
- Sonic Dipole (fast shear azimuth): 14 wells
- Ranked and Scaled according to Data Quality
- Special Thanks to Our Data Contributors



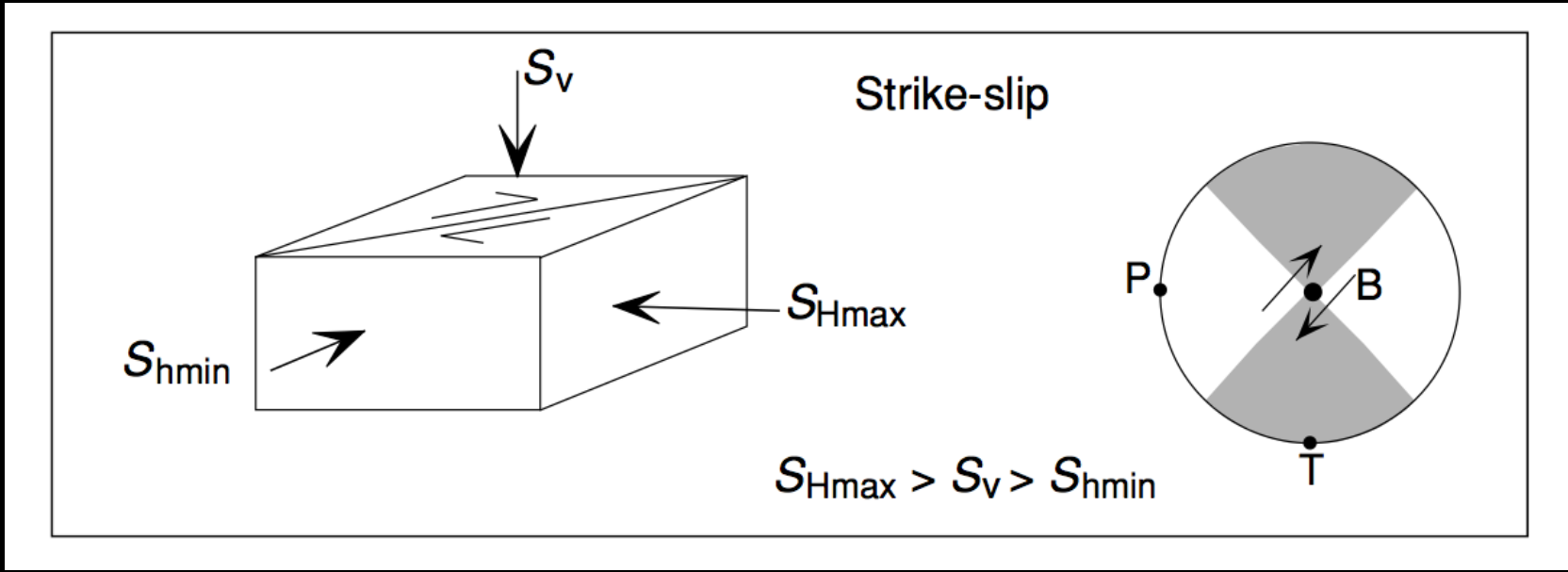
77 New Stress Data Points



Study Area (McNamara, 2015)

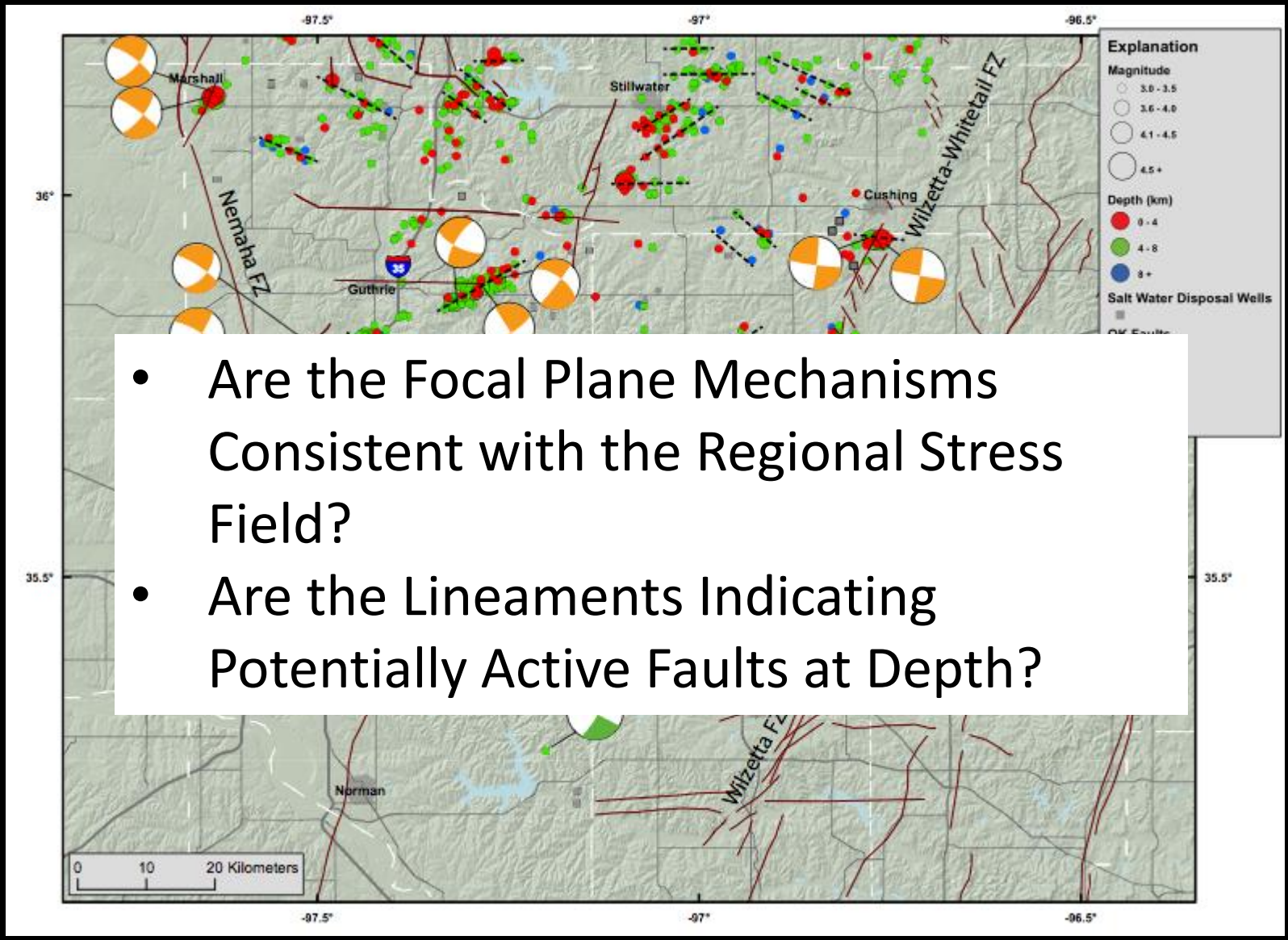


Tectonic Stress and Faulting



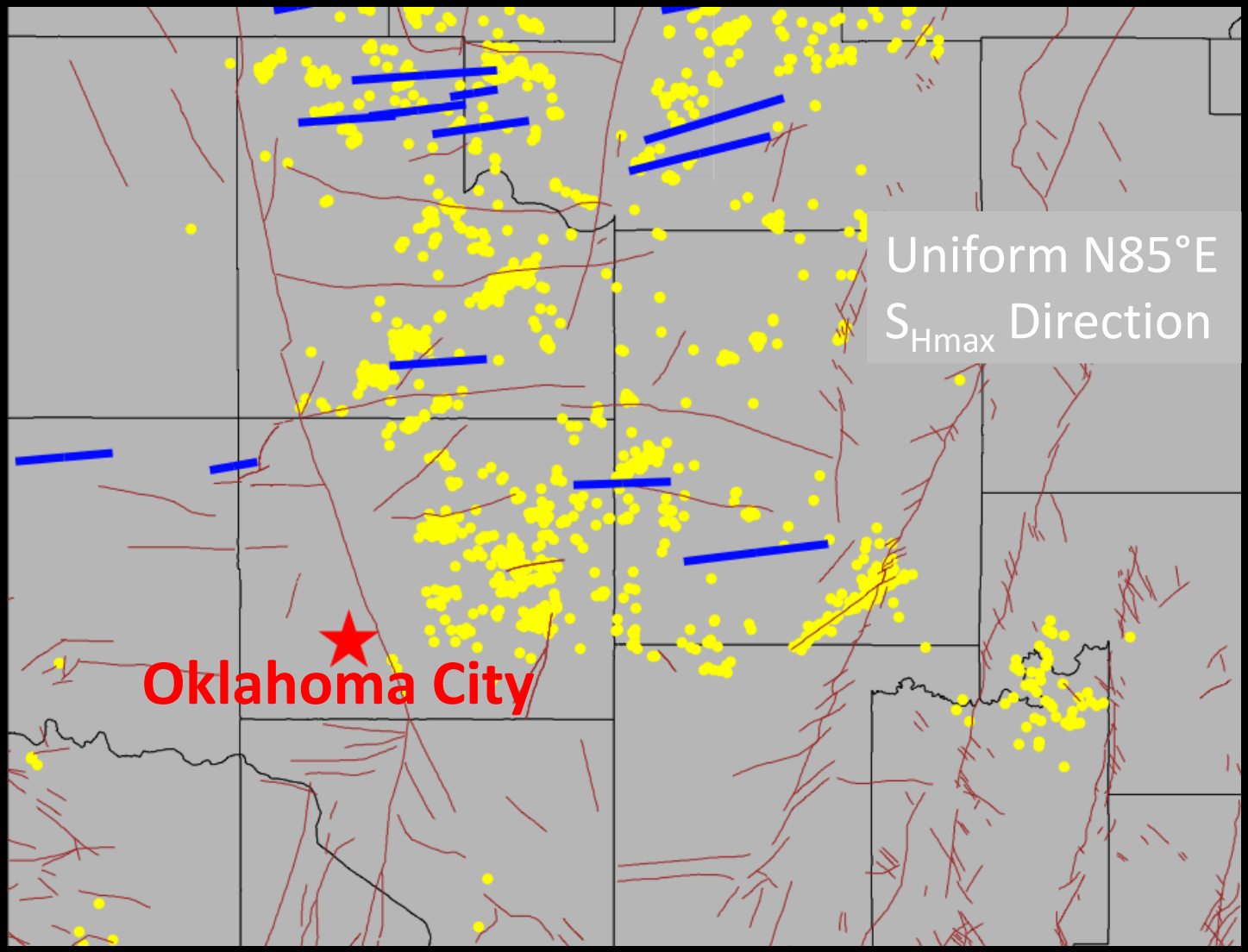
Strike-Slip Earthquakes in Oklahoma

Study Area (McNamara, 2015)

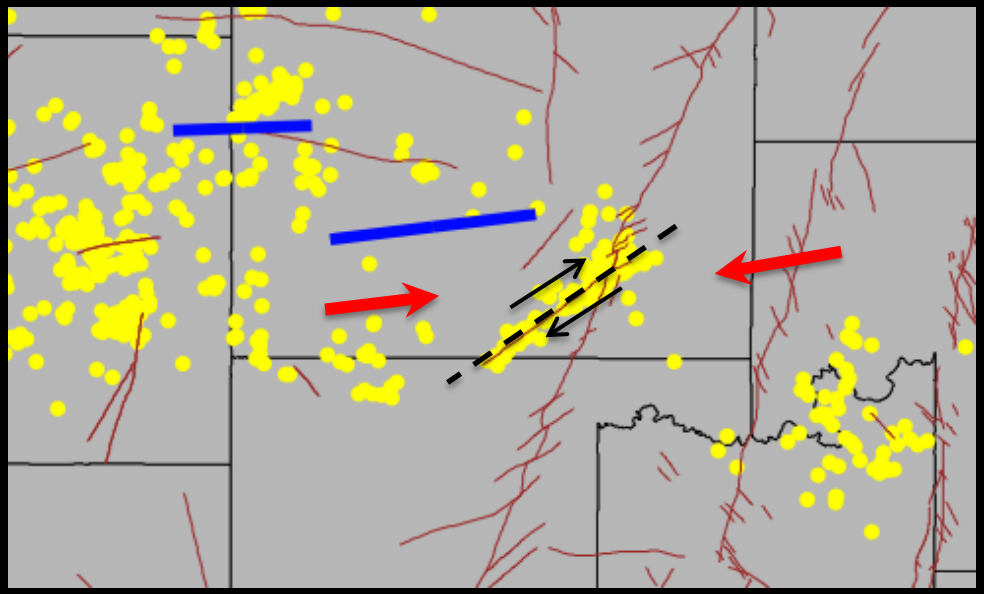


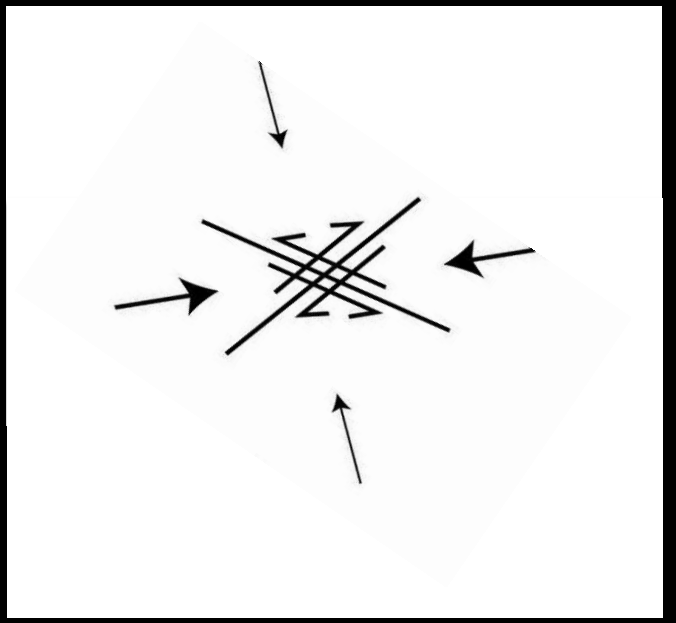
- Are the Focal Plane Mechanisms Consistent with the Regional Stress Field?
- Are the Lineaments Indicating Potentially Active Faults at Depth?

S_{Hmax} EQs and Mapped Faults



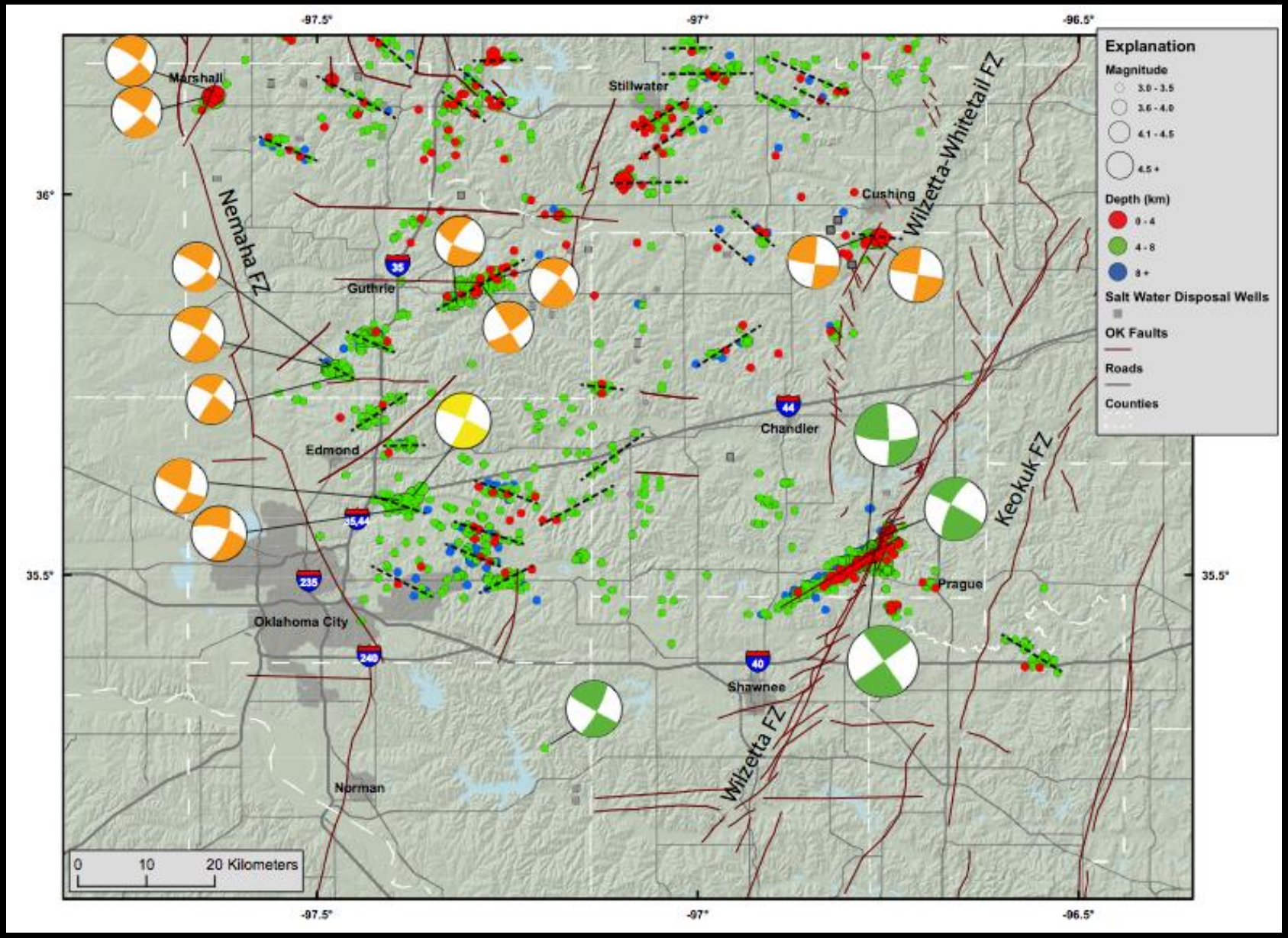
2011 Mw 5.7 Prague Sequence



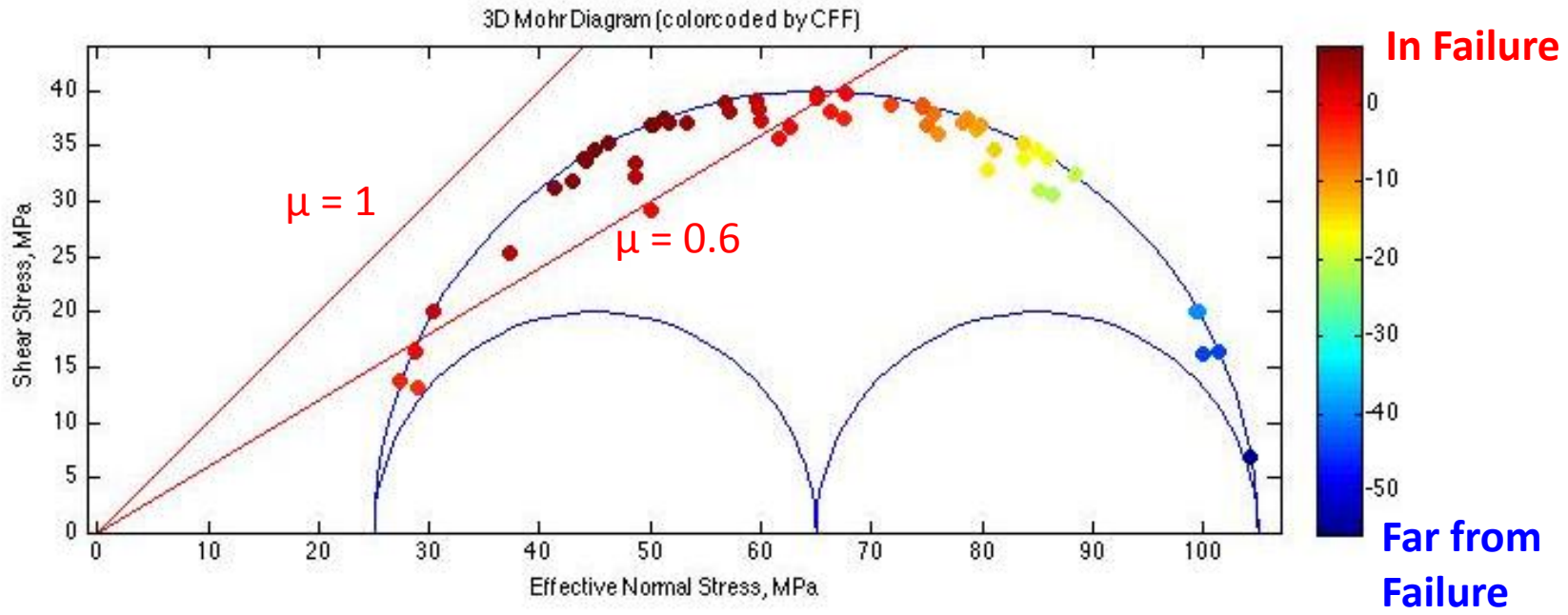


"Prague" Fault
at expected 30˚ angle to S_{Hmax} for
active strike-slip deformation

FM's in Study Area

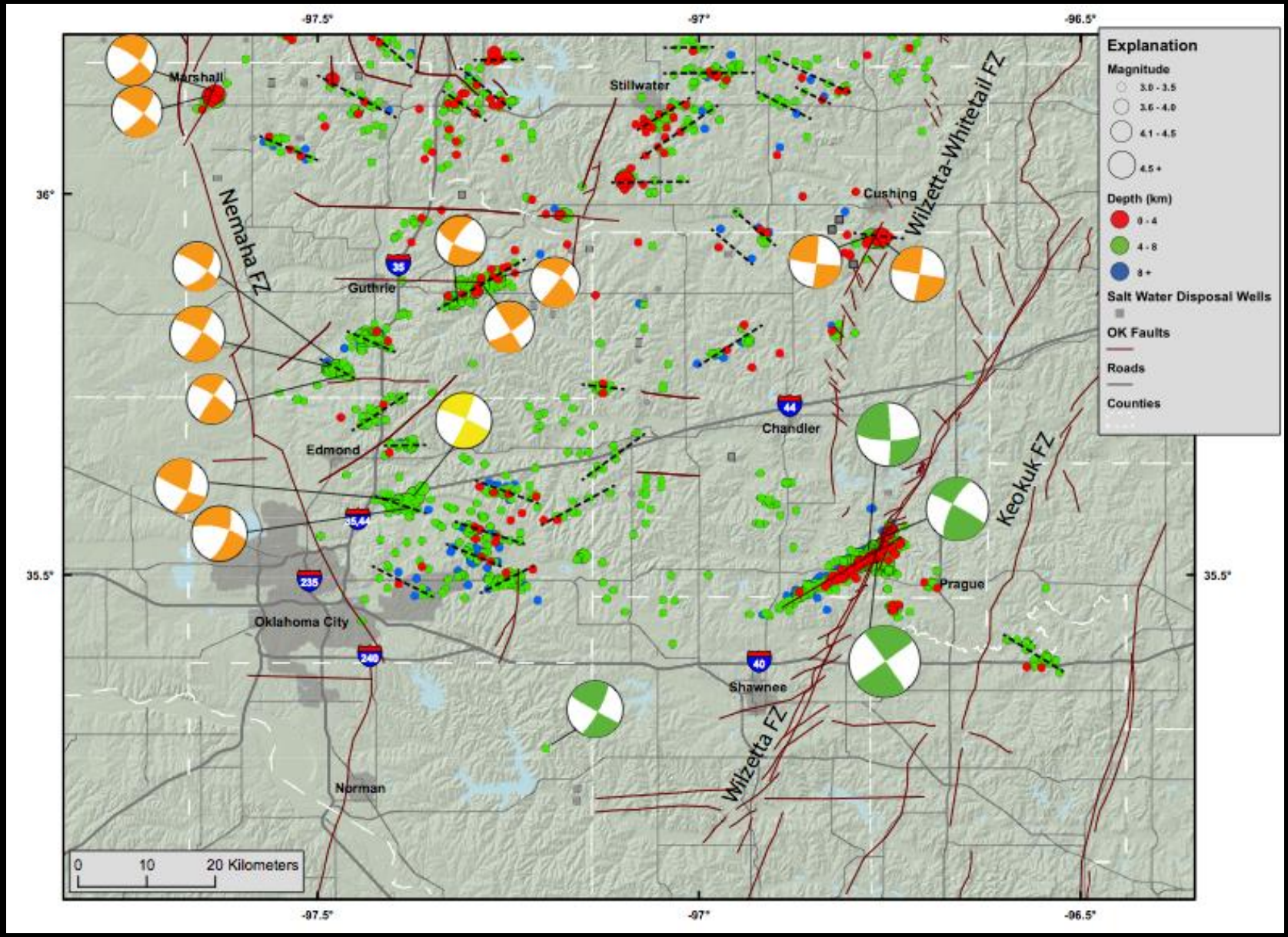


Mohr-Coulomb Failure Analysis of Focal Mechanism Planes

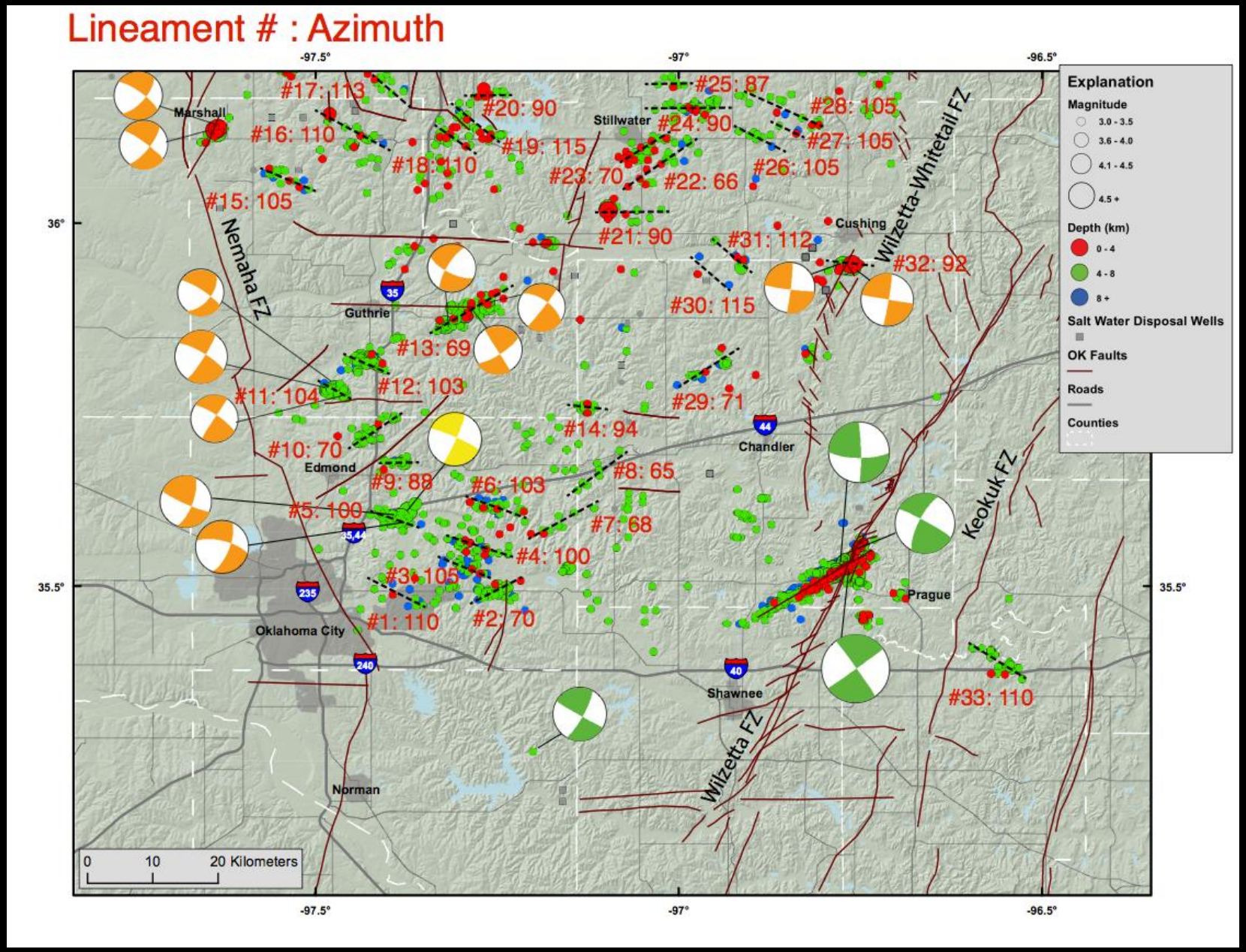


There are 29 M ≥ 4.0 Earthquakes in the Study Area
28 Have a Fault Plane Consistent with Strike-Slip Faulting
in a N85°E Stress Field (±20°)

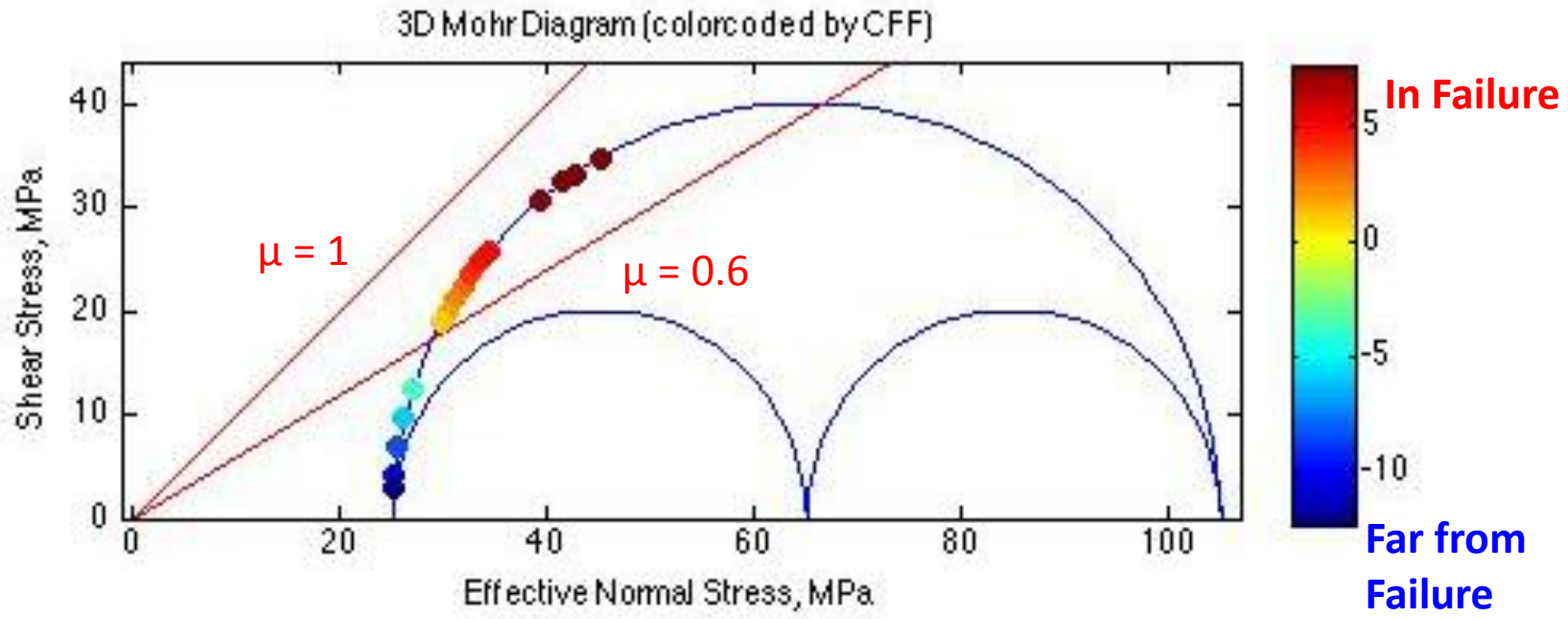
Lineaments


-97.5°
-97°
-96.5°
36°
35.5°
Marshall
Stillwater
Cushing
Guthrie
Edmond
Chandler
Prague
Oklahoma City
Shawnee
Norman
Nemaha FZ
Wilzetta-Whitetail FZ
Keokuk FZ
Wilzetta FZ
35
44
235
40
0 10 20 Kilometers
Explanation
Magnitude
3.0 - 3.5
3.6 - 4.0
4.1 - 4.5
4.5 +
Depth (km)
0 - 4
4 - 8
8 +
Salt Water Disposal Wells
OK Faults
Roads
Counties

Lineaments


Lineament # : Azimuth
-97.5°
-97°
-96.5°
36°
35.5°
#17: 113
#16: 110
#15: 105
#20: 90
#19: 115
#18: 110
#25: 87
#24: 90
#23: 70
#22: 66
#28: 105
#27: 105
#26: 105
#21: 90
#31: 112
#32: 92
#30: 115
#13: 69
#12: 103
#11: 104
#29: 71
#14: 94
#10: 70
#8: 65
#9: 88
#6: 103
#5: 100
#7: 68
#4: 100
#3: 105
#1: 110
#2: 70
#33: 110
Marshall
Stillwater
Cushing
Guthrie
Edmond
Chandler
Prague
Oklahoma City
Shawnee
Norman
Nemaha FZ
Wilzetta-Whitetail FZ
Keokuk FZ
Wilzetta FZ
35
44
235
240
40
35,44
Explanation
Magnitude
3.0 - 3.5
3.6 - 4.0
4.1 - 4.5
4.5 +
Depth (km)
0 - 4
4 - 8
8 +
Salt Water Disposal Wells
OK Faults
Roads
Counties
0
10
20 Kilometers

Mohr-Coulomb Failure Analysis of Apparent Lineaments



Of the 33 Identified Lineaments in the Study Area
26 are Consistent with Strike-Slip Faulting
in a N85°E Stress Field

Conclusions

- There is a consistent stress field throughout much of Oklahoma, with an ENE S_{Hmax} direction and a pure strike-slip faulting regime
- We can identify potentially active faults with detailed knowledge of the in situ stress field

Thank You