PS Principal Stress Orientations and Relative Stress Magnitudes in Unconventional Oil and Gas Basins, Central and Eastern USA*

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Abstract

Over the past four years, we have compiled >450 orientations of the maximum horizontal stress (S_{Hmax}) in the central and eastern USA. We have also mapped the relative principal stress magnitudes, revealing systematic changes in faulting regime across the continent. The northeastern USA and southeastern Canada are characterized by reverse and reverse-/strike-slip faulting, with S_{Hmax} oriented ENE-WSW to NE-SW. The faulting regime is more extensional southward and westward, which profoundly affects operations in the Utica and Marcellus plays of the Appalachian Basin. Horizontal hydrofracs are expected in northeastern areas, where reverse faulting is active, but vertical hydrofracs are expected to the southwest, where strike-slip faulting is active. In much of Oklahoma, including the SCOOP and STACK plays, S_{Hmax} is ~E-W. We observe a transition northward from strike-slip/reverse in southwest Oklahoma, strike-slip in central Oklahoma, normal/strike-slip in north-central Oklahoma, and normal faulting in southern Kansas. The Denver-Julesburg Basin to the northwest experiences normal/strike-slip faulting, but S_{Hmax} rotates broadly clockwise northward from SW-NE in southern Colorado to NW-SE in southeast Wyoming, and then again to NE-SW in the Williston Basin of western North Dakota. The faulting regime also becomes more extensional southward from southern Oklahoma, with normal/strike-slip faulting and ~NNE-SSW S_{Hmax} directions in the central and southern Fort Worth Basin. Sedimentary rocks along the Gulf Coastal Plain, including most of the Eagle Ford and Haynesville areas, experience predominantly normal faulting, with S_{Hmax} sub-parallel to the coastline. In the eastern Permian Basin of west Texas and southeast New Mexico, and the Raton Basin in southeast Colorado and northwest New Mexico, S_{Hmax} is ~E-W and normal/strike-slip faulting is active. However, a rapid transition occurs westward to normal faulting and N-S S_{Hmax}, reflecting the influence of Rio Grande Rift extension. S_{Hmax} regains a large E-W component outside of this extensional area, including the Uinta-Piceance, Green River, and Wind River basins of the Colorado Plateau and central Rocky Mountains. Finally, in the Basin and Range Province between central Utah and eastern California, the faulting regime becomes extensional again and S_{Hmax} is NNE-SSW. Together, these remarkable but coherent variations in the stress field provide operators with exceptional power for predicting the fractures that will be active during stimulation.

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Principal stress orientations and relative stress magnitudes in unconventional oil and gas basins, central and eastern USA

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Over the past several years, we have compiled > 600 new orientations of the maximum horizontal principal stress (S_{Hmax}) and mapped the faulting regime (A_ϕ). The map reveals marked variability in some areas, especially near the extensional parts of the western and central USA, and it confirms gradual changes in other areas. Using this stress map, operators can predict the populations of pre-existing fractures that will be active during stimulation.

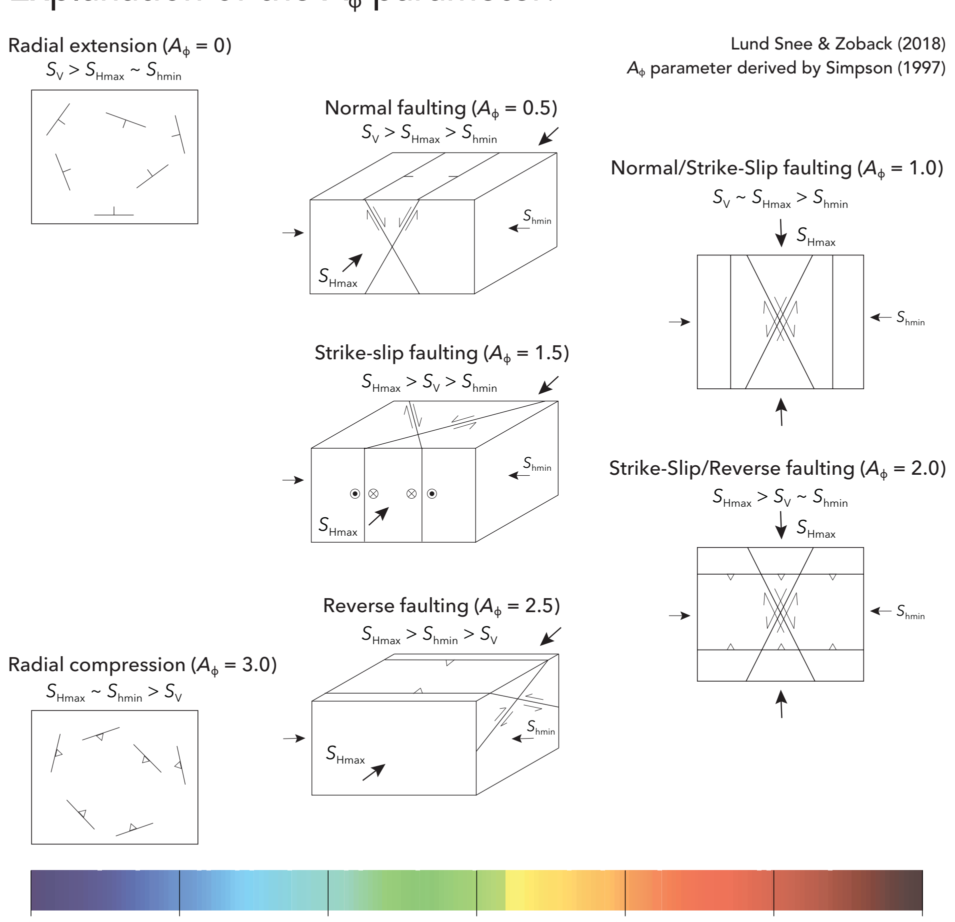
Overview

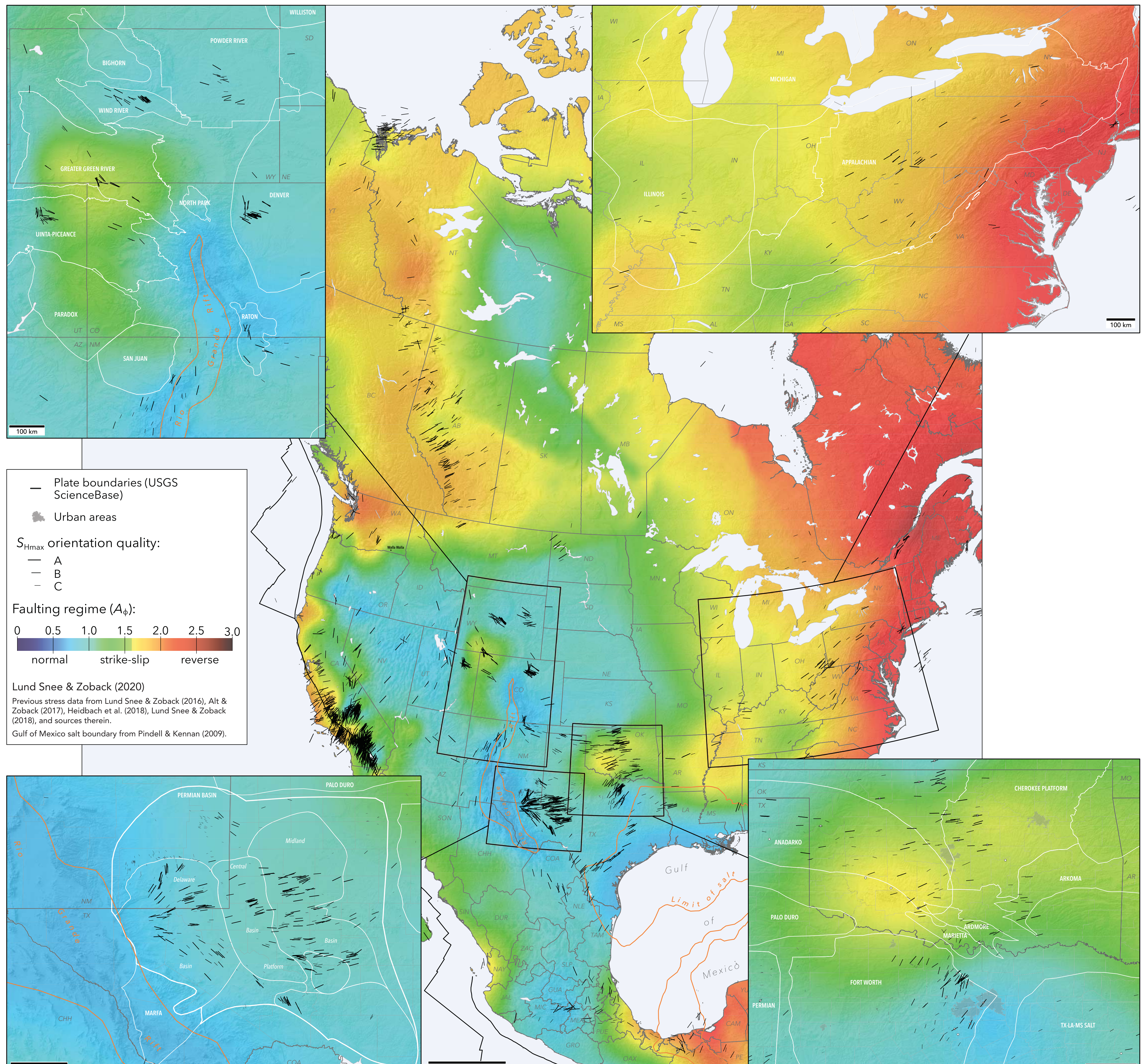
Our new stress map includes >600 new orientations of the maximum horizontal principal stress (S_{Hmax}), as well as a map of the relative principal stress magnitudes (faulting regime), plotted using the A_ϕ parameter (Simpson, 1997). In addition to >1000 new A_ϕ constraints, we conducted 42 new focal mechanism stress inversions and compiled values from published sources including Southern California inversions from Yang & Hauksson (2013). These maps are based on the next-generation stress dataset for North America by Lund Snee and Zoback (2020).

The new data confirm remarkably consistent NE–SW to ENE–WSW S_{Hmax} orientations and reverse and strike-slip/reverse faulting in the eastern USA and Canada, including most of the **Appalachian Basin**. However, the map shows a transition westward to strike-slip faulting in the South and Midwest, USA. Normal and normal/strike-slip faulting are active near thermally uplifted areas, including in the **Denver**, **Powder River**, and **Permian Basins**. In contrast, the faulting regime is broadly strike-slip in the **Uinta Basin**, **Wyoming basins**, and **Oklahoma**.

S_{Hmax} rotates systematically and at different scales, including fine-scale rotations up to 90° over 10s of km in several locations at the margins of extensional provinces such as the Rio Grande Rift. Notably, the **Delaware Basin** within the **Permian Basin** is subject to a pronounced, basin-wide rotation. Other major (~70°) but much more gradual rotations occur between southern **Oklahoma** (~N085°E) and the **Fort Worth Basin** (~NNE–SSW), and between the **Fort Worth Basin** and **Permian Basin**. These profound variations reflect regional sources of stress superimposed onto the plate boundary stresses.

Explanation of the A_ϕ parameter:





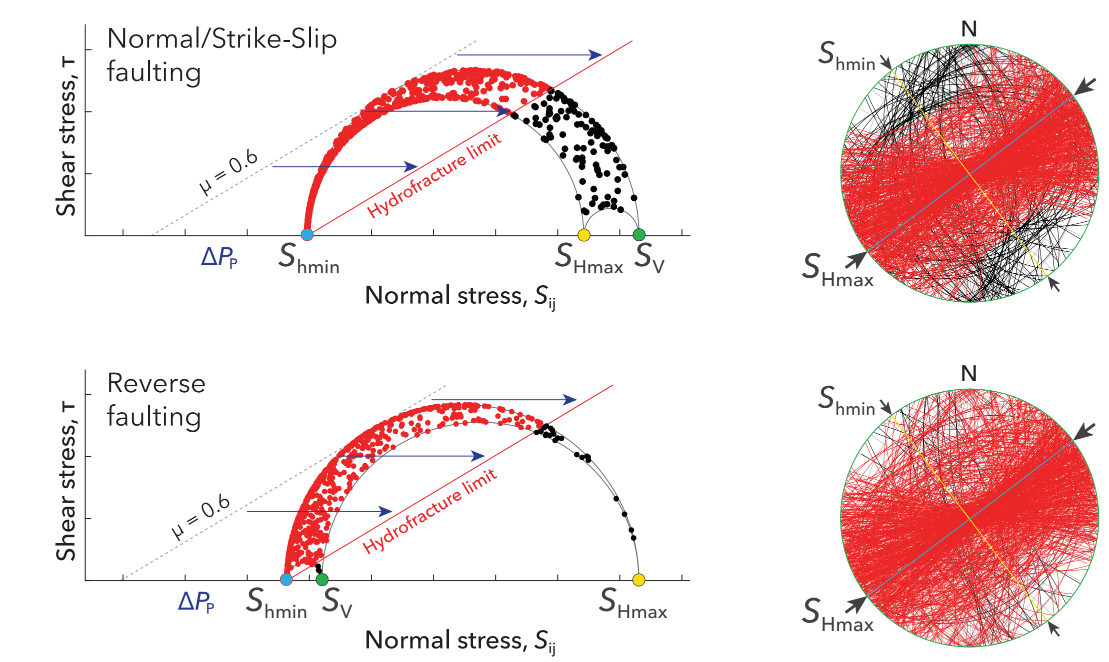
Impacts for unconventional energy development

The new maps have two primary applications for development of geothermal and unconventional oil and gas resources:

1.) Identifying the ideal directions to drill horizontal wells, and

2.) Understanding how stimulation will occur.

Because hydraulic fractures are planes that propagate parallel to the maximum and intermediate principal stresses, wells should be drilled perpendicular to S_{Hmax} and parallel to the minimum horizontal principal stress (S_{hmin}). For the first time, the S_{Hmax} orientations across nearly all tight oil and gas basins are reasonably well known, reducing uncertainties associated with planning well paths.



With knowledge of the S_{Hmax} orientation and relative principal stress magnitudes, it is straightforward to predict the subset of pre-existing fractures that will slip during stimulation to create an interconnected, permeable network. However, fractures of some orientations can *never* be made to slip within the stress field because pore pressure cannot reach significantly greater than the fracture gradient ("hydrofracture limit").

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