



Formation Ductility and its Critical Role in Hydrocarbon Entrapment and Hydraulic Fracturing Geometries*

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May 27, 2026

* & Induced Seismicity Abatement, etc.

Melzer Consulting



Abstract

The roles that plastic, i.e., non-brittle, formations are actively playing in the subsurface is getting greater attention today. Conversations generally involve either drilling difficulties or their influence on hydraulic fracturing geometries. In those two arenas it is the so-called clay-rich shale zones that prompts the interest. It stems from the oil and gas industry's worries about avoiding drilling failures and in modeling visco-plastic formation roles in forecasting hydraulic fracture geometries.

But this plasticity, alias visco-plasticity (VP), has two other important roles to play 1) in hydrocarbon maturation, migration, and accumulation and 2) where reservoir fluids containment occurs during the process. The latter role has a more current and analogous issue related to over-pressuring and over-loading formations during large volume water disposal and CO₂ sequestration projects. VP formations (VPFs) are critically important considerations in all the aforementioned processes.

VPF's sealing properties lie in their ability to flow when pressurized, i.e., their plasticity. Those same clay-rich zones in the macro-scale basin sediments play a similar role when organics are refined in-situ to oil and gas and try to escape to the shallower, lower pressure zones.

Embedded clay-rich layers in basin sediments, important in drilling and hydraulic fracturing, also play a role in entrapment allowing high oil cuts even in the lowermost sections of thick formations.

We will review the typical VP formations while extending insights to fluid seals and their vital roles in hydrocarbon production and entrapment. Several case histories in key regional transverse crustal-based faults will be shown.



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Outline of Talk

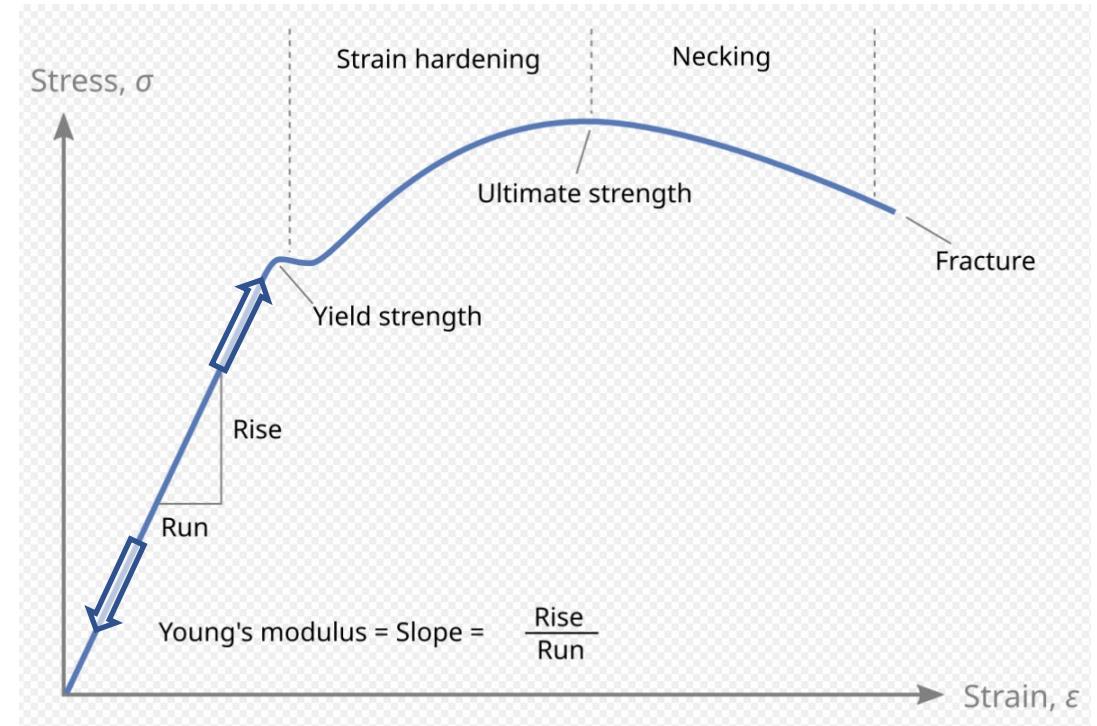
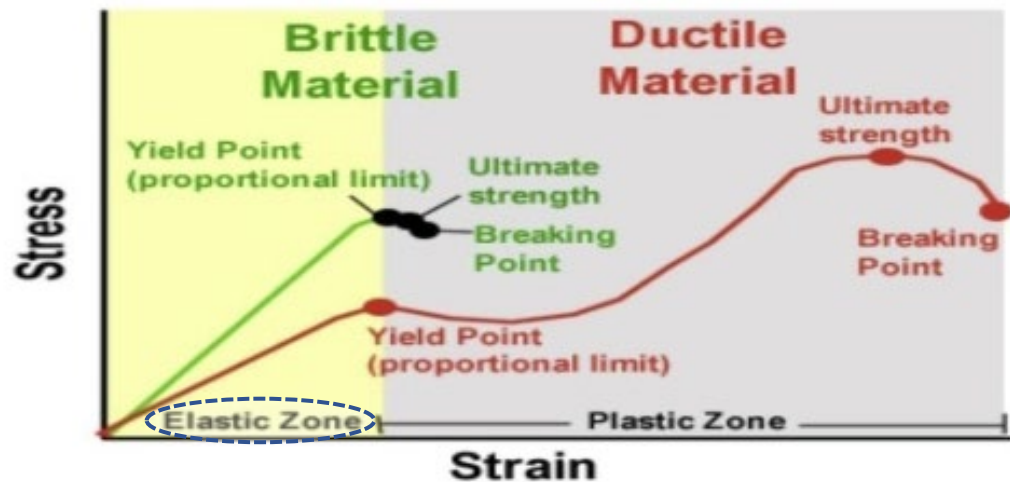
- I. What is Elasticity; What is Ductility (i.e., Visco-plasticity {VP}), Creep?
- II. Why the Special Worry With VP Formations (VPFs)?
- III. Permian Basin Dynamic Stress History (the Orogens, Inferred Stress Histories)
- IV. What Lithologies can be VP? aka “creepers”
- V. In-Situ Stress Frameworks and the Role of Geologic History in forming Regional Folds and Natural Faults
- VI. Degree of VP and How to Best to Measure
- VII. Summary

Section I

Definitions: Elasticity & Beyond

Elasticity is the ability of a material to return to its original shape and size after a distorting force is removed

Brittle and Ductile Materials





What is Ductility (i.e., Visco-plasticity)

- Ductility in engineering is the physical property of a material, particularly metals, to plastically deform (stretch, bend, or draw into thin wire) under tensile stress without fracturing
- Geology: In earth science, it refers to rock deformation under high pressure and temperature without breaking.
- Visco-plasticity is a theory in continuum mechanics that describes the rate-dependent, irreversible (inelastic) behavior of solid materials. It applies to materials that undergo permanent deformation when a specific yield stress is exceeded, with the deformation rate depending on how fast the load is applied

definition of ductility **in science**
definition of ductility **in engineering**
definition of ductility **and malleability**
definition of ductility **in chemistry**
definition of ductility **in materials**
definition of ductility **in physics**

Let's think about the subsurface where the formations are confined. Ductile materials will deform inelastically under additional stress **without** fracturing.

DUCTILE FORMATIONS AT DEPTH

- 1) Some Clay-rich Basin Deposits
- 2) Salt beds
- 3) Anhydrite
- 4) Others

Some materials are
Ductile at Any Incremental Stress

Here is another Term of Value: What is Creep?

Creep is a failure mode in which a material deforms or thins over time when subjected to a continued stress (load) Let's look a bit harder at that term

Creep Defined (from several sources)

- A time-dependent, permanent deformation of shale 'rock' or most evaporitic rocks under constant stress, often triggered by drilling-induced stress changes, such as reduced mud weight. In some shales it is driven by high clay/organic content and can cause borehole closure, casing damage, and decreased fracture conductivity.
- The process involves visco-elastic and visco-plastic (*vp*) deformation, often accelerated by high differences in stress states, temperature, and moisture.
- Drilling Impacts: Salt beds and creeping shale often have in situ stresses near their shear capacity*. Drilling activities (e.g., removing rock) can cause the salt or shale to move or "creep" into the wellbore, creating stability issues.
- Creep is not uniform, with studies showing highest deformation when any bedding planes are at a steep angle to the stress (think drilling curves)

* We will come back to this reference to effective natural sealing rocks

Section II

Why Concern Yourself with Ductile Formations (VPFs) ?

APPLICATION

- Drilling
- Well Stimulations
- Hydrocarbon Entrapment (or Lack Thereof)
- Produced Water (or CO₂) Disposal
- Diapirs

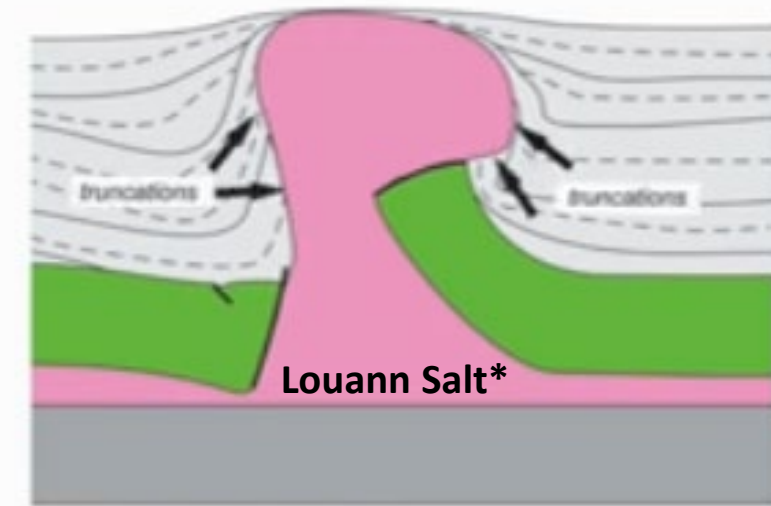
EXAMPLE; CASE HISTORY

- Barnett Curves (Collapse)
- Clay-rich Basin Sediments
- Vertical (or Horizontal) Seals
- Basement (Crustal) Stress Communication
- Salt and Shale Structures

Real World Examples (1)

- Salt Domes in the Gulf Coast?
- How about that Problematic Clay-Rich Zone in the Barnett?
- And How about Zones Resistance to Frac'ing?

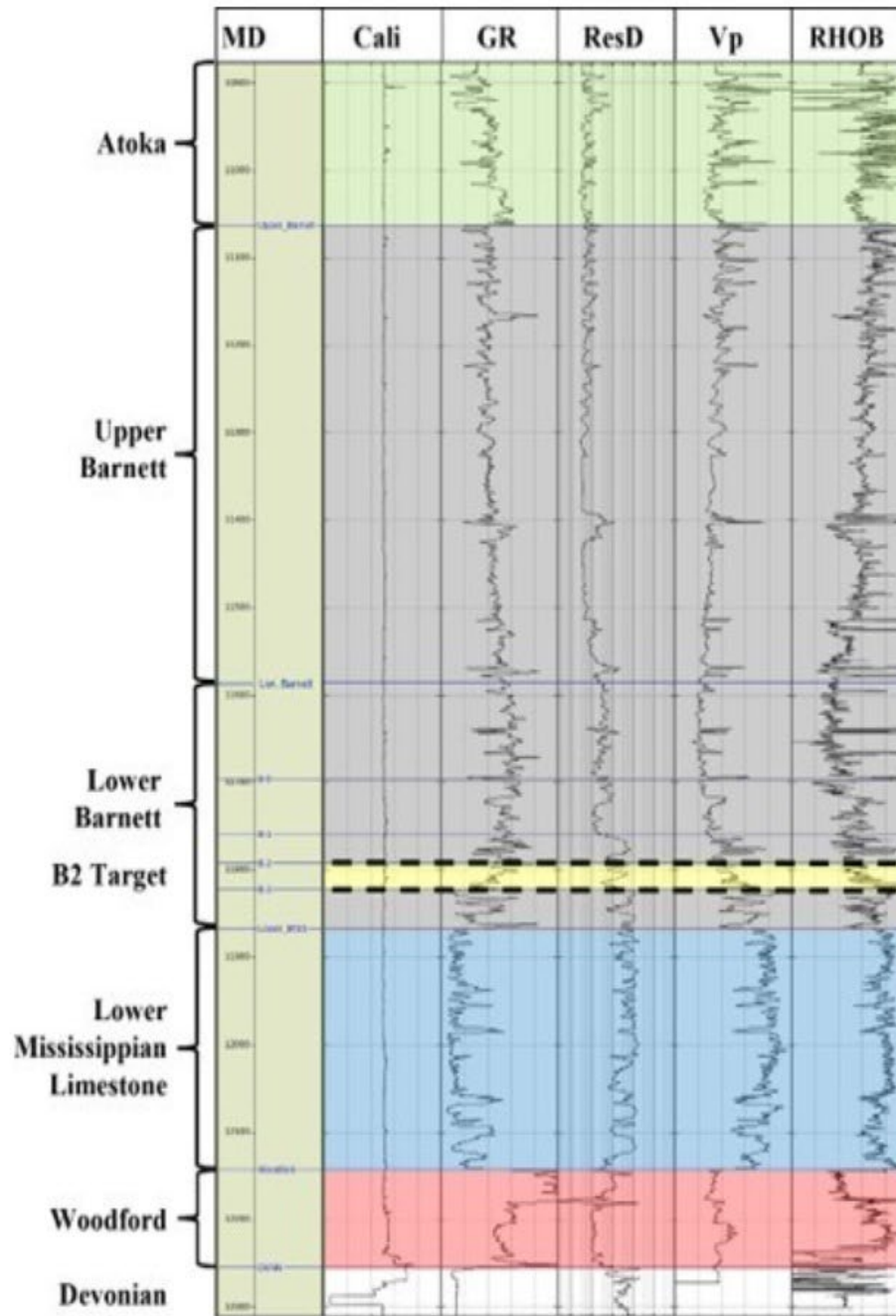
Submarine salt mobility with sedimentation



* Up to as much as 4000' thick in the diverging No. & So. American Plates in the Jurassic

Real World Examples (2)

- Salt Domes in the Gulf Coast?
- How about that Problematic Clay-Rich Zone in the Barnett?
- And How about Zones Resistant to Frac'ing?



↕ The problematic highly ductile shale Typical Landing zone

• Adapted from Lewis et al, URTEC Paper DOI 10.15530/2024-4055274

Figure 2. Formation expressions on wireline logs from a vertical well within the study area.*

Real World Examples (3)

- Salt Domes in the Gulf Coast?
- How about that Problematic Clay-Rich Zone in the Barnett?
- And How about Zones Resistant to Frac'ing?

Re: Zoback and Singh**

Their Research Paper Published this Year is Directed to Allow a Better Understanding of Hydraulic Fracturing Shale Sequences with Effects of Interbedded "Clay-rich" Shales with Visco-plastic Behavior

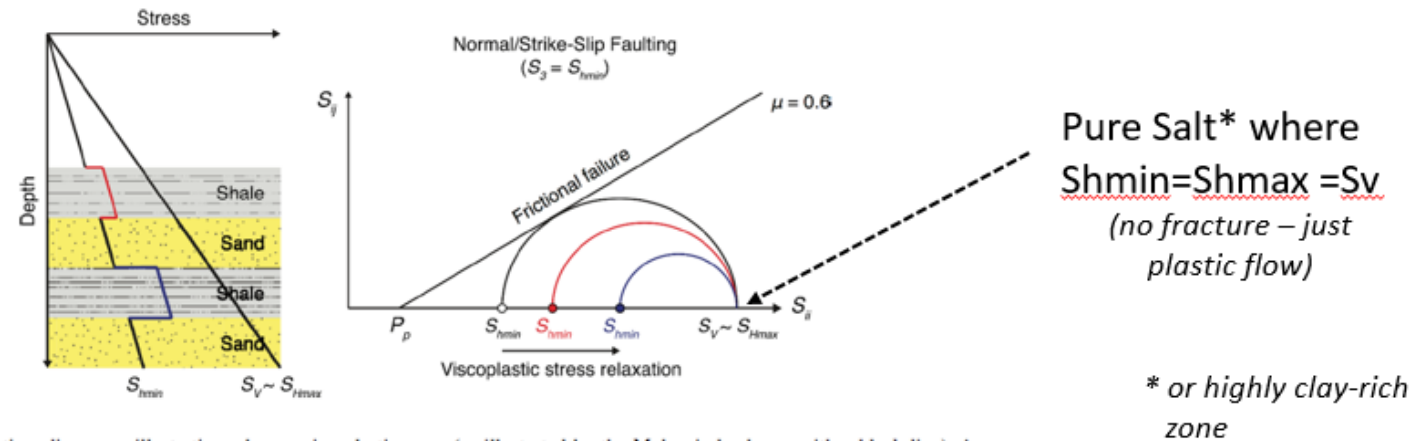


Fig.8 Schematic diagram illustrating how viscoelastic stress relaxation results in decreasing stress anisotropy due to increasing the magnitude of the least principal stress (after Zoback and Kohli 2019) representative of a strike-slip/normal stress state as illustrated in Fig. 5b ($S_v \approx S_{Hmax} \geq S_{Hmin}$). The simplified cross-section on the left shows the least principal stress in the sands being consistent with frictional equilibrium

(as illustrated by the Mohr circle shown with a black line). A moderate increase in the magnitude of the least principal stress above the upper sand results from a minor amount of viscoplastic stress relaxation whereas a greater amount of stress relaxation in the shale below the sand creates a larger stress difference and thus a more effective barrier to vertical fracture growth

* or highly clay-rich zone

** Zoback, M.D. and Singh, A. (2026), "Development of Continuous Estimates of the Least Principal Stress with Depth for Application to Multi-stage Hydraulic Fracturing, Geomechanics and Geophysics for Geo-Energy and Geo-Resources, Special Issue: Optimizing Production and Recovery from Naturally and Hydraulically Fractured Formations, 25 Feb 2026; <https://link.springer.com/article/10.1007/s40948-026-01119-5>

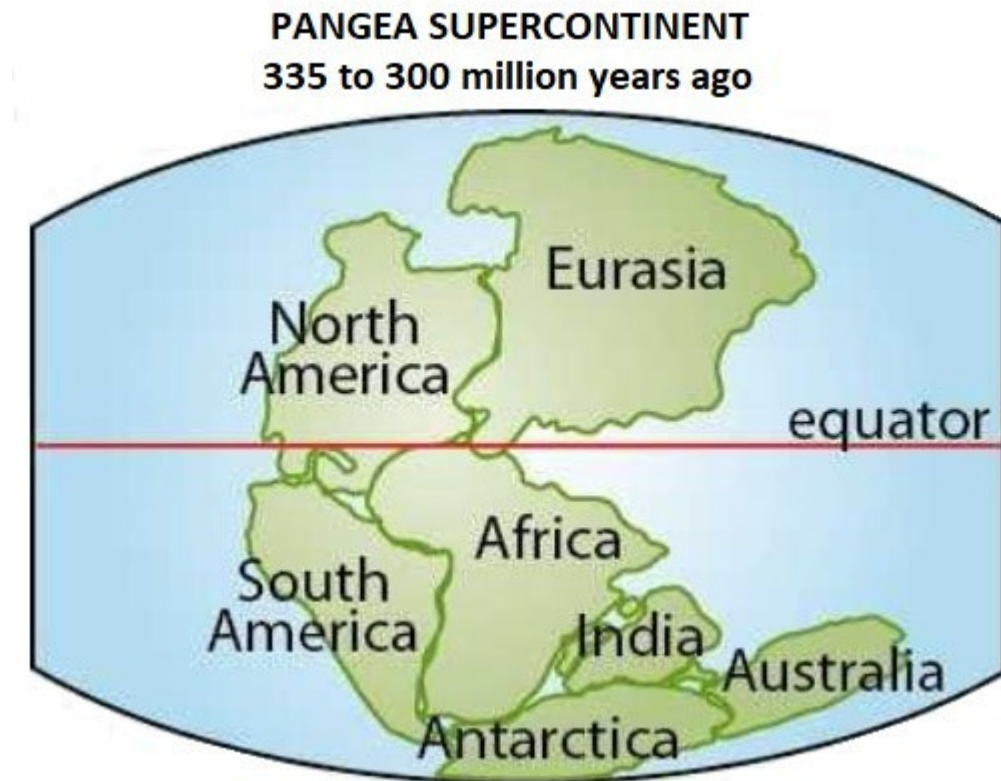


Section III- Geologic Basins are Dynamic: Permian Basin Dynamic Stress History (the Orogens, Inferred Stress Histories)

A Reconstruction History
of the Major Tectonic Stages of the Permian Basin
With a Quick Look at the Gulf Coastal Basin Area

Formation of the Supercontinent Pangea, the Carboniferous Foreland Basin, Shear Stresses in the PB, then the Breakup and Gulf Coast Basin Formation

Pangaea formed approximately 300 to 335 million years ago during the late Paleozoic era, as plate tectonics forced earlier landmasses—the So American /African Plate (Gondwana) and No. American/Asian Plate (Laurasia)—to collide and unite. The forming supercontinent (Pangea) was assembled via continental drift resulting in massive compressive and shear forces before breaking apart roughly 200 million years ago. Rifting and stress relief followed (Late Triassic - Early Jurassic, ~200 Ma) as Pangea separated, leading to crustal thinning and the creation of the Gulf Coast Rift Basin. Its origin is dated to the Early Jurassic as North America separated from South America and Africa. The massive Luann evaporitic salt formation (middle Jurassic ~170 million yrs) is the "mother salt," whose ductile properties formed (as it was buried) over 500 salt domes and other tectonic features in the Gulf Coastal region.

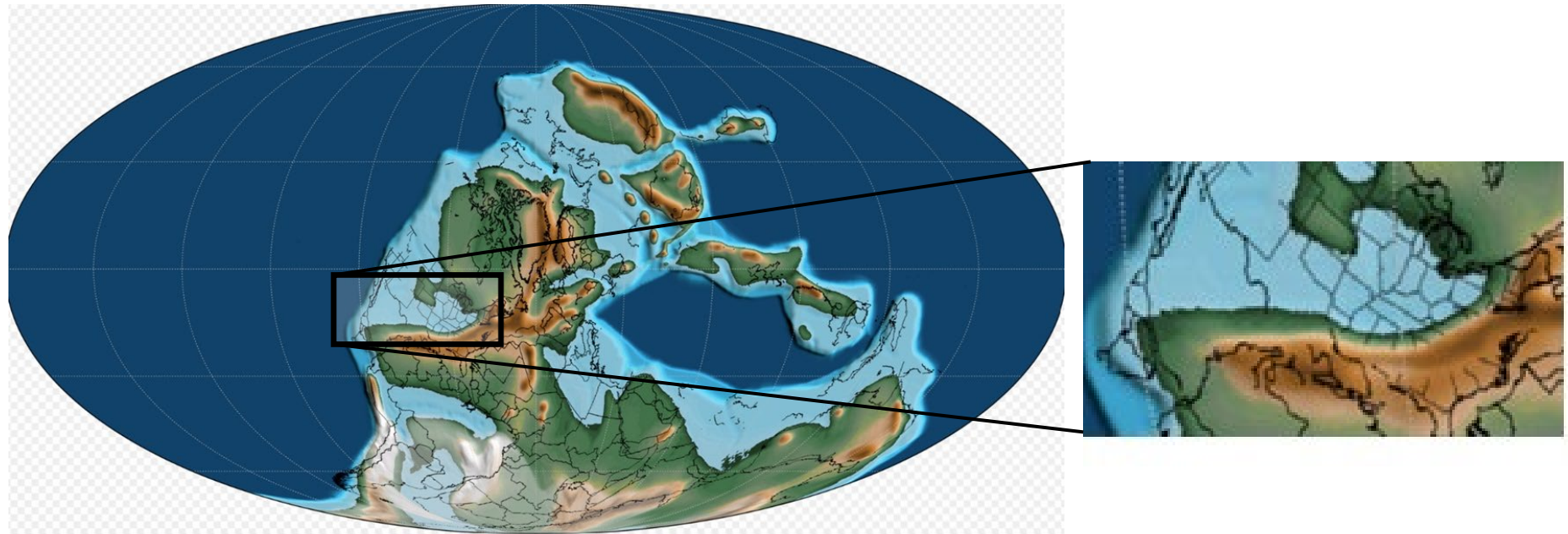


The Imminent Continents' Collision

Early Ouachita Tectonics in the Permian Basin

The Huge Foreland Carboniferous Basin Prior to the Collision

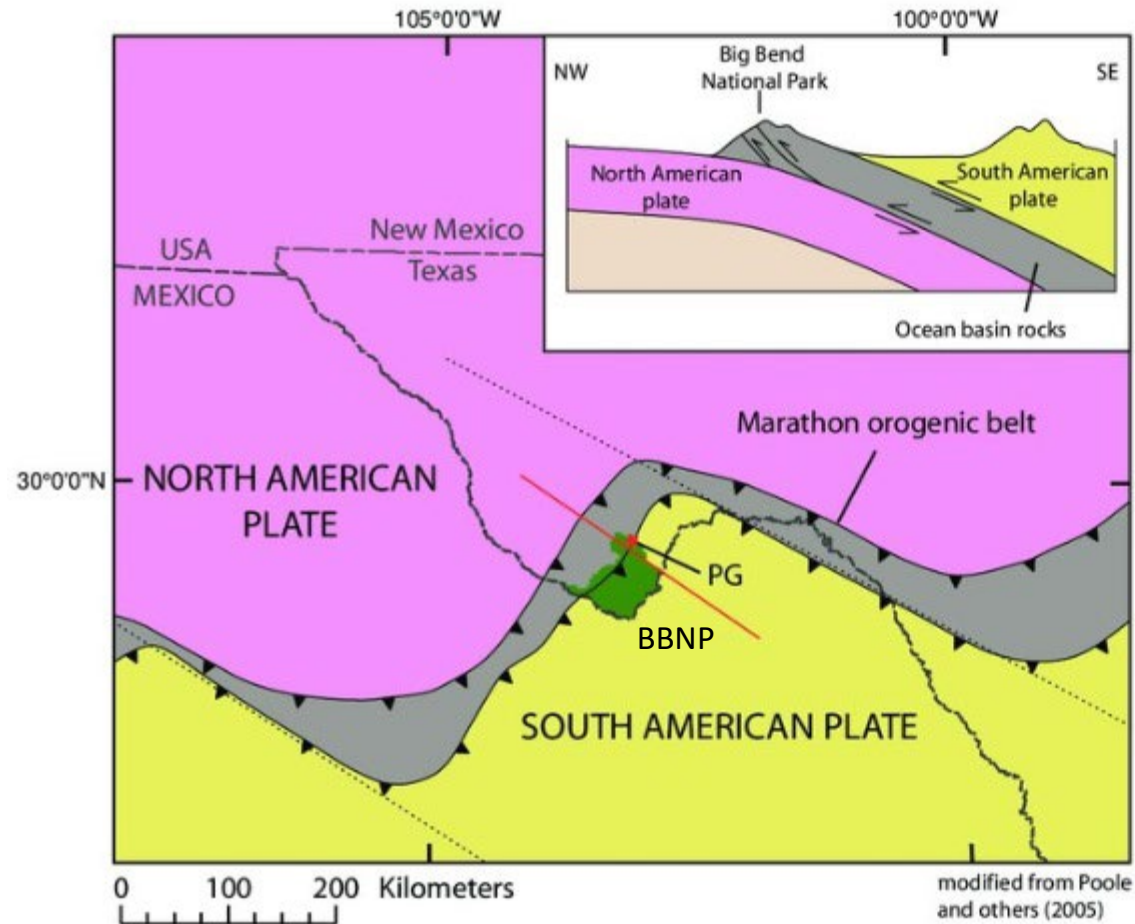
The Carboniferous Period
330 million years ago



A mollweide map of Earth 330 million years ago, overlaid by a black outline of present-day countries in their respective locations.

Scotese, Christopher R.; Vérard, Christian; Burgener, Landon; Elling, Reece P.; Kocsis, Ádám T. - "Phanerozoic-scope supplementary material to "The Cretaceous World: Plate Tectonics, Paleogeography, and Paleoclimate (doi:10.1144/sp544-2024-28)" from the PALEOMAP project". doi:10.5281/zenodo.10659112

SW Texas Ouachita Related (Collision of No. & So. American Plates) and Left Lateral Fault Development



Map showing the Marathon orogenic belt and subduction zone formed from the collision of the plates. The black lines are the traces of the left-lateral transform fault to be discussed later. The inset figure cross section line is shown in red. PG is short for Persimmon Gap located just north of Big Bend National Park (BBNP).



Step 1. Reconstructing the PB Tectonic Stages

Major Tectonic Stages of the Permian Basin

Stage 1. **Tobosa Basin** – Early Paleozoic through Middle Mississippian when the Carboniferous Foreland Basin forms and the Coming Ouachita Collision* is first evident.

Stage 2. **Ouachita** starts in the late Miss. Major movement thru the lower Permian [Wolfcamp]. The critical NNE-ESE Lineaments either start here or possibly even earlier. CBP uplift begins developing

Stage 3. **Development of the Delaware and Midland Basins.** Maximum subsidence of the Delaware begins mid-Wolfcampian, post-dating the development of the Central Basin Platform **initial** Uplift. The thick sediment accumulations in the Delaware followed the initial collision that formed the CBP.

Stage 4. **Laramide:** Entire Basin get buried deeply with Cretaceous subsidence then, beginning in early Tertiary with uplift in the western PB – anywhere from 1000' to 5000'. This stage also creates the Permian age formation outcrops and source of lateral ROZ sweep in what were the huge Paleo Oil Entrapments in the San Andres, Yeso etc.

Stage 5. The Coming Partial Compressive Stress Relief in the **Basin and Range and New Mexico Rio Grande Rift** are overlapping events. Early development of the Rio Grande Uplift and grabens in Lower Oligocene – Early Miocene [40 ma – 25 ma] and associated with the development of the Trans-Pecos Magmatic Province [Texas & New Mexico 26 – 38 ma]]. The Rapid Extension and associated Basin and Range development is lower to Middle Miocene [~25 – 15 ma]. Followed by Slow extension during Pliocene to Recent [15 ma -present]. Shift of western maximum stress from E-NE to W-NW extension during 15 – 2 Ma, resulting in NE trending graben-boundary faults in the Delaware Basin. Some faulting continuing in the Salt Flat Graben, Apache Mountains, Guadalupes, and Glass Mountains.

* The U.S. East Coast is affected earlier and called the Allegheny Collision there

Step 2. Reconstructing the PB Stress Histories

Ouachita starts the *intense compression and lateral shear stresses* seen in the Carboniferous foreland basin development then seen in the PB in the late Miss. Major movement thru the lower Permian [Wolfcamp]. The critical NNE-ESE left lateral transverse faults either start here or possibly even earlier. CBP uplift begins developing

Development of the Delaware and Midland Basins. *Continued compression and maximum subsidence* of the Delaware and Midland Sub-basins begins mid-Wolfcampian, post-dating the development of the Central Basin Platform's **initial** Uplift. The thick sediment accumulations in the Delaware followed the initial collision that formed the CBP.

Laramide: *Continued compressive forces* as entire Basin get buried deeply with Cretaceous subsidence then, beginning in *early Tertiary with uplift in the western PB* – anywhere from 1000' to 5000'. This stage created the 'oven refining' of the organics and uplifted the west side Permian to outcrops and source of lateral ROZ sweep in the San Andres, Yeso etc.

Basin and Range and New Mexico Rio Grande Rift are overlapping events creating *relief of some of the lateral compressive stresses* especially in the western half of the PB. Early development of the Rio Grande Uplift and grabens in Lower Oligocene – Early Miocene [40 ma – 25 ma] and associated with the development of the Trans-Pecos Magmatic Province [Texas & New Mexico 26 – 38 ma]]. This created rapid extension and associated Basin and Range development is lower to Middle Miocene [~25 – 15 ma]. *More stress relief and slow extension* during the Pliocene to Recent [15 ma -present]. Shift of western maximum stress from E-NE to W-NW extension during 15 – 2 Ma, resulting in NE trending graben-boundary faults in the Delaware Basin. Some faulting continuing in the Salt Flat Graben, Apache Mountains, Guadalupes, and Glass Mountains.

Compressive and Shear Stresses

Partial Compressive
Stress Release



Section IV

Now Back to the Subject of Ductile Formations and their Significance

And the Classically Understood Ductile Lithologies

1. Evaporites (Salt beds, Anhydrites)
2. Clay-rich Shales



VPFs Threshold Pressures to Flow

- Salt

The threshold pressure on bedded salt to flow—often referred to in geomechanics as the creep threshold stress or yield threshold—typically requires a differential stress of 150 to 1500 psi. Below this critical threshold, salt behaves elastically. When this pressure gradient is exceeded, the rock exhibits ductile, time-dependent creep.

- Shales

- Clay Bed physical flow (Failure/Landslides). The minimum pressure or shear stress required to make the clay bed itself flow (as a submarine landslide, debris flow, or fluid mud), depends on its Yield Stress.

- Yield Stress: Yield stress is the minimum shear pressure required to break the structural network of the clay and cause it to act like a fluid rather than a solid. It usually ranges from roughly 50 Pa (7 psi) in weak-gel states to thousands of Pa (>>150 psi) for relatively stiff, compacted clays.
- Water Content: The yield stress drops precipitously as water content increases. If the bed's bulk density is less than 1.2 g/cc (heavily saturated with water), it is essentially fluid mud and will flow continuously under very low pressures.
- Permeability of the Clay: If the clay somehow retains its moisture (without consolidating to a stiff shale), the clay retains its ability to flow. Example of this are shale diapirs and the Problematic Clay-rich Shales at Depth.



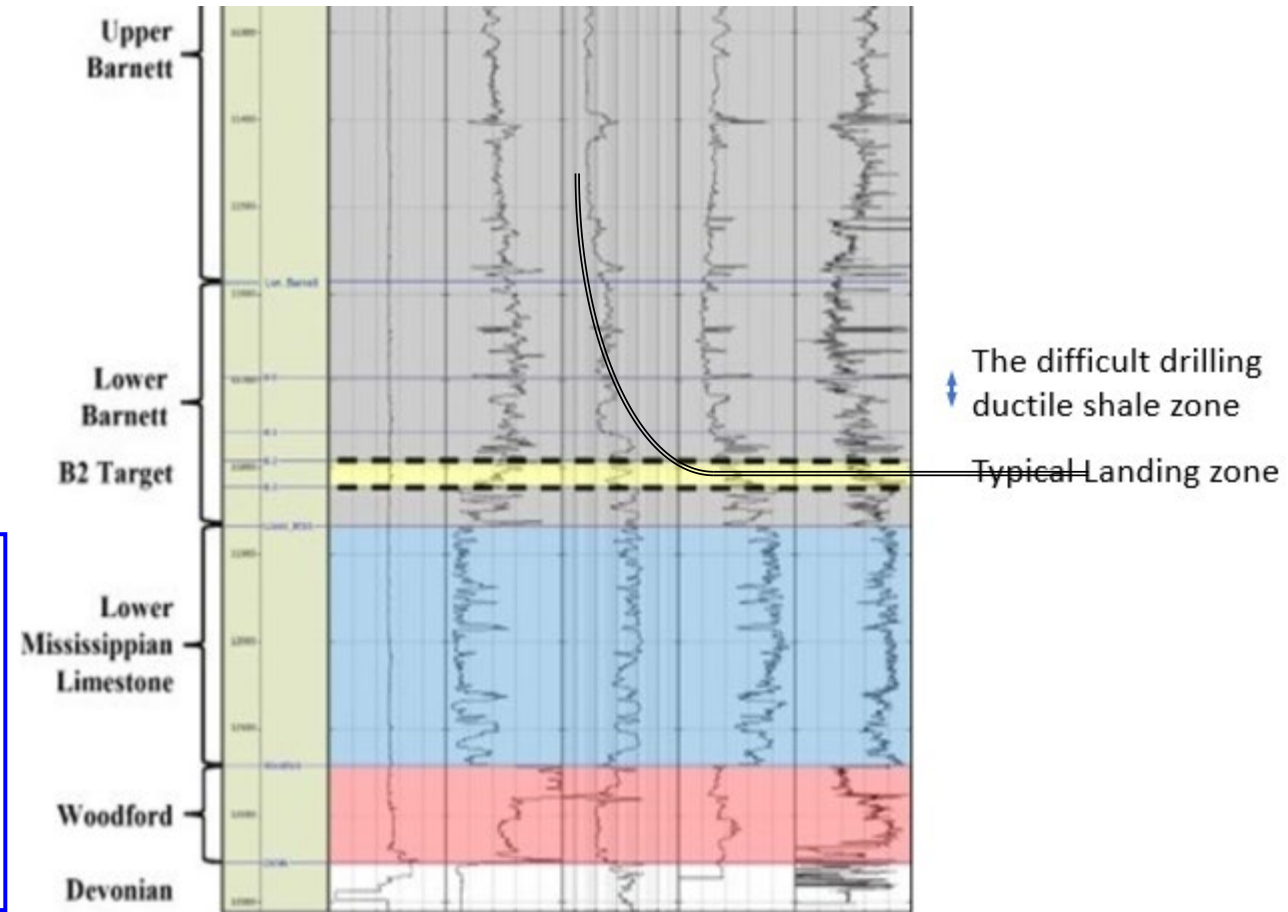
Factoids on Possible Clay-Rich Shales

- Swelling clay minerals (expansive clays) are 2:1 layer-silicates that expand in volume by adsorbing water between their structural layers. The most common and highly expansive mineral in this group is montmorillonite (a type of smectite).
- Smectite Group (Montmorillonite/Bentonite): These are the most expansive minerals known. The internal crystal surface area is incredibly large, allowing massive amounts of water to be drawn in electrochemically.
- The primary geological source of swelling clays (smectites like montmorillonite) is the chemical alteration of volcanic ash deposited in marine or alkaline environments. Over millions of years, these deposits transform into clay-rich sedimentary rocks and highly expansive soils.
- In shale diapirs (also known as mobile shales or mud diapirs), the mobile core is dominantly composed of highly hydrated, undercompacted, and overpressured smectite group clays, alongside intermediate mixed-layer illite-smectite (I/S) minerals.
 - For a shale body to become ductile and rise buoyantly through overlying strata, it must maintain a low shear strength and high pore-fluid volume. The specific clay mineralogy dictates this behavior.

Let's Return to the Real-world Examples

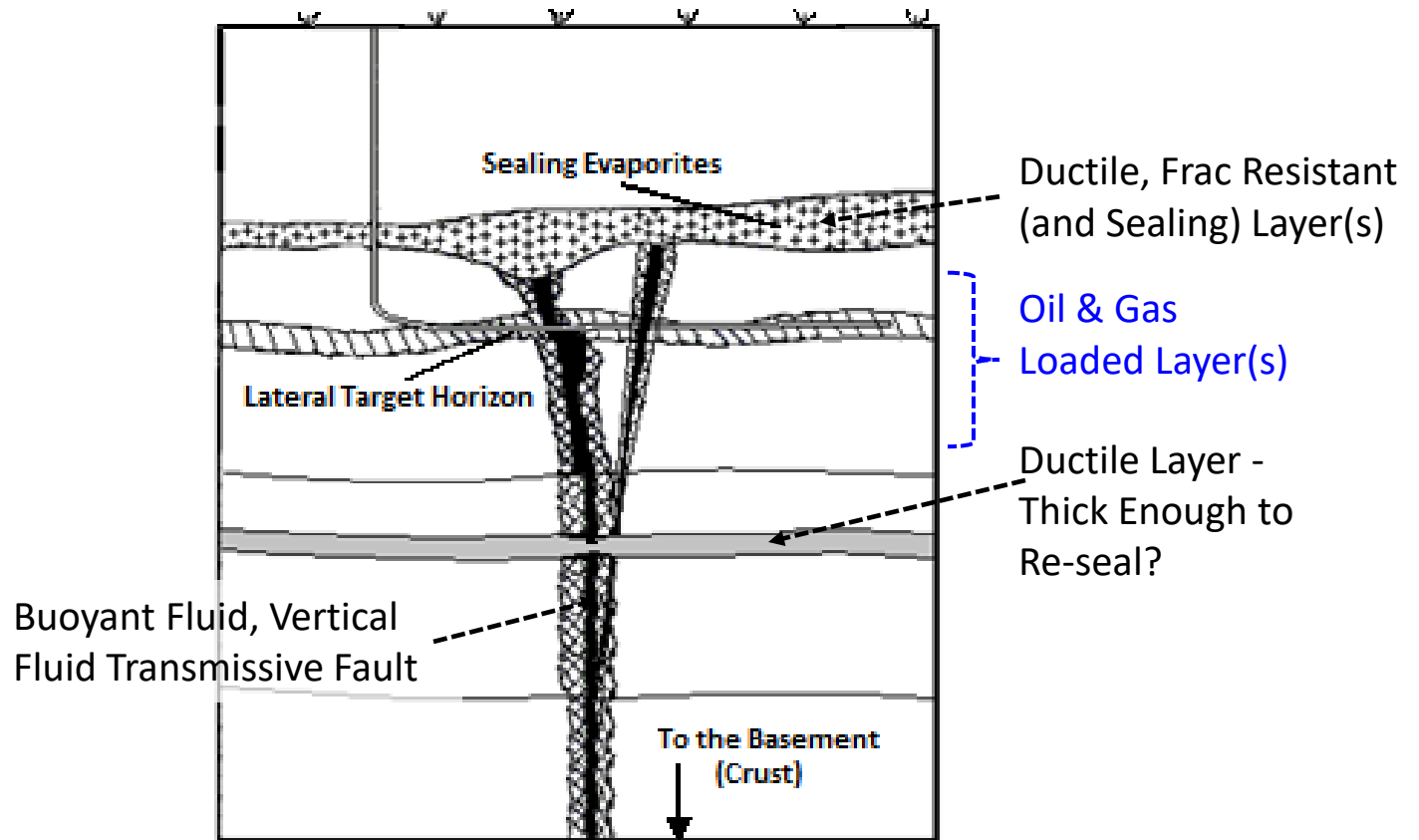
Drilling the Barnett “Curve”

- Encounters the Ductile Clay-rich VP Lower Barnett Shale in the ‘Curve’ Before Landing the Well Lateral Sections Below
 - Good Designs Keep Curve Angle in VPF Less than 45 degrees
 - Requires Heavy Mud Columns and Oil Base Muds
 - Several Examples where Zone Caused Loss of Hole
- Although Not a Thick Zone, it can Act as Stimulation Ceiling and Offer Isolation from Overlying Fluids
 - Barnett Oil/Gas Generation - Trapped Below the VF Ductile Zone thus Offering Production with Low Water Cuts and High GORs



Hydraulic Fracturing Basin Sediments For Zonal Isolation from Above (and Below as from Crustal Rocks)

1. Thick VPFs Act as Frac Barriers
 - A. For Mother Nature's Hydrocarbon Generation and Migration
 - B. For Man's Hydraulic Fracturing Treatments
2. As in PB Barnett Example, VPFs will Contain Fluids from Escape
3. Even in Vertically Faulted Basins, thick VPs Can Reseal Fluid Transmissive Fractures
4. As in Permian and Williston Basins, Thick Evaporite Caps Prevented Oil/Gas Vertical Escape
5. Carbonate Ramp Reservoirs have Many Examples of Laterally and Vertically Sealed Stratigraphic Traps





Let's Dive Deeper Into the Seismicity Issue

Basement (Crustal) Stress Communication

ISSUE

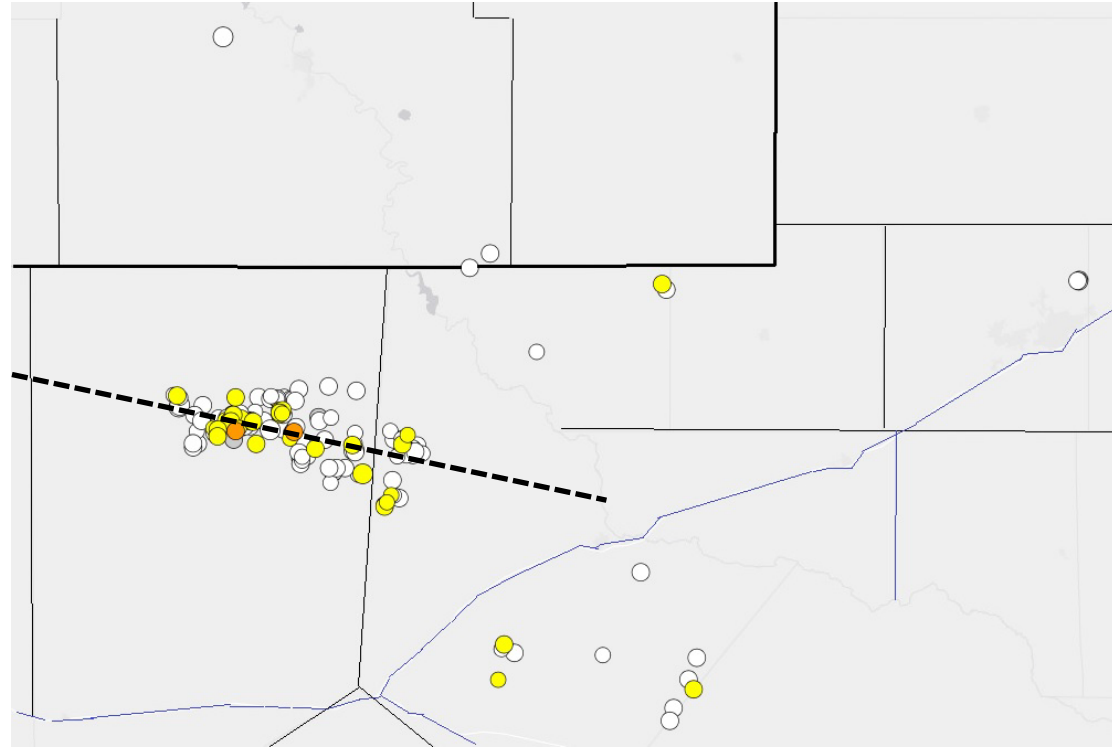
- Oklahoma (Arbuckle Fm) and Ellenburger (PB) Injection Resulting in Induced Seismicity

PROBLEM

- Enhanced Pore Pressures in the Fractured Disposal Formation Communicating to Basement Rock Faults with No VP Seal Between

For Isolation from Crustal Rocks

- Overpressured Zones Can Transmit Pore Pressures Down and Reactivate Crustal Faults Causing Seismicity
- Deep, Thick VPs Can Insulate the Downward Pore Pressures and Avoid Seismicity from Overlying Injection Zones
- VP Presence Can Create Ideal Water (and CO₂) Disposal Zones



Solution: Move to Shallower Zone Disposal??



Section V

In-Situ Stress Frameworks and the Role of Geologic History in forming Regional Folds and Natural Faults

Step 2. Reconstructing the PB Stress Histories

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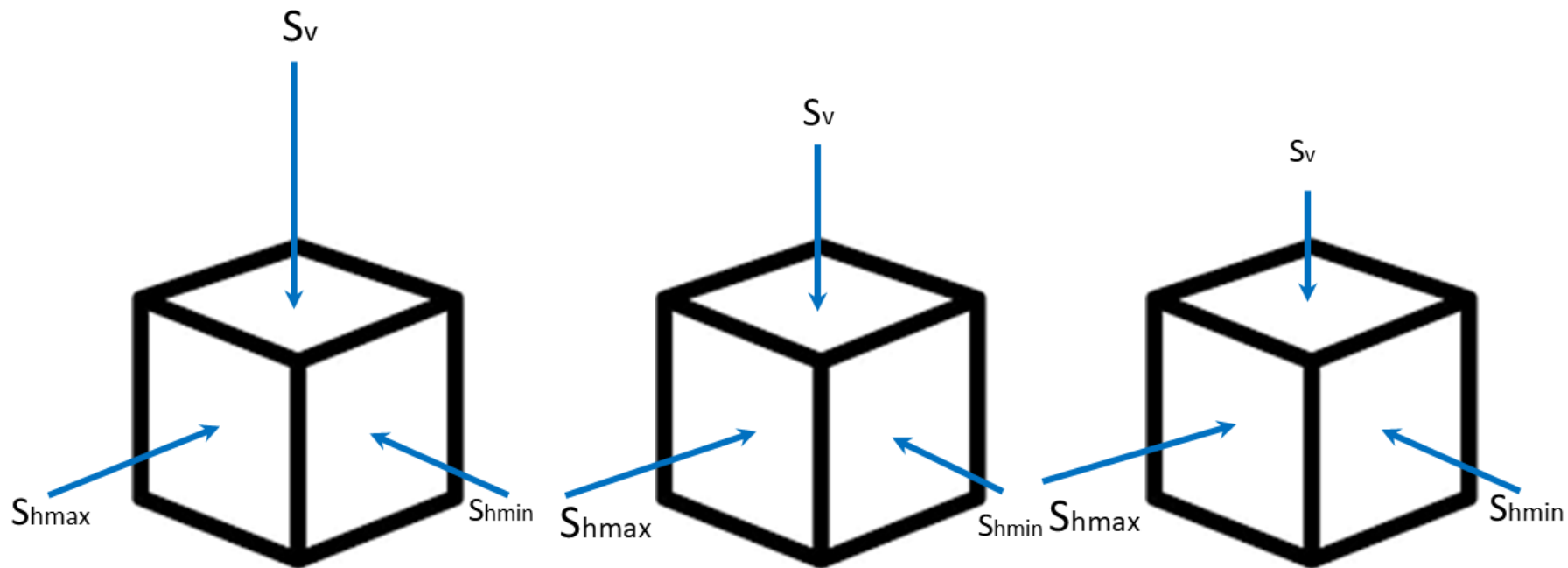
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Compressive and Shear Stresses

Partial Compressive
Stress Release

Normal Faulting, Strike-Slip, and Thrust Faulting Stress States

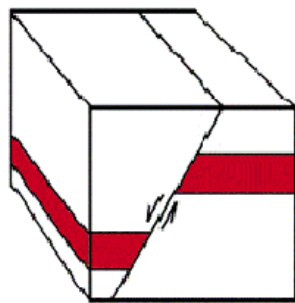
Principal Stress States and Fault Tendencies



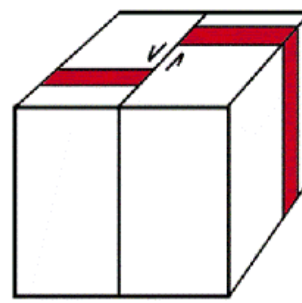
$S_v > S_{hmax} > S_{hmin}$

$S_{hmax} > S_v > S_{hmin}$

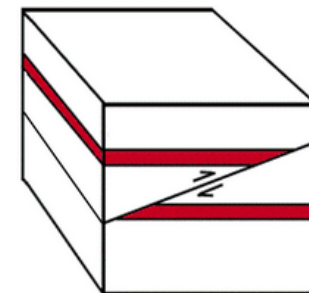
$S_{hmax} > S_{hmin} > S_v$



normal fault

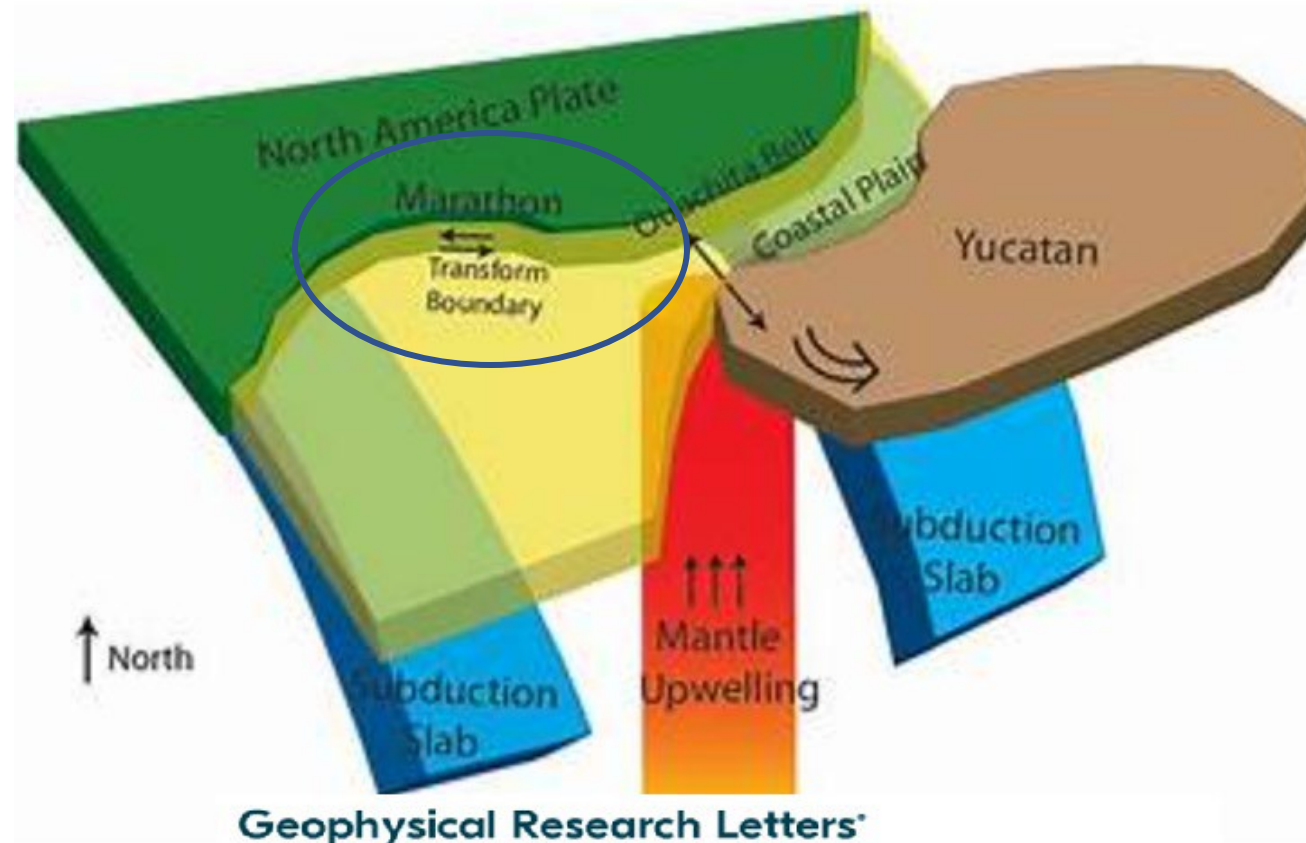


strike-slip fault



Thrust Fault

Ouachita Tectonics in the Permian Basin (2)



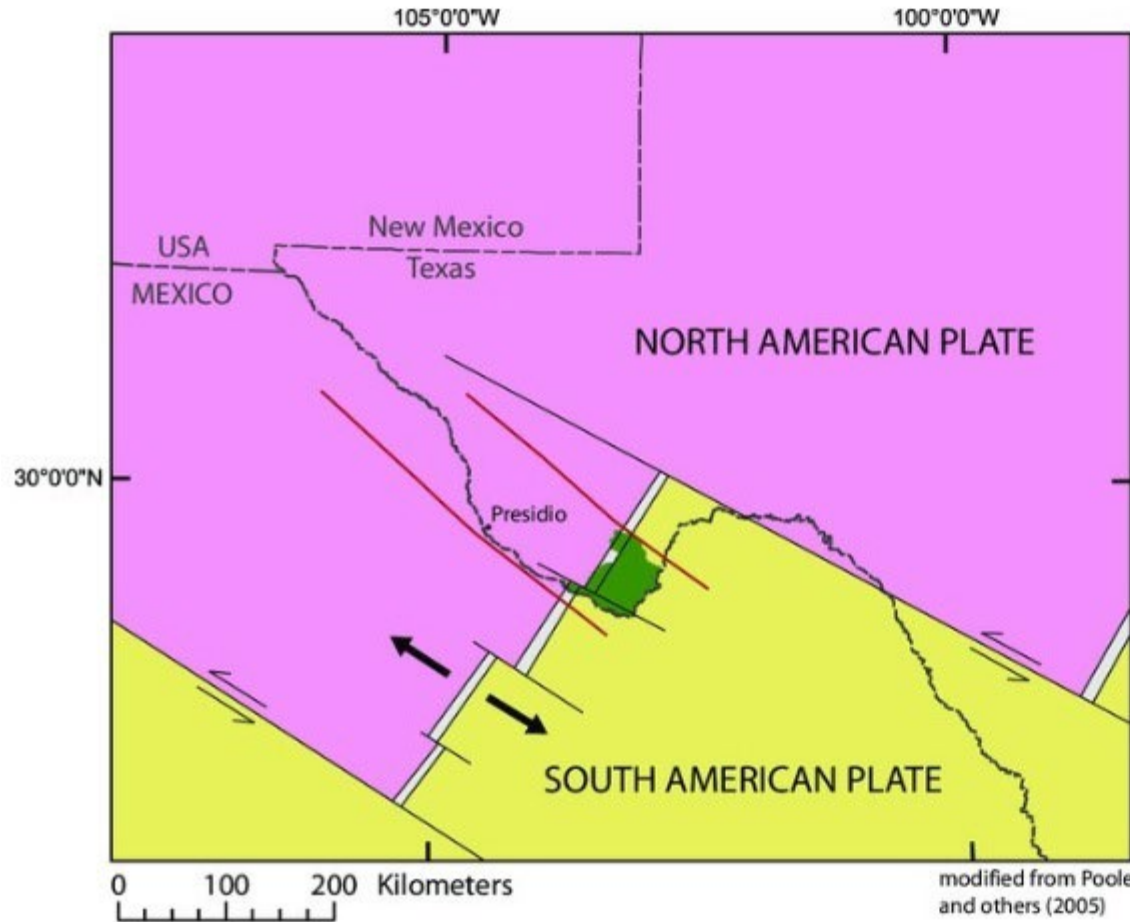
Research Letter | [Free Access](#)

Lithospheric velocity model of Texas and implications for the Ouachita orogeny and the opening of the Gulf of Mexico

Yao Yao [✉](#) Aibing Li

First published: 16 November 2016 | <https://doi.org/10.1002/2016GL071167> | [VIEW METRICS](#)

SW Texas Ouachita Related (Collision of No. & So. American Plates) and Left Lateral Fault Development (1)

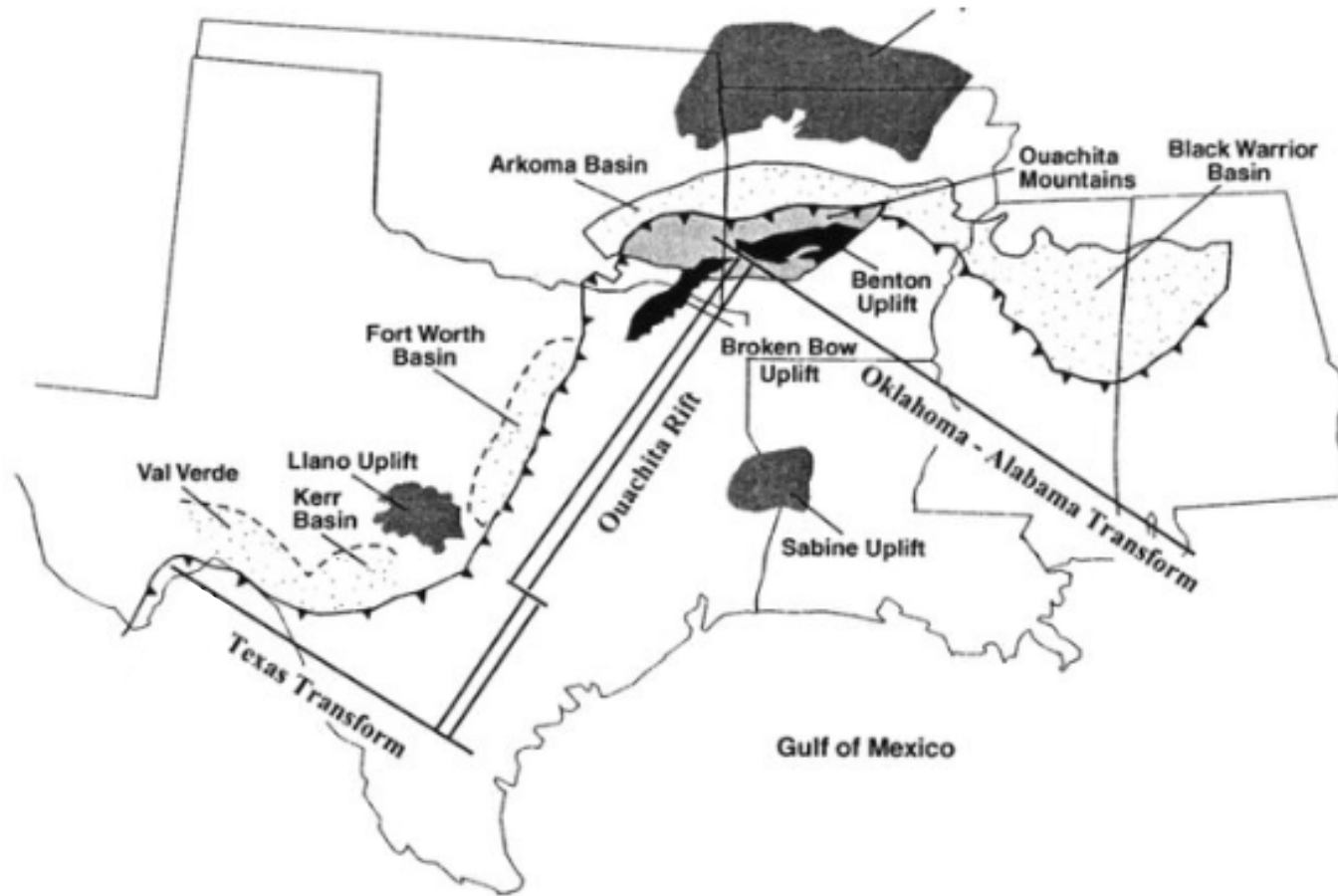


Index map showing transform faults and lineaments related to Proterozoic rifting along the southern edge of North America. Solid black lines are Neoproterozoic continental transform faults (Poole and others, 2005; Thomas, 1991); arrows show relative motion of continental plate offset; gray double-banded line is main rift zone between North and South American plates; solid red lines are Texas lineament (Albritton and Smith, 1957; Muehlberger, 1980); and dark green area is BBNP.

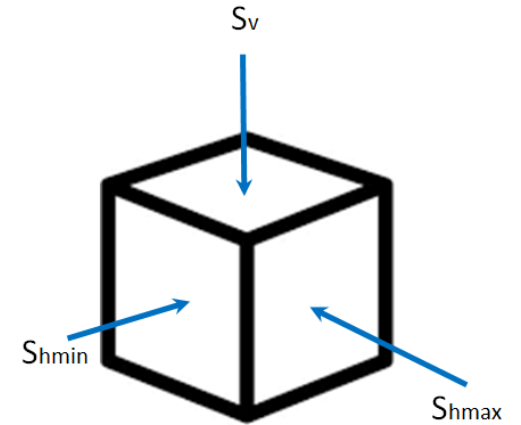
Ouachita Collision Tectonics

Adapted from Figure 1 in
 “Gravity constraints on lithosphere flexure and tectonic structure of the late Paleozoic Ouachita orogen in Ark and So. Central NA”

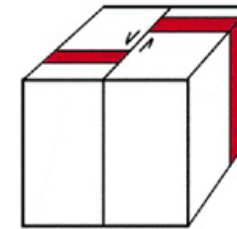
April 1998 *Tectonics* 17(2):187-202
 DOI: 10.1029/97TC03786



Shear Conditions and Strike-Slip Faulting



$$S_{hmax} > S_v > S_{hmin}$$



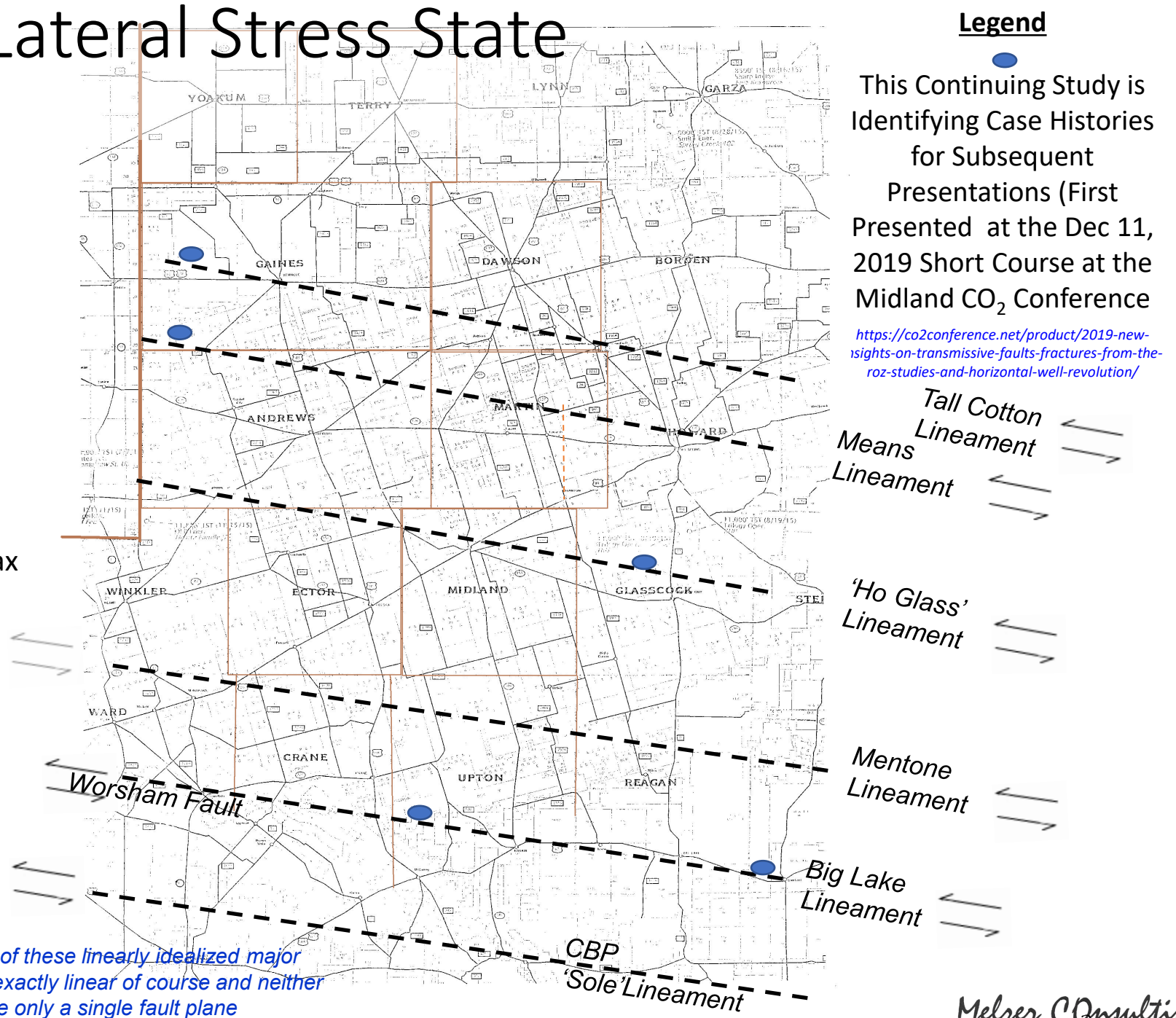
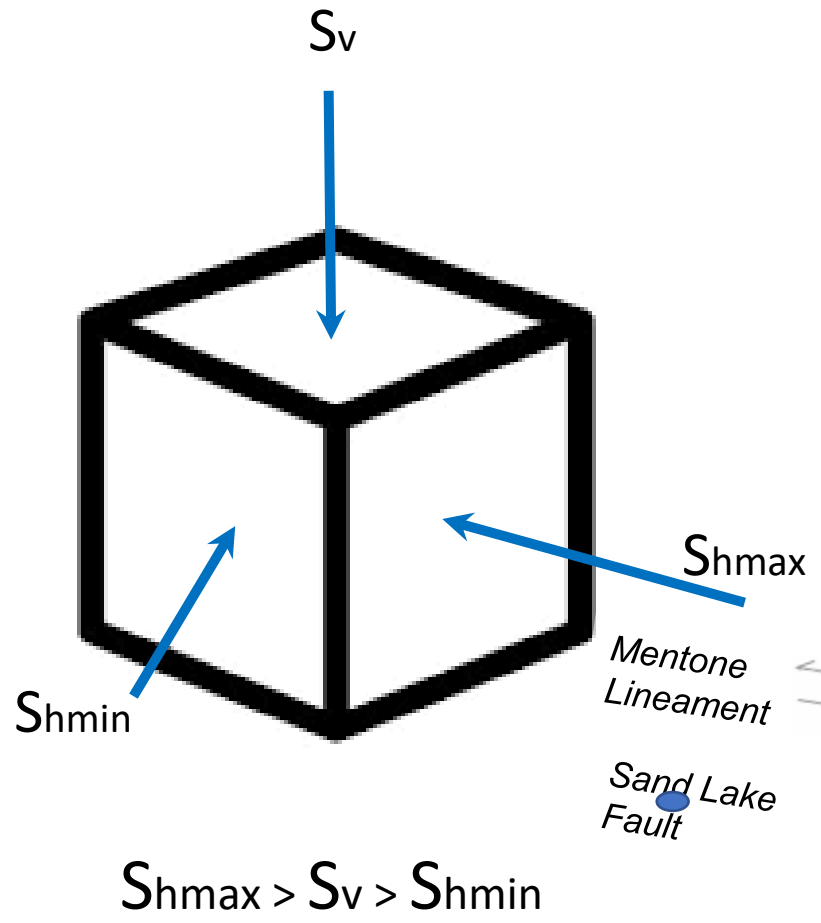
strike-slip fault

Intense lateral pressures in one direction with high vertical confinement create folded structures eventually rupturing with transverse (strike-slip) faults



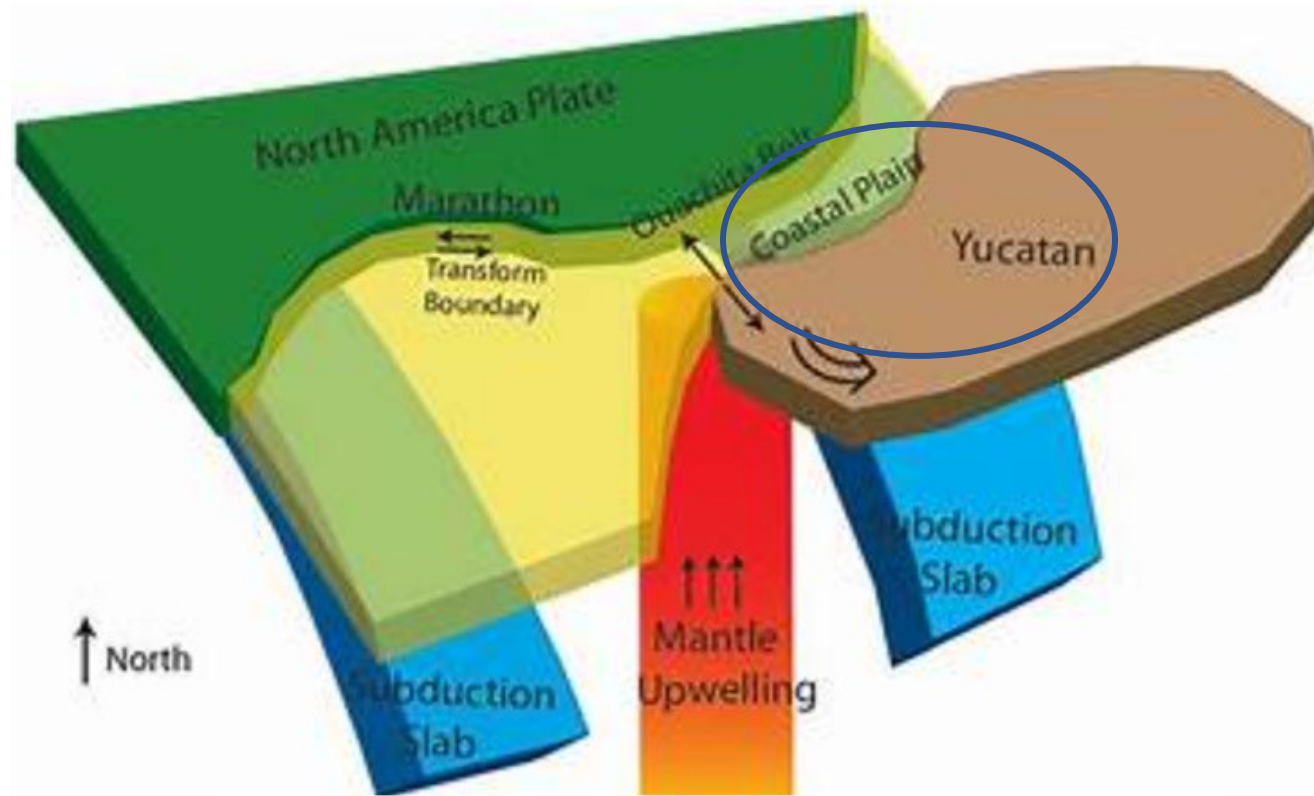
PB Ouachita Left Lateral Stress State

~Roughly NNW-ESE



* Note that none of these linearly idealized major Crustal Faults are exactly linear of course and neither will they be only a single fault plane

Post Ouachita Supercontinent Pangea Breakup: Horizontal Stress Relief with Spreading Plates in the Gulf Coast (2)



Geophysical Research Letters

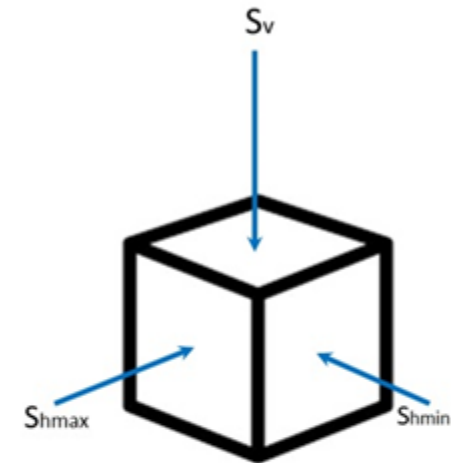
Research Letter | [Free Access](#)

Lithospheric velocity model of Texas and implications for the Ouachita orogeny and the opening of the Gulf of Mexico

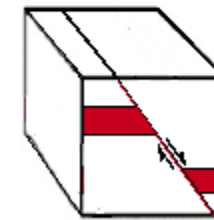
Yao Yao [✉](#) Aibing Li

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Diverging Plates and Normal Faulting

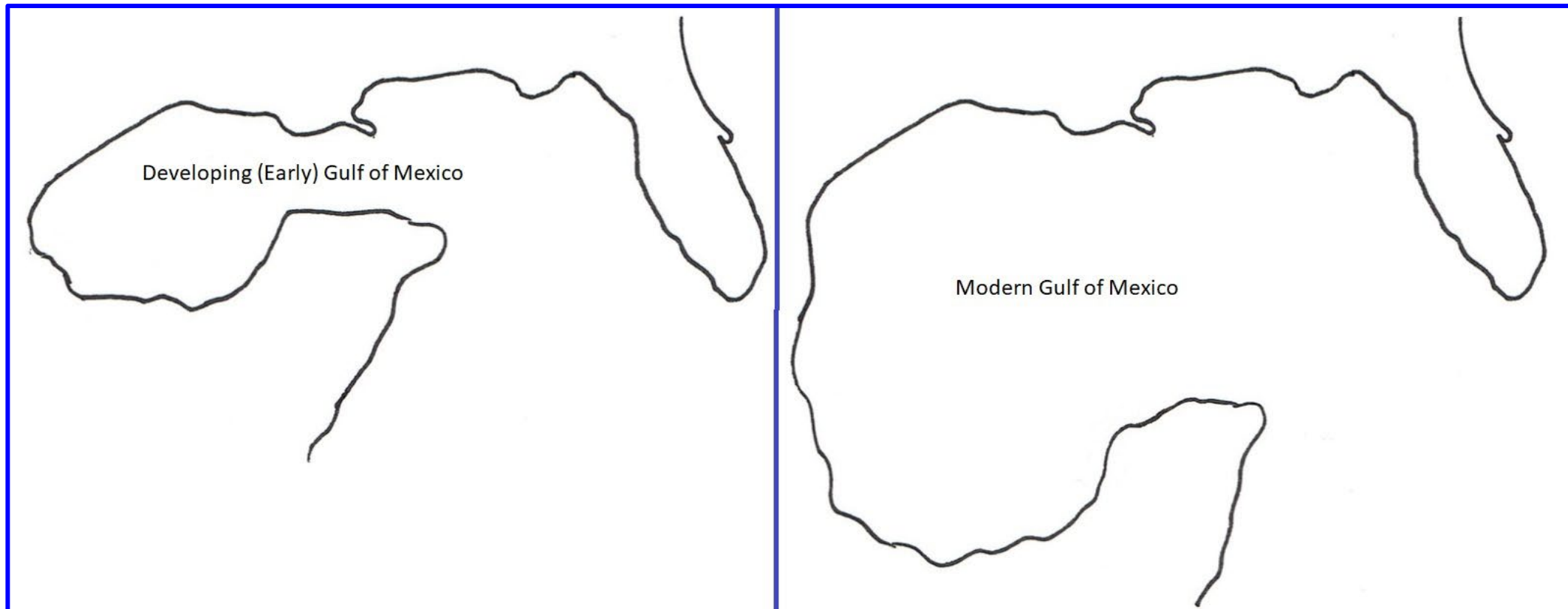


$$S_v > S_{hmax} > S_{hmin}$$



Spreading plates reduce lateral stresses as sediments fill the Gulf with increasing vertical stresses

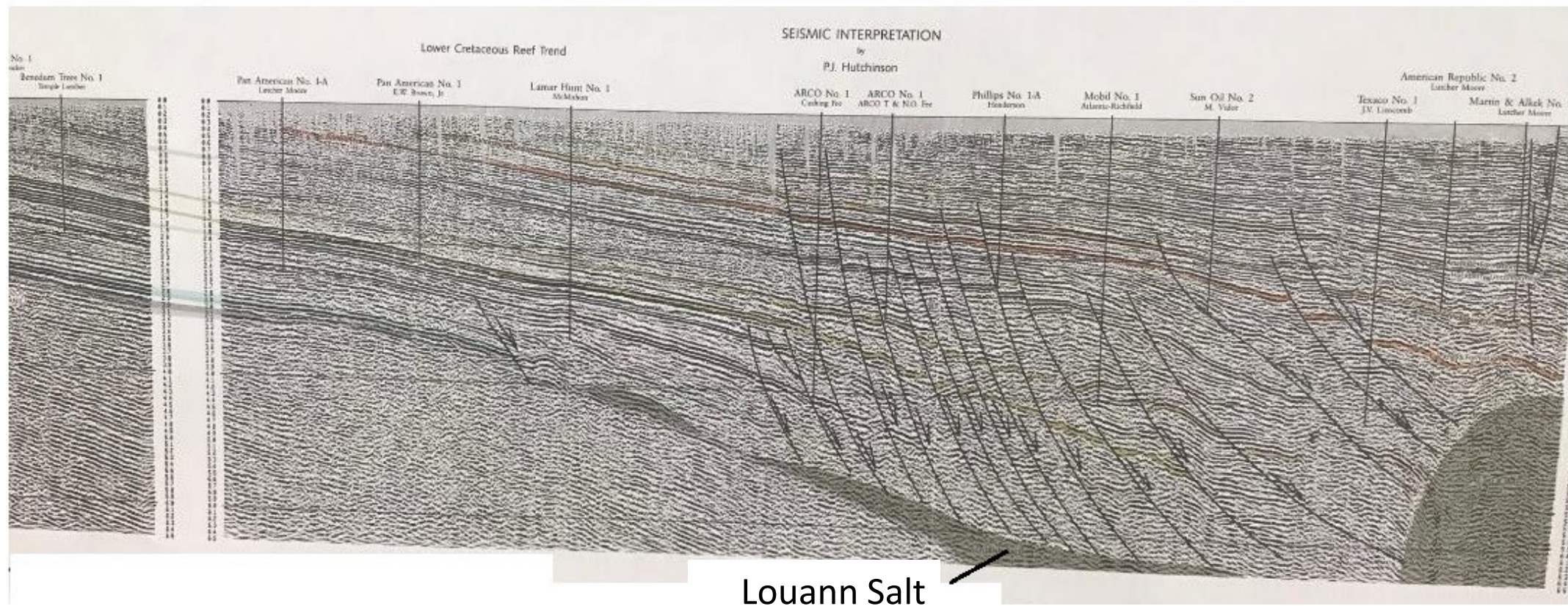
Intermittent Isolation (Restricted Marine) of the Gulf & Jurassic Age Deposition of the Louann Salt



<https://en.wikipedia.org/wiki/File:GulfGif.gif#/media/File:GulfGif.gif>

“Down to the Coast” Faults as No. & So. American Plates Diverge and No American Sediments fill the Void

Example Gulf Coast Cross Section



Recap of the Two Contrasting Cases Permian Basin & Gulf Coast Faulting

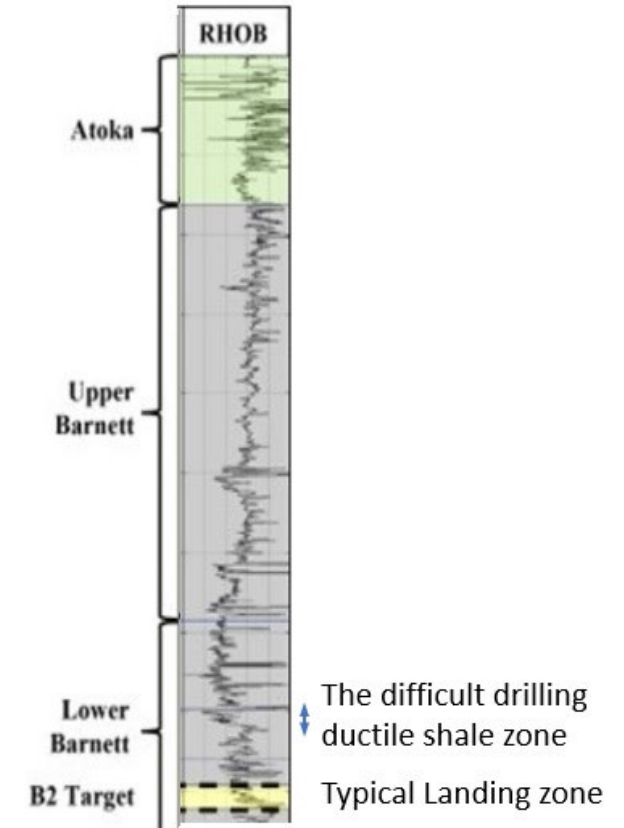
- Permian Basin
 - Ouachita Orogeny (Collision of No & So American Plates)
 - Predominant Compressive Forces; Horizontal Anisotropic Stresses and Formation of Central Basin Platform and Delaware and Midland Sub-basins
 - Left Lateral Transverse (Vertical) Faulting
 - Evidence of Recurrent Movement Over Geologic Time
 - Ongoing Reactivation During Localized High Volume Formation Water Disposal
 - Late Stage and Open Ocean Isolated Basin with VPF Ochoan Salts/Anhydrite Cap Sealed Vertical Faults and Confined Deep Fluids
- Gulf Coast
 - Post Ouachita Orogeny with Spreading of Plates, Horizontal Stress Relief
 - VPF Jurassic Aged Thick Salt Deposition
 - High Volume Sediment Filling of Gulf Basin Stimulating Plastic Flow of Instable Salt Basement, Salt Piercement and Pillar Features



Section VI

Now, How to Identify & Measure Degree of Plasticity?

- For Basinal Deposits
 1. Open Hole Caliper Logs Showing Wellbore Creep
 2. Shaliness, Low Density/High Porosity, Sonic Crossplots
 3. Lower Degree of Organic Maturity
 4. Differential Fracture Injection Tests (DFITs) aka Minifrac
- For Other Lithologies
 - Mineralogy Logs to Identify Clay Types & Evaporites
 - Low Density with 'Normal' Sonic Velocities
 - Differential Fracture Injection Tests (DFITs) aka Minifrac



The Good News is that Reflection Seismic Surveys Will Generally See the Reflectors if they are thick enough (>20 feet)

Section VII

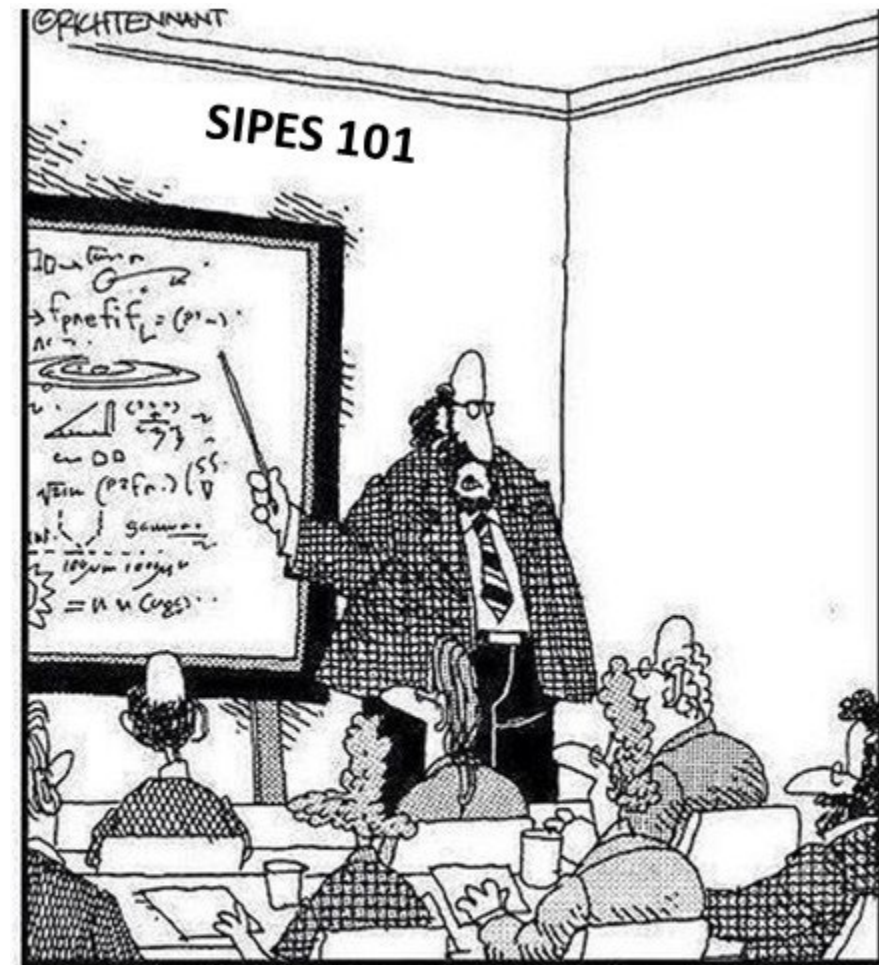
Summary

- Visco-Plastic Formations Can Play a Number of Roles (& in Many Basins)
 - For Example: Increase the Costs of Drilling, Affect Hydraulic Fracturing Geometries, Whether a Basin Can Even Retain Hydrocarbons, Insulate Injection Zones from Vertical Loss of Containment, Insulate Basement Faults from Overlying Excess Pore Pressures to Lower Risks of Induced Seismicity
- Regional Basin Geologic History Reconstruction can Assist with Understanding Stress State Histories, Fault and Fracture Types/Properties, and Lead to New Prospect Development Strategies
- Help Explain Apparent Thickening and Thinning of Formations in Seismic Profiles for
 - 1) Identifying Low Risk Containment Intervals for either Water or CO₂ Disposal
 - 2) Possible Instable 'Footing' with Increased Disposal Formation Loads

Thanks to SIPES

and also to my obsession-driven
journeys with

Andy Bell, Bob Trentham, Bob Lindsay,
Farhan Alimahomed, and Mark Zoback

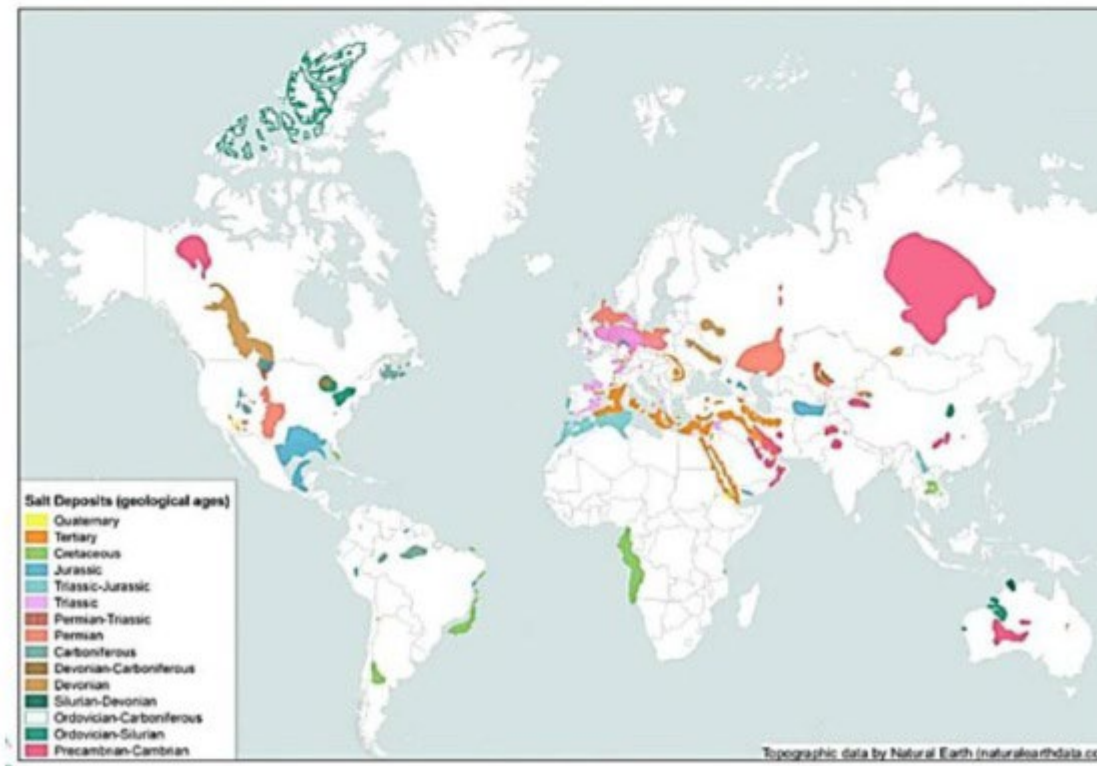


"Along with 'Antimatter,' and 'Dark Matter,'
we've recently discovered the existence of
'Doesn't Matter,' which appears to have no
effect on *oil and gas* whatsoever."



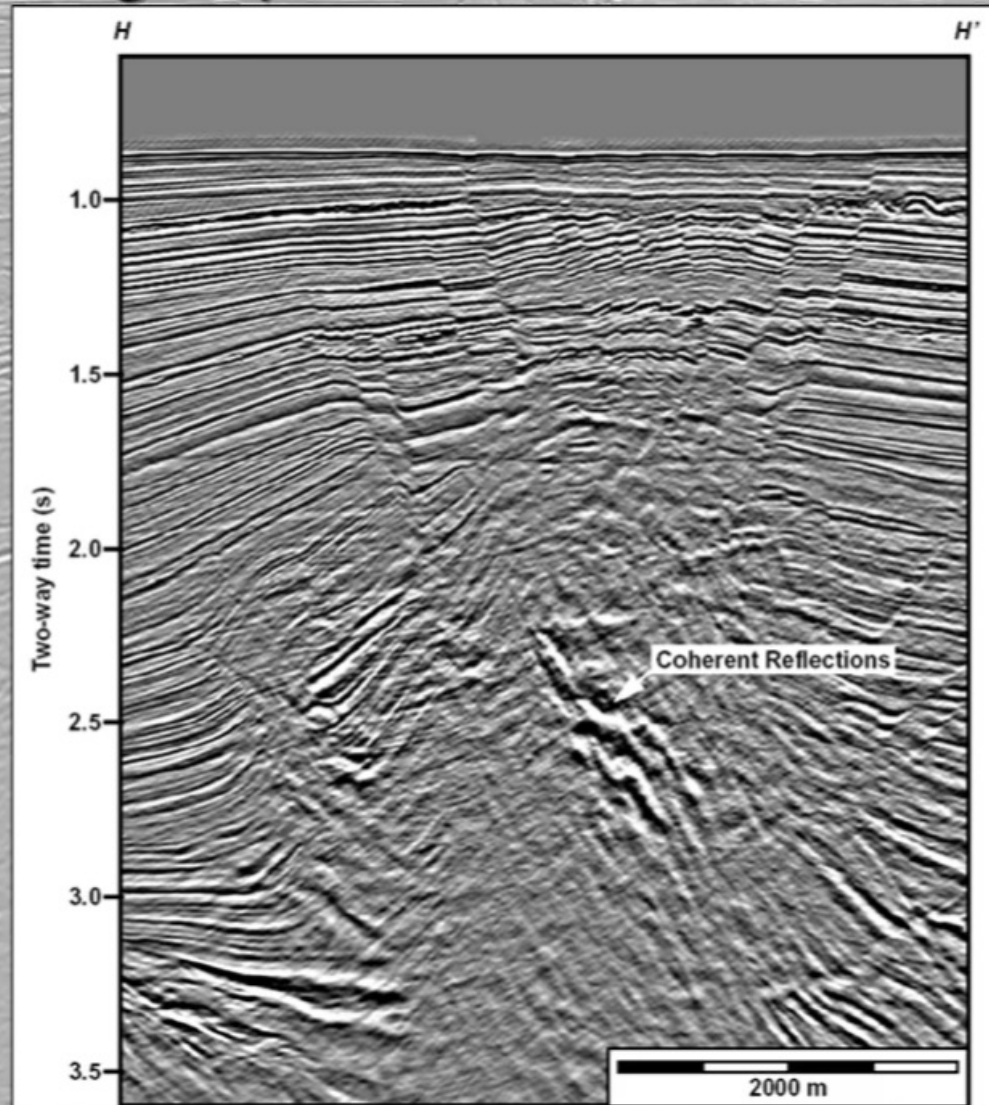
Supplementary and Backup Slides

Salt Basins in the U.S. and Worldwide



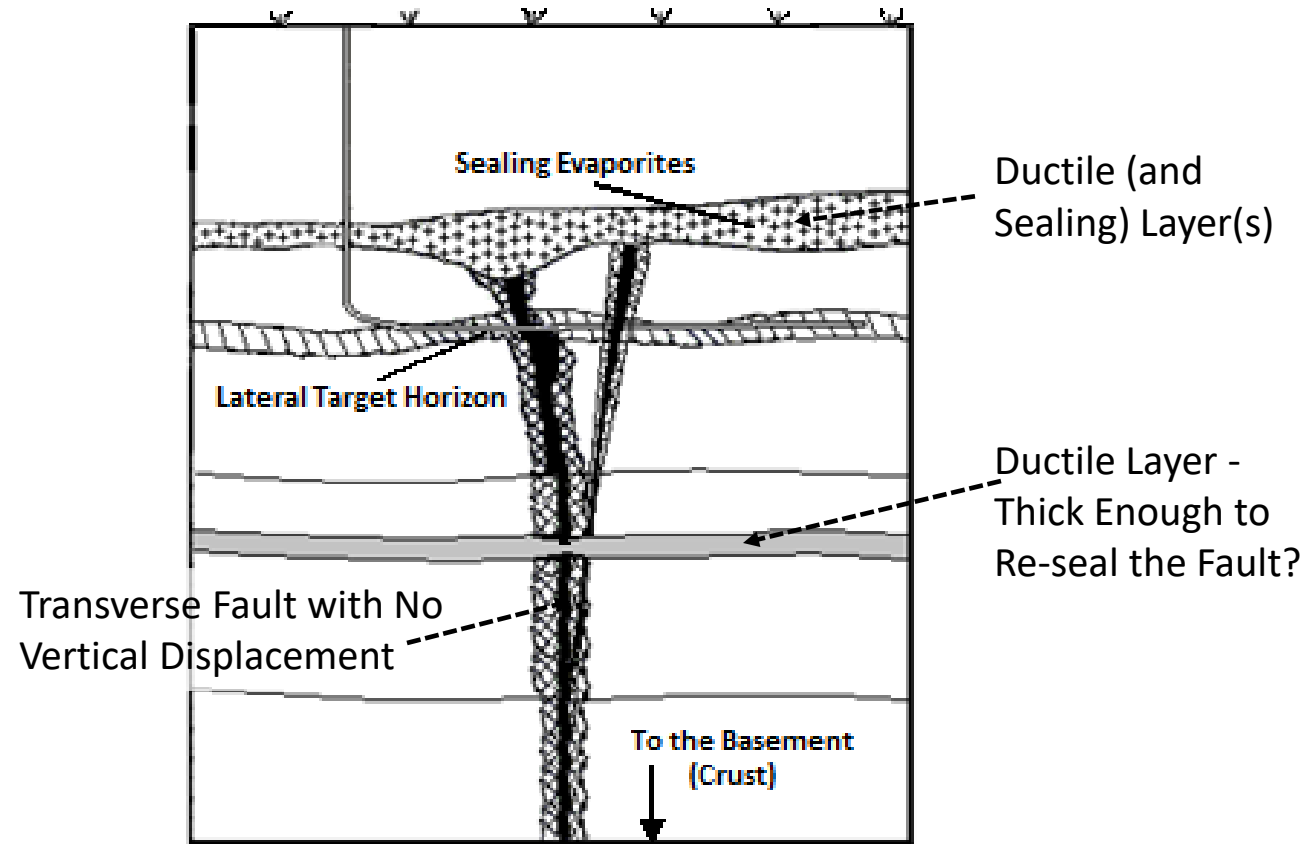
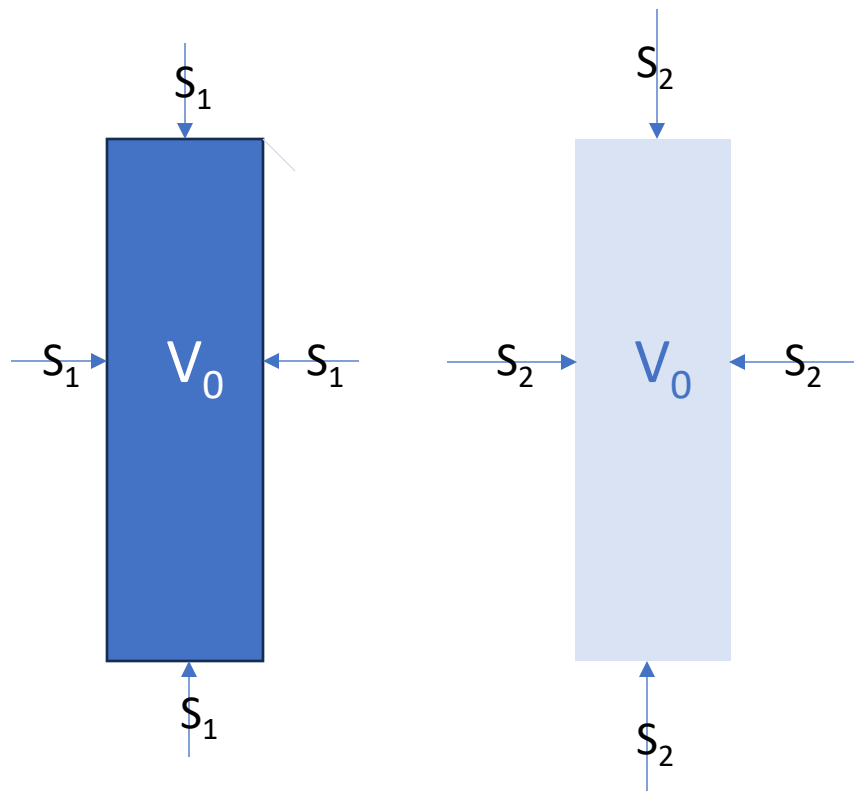
Shale Diapirs (Offshore Nigeria)

Vertical seismic section showing coherent reflections within a shale ridge.



(Haskell et al., 1999)

Incremental Vertical Load & In-situ Confinement of Ductile Rocks (IsoStatic)





Additional Subjects for Another Day

- 1) Better Quantification of the Levels of Clay-rich VPFs (i.e., Degree of VP)
- 2) Assimilate the Mounting Evidence of Major Transverse Faults in the PB
- 3) Expose the Growing Pore Space Crisis and the Mineral Rights - Storage Rights Skirmish over Waste Fluid Injection
- 4) Vet Some New "Bolt on" Microbial Science to Finally Explain Mixed- and Oil-wet Reservoirs