

Overview of CO₂ Storage Options

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28th Annual CO₂ Conference Director
(Permian Basin)



Outline

- I. Surface Capture Momentum
- II. Terminology; Large Volume Injection Options
- III. Capital Commitments and Storage Security
- IV. Possible Geohazards and Risking of Long-Term Storage
- V. A Geohazard Example
- VI. Summary

Surface Capture Momentum

Worldwide Chart of CO₂ Capture – Actual and Projected

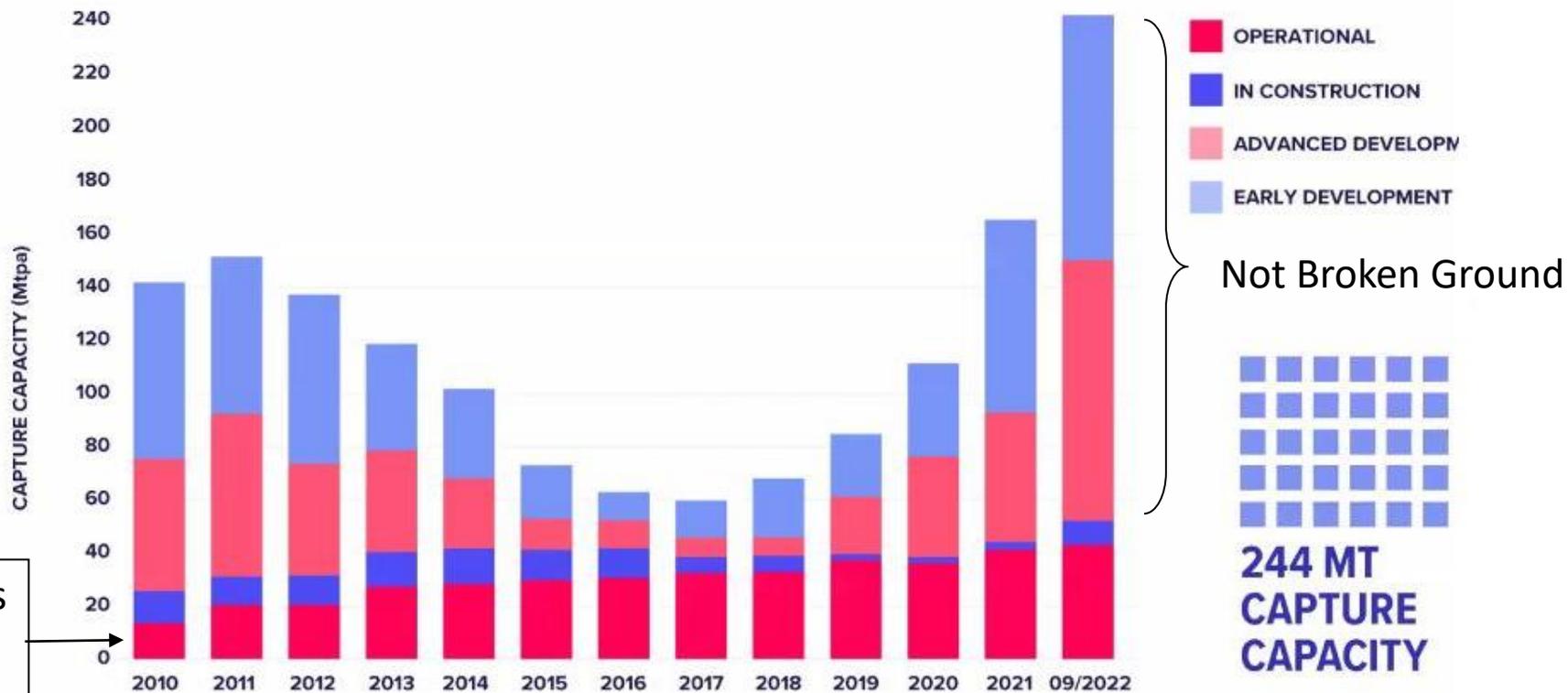
GROWTH IN 2022*

CCS IN 2022

CARBON CAPTURE AND STORAGE CONTINUES ITS UPWARD MOMENTUM, WITH DOZENS OF PROJECTS ANNOUNCED AND MOVING INTO DEVELOPMENT OVER THE PAST 12 MONTHS.

61+ FACILITIES

61 new facilities were added to project pipeline in 2022 bringing the current total to 30 CCS projects in operation, 11 under construction, and 153 in development.



* Just Released Global CCS Institute Report (Oct '22) - <https://status22.globalccsinstitute.com/>

The GCCSI Projects are Capture Facilities; the Incentives and Public Pressure are All Surface Facility Related

What about the Subsurface (Storage) Sites?

What are the Options?

Early Storage Considerations

- Incentives, by Design, are All with the Capturing Entities
- Capture Costs Possess Significant CAPEX and are the Leading Investments
- What if Secure Storage Cannot be Guaranteed near all Sites?
- Careful Consideration of all Storage Risks is Imperative

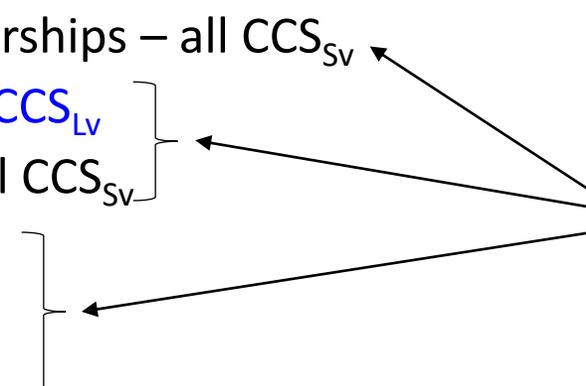
Let's Try and 'Frame up' this Carbon Storage World
And What are Examples of the Storage Risks?

Let's Call these Geo-factors

A CCGS* Framework & Terminology Used Herein with Special Attention to **Large Volume** Analogs in Geological Storage

- Carbon Capture and Storage (aka Deep Saline Formations) - CCS
- Carbon Capture Utilization and Storage - CCUS
 - Small Volume Options (CCUS_{sv})
 - Large Volume Options (CCUS_{lv})
- What About Field Analogs?
 - US DOE Sequestration Partnerships – all CCS_{sv}
 - A Few International Projects CCUS_{lv}
 - Private Acid Gas Injection - all CCS_{sv}
 - Salt Water Disposal (SWD_{sv})
 - Large (SWD_{lv})
 - Small Volumes (SWD_{sv})
 - CO₂ EOR – both **Large** and Small Projects

Enhanced Reservoir Pressures



Geological Storage: Risk Factors to Consider

Possible Geohazards

- Seal Integrity (Top and Bottom)
- Lateral Continuity of the Reservoir
- Asymmetry of Plume Expansion
- Fluid Transmissive Fractures
- Induced Seismicity (Lessons Coming now from Large Volume Water Disposal)
- Leaky Wellbores
 - Soft Sediments
 - Hard Rocks
- Formation Overload
 - Soft Sediments
 - Hard Rocks



‘Invaluable’ Case-History-Based Insights from the Decades of Oil & Gas Experience

Project Parameters to Consider

Related to the Geo-factors

- Cost of Capture & Transport to Secure Sites
 - Remembering that 45Q Credits go to the Capturing Companies
- Time Delays to Characterize, Assess Risks, and to Permit Subsurface Sites
- Performance Guarantees, Financial Assurance/ Bonding/ Insurance
- Unintended Consequences of Large Volume Injection
 - e.g., Migration, Induced Earthquakes, Formation Overload, etc.
- Effective Reservoir ‘Accommodation Efficiency’* for Plume Size & Shape Estimates for Storage Rights Aggregation

* The % of Modeled Reservoir that the CO₂ Actually Invades - Analogous to Sweep Efficiency in a Flood – Will Absolutely be Substantially Less than 100%

Now Let's Dive into Just One of these
'Geofactors' that Project Development
Teams Need to Consider

Tectonics and Fault Type Stress States

(with New Insights from the Horizontal Unconventional Drilling Explosion*; Apologies for Breaking this Down to the Simple Basics)

** ...and the large water volumes produced from the horizontal wells and disposed into nearby injector wells*

Geological Storage: Risk Factors to Consider

Possible Geohazards

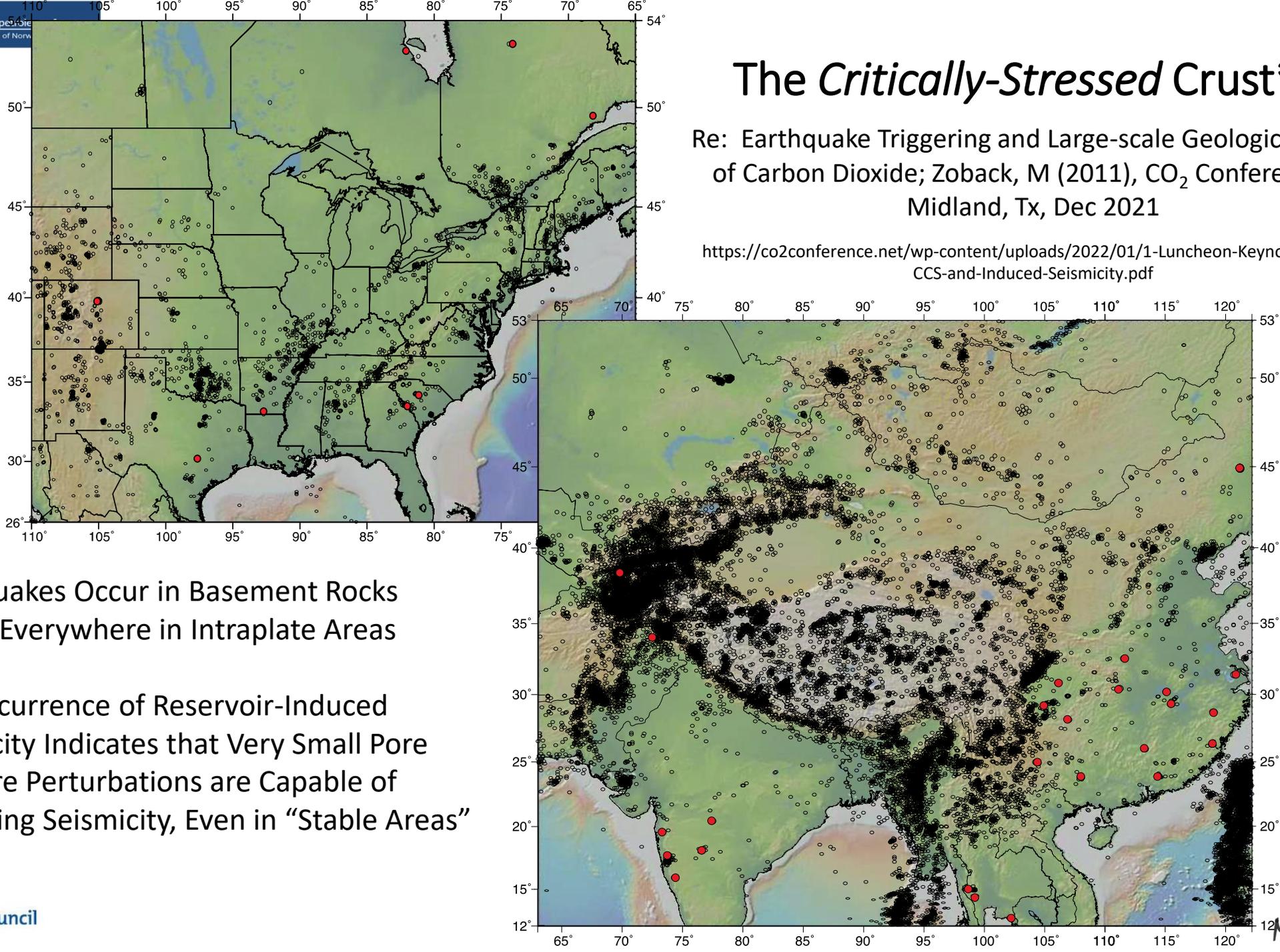
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Let's examine this one in particular

The Critically-Stressed Crust*

Re: Earthquake Triggering and Large-scale Geologic Storage of Carbon Dioxide; Zoback, M (2011), CO₂ Conference in Midland, Tx, Dec 2021

<https://co2conference.net/wp-content/uploads/2022/01/1-Luncheon-Keynote-Zoback-CCS-and-Induced-Seismicity.pdf>



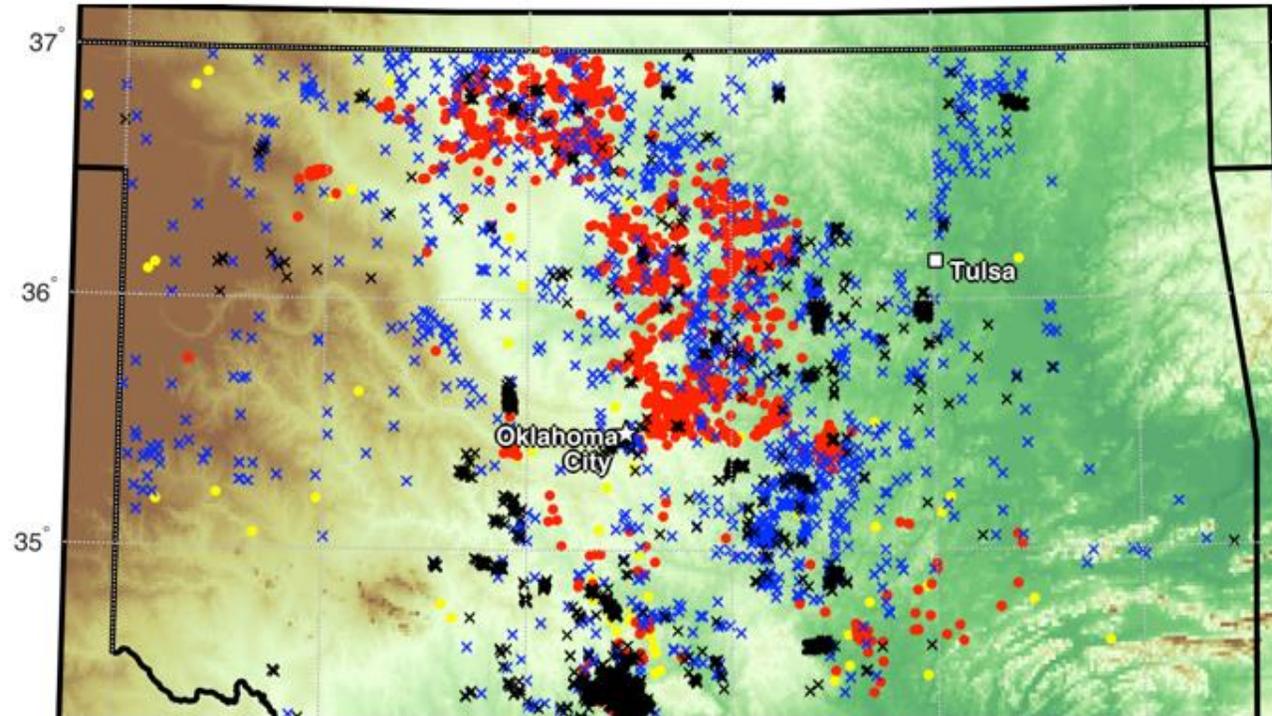
- Earthquakes Occur in Basement Rocks Nearly Everywhere in Intraplate Areas
- The Occurrence of Reservoir-Induced Seismicity Indicates that Very Small Pore Pressure Perturbations are Capable of Triggering Seismicity, Even in “Stable Areas”

Injection-induced (“Triggered”) Seismicity

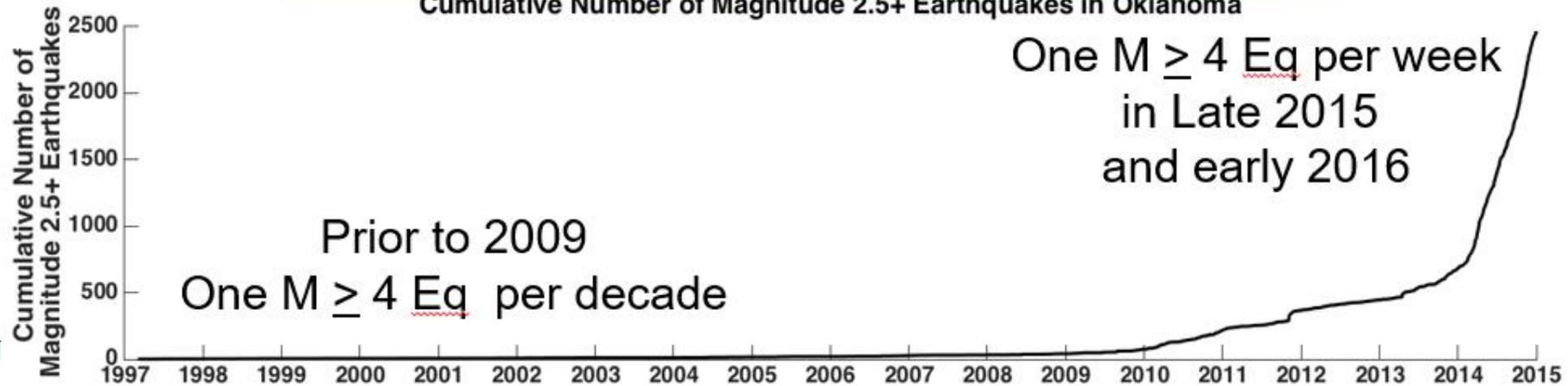
Is Injection into Basal Formations Viable? Triggered Earthquakes in Oklahoma

Re: Earthquake Triggering
 and Large-scale Geologic
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 Zoback, M (2021), CO₂
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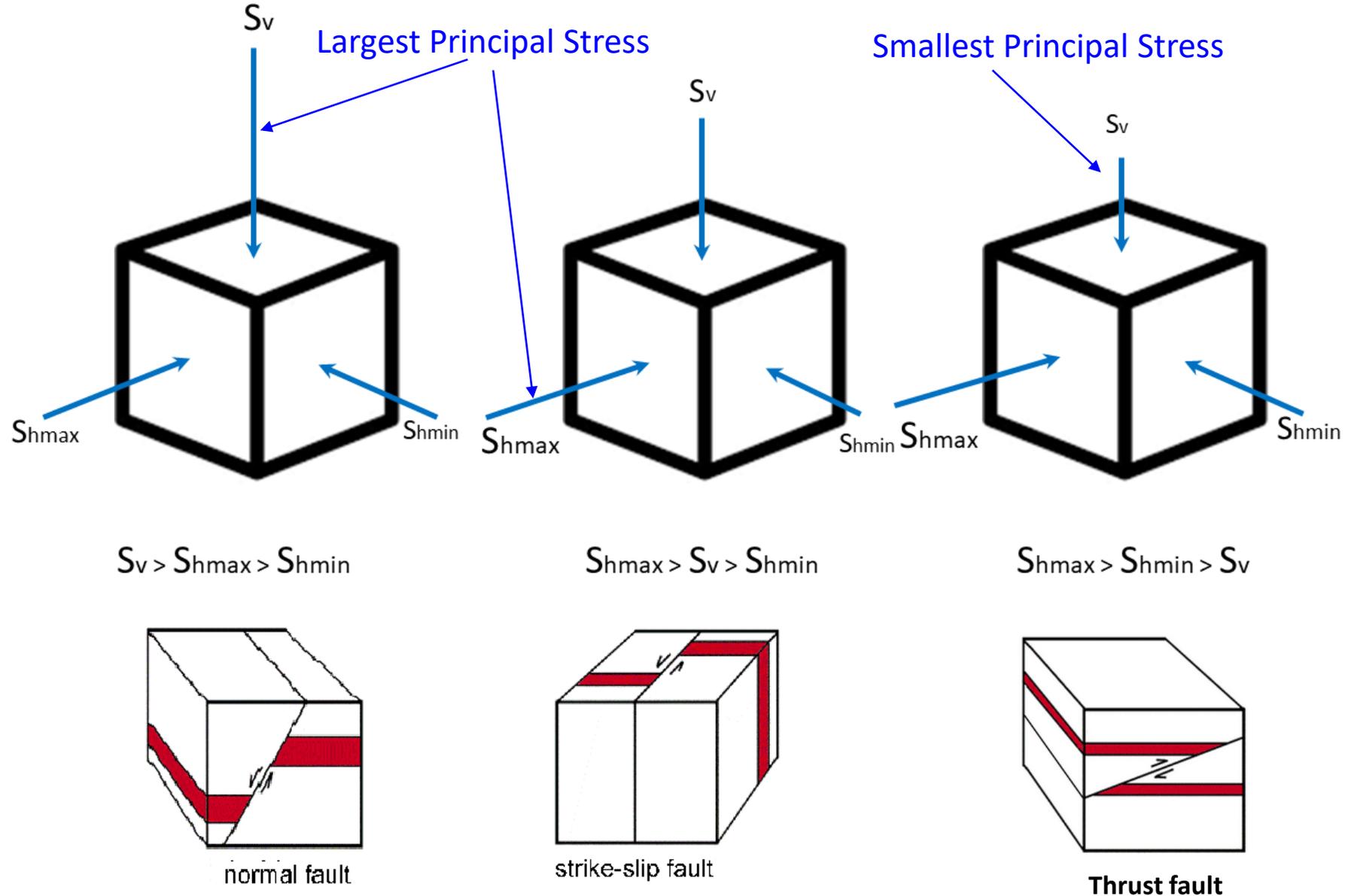


Cumulative Number of Magnitude 2.5+ Earthquakes in Oklahoma



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

Principal Stress States and Fault Tendencies



Relative Stress Magnitude (A_Φ)

$$A_\Phi = (n + 0.5) + (-1)^n * (\Phi - 0.5)$$

Where $\Phi = \frac{S_2 - S_3}{S_1 - S_3}$ and S_1, S_2 & S_3 are the Maximum, Intermediate and Minimum Principal Stresses

$n = 0$ for Normal Faulting

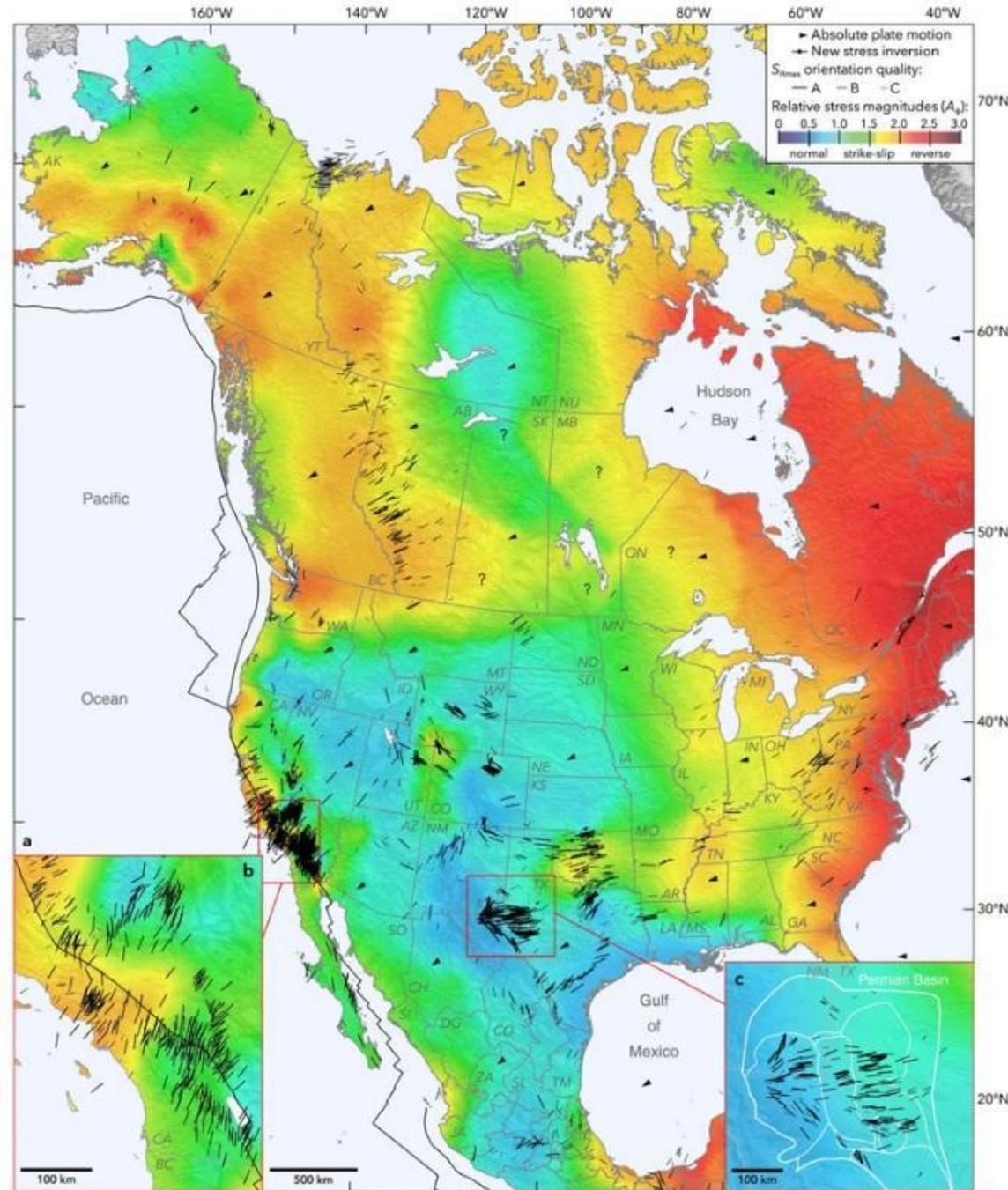
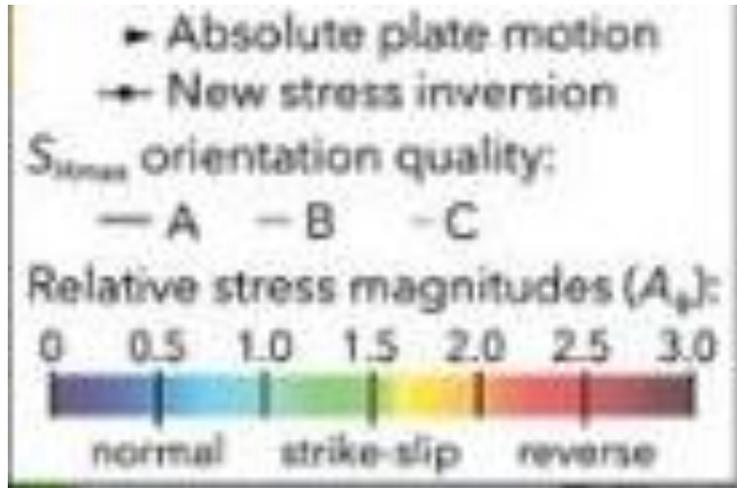
$n = 1$ for Strike Slip Faulting

$n = 2$ for Thrust Faulting

* After Lund Snee, J-E. and Zoback, M.D. (2022), State of Stress in Areas of Active Unconventional Oil & Gas Development in North America, AAPG Bulletin, V. 106, No. 2, (Feb 2022). PP. 355-385

Seismic Stress States and Fault Tendencies*

aided by the Proliferation of Unconventional O&G Well Development



* After Lund Snee, J-E. and Zoback, M.D. (2022), State of Stress in Areas of Active Unconventional Oil & Gas Development in North America, AAPG Bulletin, V. 106, No. 2, (Feb 2022). PP. 355-385

CCS and Understanding the Crustal State of Stress Changes

- Modern and Paleo Conditions (Changes thru Geologic Time)
 - Current (Modern) State of Stress
 - Measurements are Possible (borehole deformation, microfracs, step-rate tests, etc.)
 - Reconstructing Regional Tectonic Stages (Changed Stress States can be Multiple)
 - Crustal Fracture and Fault Evidence Can be Indicative
- Stress States Changes Due to Large Volume Injection
 - Surface Seismic Arrays
 - Micro-seismic Surveys

Summarizing

Project Parameters to Consider

Related to the Geo-factors

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Summary

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‘Invaluable’ Case-History-Based Insights from the Decades of Oil & Gas Experience*

* **Absolute Imperative to have the Oil & Gas Industry’s Experience Integrated into the CCS Risk Assessments**

Thank you Arne and the NFIP

Note this agenda in particular



CCUS/EOR CONFERENCE

BRINGING FIELD-TESTED EXPERIENCE TO CO₂ EOR AND CO₂ CAPTURE PROJECTS

MIDLAND, TEXAS | DECEMBER 5-8, 2022 | CO2CONFERENCE.NET

For More information, see www.CO2Conference.net

Schedule of Events: 2022 CO₂ Conf Week: Midland, Texas
(Venue: Midland's Downtown Bush Convention Center)

	Mon 12/5	Tues 12/6	Wed 12/7	Thur 12/8
7am				
7:30am		Check-in: Bush Convention Center (BCC)	Check-in: Bush Convention Center (BCC)	Check-in: Bush Convention Center (BCC)
8am	Check-in BCC			
9am		Session I: CCS & CCUS Workshop - Morning Keynote by Brad Crabtree, Ass't Sec of Fossil Energy and Carbon Mgmt - State & Federal Policy Updates, and Market Developments	AM Short Course Session: CCS Project Drivers, CCS vs CO ₂ EOR Project Experience	Session III: CO ₂ EOR Case History Examples, US and International CO ₂ EOR Case Histories
10am				
11am				
12pm	2022 Field Trip - CapturePoint LLC (Host) at the Emma CO ₂ Project in Ector Co., TX	Luncheon - Keynote Speaker: Chuck McConnell, Executive Director, Carbon Management and Energy Sustainability, Univ Houston	Luncheon and Marketing Break - No Luncheon Speaker	Luncheon and Marketing Break - No Luncheon Speaker
1pm				
2pm		Session II: CCUS Workshop - Key Elements of Large Scale CCS & CCUS Project Planning	PM Short Course Session: CCS vs CO ₂ EOR Storage Risks, Project Considerations; Hurdles	Session IV: CO ₂ EOR Case History Examples, US and International CO ₂ EOR Case Histories & CO ₂ EOR Srvy Update
3pm				
4pm				
5pm				Bush Portion of Conf Wk Ends 5:00 PM