Salt Tectonics and Reservoir-Seal-Trap Distribution:

A Geological Approach for Locating Saline Aquifers for Hydrogen Storage

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AIR PRODUCTS

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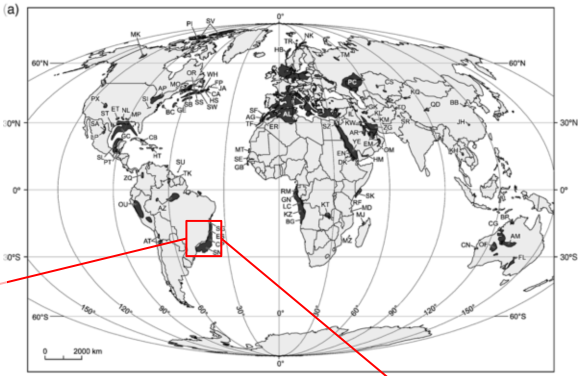
Salt Tectonics: What is it? Where is "it" found?

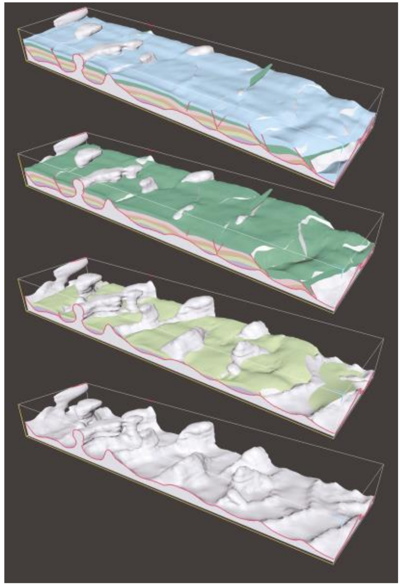
Salt tectonics is the geological study of how salt bodies evolve over time and space

- Salt bodies are affected by sediment distribution, and vice versa, while simultaneously creating faults in the surrounding stratigraphic system
- Salt basins are found worldwide – they are the remains of oceans cut off from their source by plate tectonics over time
  - **The global distribution of salt basins allows for reliable saline aquifer system exploration worldwide**

Global Salt Basins

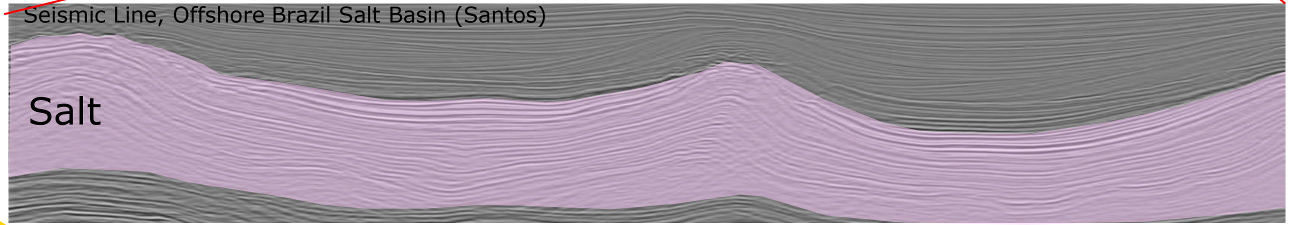


Hudec et al., Earth Science Reviews (2007)



Guglielmo et al., AAPG (1997)

Seismic Line, Offshore Brazil Salt Basin (Santos)



Modified from Pichel et al., Journal of Structural Geology (2018)

Understanding *how* these elements evolve together – salt, sediments, and faults – allows geologists to pinpoint where suitable saline aquifers for gas storage may be found

Reservoirs, Seals, Traps

We can use the same terminology from the oil and gas industry to apply to Saline Aquifer systems:

Reservoir:
A body of rock that is porous and permeable. Fluids, such as oil, gas, and water, flow through these bodies. Usually sandstones and carbonates.

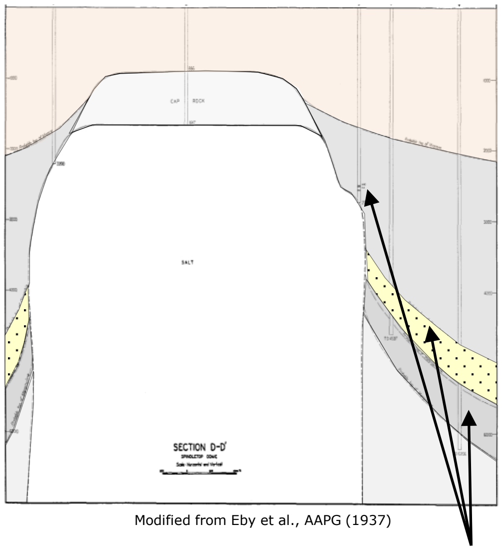
Seal:
Impermeable layer of rock surrounding a reservoir. Generally shales, but salt and cemented carbonates also make excellent seals.

Trap:
3D geological configuration of reservoirs and seals that allows fluids to accumulate and concentrate in a single location. Can be formed with salt, faults, stratigraphy, or anticlines.

- The geologic "container"

Salt forms localized environments in which all three pieces can develop in one place, and often simultaneously, around the feature.

Classic view of salt dome reservoirs
Spindletop, 1937

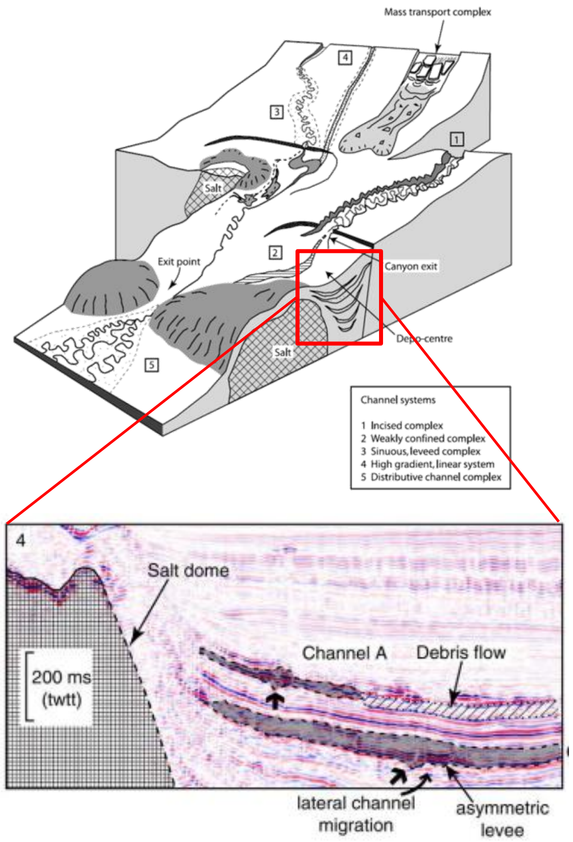


Modified from Eby et al., AAPG (1937)

- What are these layers?
- How do they get there?
- How do we find the "right" layers are for saline aquifers?

Reservoir and Seal Formation:
Sediment Distribution around Salt Bodies

- "**Halokinetic** sequences" – 'halo' = salt, 'kinetic' = moving
  - Rock layers around salt features that are shaped by the movement of salt
- Salt is **mobile** and **buoyant**
  - As a **mobile** substance, salt gets 'pushed' away from bodies of sediments flowing towards it
  - However, as a **buoyant** substance, salt that gets pushed away tends to get pushed *up*, leaving it as a relative topographic high – and sediments will flow around the highs and into the new lows formed around the moving salt body
- Once a topographic system becomes established, sediments tend to aggregate and 'organize' in density-driven patterns
  - Denser particles, such as sands, will preferentially accumulate in topographic lows, while less dense particles (such as clays) can travel further from the sediment source (ex., rivers, turbidites) and can settle topographically higher in the system, around the sands
    - Sand systems become potential **reservoirs** (sandstones) of saline aquifers
    - Clay layers become potential **seals** (shales)



Note: Channels are just one examples of many types of stratigraphic feature that occurs around salt. The purpose of highlighting these is to indicate some stratigraphic types that may be commonly found around salt domes at depths shallow enough to be suitable for hydrogen storage.

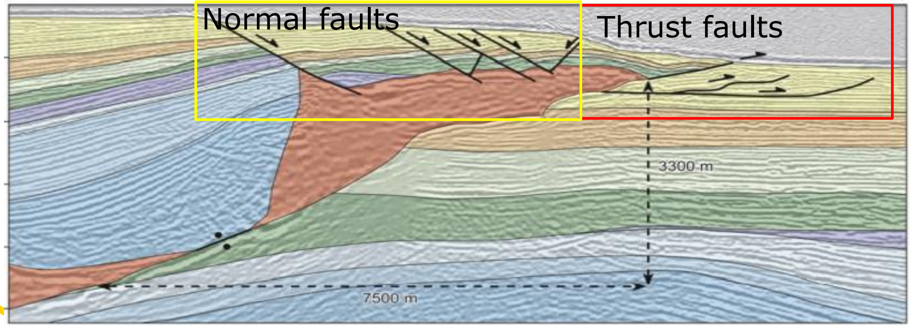
Above images from Gee et al., Marine and Petroleum Geology (2006)

Fault distribution around salt bodies

As salt moves over time, so do the sediments that surround it. This movement creates structural changes by way of **faults** and shear zones – within, alongside, and adjacent to the salt features. Faults can create fluid escape pathways – or limit the size of the container (i.e., the **trap**).

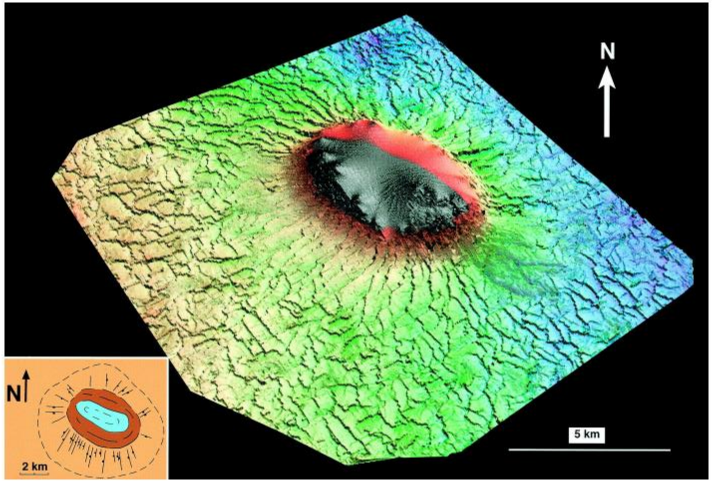
Normal (extensional) faults can occur where gravity-dominant deformation affects salt bodies. As salt moves downhill, or is stretched apart by sediment loading, the rock layers around will be in tension, and form normal faults to compensate.

Thrust (contractional) faults can occur at advancing "toe" of a salt sheet, plowing rock layers ahead of it.



Modified from Hudec et al., Journal of Structural Geology (2009)

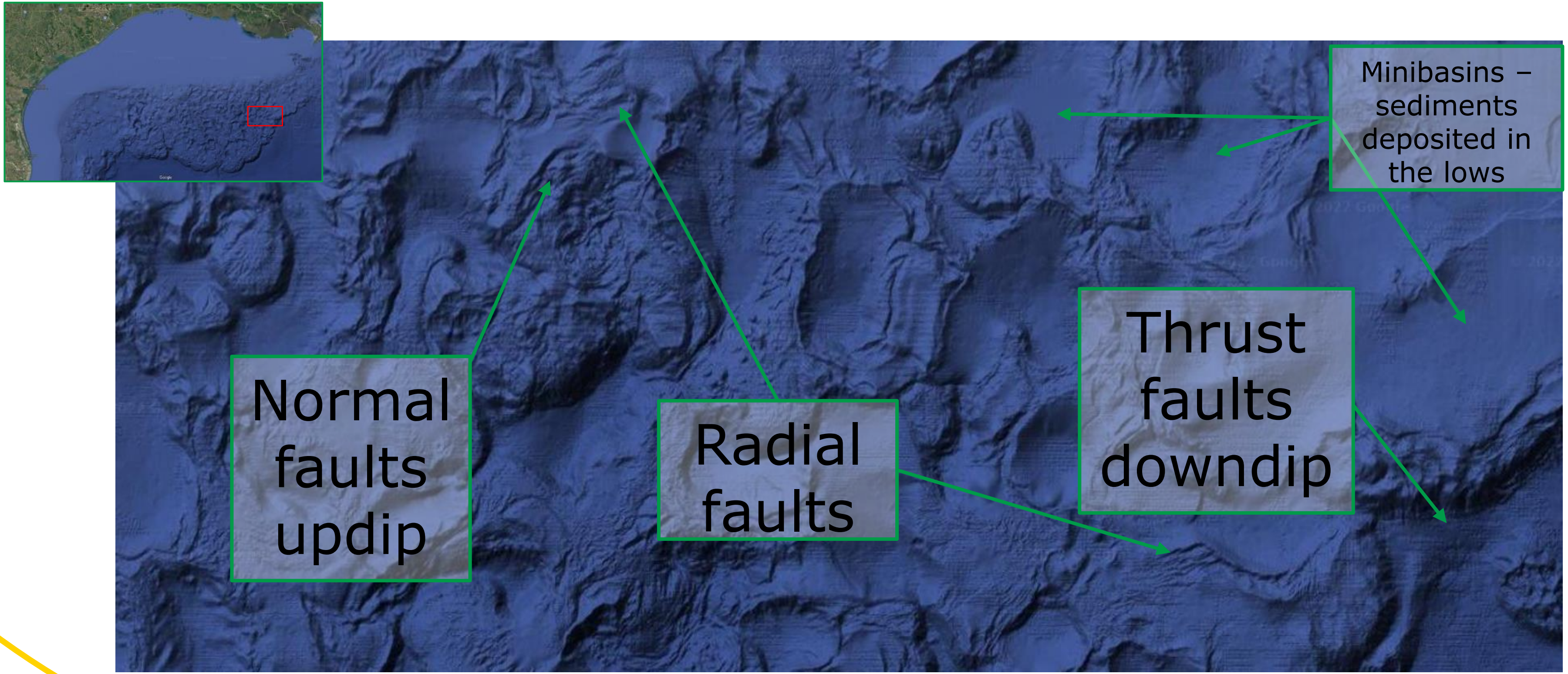
Radial faults occur as salt expands upwards, breaking the sediments around it



Davison et al., Marine and Petroleum Geology (2000)

Note: Above are just three examples of many types of faulting that occurs around salt. The purpose of highlighting these is to indicate faulting types that may be commonly found around salt domes at depths shallow enough to be suitable for hydrogen storage.

Fault distribution around salt – Gulf of Mexico



Google Maps Satellite Imagery

Application of Salt Tectonics Principles for Saline Aquifer Exploration

Geologists have been locating saline aquifers around salt for over a century…and have historically been considered failures (no hydrocarbons)

Salt systems provide a global resource in which saline aquifers can be found – and the reservoirs, seals, and traps that will be necessary for hydrogen storage.

So how do we find them?

1) Well logs
   - The most basic, and common, log suites have always measured lithology (SP, GR, etc.) and fluid type (Res)
2) Seismic
   - Seismic (2D, 3D, 4D) data is used to delineate basic shapes in the subsurface, including facies types (like channels, seen before) and faulting

Saline aquifers around salt, 1951

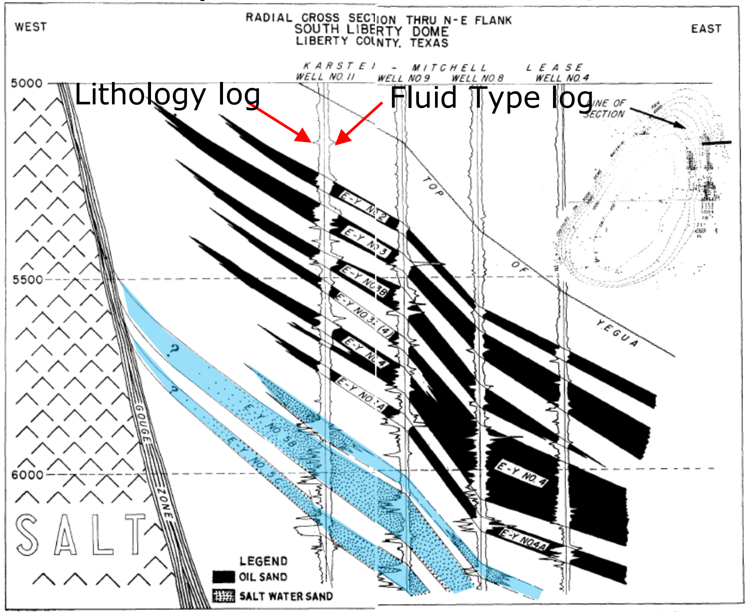


FIG. 5.—Radial section through northeast flank of South Liberty dome, showin attitude of beds. Average dip of Yegua and Cook Mountain beds, approximately 50°.

Halbouty et al., AAPG (1951)

Using new and historical data, as well as a geological understanding of where to find critical features, geologists can re-use the "failures" of the past for a new purpose – saline aquifer hydrogen storage

Questions?

Thank you
tell me more