

Outcrop Observations and Analytical Models of Deformation Styles and Controls at Salt-Sediment Margins*

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Abstract

A key problem in sediment-salt margins is interpreting the updip trap mechanism against the salt diapir. Are faults developed at the margins or is the trap a juxtaposition of the sediment against the diapir? Outcrop studies from three basins with sediments dipping steeply against a residual salt diapir, microstructural analysis and analytical models provide insight into the process. Exposures in the Lusitanian Basin in Portugal of steep Jurassic sandstones and shales against a diapir show distributed grain crushing and few deformation bands. Larger throw faults were not observed.

Siliciclastic beds in the La Popa Basin in Mexico have steep dips away from the diapir. The sandstones are cemented with quartz leaving little host porosity. No larger throw faults are exposed, but distributed grain fracturing occurred pre-cementation. Deformation bands occur locally but are not wide spread. The Carboniferous Mabou Group of shale and sandstone along the coast of Cape Breton, Nova Scotia steepen against evaporite diapirs. Small throw faults occur in shale rich sections, but are not observed in thicker sand sections. The sandstones contain deformation bands with cataclasis as damage zones to larger throw faults. Distributed grain fracturing predates quartz cementation. The outcrops show a common deformation response by distributed grain fracturing but few deformation bands and faults. Small throw faults are more common in thinly bedded sandstones and shales. In the context of a simple 2D analytical model, a diapir modeled as a viscous fluid between rigid walls displaced with a constant rate of shortening will continue to narrow without wall rock deformation. At a critical diapir width the wall rock will deform, preserving a residual diapir thickness.

The critical width of the diapir before wall deformation is a function of the shortening rate, salt viscosity, and height of the diapir. The general absence of macro faulting in the outcrops may be interpreted as shortening absorbed by a thick salt diapir with insufficient differential stress for sediment failure. The observations, however, suggest a mean effective stress in the sediments sufficient for distributed grain fracturing. The observed deformation styles are unlikely to have a significant impact on flow, and juxtaposition against the diapir is likely to be a more important seal than local mesoscale faulting for the geohistories and geometries observed.

References

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Giles, K.A. and T.F. Lawton, 1999, Attributes and evolution of an exhumed salt weld, La Popa Basin, northeastern Mexico: *Geology*, v. 27/4, p. 323-326.

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Outcrop observations and analytical models of deformation styles and controls at salt-sediment margins

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Rock Deformation Research

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Introduction

- Sediments upturned and attenuated against salt diapirs or ridges are common in the subsurface and serve as important traps.
- Seismic imaging against these diapirs is often of poor quality, however, and much of the deformation is below seismic resolution.
- Studied outcrop examples as analogues of salt-sediment margins in three locations;
 - Portugal, Mexico, Nova Scotia (Canada)
- Mapped structures in detail and characterized microstructural deformation.
- Developed simple analytical model of process.

Outcrop Location – La Popa Basin

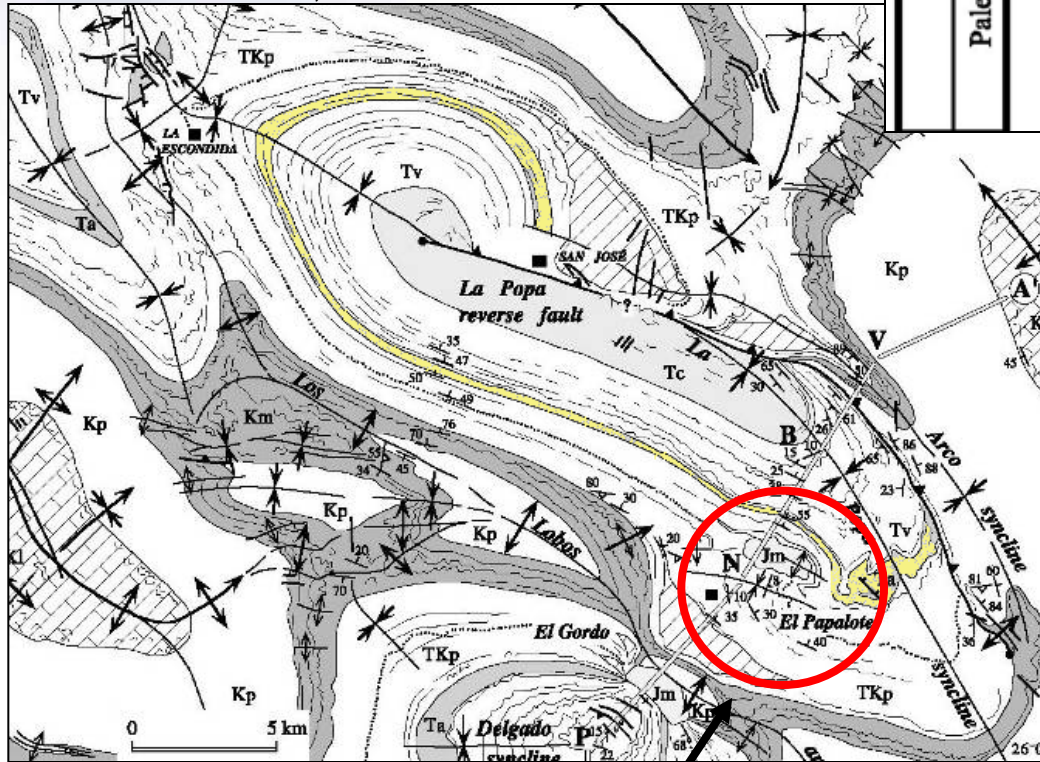
Mexico



La Popa Basin, Mexico

Map of salt weld and diapirs

From Giles and Lawton, 1999



El Papalote Diapir

Time		Stratigraphic Units		Interpretation
Paleogene	Eocene		Carroza Fm (Tc)	marine mudstones
			Viento Fm (Tv)	marine sandstones
			Adjuntas Fm (Ta)	fluvial deposits
	Paleocene	Upper Potrerillos Fm (Tpu)	upper sandstone mbr (Tpss)	tide-dominated sandstone
			upper mudstone mbr	marine mudstone; Upper Gordo lentil (Tpgu), La Popa lentil (Tlpl), North Chivos lentil (Tpc)

- Foreland of Sierra Madre fold belt in Mexico.
- L. Jurassic evaporite.
- Diapirism initiated as early as Aptian.
- Siliciclastics deposited over widespread early carbonate deposition.
- *Late Cretaceous to Eocene shortening.*

Diapir La Popa Basin, Mexico

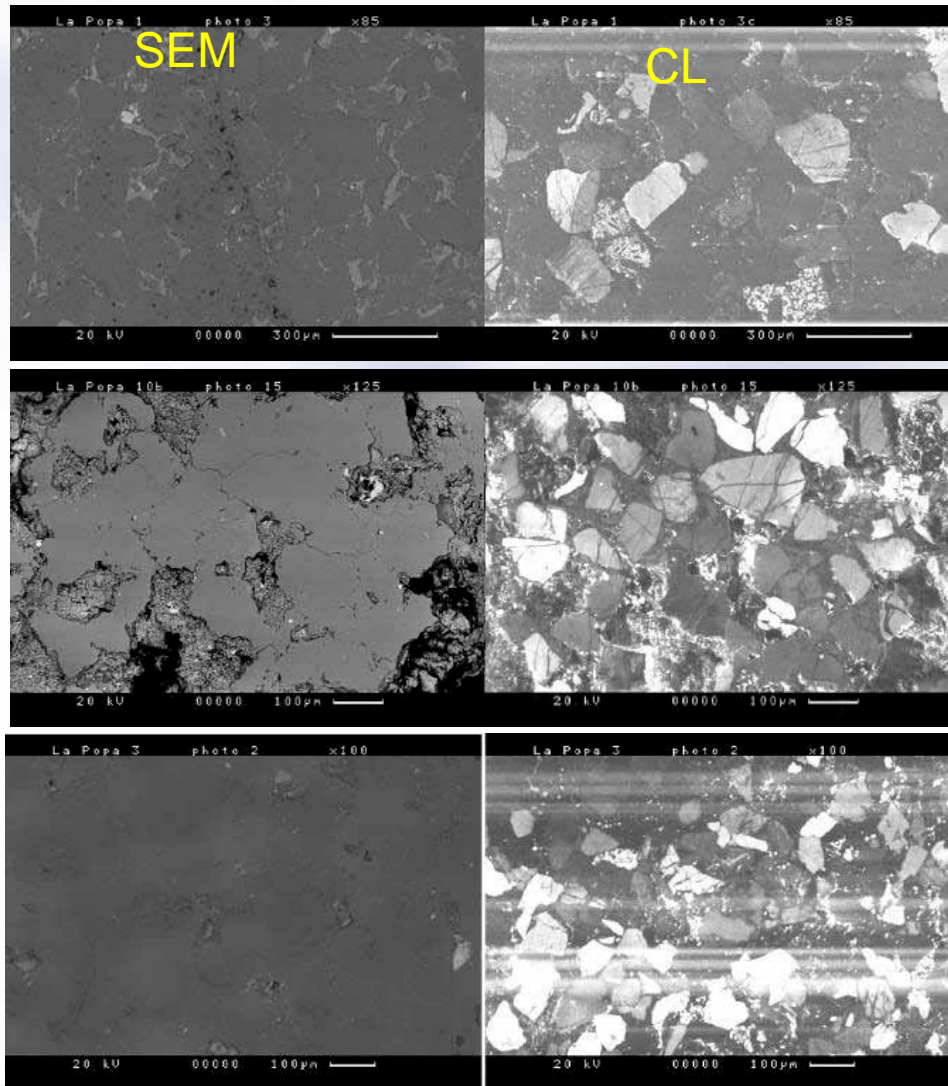
El Papalote Diapir



Steep dips along sandstones on diapiric margins.

No macroscopic faults observed except occasional deformation bands.

Sandstone deformation



Early quartz fracturing followed by quartz cementation.

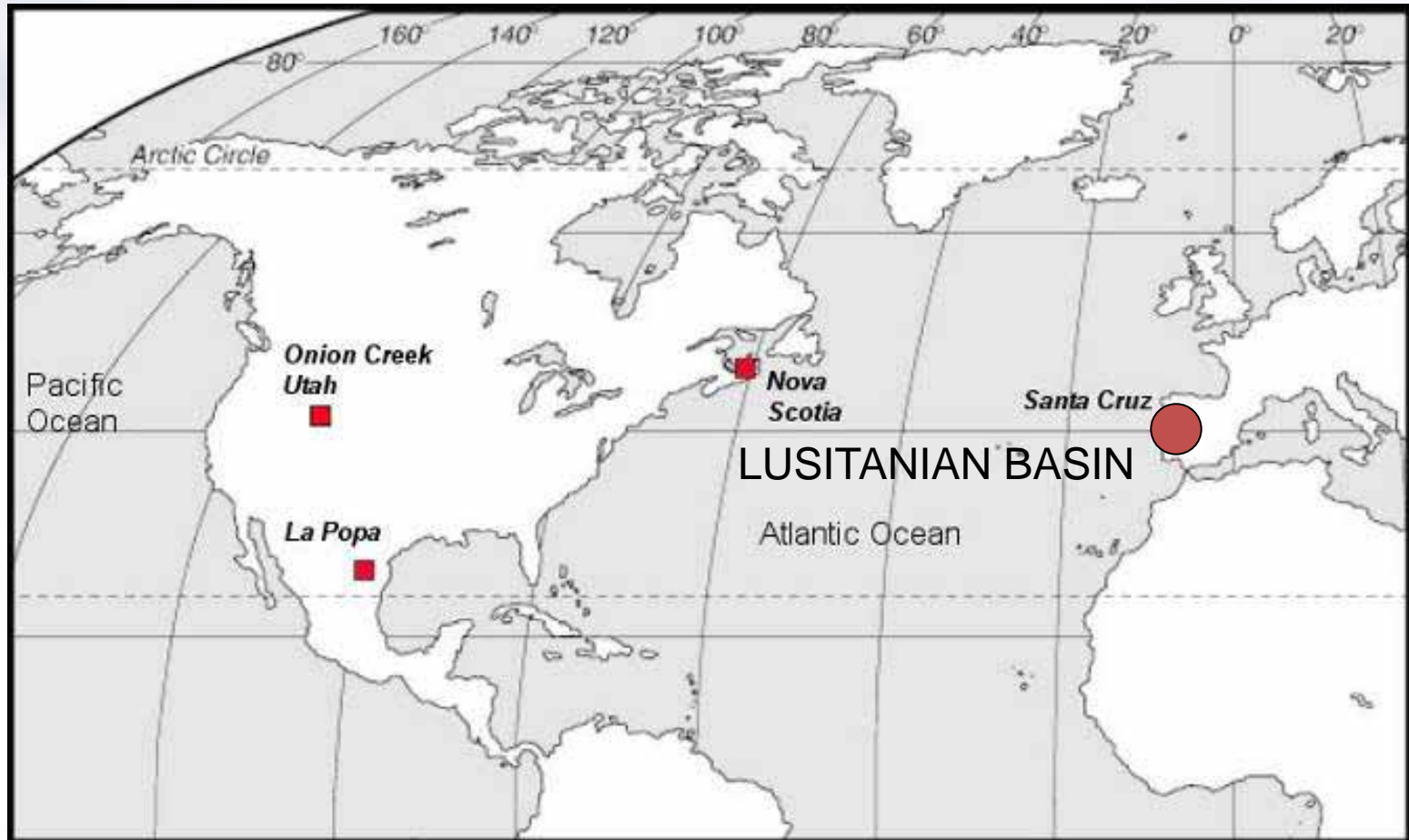
Cementation controlled by amount of clays – higher clay content limits quartz precipitation.

No post cementation quartz grain fracturing although open or filled fractures are common.

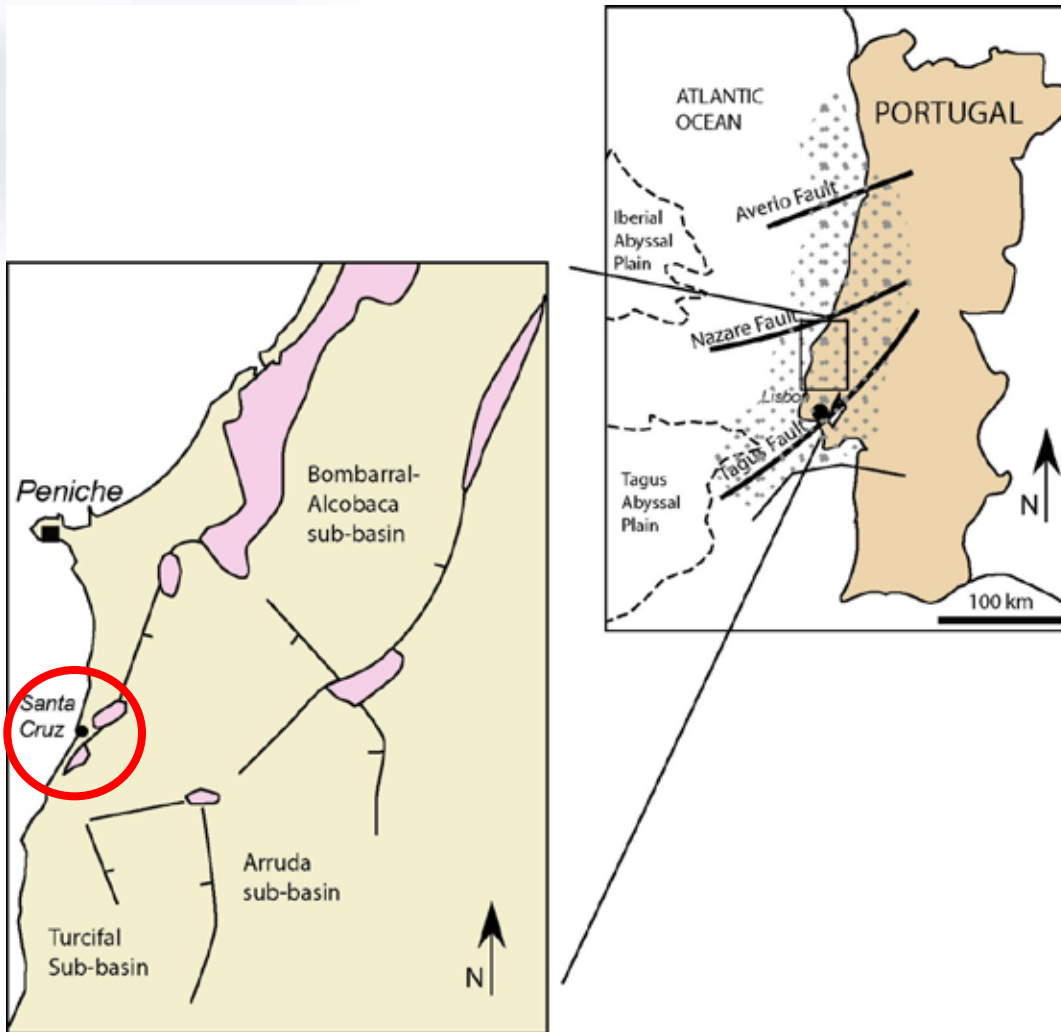
Distributed grain fracturing is early.

Outcrop Locations – Lusitanian Basin

Portugal

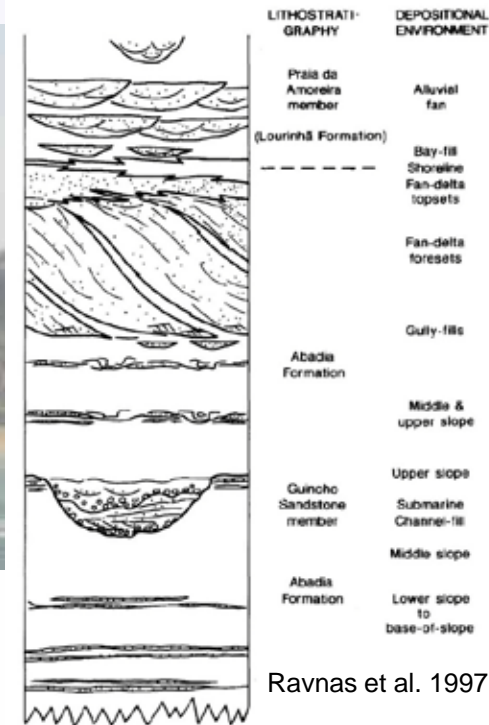


Salt outcrops in Portugal



- Exposed evaporite section. Mapped as vertical welds in places.
- Rift basin setting with salt deposited late Triassic to early Jurassic with opening of northern Atlantic
- Major diapiric activity during Oxfordian-Kimmeridgian
- *Miocene – Alpine regional shortening.*

Outcrop exposure of upturned beds



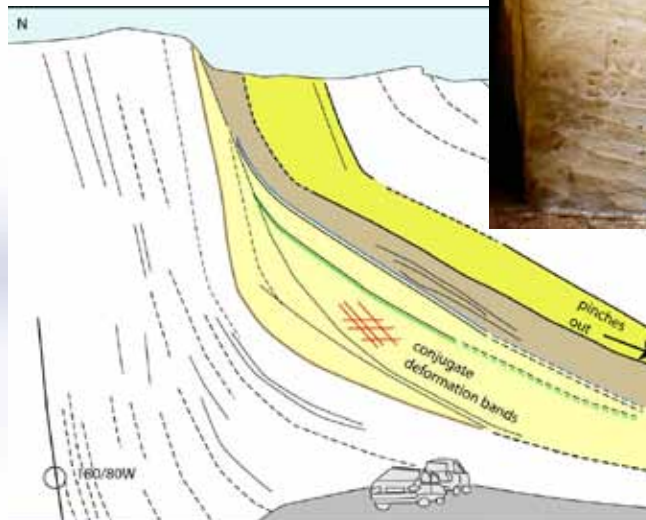
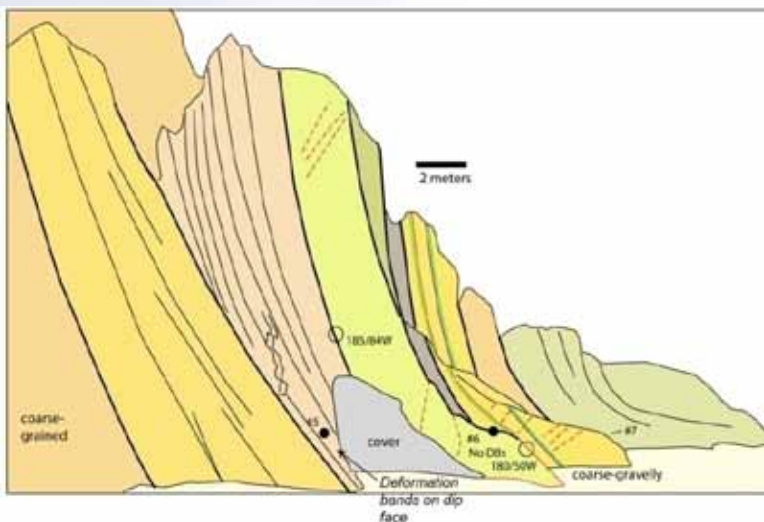
Steep beds in thick sandstone section.

Ravnas et al. 1997

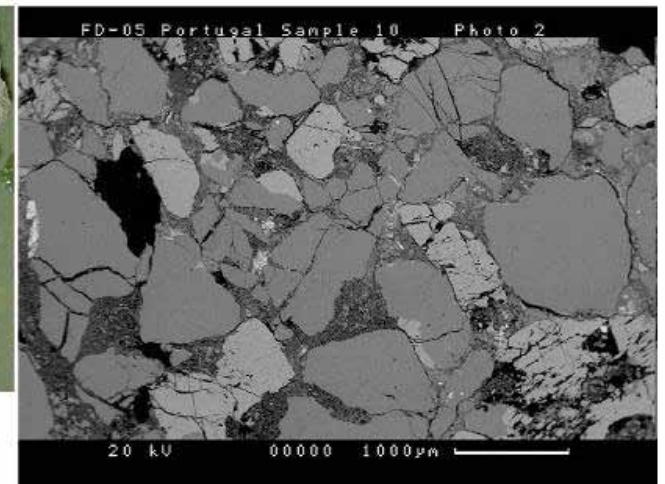
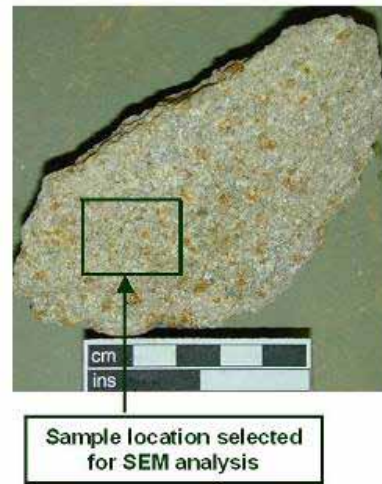
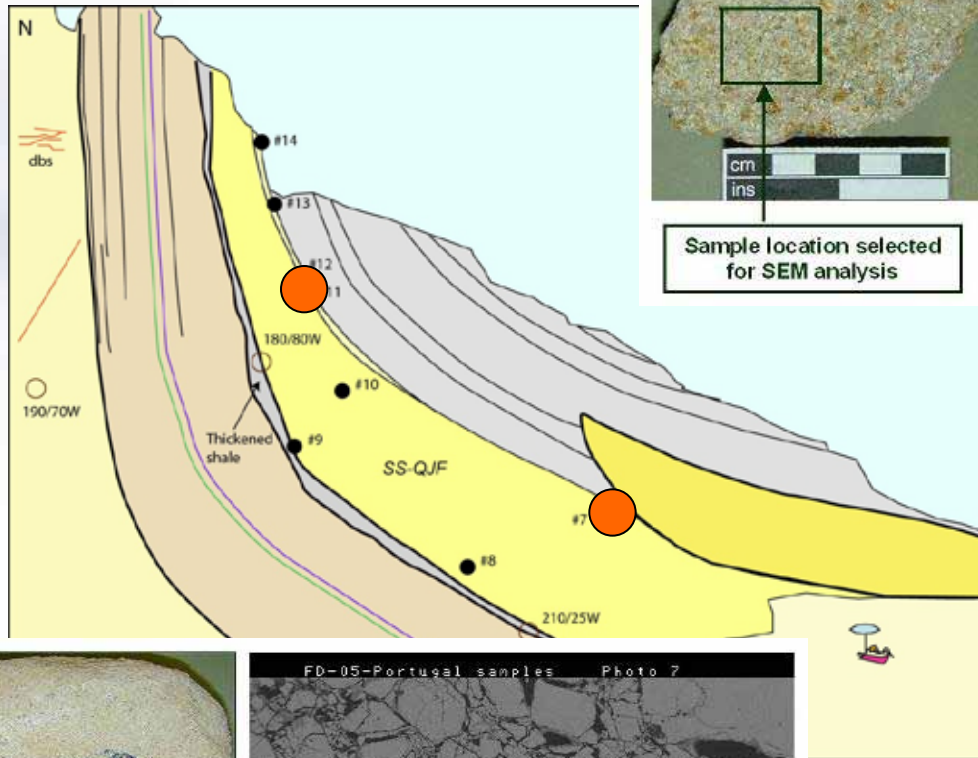
Steep sandstone beds



- No macroscopic faults.
- Low density and clustered swarms of deformation bands.



Grain fracturing



Distributed grain fracturing in sandstone.

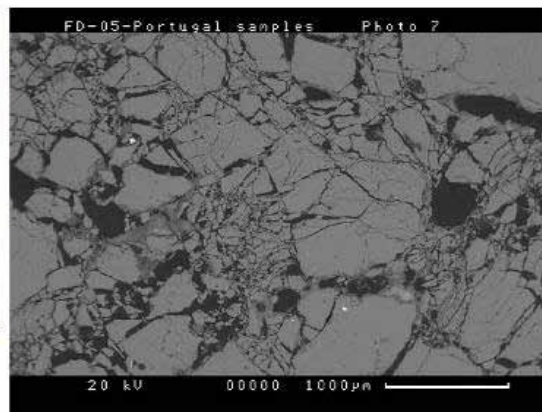
Quartz cements do not post date fractures.

Bed thinning interpreted as stratigraphic channels.

Thickness in most beds preserved.

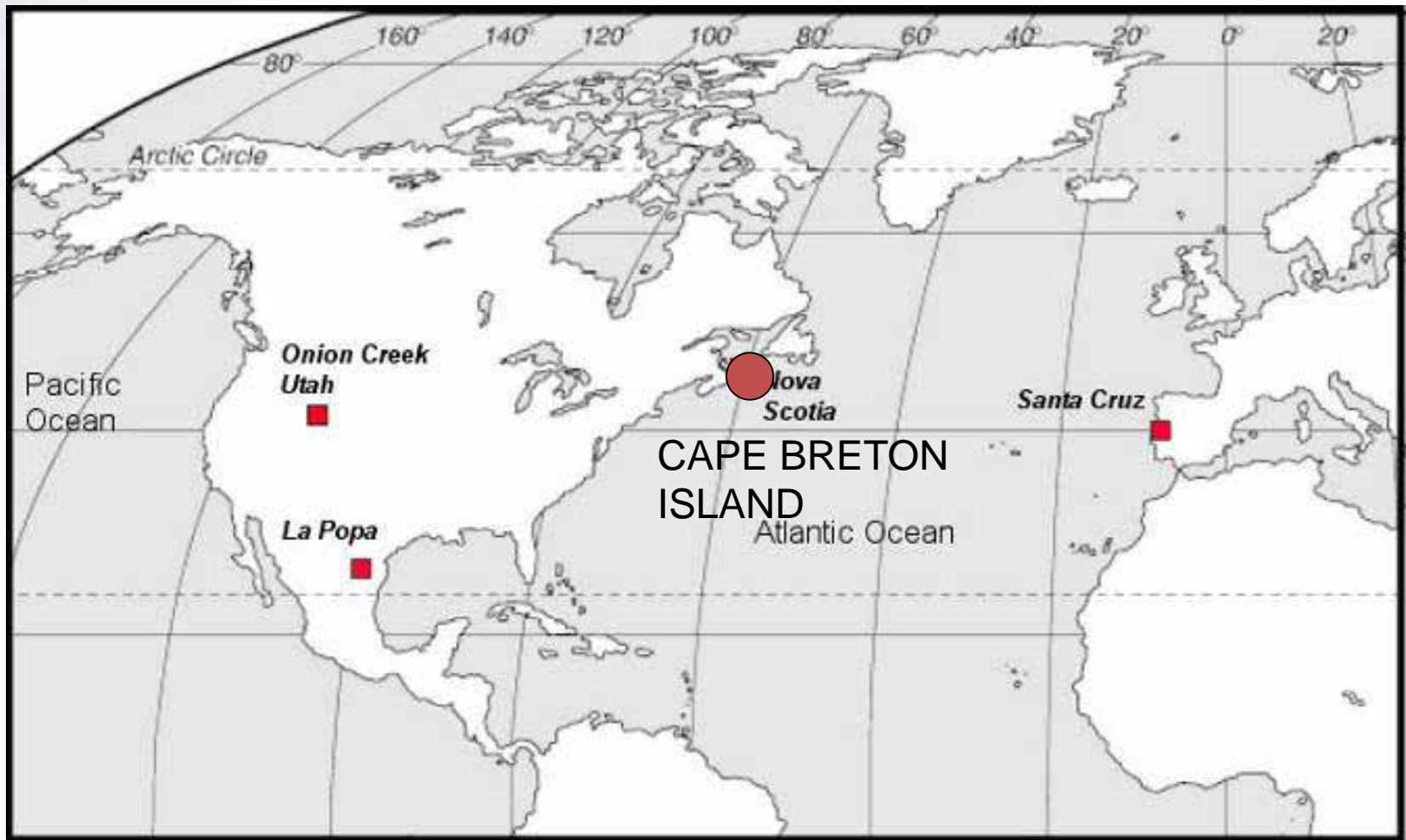


Sample location selected for SEM analysis

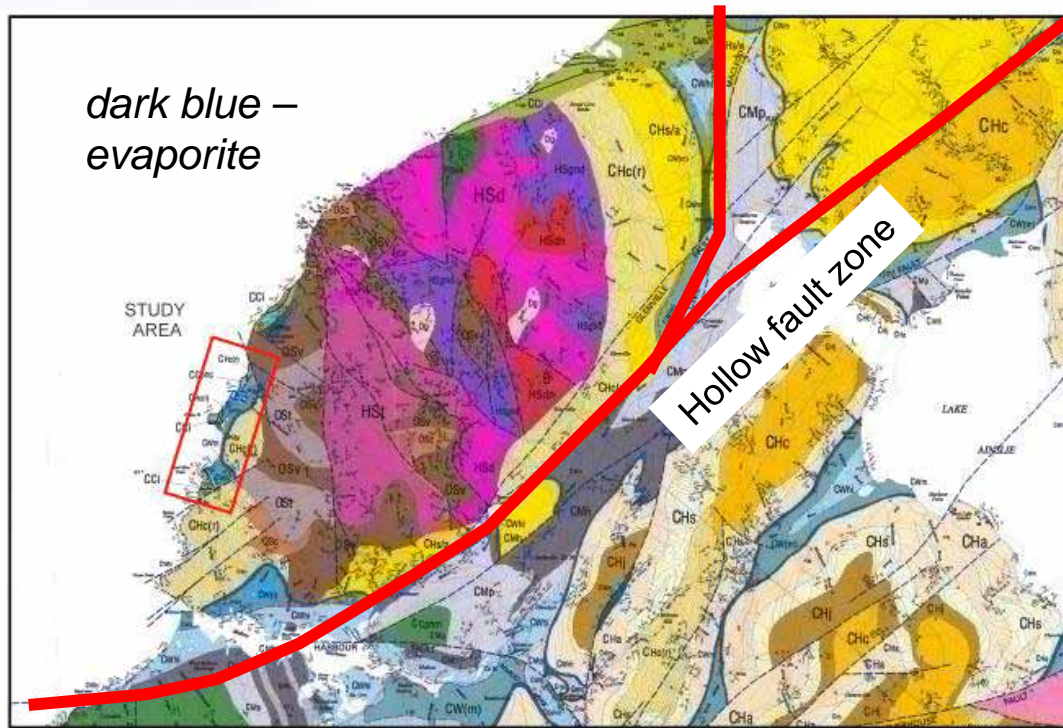


Outcrop Locations

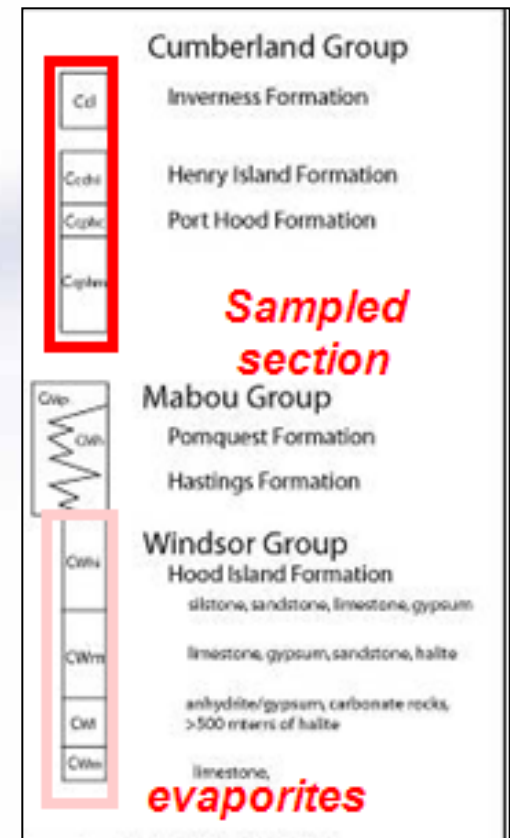
Nova Scotia



Western Cape Breton – Geological Map



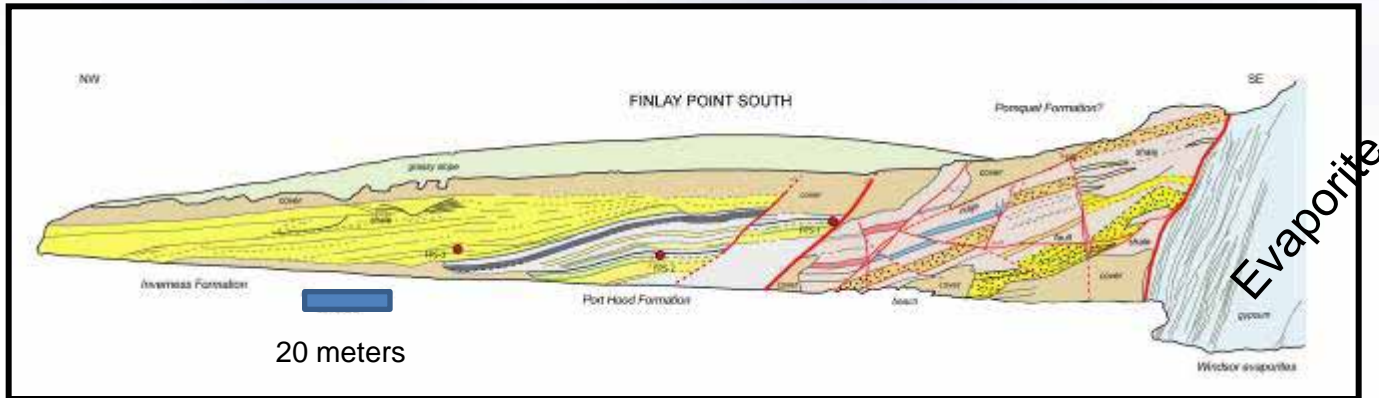
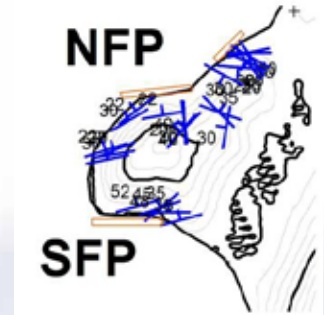
Carboniferous



Carboniferous evaporites in diapir with siliciclastic deposition against the diapir

cf. Alsop et al, 2000

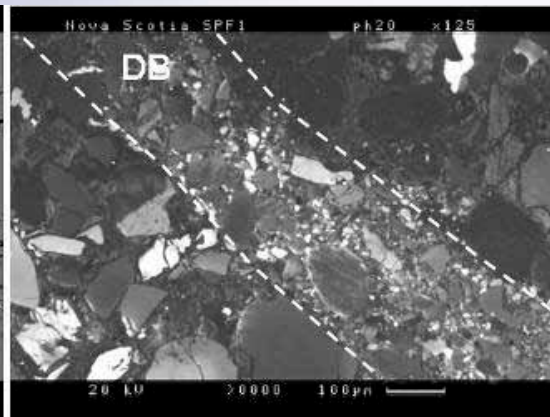
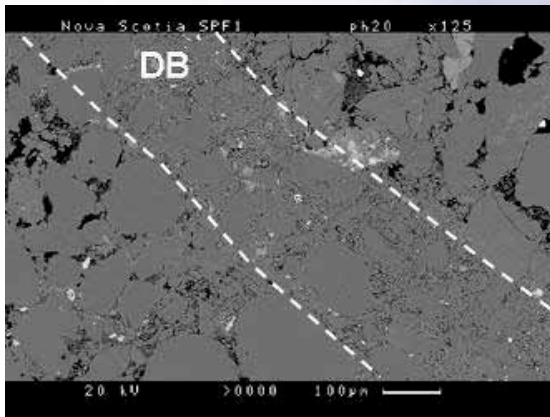
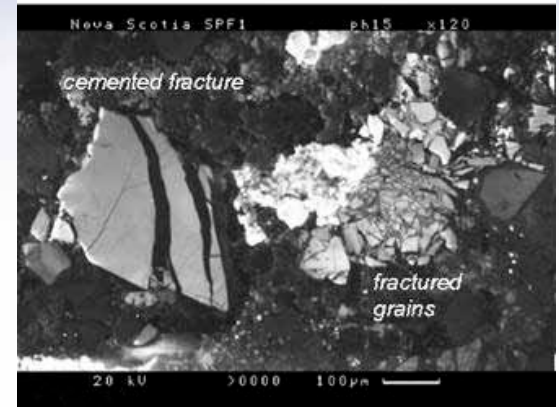
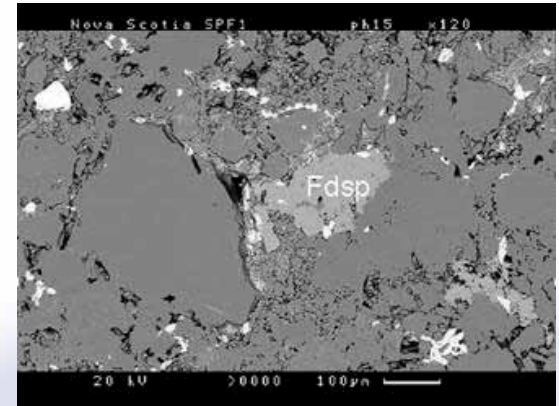
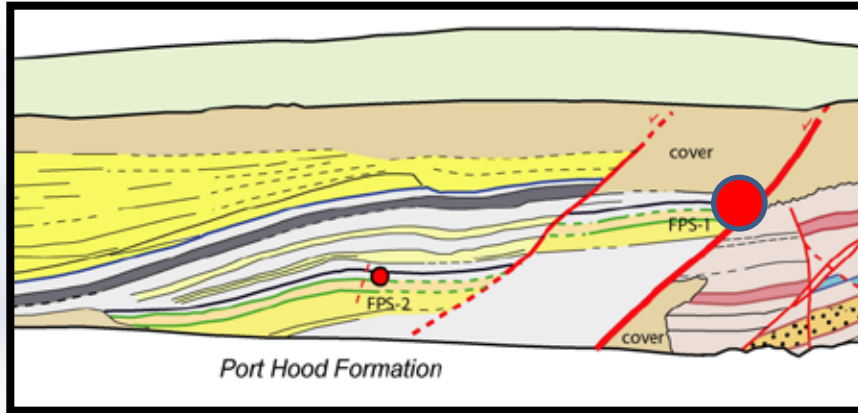
South Finlay Point



More heterolithic section adjacent to evaporite is faulted with normal and reverse offset.

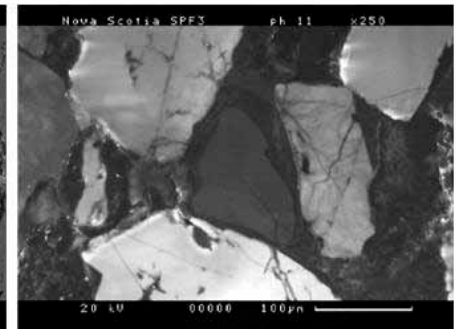
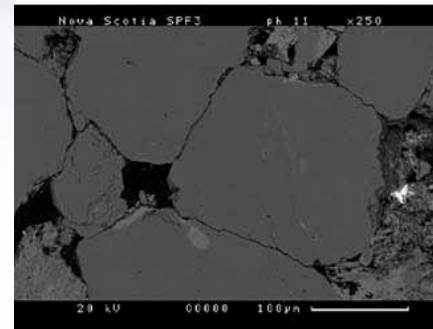
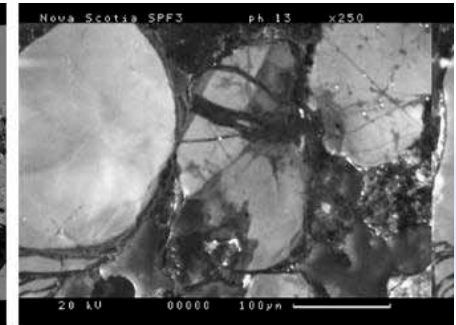
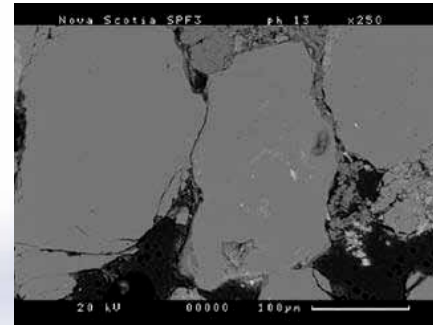
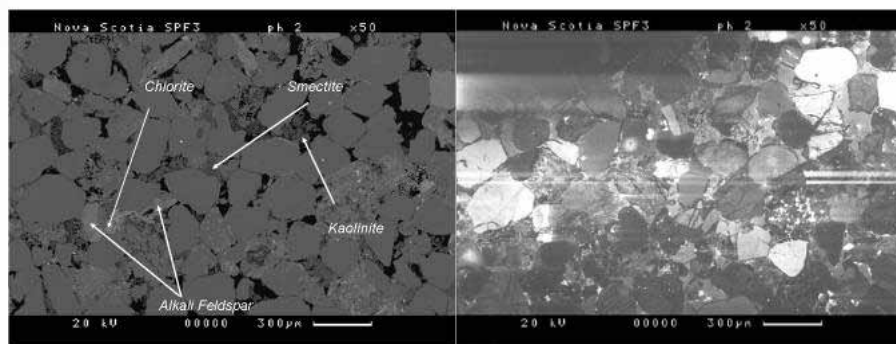
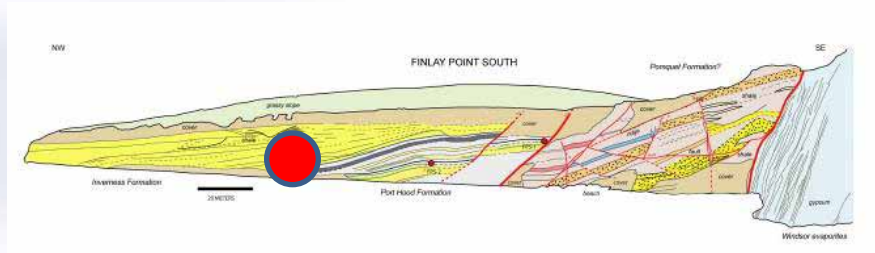
Few faults in more homogeneous sands but several deformation bands.

Sample 1



Deformation bands as damage zone in sandstones adjacent to larger throw faults. Cataclasis in deformation band. Cementation in deformation band early and post cataclasis.

Sample 3



- Cathode luminescence shows early grain fracturing and later quartz cementation.
- Minor fracturing and cement also post -date early cement.

Summary

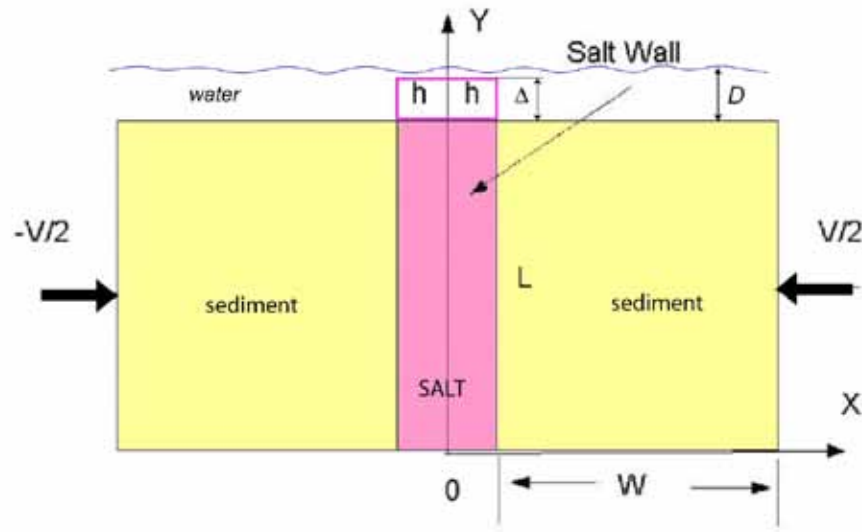
Common styles in lower net-to-gross sandstone section

- early distributed grain fracturing
- minor development of cataclasis in deformation bands – usually associated with larger throw faults.
- few macroscopic faults but usually associated with heterolithic sections of sandstones and shales.
- cementation of grains (degree of cementation varies)
- in some cases, second stage of fracture development.
- later shortening common to the evolution.

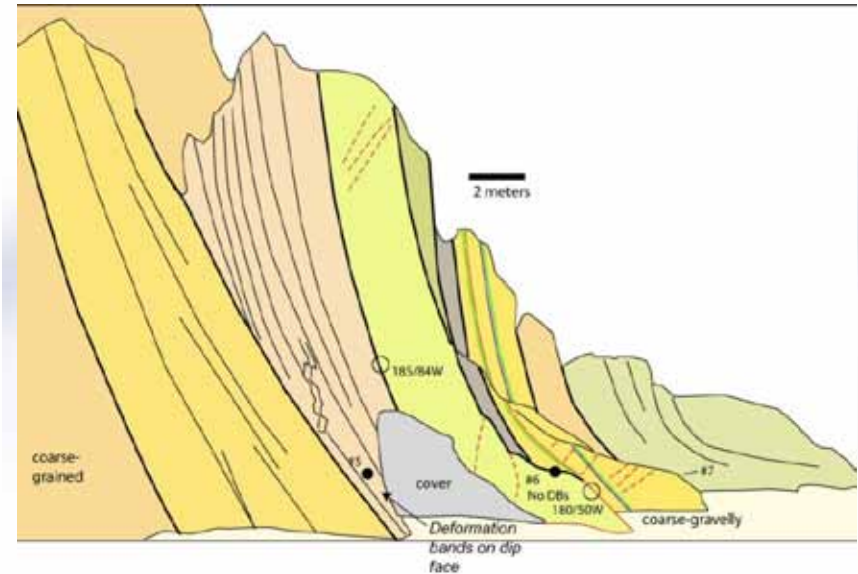
What are structural controls on distribution of deformation adjacent to diapirs?

Vertical salt weld analytical model

Model



Observation



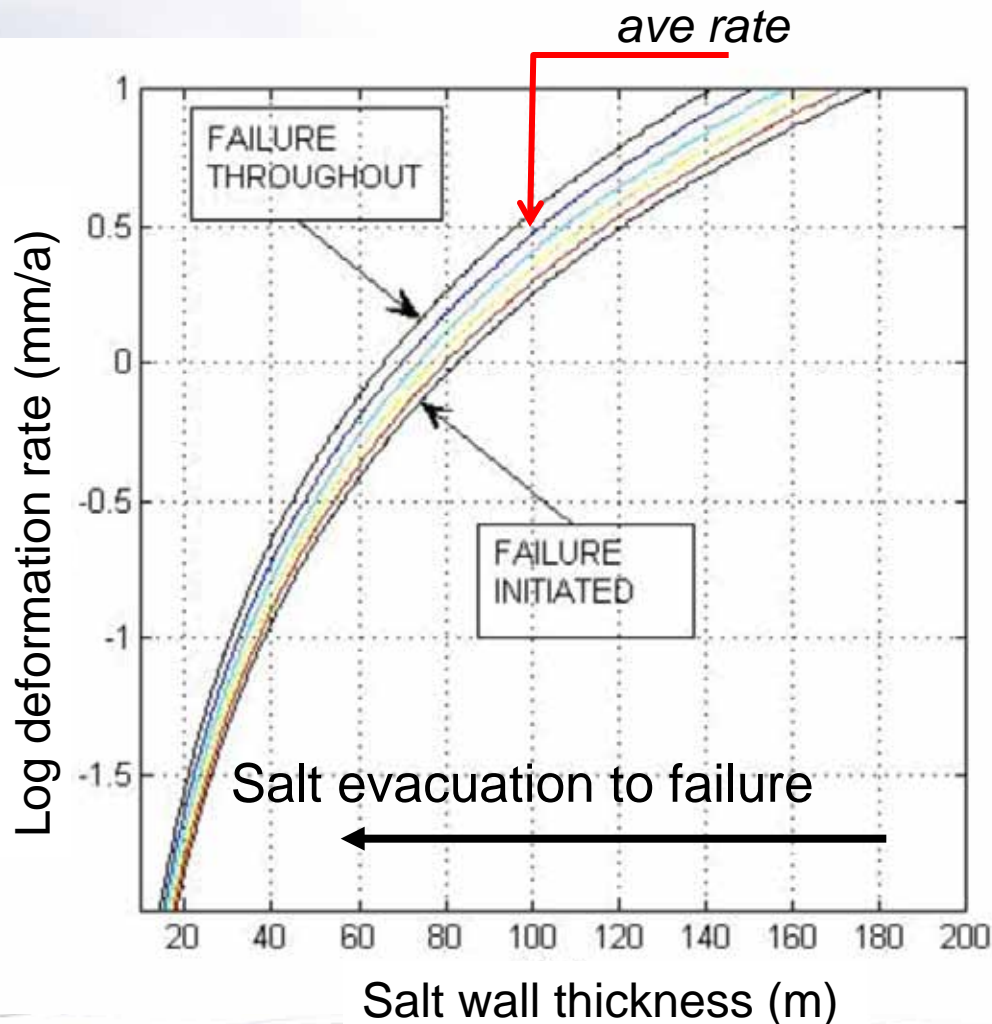
Sediment modeled as homogeneous block moved horizontally against viscous vertical salt stock with constant velocity.

Equate failure stresses in sediment block with stresses in salt to determine conditions favoring failure of sediment to salt extrusion.

Condition for failure: $y/L = [(8h^3r g)/(3hVL)] - 1$ where r is density of salt and h is the viscosity. Failure occurs at the surface for $y/L \geq 1$ or at greater depth for $y/L < 1$.

For friction at 30°

Salt evacuation against sediment failure



Curves show the conditions for failure of the sediments over evacuation of salt.

With loading salt stock narrows to limit where sediments fail.

Difficult to evacuate salt in vertical well to thicknesses much less than 100 meters for average deformation rates.

For friction at 30°

Synthesis

- Outcrop analogs of sediment-evaporite interfaces with beds steepened against the diapir show limited macroscopic faulting.
- The evidence is that most of the deformation is distributed at the grain scale with grain fracturing in many of the sandstones.
- Quartz cementation observed in many structures is interpreted as due to later deeper burial with increased temperatures.
- Simple analytical models suggest that salt evacuates and contracts with shortening. The deformation in the sediments occur at a threshold thickness dependent on the shortening rate, salt viscosity and density.
- A residual salt diapir will remain where deformation will only occur in sediments.

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