Fluid Systems around Salt Diapirs*

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Abstract

The geological environment surrounding salt diapirs is one of the more complex and challenging settings in which to conduct hydrocarbon exploration and production. A growing diapir can influence the nearby sedimentary environment and thereby control the geometry, distribution, and quality of reservoir and seal facies in its vicinity. Depending on the mechanism of emplacement, dissolution, and subsequent deformation, diapirs can induce and/or concentrate significant faulting and fracturing of the strata surrounding them. These faults and fractures can serve as conduits for vertical flow and lead to abundant stacked pay zones, or they can serve as barriers to lateral flow, causing complex compartmentalization and limiting reservoir drainage areas. The high thermal conductivity and solubility of evaporites further complicates the fluid system in the vicinity of diapirs, and studies of borehole fluids have identified strong thermal and salinity gradients that appear to create complex thermohaline convective flow systems near diapirs.

To better understand the spatial and temporal variability of fluid systems around salt diapirs, we studied paleofluid systems in the vicinity of three surface-exposed structures: (1) the Onion Creek diapir in the Paradox Basin, eastern Utah, (2) the El Papalote diapir in the La Popa Basin, northeastern Mexico, and (3) the Bakio diapir in the Cantabrian Basin, northern Spain. These diapirs formed in depositional environments ranging from terrestrial/subaerial to shelfal and deep marine, and as a consequence allow us to assess the influence of depositional setting on fluid system structure. Our research approach focuses on paleofluids that moved through fault and fracture networks in the vicinity of these diapirs, and from which vein minerals precipitated. We used mesoscopic structural analysis to document the geometry and timing of fractures and faults in each study area, and then employed thin section petrography, SEM, fluid inclusion microthermometry, and C, O and Sr isotope geochemistry to characterize the fluids that formed the veins. Our results allow us to outline the general structure and evolution of diapir-related fluid systems, and to identify and rank the variables that exert the greatest influence on these systems in different depositional settings. Though the systems are similar in many ways, stratigraphic variables seem to exert the greatest influence on the distribution and movement of fluids.

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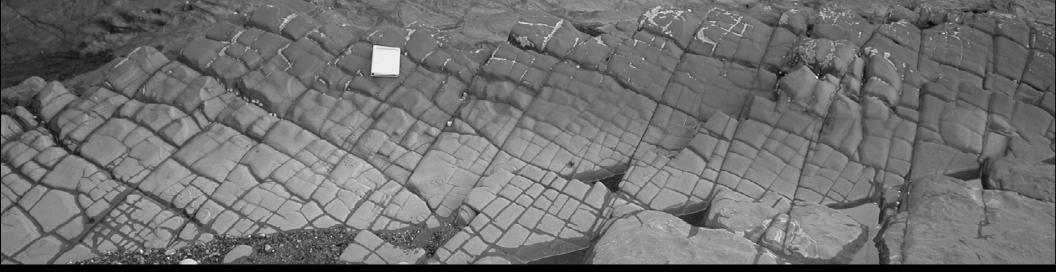
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Fracture network near Bakio diapir

Fluid systems around diapirs

contrasting stratigraphic controls in different depositional settings



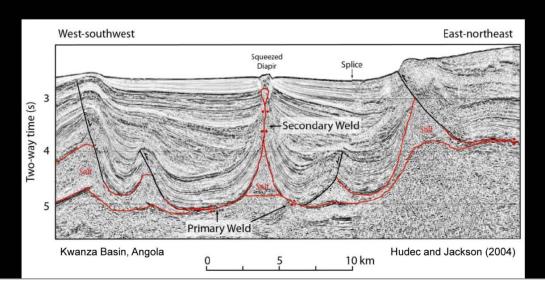
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Motivation



- Salt-related fluid systems are structurally and stratigraphically complex
 - Understand relative significance of these variables



Presenter's notes:

- Spatial variability in surrounding stratigraphic and structural architecture
 - Complex distribution of seal, reservoir, faults, and fractures
- Don't understand the hydrological implications
- Temporal variability of hydrological behavior
- We want to understand the relative significance of stratigraphic and structural variables in controlling fluid distribution For all fluid systems
- How does stratigraphic architecture influence fluid migration and distribution?
- How does stratigraphic architecture influence deformation patterns?

We do this in other settings besides diapirs, for example: Nuncios fold, Jura, La Popa weld

Research approach



Paleofluid system analysis

- Fluid composition and temperature
 - Isotopes (C, O, Sr)
 - Fluid inclusions
 - Minor and trace element analysis
- Fluid transport and storage
 - Meso- and microscopic structural analysis



Bakio, Spain

- Where did fluids originate?
- How long were they in the system?
- What was the fluid transport path?
- What was the fluid system structure?
- Permanence or impermanence of fault and fracture transport paths or barriers?

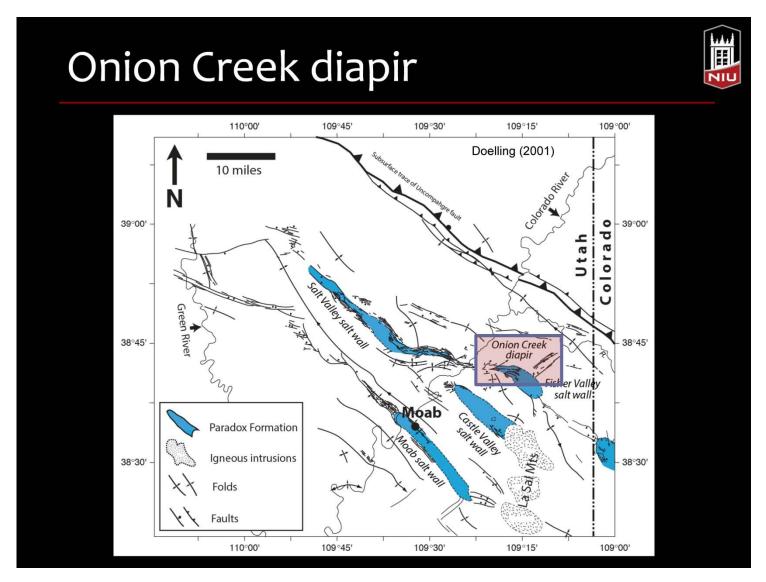


- Onion Creek, Paradox Basin, Utah
 - Subaerial, terrestrial
- El Papalote, La Popa Basin, Mexico
 - Shelfal, marine
- Bakio, Basque-Cantabrian Basin, Spain
 - Deep(er) water, marine

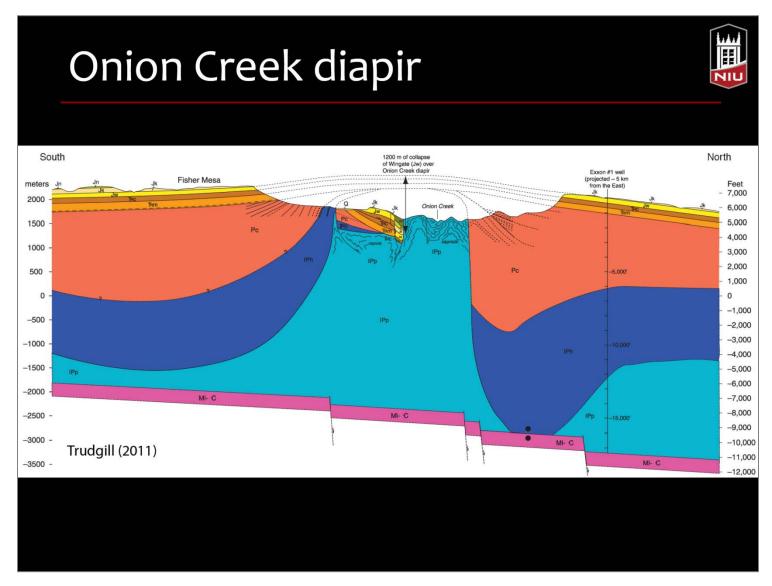
Studied diapirs in different depositional settings.

Talk organized to emphasize comparisons between fluid systems in these different settings.

- Deformation patterns
- Fluid characteristics
- Fluid system structure



- Paradox Formation deformed into a series of salt walls.
- Driven by southwest progradation of clastics shed from the Ancestral Rockies, Uncompange uplift.
- Onion Creek "diapir" is the crest of the Fisher Valley salt wall, so not a diapir in a strict sense.
- La Sal intrusive complex develops in Tertiary and produces significant structural relief

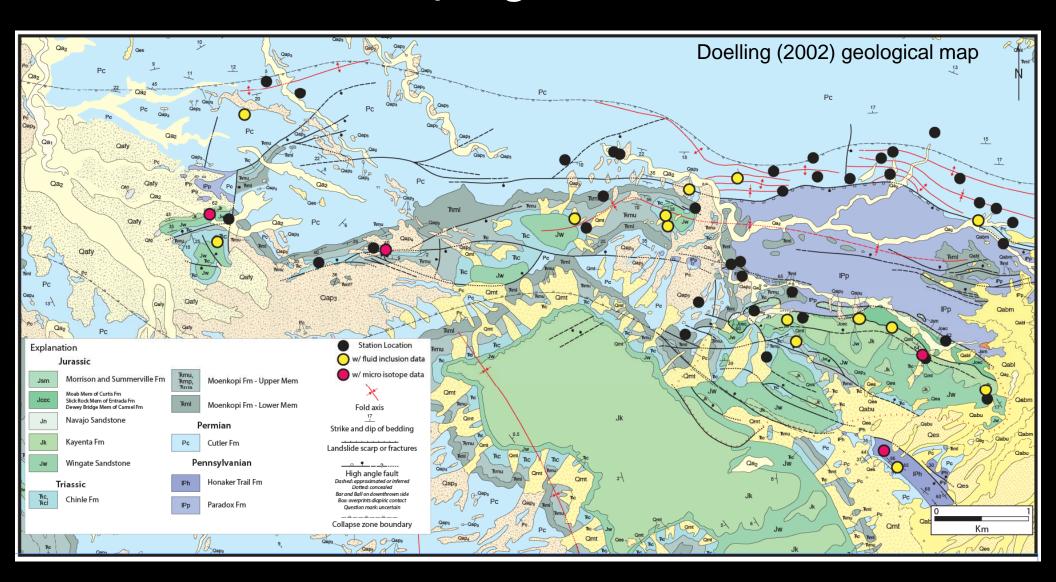


- North-south cross section by Trudgill (2011); salt walls localized above basement steps
- Sourced by Paradox Formation evaporites.
- Honaker Trail and Cutler show growth and helped to drive the formation of the salt wall regionally.
- Extensive collapse of diapir roof.

Onion Creek diapir



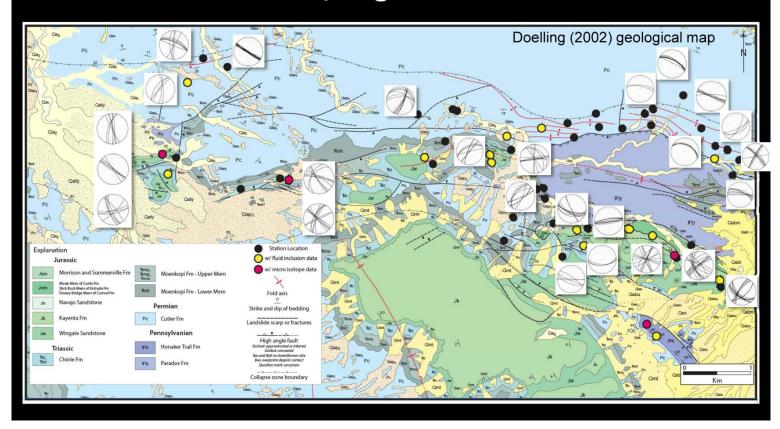
55 data and sampling stations



Onion Creek diapir



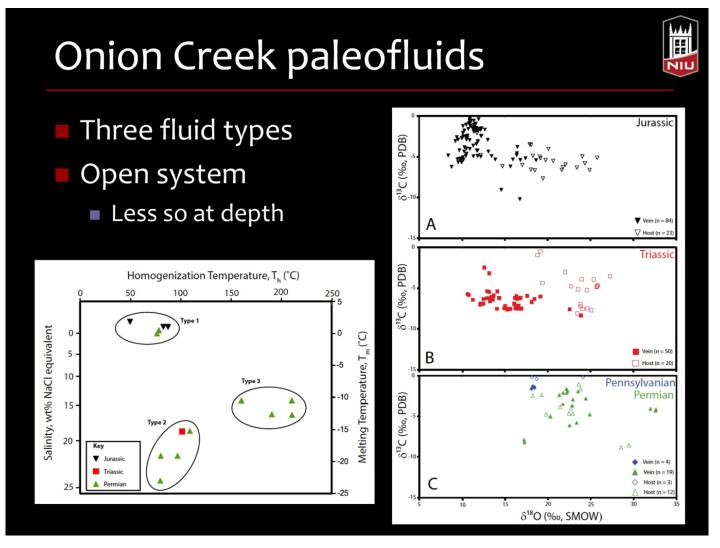
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- Largely E-W trending salt wall here
- Outcrops dominated by Cutler to north, with extensive collapse blocks to south
- Fractures and faults largely parallel and normal to the salt wall
- More chaotic network with lots of oblique fractures locally, but mostly on south

Onion Creek fracture network Less organized up section Significant reactivation Fractures in Triass Fractures in Permia

- Looking down on steeply dipping bedding with west to left
- Rosetta Stone outcrop used to unravel timing (strike-normal oldest, strike, strike-oblique youngest)
- Fracture network less organized up section
- Strong evidence for reactivation and kinematic linkage between fractures of different orientations

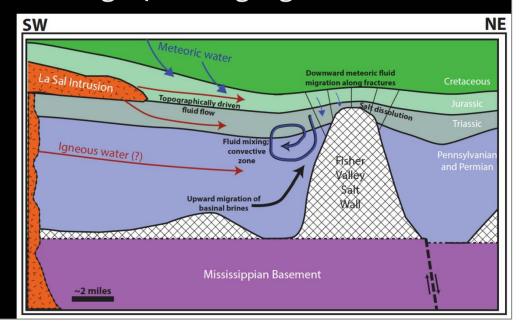


- Interpret fluid compositions, temperatures and origins from stable isotopic and fluid inclusion work
- Isotope plots intended to fingerprint fluids and assess relations between host rocks and fluids
 - Open vs. closed fluid systems?
 - Fluids different from host rocks in Triassic and Jurassic, similar to host rocks in Pennsylvanian and Permian
- Three fluid types: meteoric, moderate and higher salinity
- Stratigraphic restriction of the fluids

Onion Creek paleofluid system



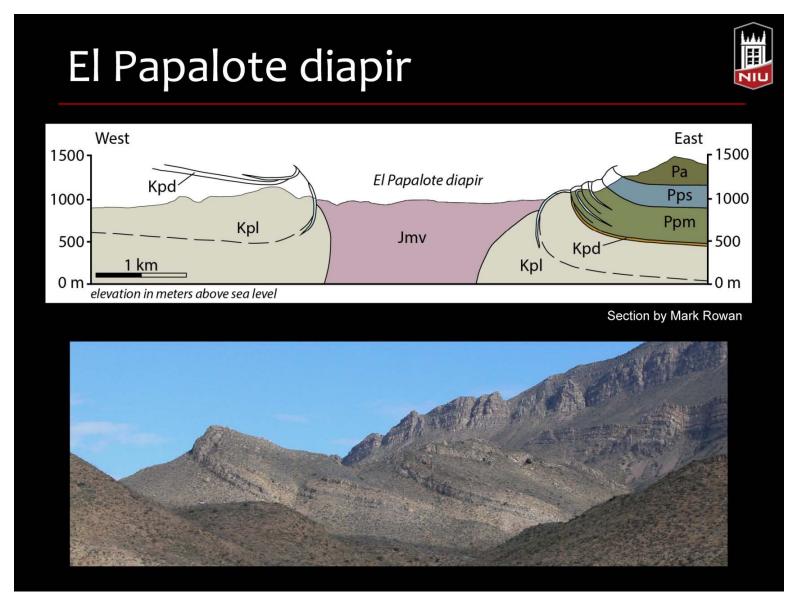
- Dominated by mixing
 - Shallow meteoric deep brine
- Insignificant stratigraphic segregation



- Three-part fluid system dominated by mixing
- Shallow meteoric system and deep brine system
 - Intermediate mixed system
- Insignificant stratigraphic segregation of fluids
 - Maybe because of abundant sands

El Papalote diapir 310000 320000 330000 100° 45′ W United States 2900000 Nc 2890000 2890000 La Popa weld Kpl Kps Ku 26° 0' N 2880000 26°0'N 2880000 6 9 12 km 310000 320000 100° 45′ W 330000

- Located in La Popa Basin
- Two diapirs; Gordo in crest of fold, El Papalote in backlimb
 - Both subjected to shortening post emplacement

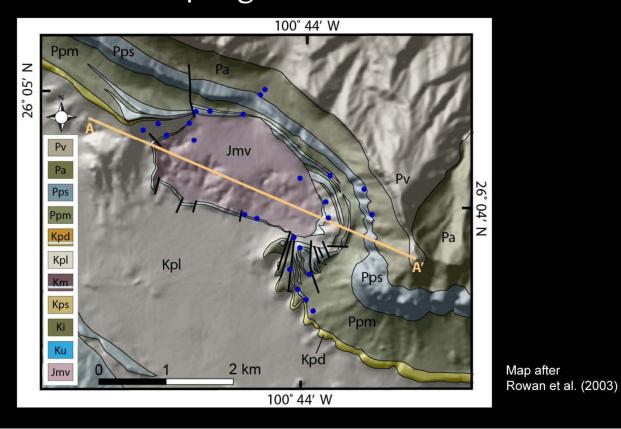


- East-west cross section across El Papalote diapir showing carbonate lentils and unconformities
 - One of the better examples of upturning and halokinetic unconformities
- Not truly a vertical cross section slightly inclined

El Papalote diapir



28 data and sampling stations

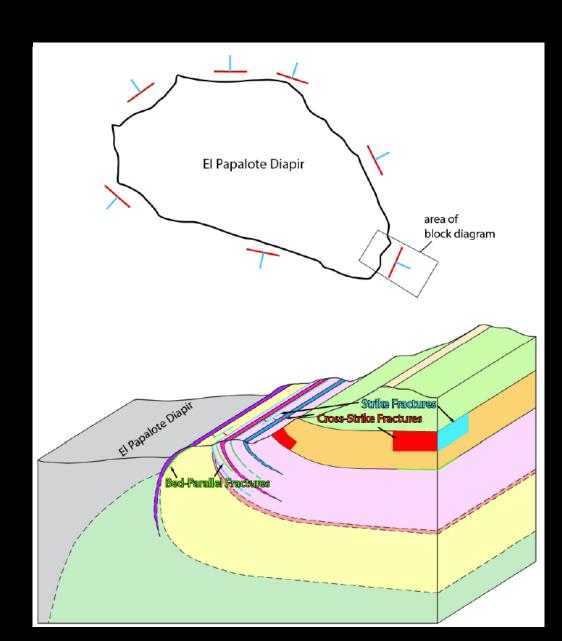


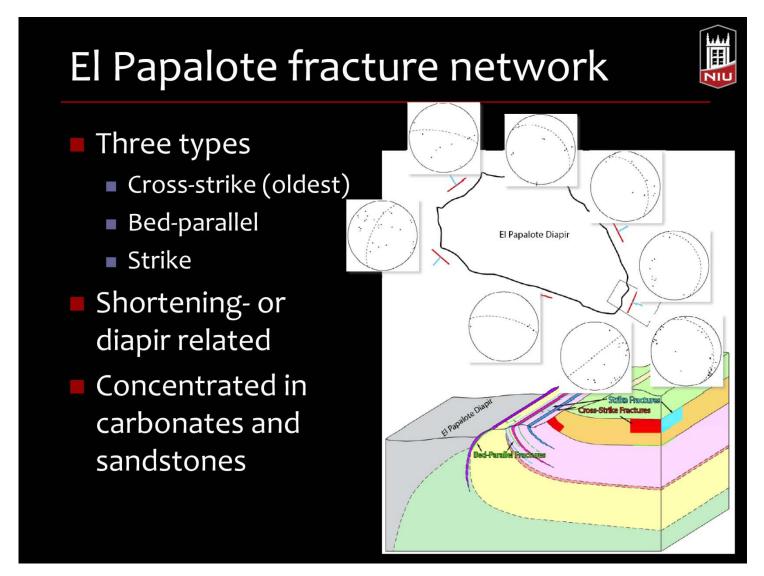
- Host rocks all dipping northeast
- Carbonate lentils ring the structure; all upturned to subvertical locally and dip more gently further from diapir
- Minor radial faulting

El Papalote fracture network

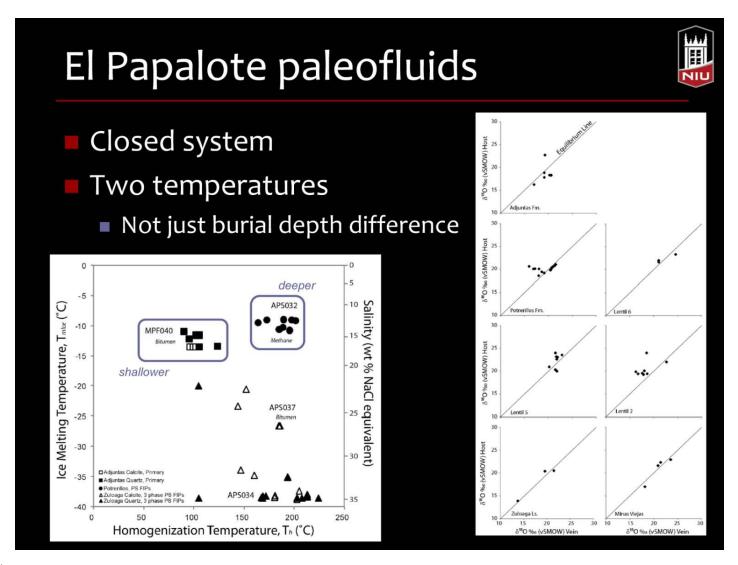


- Three types
 - Cross-strike (oldest)
 - Bed-parallel
 - Strike
- Shortening- or diapir related
- Concentrated in carbonates and sandstones





- Fractures divided into bed-parallel, cross strike and strike
 - Many of the cross-strike are shortening related these are oldest
 - Strike and bed-parallel are related to diapirism
- Upturning of bedding and slip on unconformity surfaces near the diapir
- Fewer fractures in mudstone intervals

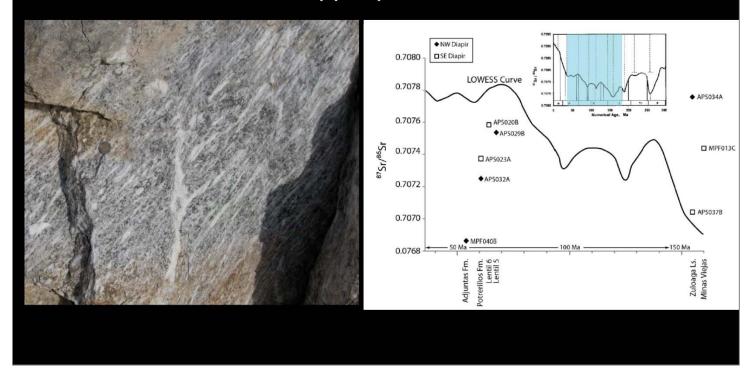


- Different way to assess open or closed nature of fluid system: host vs. vein plots
 - Most fluids match their host rocks suggesting closed system
 - Suggests stratigraphic segregation and little vertical communication
- Temperature different too high to be accounted for just by burial
- High salinities in blocks entrained in diapir
 - Similar, moderate salinities elsewhere

El Papalote paleofluids



- Diapir dissolution
 - Concentrated in upper part of section

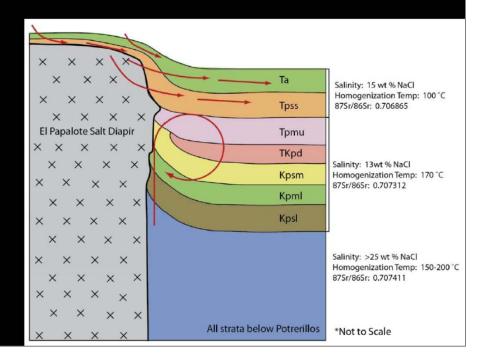


- Photo of sheared texture in evaporite in the diapir
- Can use strontium isotopes as a better indicator of fluid source
 - Test whether fluids are truly just locally derived
- Strontium isotopes in seawater vary systematically through time
 - Lower Sr ratios suggest interaction with diapir, higher Sr ratios in diapir suggest formation fluid dilution

El Papalote paleofluid system



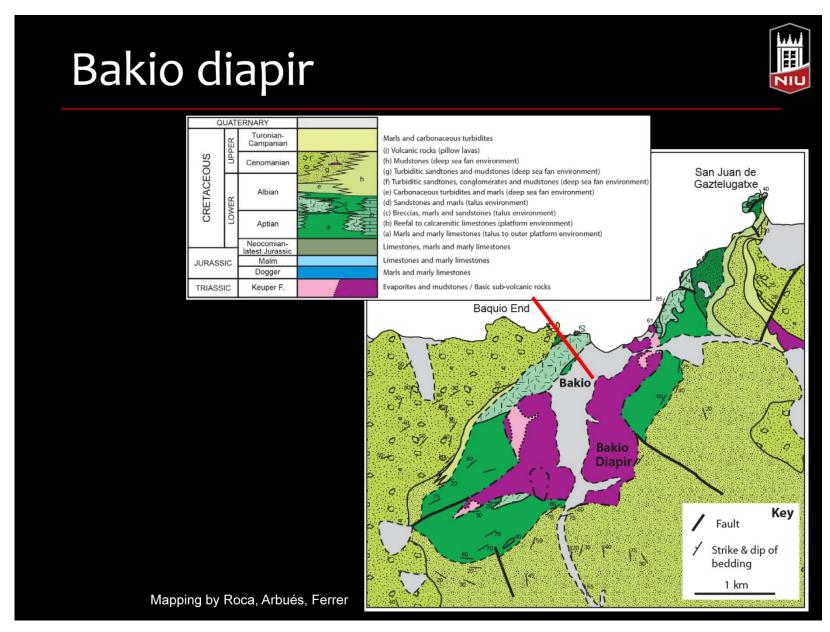
- Vertically segregated into a two-tiered system
 - Potrerillos mudstone seal
 - Halokinetic sequences boundaries are important



- Two-tiered system that is stratigraphically segregated
- Dissolution of salt most extensive in upper compartment from Sr isotopic data
- Hot water trapped beneath Potrerillos mudstone seal
 - Halokinetic unconformity below Potrerillos seems significant in sealing

Bakio diapir 3º W 2º W Santander This study area San Sebastián Evaporites Quaternary Neogene Synclime Paleogene Late Cretaceous Early Cretaceous Aptian-Albian L. Jur.-E. Cret. BC = Basque-Cantabrian Basin AM = Asturian Massif Mid-Late Jurassic BB = Bay of Biscay Salinillas de Buradón Early Jurassic DB = Duero Basin Triassic (Keuper) diapiric structure EB = Ebro Basin PY = Alpine Pyrenean fold-thrust belt Triassic (Bunt.) Logroño 🏠 2º W Pre-Mesozoic Ábalos et al. (2008)

- Diapir located in Basque-Cantabrian Basin; westward extension of Pyrenean fold-thrust belt
- Abundant salt structures sourced from Triassic Keuper evaporites
- Diapir exposed in small seaside resort town of Bakio



- Northeast trending, oblong salt diapir
- Complex set of facies changes in close proximity to the diapir including: carbonate debrites, marls, sandstones, and carbonate platform deposits
- We separate these by depositional environment type hereafter
- Most exposures along coastline

Bakio diapir SSE NNW **-200** 200-100 100-Bakio Diapir SL SL-200 m L-100 -100 Section by Mark Rowan m

- SSE to NNW section by Mark Rowan showing geometry of halokinetic sequences
 - One major and three more minor halokinetic unconformities identified
- Subvertical rocks exposed in coastal terraces and accessible at low tide
- Abundant carbonate debrites throughout the section

Bakio diapir



20 data and sampling stations



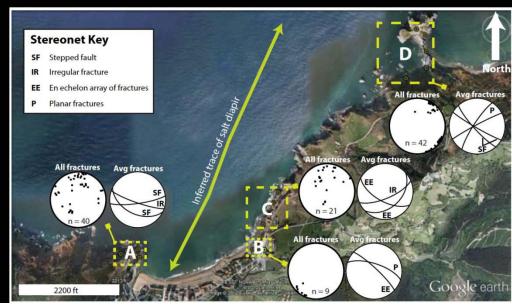
- Google Earth view looking obliquely SSW
- Note the diapir trace
 - Exposures of evaporites on east end of beach
- Exposures we worked are concentrated in three areas fractures abundant in all three

Bakio fracture network



- Parallel and perpendicular to salt wall
 - Along-strike and down-dip extension
 - Larger faults are late(r)
- Regular and abundant fractures in

sandstones



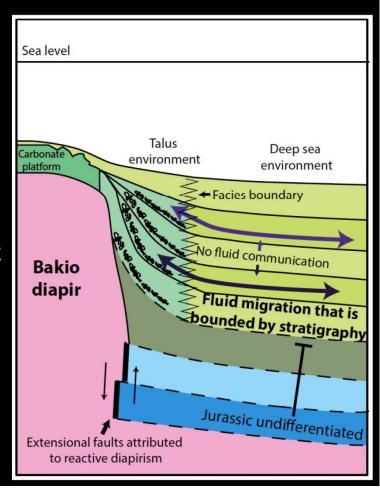
- Google Earth view down on the coastline
 - Divided into four subregions based on facies present and structural/stratigraphic setting
- Four types of fractures: planar fractures, en echelon arrays, stepped faults, irregular fractures
- Most abundant and best developed fracture networks in well-bedded turbudite sandstones.

Bakio paleofluids (A) Closed system δ¹³C (PDB) Stratigraphically 3-Host (‰) segregated Deep Sea Fan **Platform** Limestone ▼ Limestone Limestone Marl Sandstone Debrite Vein (%) (B) $\delta^{18}O$ (SMOW) Host (‰) Deep Sea Fan **Platform** 20 Limestone Limestone ▼ Limestone Marl Sandstone Debrite 20 25 30 Vein (‰)

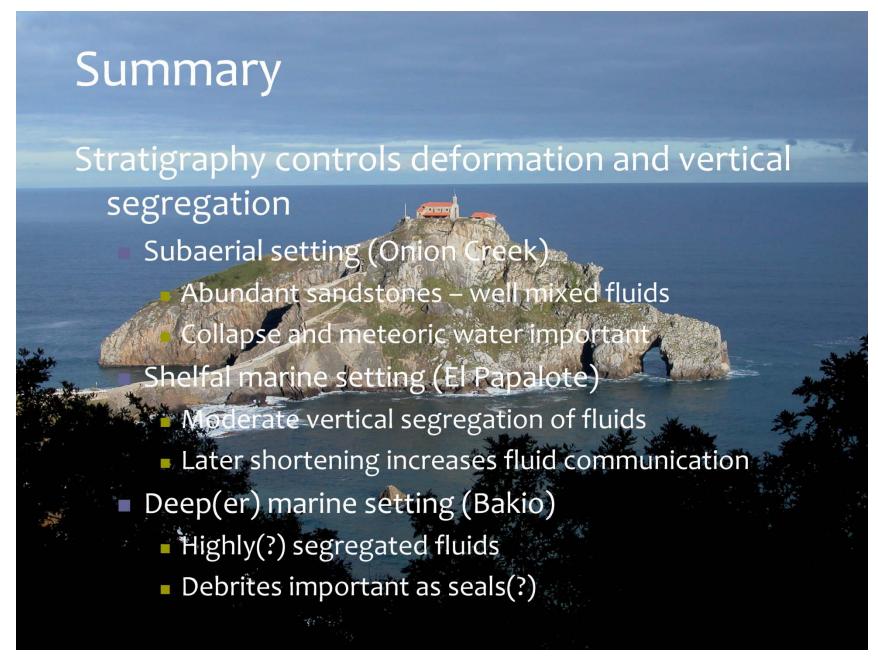
- Host vs. vein plots suggest that regardless of depositional environment, fluids match host rocks
- Closed system with little vertical fluid communication
- Maybe tough to say because host rocks are so similar
- Unfortunately no Sr data yet, and no fluid inclusion data yet

Bakio fluid system

- Stratigraphically segregated
 - Limited vertical mixing
- Halokinetic sequences important
 - Debrites play important role as seals(?)



- Stable isotopes seem to suggest a highly segregated system
 - Little to no vertical communication
- Halokinetic sequences may play a role as vertical seal
 - Debrites might be important in this
- Sr isotopes will help us refine this model very soon



- Stratigraphy is variably important but generally more important than structure.
- Stratigraphy controls the deformation style and to some degree, the intensity.