The University of Texas at El Paso
Salt-Sediment Interaction Research Consortium
(SSIRC)
Proposal
Phase 2 May 1, 2017- May 1, 2022

Phase 2 SSIRC Research Team

The University of Texas at El Paso
Dr. Kate Giles: *Sedimentology, stratigraphy, salt tectonics*
Dr. Rip Langford: *Sedimentology, stratigraphy*
Dr. Ben Brunner: *Low temperature Geochemistry (O, C, S isotopes)*
Nila Matsler: *Contracts & book keeping*
Postdocs & Graduate students: Currently 2 postdocs, 4 PhD & 6 MS

Rowan Consulting Inc
Dr. Mark Rowan: *Structure and salt tectonics*

Northern Illinois University
Dr. Mark Fischer: *Structure, fluid flow and diagenesis*
Graduate students: Currently 2 MS

Dr. Carl Fiduk-: *Salt tectonics, Seismic interpretation*

Collaborators:

Universitat de Barcelona, Geomodels Group
Dr. Josep Anton Muñoz*: Structure and tectonics*
Dr. Eduard Roca: *Structure and tectonic*
Dr. Oriol Ferrer: *Structure & Analog/ sandbox modeling*
PhD Frederic Escosa: *Structure*

Polish Academy of Sciences
Dr. Piotr Krzywiec: Structure, salt tectonics, seismic interpretation
Mid-Polish Trough

Purpose of Research

The Phase 2 SSIRC research team will continue to examine the near-salt environment from a structural, sedimentological, stratigraphic, temperature gradient, fluid flow & geochemical characteristics standpoint. The goal of this research is to increase our understanding of the origin, timing, nature and regional framework of a series of key salt features that have been shown to play important roles in hydrocarbon traps found in salt basins worldwide. Results from our research efforts are intended to increase predictability of salt-system characteristics and distribution within salt basins.

The key salt features we will focus on are:

- Welds
- Megaflaps
- CHS and Minibasin Fill Geometries
- Thermohaline Circulation Systems
- Salt Associated Faults
- Salt Shoulders & Diapir Collapse
- Lateral Caprock
- Suture Zones
- Encased Basins, Salt Sheets/Canopies
- Intrasalt Deformation
- Subsalt Rubble Zone
- Gravity Driven Deformation

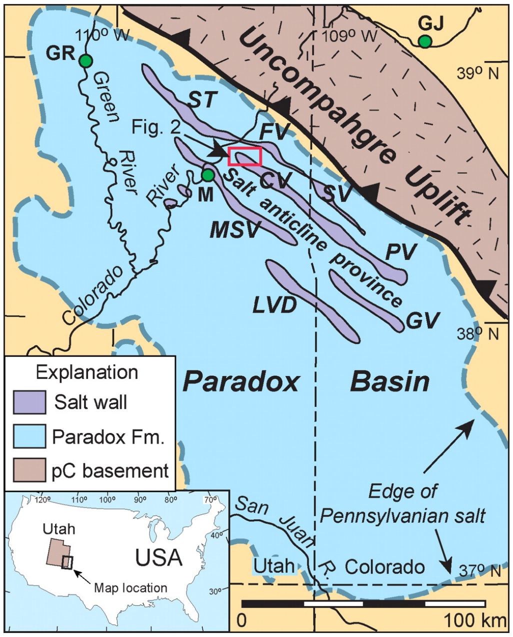
Integrated Datasets to be Utilized

- Field Analog 1: Paradox Basin, Utah & Colorado
- Field Analog 2: Willouran & Flinders Ranges, South Australia
- Field Analog 3: Pyrenees & Prebetics, Spain
- Seismic – 2D and 3D: Paradox Basin, Gulf of Mexico, Mid-Polish Trough, and others
- Well Logs
- Analog Modeling
- Stable Isotopes (C, O, S)
- Radiogenic isotopes (U, Pb)
- Fluid inclusions
- XRF & XRD Mineral Identification
- Thermal & Fluid-Flow Modeling

Field Analog Study Areas

Detailed geologic summaries of each of these areas are provided in Appendix A of the SSIRC Phase 1 proposal. In Phase 2 we are focusing on the key features listed above that have been identified in each study area. The research team including graduate students work in sync & collaboratively to document all aspects of the salt features in the field.

1. Paradox Basin, Utah and Colorado



Pennsylvanian salt in Ancestral Rocky Mountains foreland basin with Permian fluvial/alluvial loading trigger. Passive diapirism of salt walls through Cretaceous with Tertiary salt wall roof collapse.

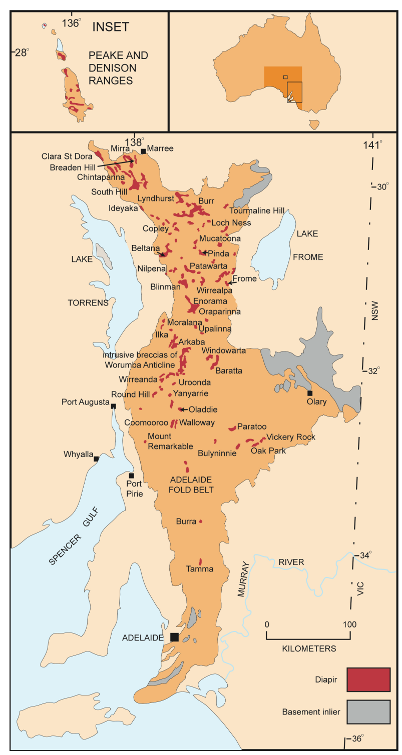
Salt features identified: salt wall termination welds, halokinetic megaflaps, tapered-CHS, radial faults, counterregional faults, salt-wall parallel collapse faults, shoulders & collapse folds (anticlines), lateral caprock, and intrasalt deformation.

Complemented by seismic and well data that show: megaflaps, minibasin-scale stratal geometries, salt-wall terminations.

2. Willouran and Flinders Ranges, South Australia

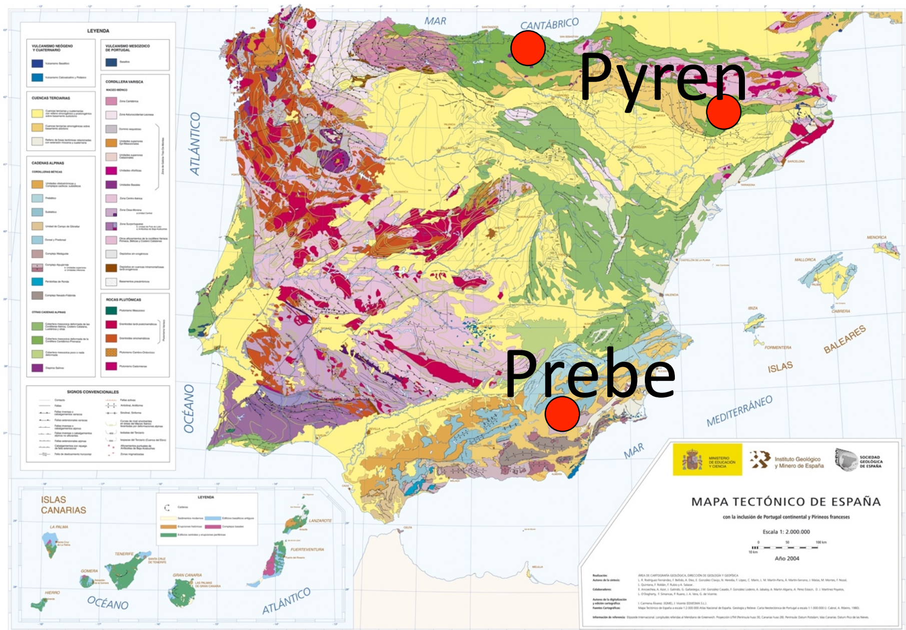
Neoproterozoic rifting and salt deposition with probable extensional reactive trigger. Generated over 100 diapirs that develop into allochthonous salt sheets and canopies in the Late Neoproterozoic continuing on into the Cambrian. The entire area was shortened during the latest Neoproterozoic-Ordovician collisional Delamerian Orogeny.

Salt features identified: secondary and tertiary welds, thrust welds, counter-regional weld, halokinetic megaflap, CHS and large-scale minibasin fill geometries, shoulders, lateral caprock, suture zones, encased basins, intrasalt deformation at both the autochthonous and allochthonous levels, and subsalt exposures.



3. Pyrenees and Prebetics, Spain

Both areas have dominantly postrift Upper Triassic salt deposition, with deformation triggered by extension in rift to passive-margin settings. Both areas experienced Cenozoic collision (Pyrenean & Betic orogenies).



Features identified: primary and secondary welds, contractional megaflaps, CHS and large scale minibasin-fill geometries, encased basins, salt sheets, subsalt rubble zone, and intrasalt deformation.

<u>Salt Features</u>

Welds

What are the attributes of different types of welds and how do they relate to fluid flow along and across the weld?

- Multi-scale characterization & fluid flow/temperature analysis utilizing subregional mapping to small scale structures. Fluid inclusion and isotopic signature of cements. Numerical modeling of fluid flow.
- Vertical secondary weld in La Popa Basin completed (*Rowan et al., 2012 – structural architecture; Smith et al., 2012 – fracture and fluid-flow analysis).* Will serve as a basis of comparison to other study areas.
- Other types of welds are present in South Australia:
    - Tertiary welds, Willouran Ranges (M. Fischer & students in progress)
    - Thrust weld, Warraweena & Mucatoona diapirs, Flinders Ranges (UB O. Vidal Royo and O. Ferrer, NIU M. Fischer, M. Rowan *in progress*). Actually comprises alternating segments of diapirs, welds, and thrusts. Intersection with tertiary weld and overlying faults.
    - Counterregional weld, Oladdie diapir, Flinders Ranges. Field mapping completed and will initiate fracture/fluid-flow analysis (NIU M. Fischer & students)

Megaflaps

What are the attributes of megaflaps, how do they form, and how do they relate to fluid flow along the margins of diapirs and welds?

- Initial paper now in press (*Rowan et al., 2016 – available "Online first" at AAPG Bulletin)* that outlines two end-member models of megaflap formation: halokinetic and contractional megaflaps. The research group will continue to test these two models and develop a suite of attributes that characterizes each model.
- Field study characterization of attributes, structural and stratigraphic analysis:
    - Halokinetic megaflap at Witchelina diapir, Willouran Ranges (UTEP PhD E. Gannaway, completed)
    - Contractional megaflap at Adons diapir, Pyrenees (UTEP PhD E. Gannaway*, in progress*)
    - Halokinetic megaflap at Gypsum Valley diapir, Paradox Basin (UTEP MS K. Deatrick, Ally Mast, & UB F. Escosa completed; Fluid-flow analysis (NIU M. Fischer initiated)
    - Halokinetic megaflap at Onion Creek diapir, Paradox Basin (UTEP MS K. Grisi initiated and will compare/contrast with GV)
    - Halokinetic megaflap at Sinbad diapir, Paradox Basin (UTEP Postdoc J. Thompson initiated)
- Seismic studies
    - Northern GoM catalog of attributes (Schlumberger 3-D data, M. Rowan)
    - Detailed 4-D analysis of 2 endmember examples (SLB data, UTEP PhD E. Gannaway)
- Analog modeling (UB O. Ferrer)
    - Halokinetic megaflaps first phase completed
    - Contractional megaflaps planned
- Build 3-D models from integrated field and seismic data (Gypsum Valley, Pyrenees)

Minibasin Fill Geometries

What are the different possible stratal geometries within minibasins and what is the nature of facies & their distribution as related to potential fluid flow and trapping?

- Recognize 3 scales/styles: Composite halokinetic sequences (tapered-CHS & Tabular-CHS), Megaflaps, and Diapir flanking tectonostratigraphic packages (DFTP).
- DFTP are conceptual/geometric models comprising various combinations of wedges that thin or thicken towards diapirs and isopachous layers.
- DFTP initial studies using primarily GoM seismic and field studies from the Willouran and Flinders ranges (M. Rowan seismic and UTEP K. Giles & R. Langford)
- CHS and facies control studies at Gypsum Valley salt wall (UTEP MS R. Delfin & R. Ronson; PhD C. Bailey)
- Seismically imaged contractional growth strata associated with salt-cored folds and squeezed diapirs in central Poland. 3-D analysis of rejuvenated diapirs and flanking folds (P. Krzywiec, M. Rowan, UTEP K. Giles)

Thermohaline Circulation

What is the thermal structure around diapirs and how is it influenced by pore fluids?

- Numerical modeling studies that combine both thermal conduction and fluid advection to develop more realistic basin scale thermohaline circulation models (NIU M. Fischer & MS D. Canova)
- Plan to test different geometries, sediment permeabilities, etc.
- Include role of meteoric water and dissolution
- Test models with field data

Diapir-Associated Faults

How do different types of faults serve to modify diapir-flanking geometries, for example the lateral terminations of megaflaps? Do they have different effects on fluid flow/entrapment near diapirs?

- Radial, counterregional, and small-scale faults have been identified in the Paradox Basin
- Field studies
    - Megaflap at Gypsum Valley diapir, Paradox (UB F. Escosa regional mapping completed; M. Fischer small scale deformation & diagenesis initiated)
    - Megaflap at Onion Creek diapir, Paradox (UTEP MS K. Grisi will map, characterize stratal geometries and facies and compare/contrast with GV)
- Seismic studies
    - Detailed 4-D analysis of 2 examples (SLB data, UTEP PhD E. Gannaway)
- Analog modeling (UB O. Ferrer)
    - Halokinetic megaflaps initiated
    - Contractional megaflaps planned

Salt Shoulders

What are the tectonostratigraphic and facies characteristics of salt shoulders? What does it tell us about how they formed and the dynamic evolution of the diapir margin? How effective are they as traps?

- Chinle-age shoulder at Gypsum Valley, Paradox Basin (UTEP MS J. McFarland completed). The Chinle GV shoulder involved erosion, solution collapse & caprock formation during a regional subaerial unconformity event. Chinle shoulder collapse achieved by rollover into central diapir, due to salt evacuation or dissolutuion, forming an elongate anticline that parallels the margin of the diapir and is confined to the shoulder area.
- Both Chinle and Cutler-age shoulders at Onion Creek diapir, Paradox Basin

Lateral Caprock

Do lateral caprocks associated with distinct stratigraphic levels have unique fabrics and/or geochemical signatures? How can we decrease the risk associated with drilling into unpredicted caprock?

- We recently proposed a new dynamic halokinetic model for the origin of lateral caprock, which provides a way of predicting lateral caprock presence predrill.

- We continue to build a database from our field based examples to test the halokinetic model along with literature data from GoM & North Sea caprock examples.
- Building an attributes database in order to perform comparative studies that may increase predictability of lateral caprock presence and their attributes (UTEP B. Brunner, K. Giles and students. Database will provide information on lithology, fabrics, stratigraphy, mineralization, geochemical make up along with C, O, S stable isotopes.
- Will explore possibility of dating lateral caprock using U-Pb series dating of petroliferous carbonate caprock facies (K. Giles, B. Brunner initiated)
- Compare Chinle and Cutler lateral caprock at Gypsum Valley, Castle Valley, & Moab diapirs, Paradox Basin (UTEP MS P. Poe & PhD A. Labrado initiated)
- Bunyeroo lateral caprock at Patawarta, Pinda, Beltana, and Warraweena salt sheets South Australia (UTEP PhD R. Kernen)

Suture Zones

What are the characteristics of suture-zone clasts? How much deformation and diagenesis have they seen relative to same age strata outside the diapir? What does this tell us about the fluid flow history and their role as conduits or drilling hazards?

- Patawarta Suture Zone, Flinders Ranges (R. Kernen initiated)
- Suture identification & preliminary mapping of other suture zones on adjacent salt sheets
- Detailed analysis of suture geometries in GoM canopies (SLB data, UTEP PhD R. Kernen)

Encased Basins

How much deformation and diagenesis have encased basins seen relative to correlative strata outside the salt? Are there any facies variations compared to equivalent strata in supra- or subsalt settings?

- Do we see differences in near-salt deformation and stratigraphy (base, top, sides)?
- Examples in the Prebetics of SE Spain
- Collaborative work with E. Roca at Barcelona
- Seismic/modeling components?

Intrasalt Deformation

What are the characteristics of intrasalt deformation in different modes of salt tectonics? When does the deformation occur? Early, late?

- Generate a catalog of examples of intrasalt deformation.
- Examine age relationships, deformation, and possible growth strata in layered evaporite sequence, Willouran Ranges, South Australia
- Will compare primary diapirs with allochthonous salt
- Plan to conduct analog modeling under different scenarios, varying the mechanical stratigraphy of the layered evaporite sequence and the mode of deformation (O. Ferrer, M. Rowan)

Subsalt Rubble Zone

What are the nature and origin of subsalt rubble zones? Are there any correlations between its presence/thickness and salt geometry? How can we predict the presence of rubble zones in subsalt positions?

- Use biostratigraphic data to document the thickness, age, and other characteristics of rubble zones in the northern Gulf of Mexico (partly completed by I. Prince [Shell])
- Evaluate salt geometry from 3D seismic data to identify any patterns
- Rubble zone outcrop, Prebetics, SE Spain contains subsalt debrite with internal shear fabric. Will initiate field project in next year or two (with E. Roca, Barcelona)

Gravity Driven Deformation

How important is gliding (tilt) versus spreading (differential loading) in producing gravity driven deformation?

- Numerical modeling to compare and contrast the two processes and their effectiveness (being initiated by M. Rowan with external modeler)
- What are the roles of dip, length, thickness ratio, density, etc?

May 1, 2017 – May 1, 2022

- Joint-industry sponsorship of SSIRC
- Annual fee of $45,000/year invoiced annually and due on May 1 of each year of contract.
- 5 year commitment (May 1, 2017 – May 1, 2022)
- Contract can be terminated at any time with 30-day written notice, but no partial refunds for year of termination

Annual Fee Expenditures

- UTEP takes 26% for overhead
- Student stipends & tuition coverage
- Travel to field areas & meetings
- Lab analyses
- Field, lab, computer equipment, supplies
- Salary: Kate Giles, Nila Matsler, Mark Rowan

Deliverables

- Written and verbal presentation of latest research results before public release. The verbal presentation will take place as part of our Annual SSIRC Consortium Sponsors Meeting (Typically in May of each year of contract. When this meeting is held in the Paradox Basin area it will include a fieldtrip highlighting the research results.
- Open access 24/7 to all research results including meeting presentations, papers, dissertations, theses, maps, geochemical data on our password protected website. Hard copy upon request.
- Access to all results before public release.
- May request private or joint sponsor fieldtrips or workshops led by the research team for a nominal fee.
- Access to SSIRC-arranged Practical Salt Tectonics Short Course by Mark Rowan.
- Access to SSIRC-arranged Near-Salt Fluid Flow and Thermohaline Circulation Short Course by Mark Fischer.