Allochthonous Salt Initiation and Advance in the Northern Flinders and Eastern Willouran Ranges, South Australia: Using Outcrops to Test Subsurface-Based Models from the Northern GOM*

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Abstract

Outcrops of the Neoproterozoic Callanna Group (~850-800 Ma) comprise an assemblage of brecciated rocks throughout the northern Flinders Ranges and the eastern Willouran Ranges, South Australia, and represent salt bodies in which the evaporite is now absent. Using field relationships and stereonet analysis, we demonstrate that the breccia bodies formed both steep diapirs and subhorizontal salt sheets. The geometries of Callanna Group breccia and adjacent and subjacent strata are used to define new models of allochthonous salt initiation and to test existing models of allochthonous salt advance, many of which were derived from seismic and well data in the northern Gulf of Mexico. We present twelve examples of steep to low-angle transitions: half represent the initial emplacement of allochthonous salt from primary diapirs and the other half-represent ramp to flat transitions within multi-level canopies. Variable stratal geometries adjacent to steep salt include (1) minibasin-scale folding, (2) tabular and tapered composite halokinetic sequences and (3) unfolded strata, whereas strata beneath base-salt flats of subhorizontal salt sheets are always undeformed. Half of the steep salt bodies have preserved roof strata that are 160 to 1,200m wide and 100 to 480m thick, steeply truncated and overlain by shallowly-dipping allochthonous breccia, whereas the other half have no preserved roof strata. We suggest two models to explain the transition from steep diapirs to subhorizontal salt: salt-top breakout and salt-edge breakout. Both models involve piston-like rise of a diapir, which variably decapitates overlying roof strata, with top-salt breakout occurring inboard of the salt flank, thereby preserving a flap of roof, and salt-edge breakout occurring at the steep salt margin. The majority of our examples of allochthonous salt that initiate from primary diapirs display salt-top breakout, whereas most ramp to flat transitions exhibit salt-edge breakout. In all cases, post-breakout, low-angle salt advance was accomplished by thrust advance or extrusive or open-toed advance, with no evidence for subsalt thrust-imbricates, basal shear or rubble zones. While key differences exist between South Australia and the northern Gulf of Mexico,

including evaporite-layer composition, depositional environment and extent of allochthonous salt, the lessons learned from the study of South Australia outcrops complement the data derived from seismic and well data in deepwater settings.

References Cited

Fletcher, R.C., M.R. Hudec, and I.A. Watson, 1995, Salt glacier and composite sediment-salt glacier models for the emplacement and early burial of allochthonous salt sheets: in M.P.A. Jackson, D.G. Roberts, and S. Snelson, (eds), Salt tectonics: a global perspective: AAPG Memoir, v. 65, p. 77-108.

Harrison, H., and B. Patton, 1995, Translation of salt sheets by basal shear: in C.J. Travis, H. Harrison, M.R. Hudec, B.C. Vendeville, F.J. Peel, and B.R. Perkins (eds.), Salt, sediment, and hydrocarbons: SEPM Foundation, Gulf Coast Section, 16th Annual Research Conference, p. 99-107.

Harrison, H., L. Kuhmichel, P. Heppard, A.V. Milkov, J.C. Turner, and D. Greeley, 2004, Base of salt structure and stratigraphy—Data and models from Pompano field, VK 989/990, Gulf of Mexico: in P.J. Post, D.L. Olson, K.T. Lyons, S.L. Palmes, P.F. Harrison, and N.C. Rosen (eds.), Salt-sediment interactions and hydrocarbon prospectivity: SEPM Foundation, Gulf Coast Section, 24th Annual Research Conference, p. 243-270.

Hearon, T.E., IV, M.G. Rowan, T.F. Lawton, P.T. Hannah, and K.A. Giles, 2014, Geology and tectonics of Neoproterozoic salt diapirs and salt sheets in the eastern Willouran Ranges, South Australia: Basin Research, doi: 10.1111/bre.12067.

Hearon, T.E., IV, M.G. Rowan, K.A. Giles, R.A. Kernen, C.E. Gannaway, T.F. Lawton, and J.C. Fiduk, *in press*, Allochthonous salt initiation and advance in the Flinders and Willouran Ranges, South Australia: using outcrops to test subsurface-based models from the northern Gulf of Mexico: AAPG Bulletin.

Hudec, M.R., and M.P.A. Jackson, 2009, The interaction between spreading salt canopies and their peripheral thrust systems: Journal of Structural Geology, v. 31, p. 1114-1129.

Jackson, M.P.A., and M.R. Hudec, 2004, A new mechanism for advance of allochthonous salt sheets: in P.J. Post, D.L. Olson, K.T. Lyons, S.L. Palmes, P.F. Harrison, and N.C. Rosen, (eds.), Salt-sediment interactions and hydrocarbon prospectivity: concepts, applications, and case studies for the 21st century: 24th Annual GCSSEPM Foundation Bob F. Perkins Research Conference, p. 220–242.

Kilby, R.E., F.A. Diegel, and M.J. Styzen, 2008, Age of Sediments Encasing Allochthonous Salt in the Gulf of Mexico: Clues to Emplacement: AAPG Annual Convention, San Antonio, Texas. Web Accessed July 4, 2014. http://www.searchanddiscovery.com/abstracts/html/2008/annual/abstracts/409166.htm.

McGuinness, D.B., and J.R. Hossack, 1993, The development of allochthonous salt sheets as controlled by the rates of extension: Sedimentation and Salt Supply: SEPM Foundation, Gulf Coast Section, 14th Annual Research Conference, p. 127-139.

Orange, D.L., M.M. Angell, J.R. Brand, J. Thomson, T. Buddin, M. Williams, W. Hart, and W.J. Berger, 2004, Geologic and shallow salt tectonic setting of the Mad Dog and Atlantis fields: Relationship between salt, faults, and seafloor geomorphology: The Leading Edge, v. 23, p. 354-365.

Preiss, W.V., 1987, The Adelaide Geosyncline - late Proterozoic stratigraphy, sedimentation, paleontology and tectonics: Bulletin Geological Survey of Southern Australia, v. 53, p. 29-34, 229-243.

Rowan, M.G., K.A. Giles, T.F. Lawton, T.E. Hearon, and P.T. Hannah, 2010, Salt-sediment interaction during advance of allochthonous salt: AAPG Annual Convention and Exhibition Abstracts, v. 19, p. 220.

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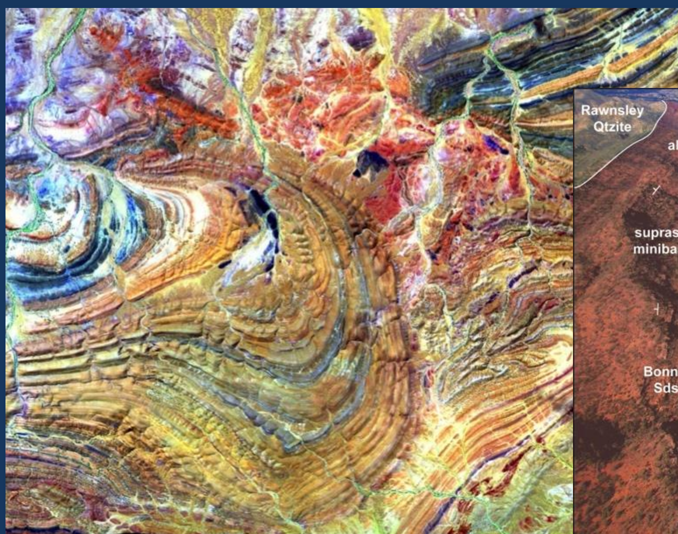

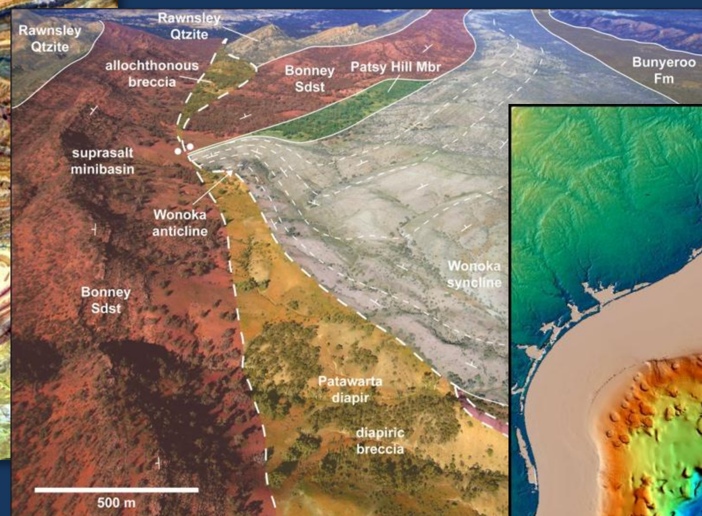

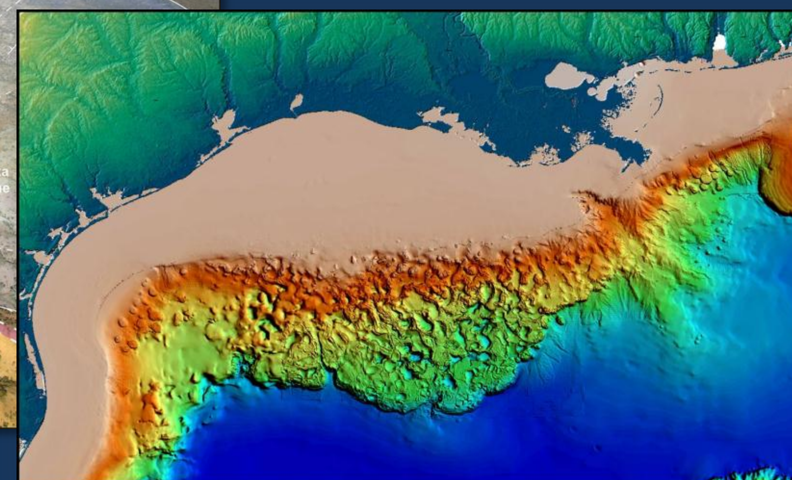

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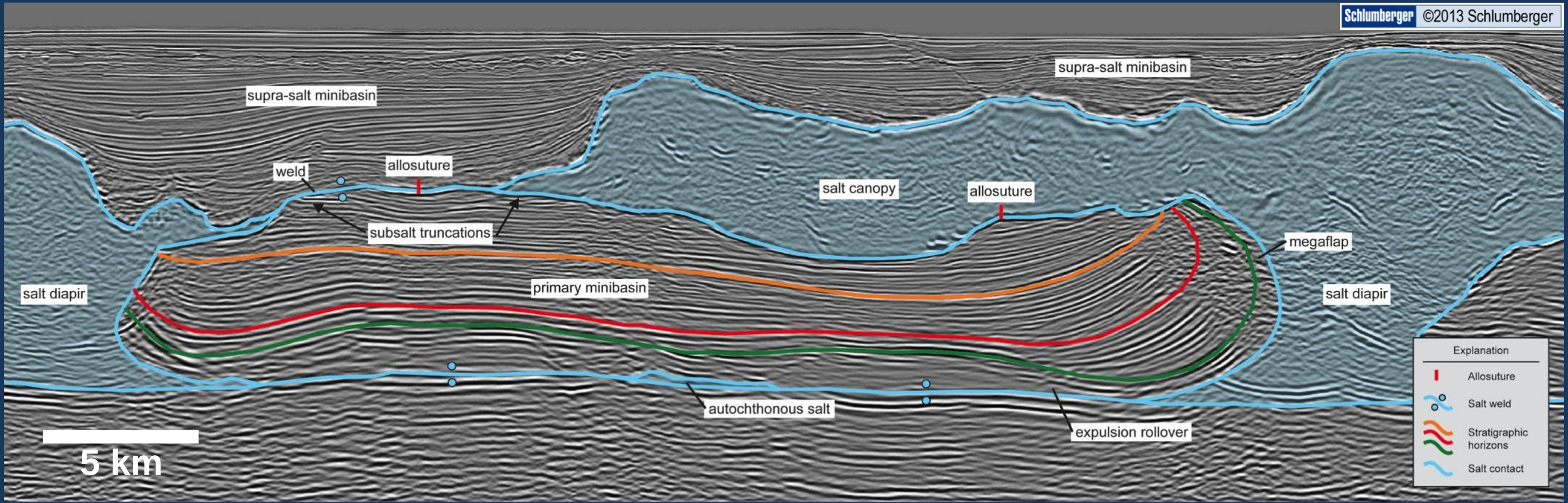
- Bruce Trudgill, Patrick Geesaman, Tyler Hannah
- Wolfgang Preiss & Sandy Menpes (PIRSA)

Objectives

- *Test models of allochthonous salt breakout and emplacement*
- *Examine the transition between steeply dipping salt to shallowly dipping salt*
- *New combined model for allochthonous salt initiation and advance*

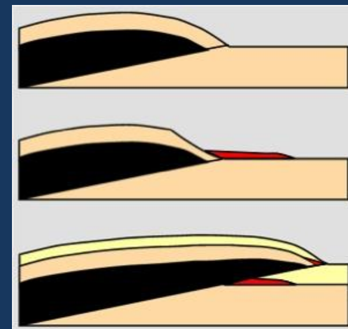
Northern Gulf of Mexico



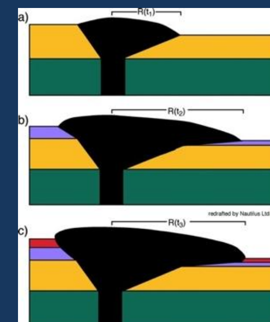
Hearon et al. (2014)

Allochthonous salt advance models

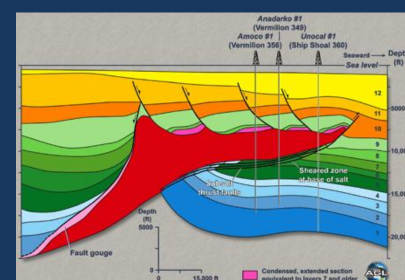
- **Slumped Carapace**
  (McGuinness & Hossack, 1993)

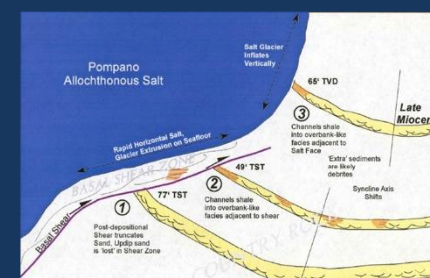


- **Salt Glacier (with or without roof)**
  (Fletcher et al., 1995)

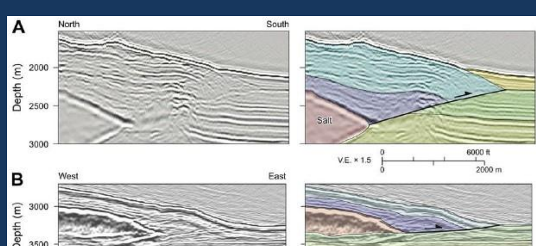


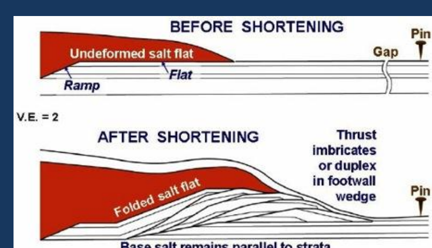
- **Basal Shear**
  (Harrison & Patton, 1995; Harrison et al., 2004)





- **Thrust Advance**
  (Jackson & Hudec, 2004; Hudec & Jackson, 2009)

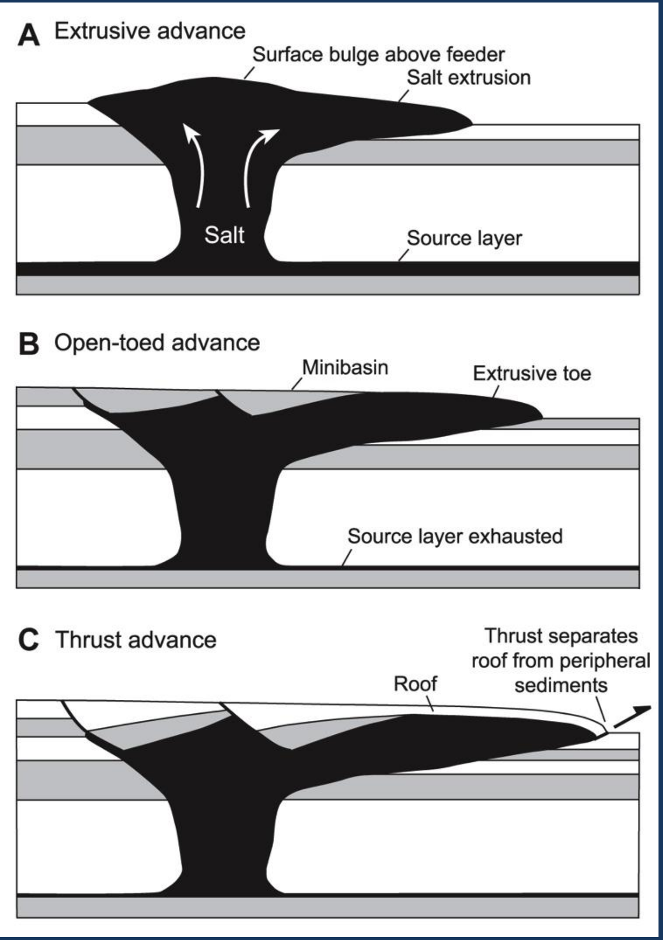


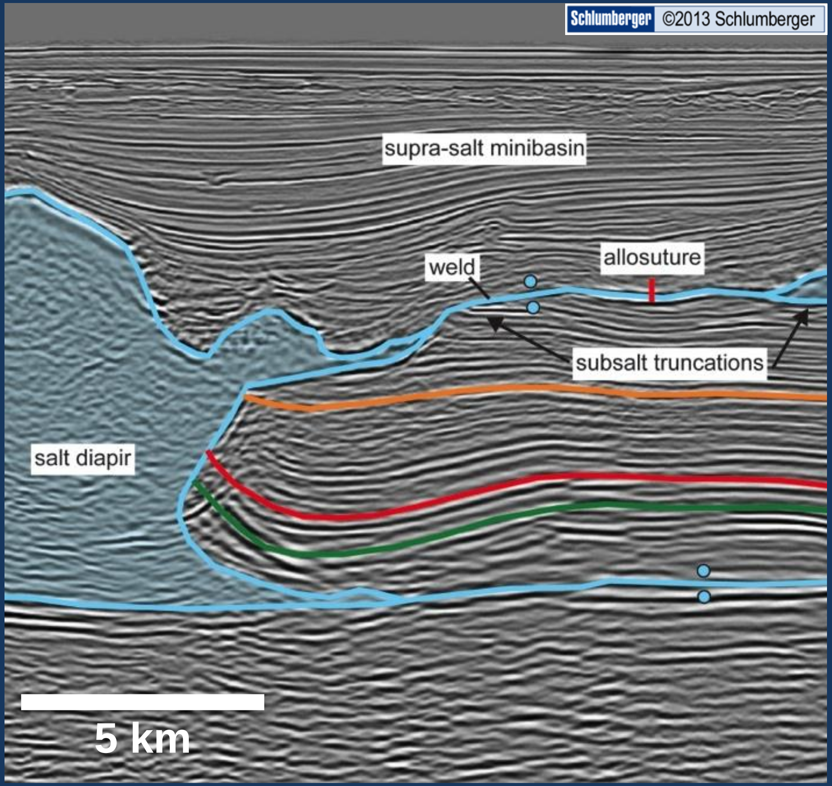


Advance vs. Initiation

Advance of allochthonous salt along ramp/flat trajectories

Transition from primary or secondary feeder to shallowly dipping allochthonous salt

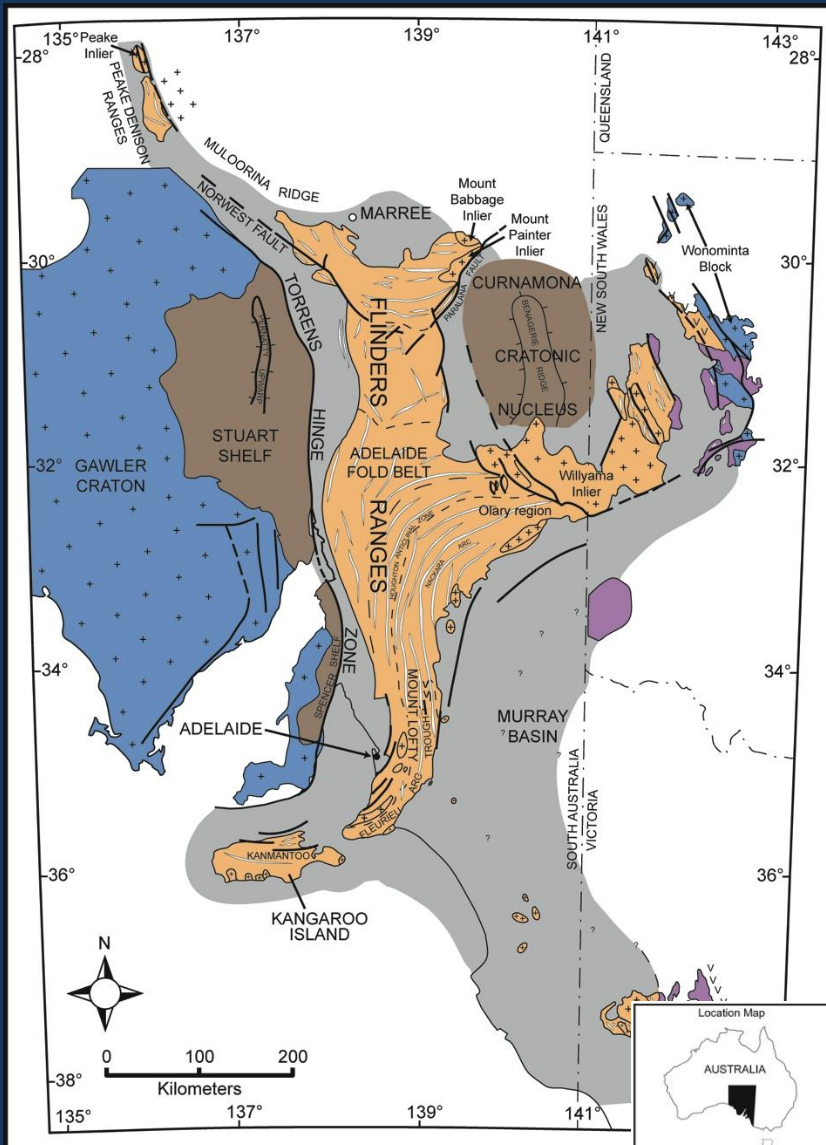


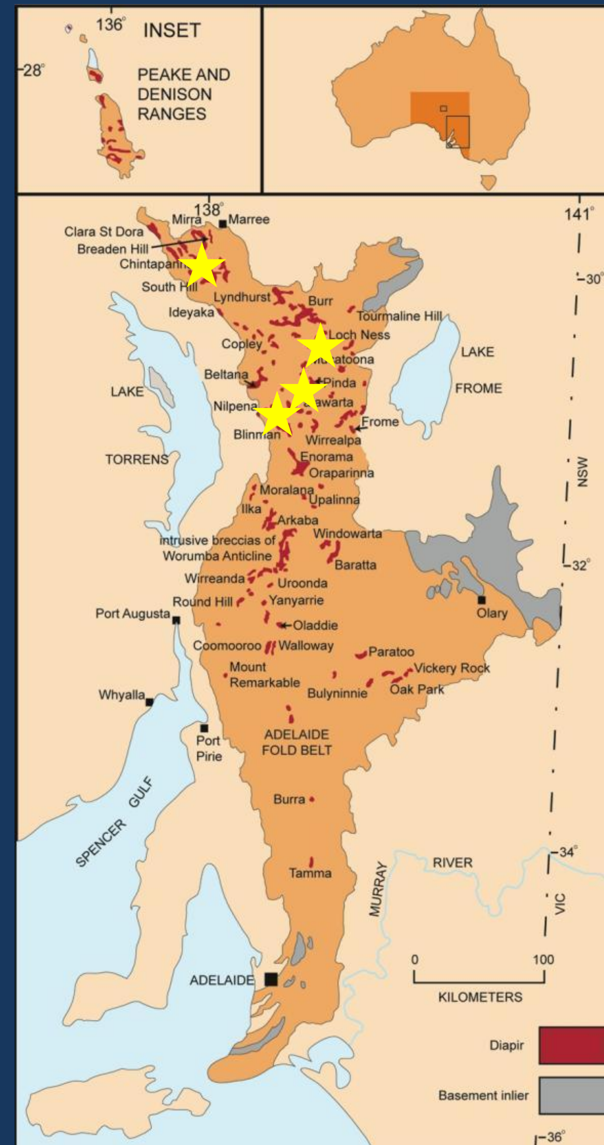


Hudec & Jackson (2009)

Hearon et al. (2014)

Adelaide Fold Belt, South Australia

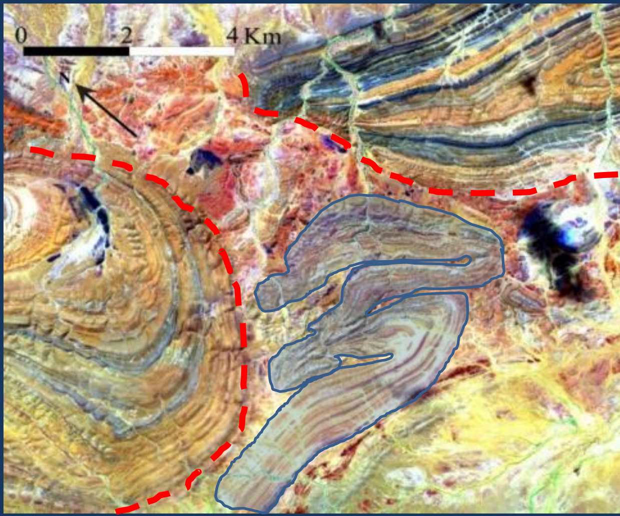


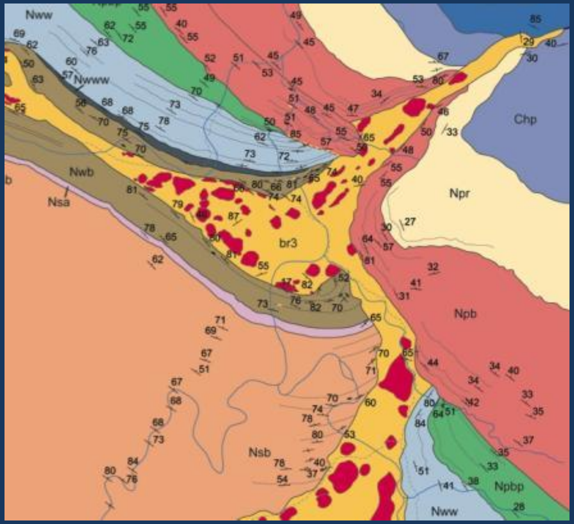


Redrafted from Preiss, 1987

Callanna Group Breccia

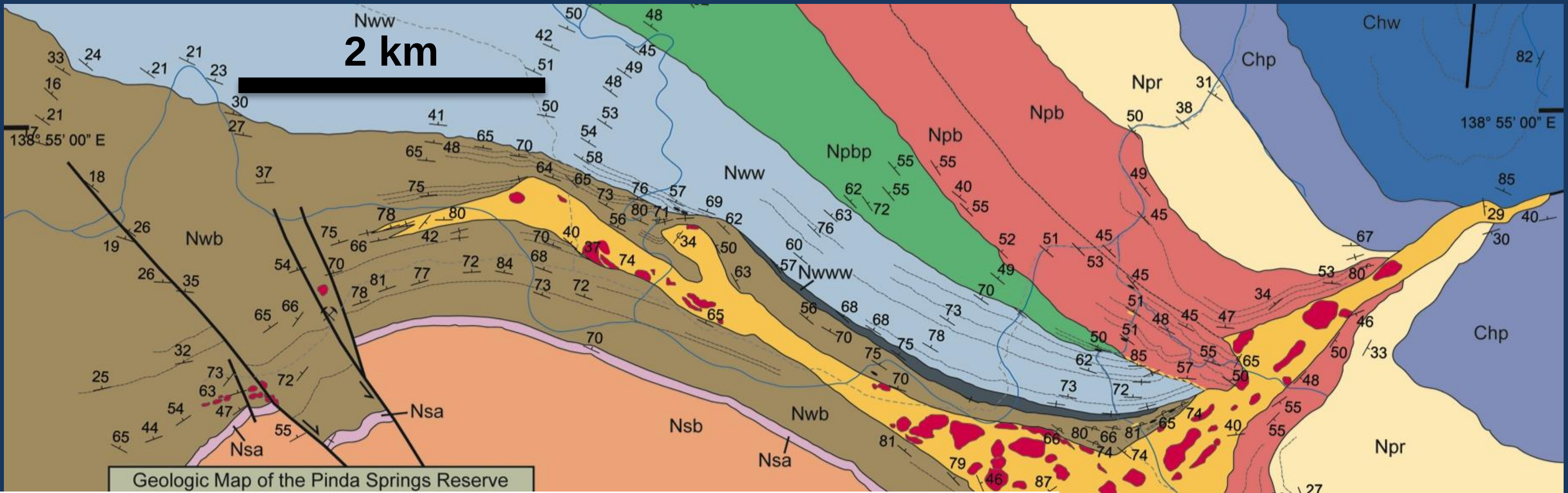
- **Brecciated assemblage of carbonate, siliciclastic and metaigneous rocks in meter to km-scale blocks = diapiric breccia**
- **Salt no longer present at surface**
- **Pseudomorphed evaporite minerals**
- **Flanking growth strata**
- **Delineates diapirs, salt welds, remnant allochthonous salt canopies**
- **Classified as a Layered Evaporite Sequence**

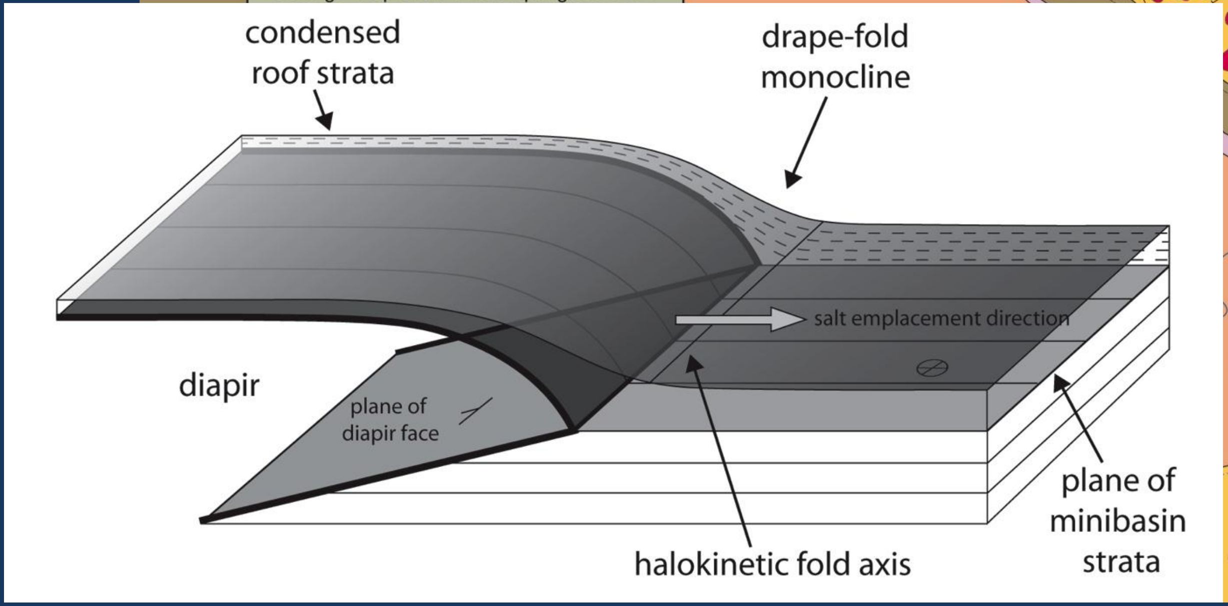




2D Map View in South Australia
Need to understand 3D relationships

Pinda diapir (map)

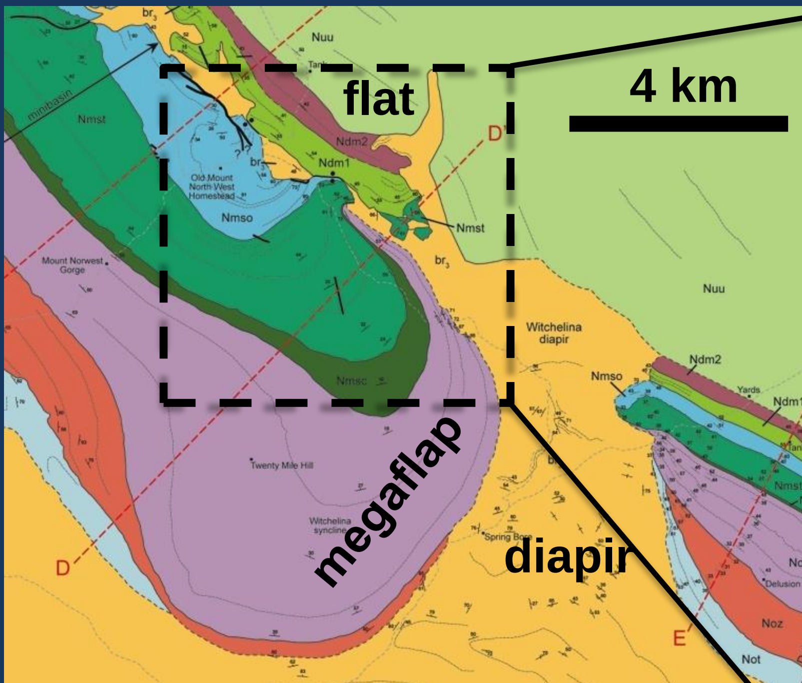


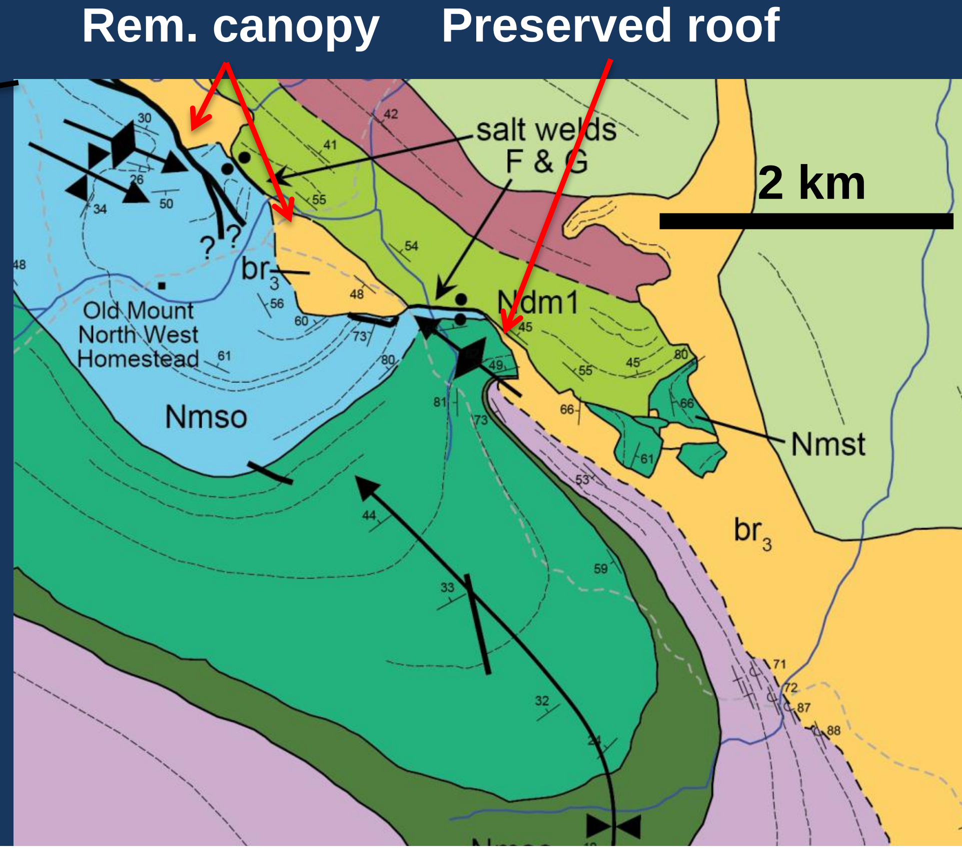


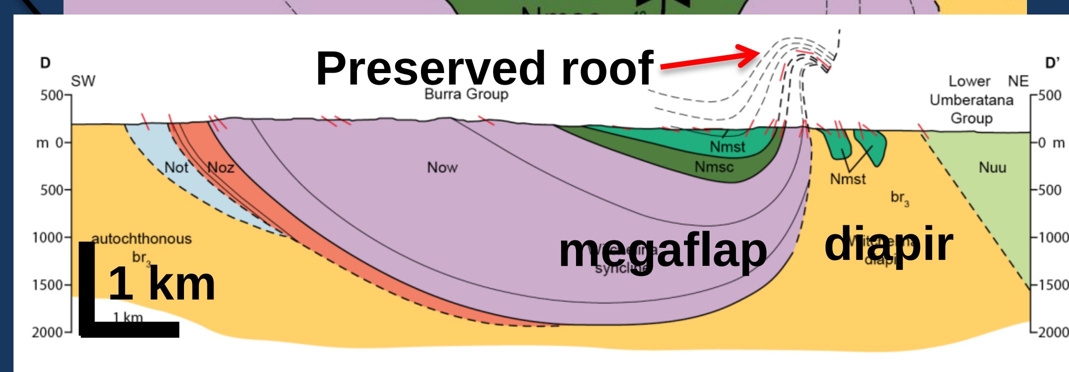
Minibasin-scale folding

Primary diapir example

Witchelina diapir (map)







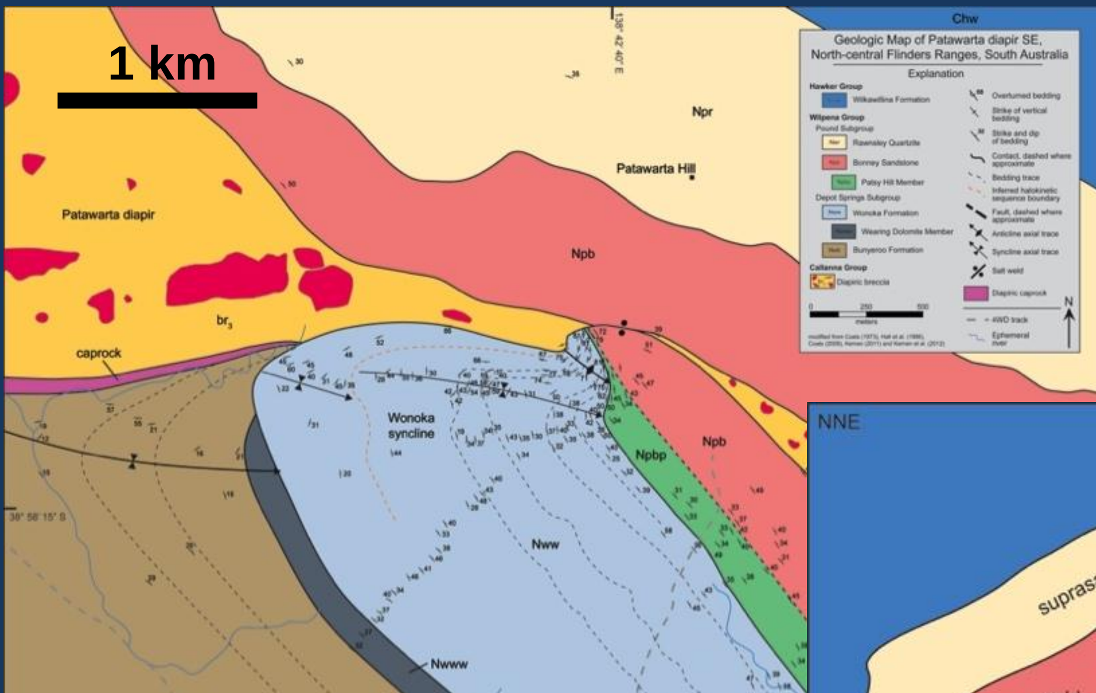
- Megaflap at transition
- Steep to overturned roof
- Subparallel strata beneath flat

Hearon et al. (2014)

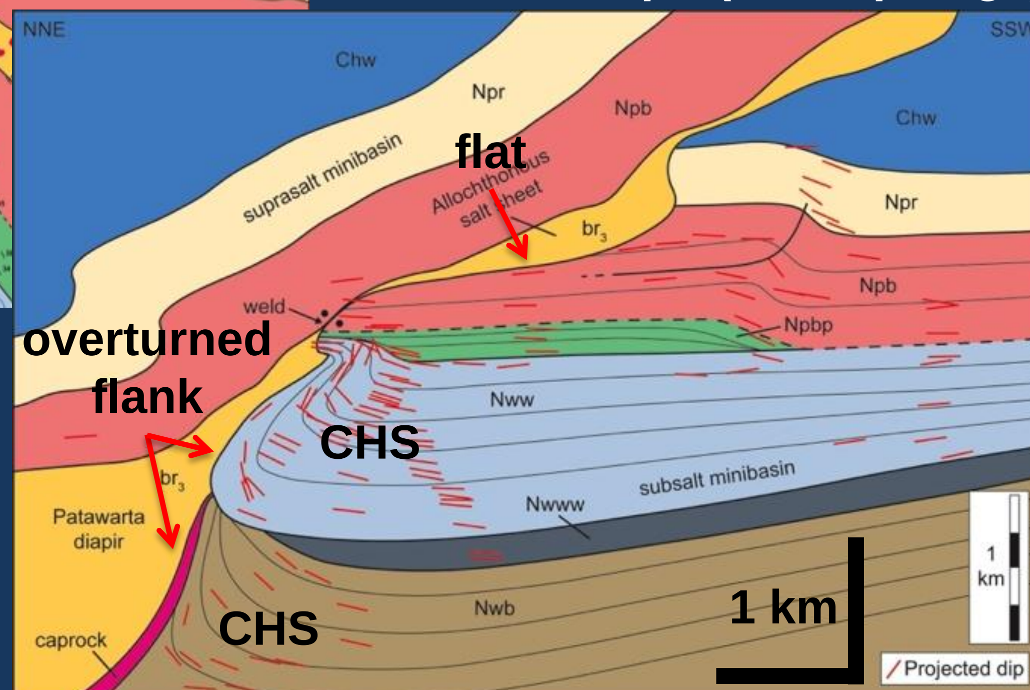
Composite Halokinetic Sequences

Ramp-to-flat example

Patawarta diapir (map)



Patawarta diapir (down-plunge)



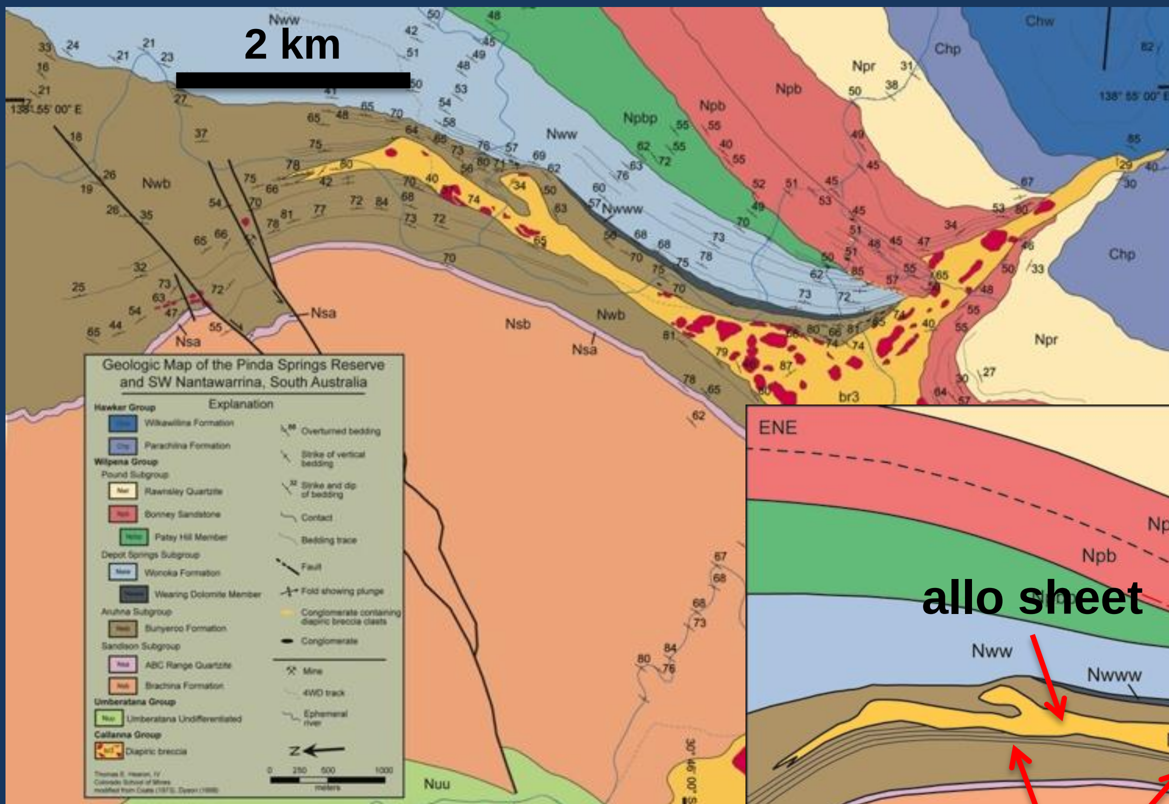
- **Tapered CHS**
- **Truncated roof at transition**
- **Subparallel strata beneath flat**

Hearon et al. (in press)

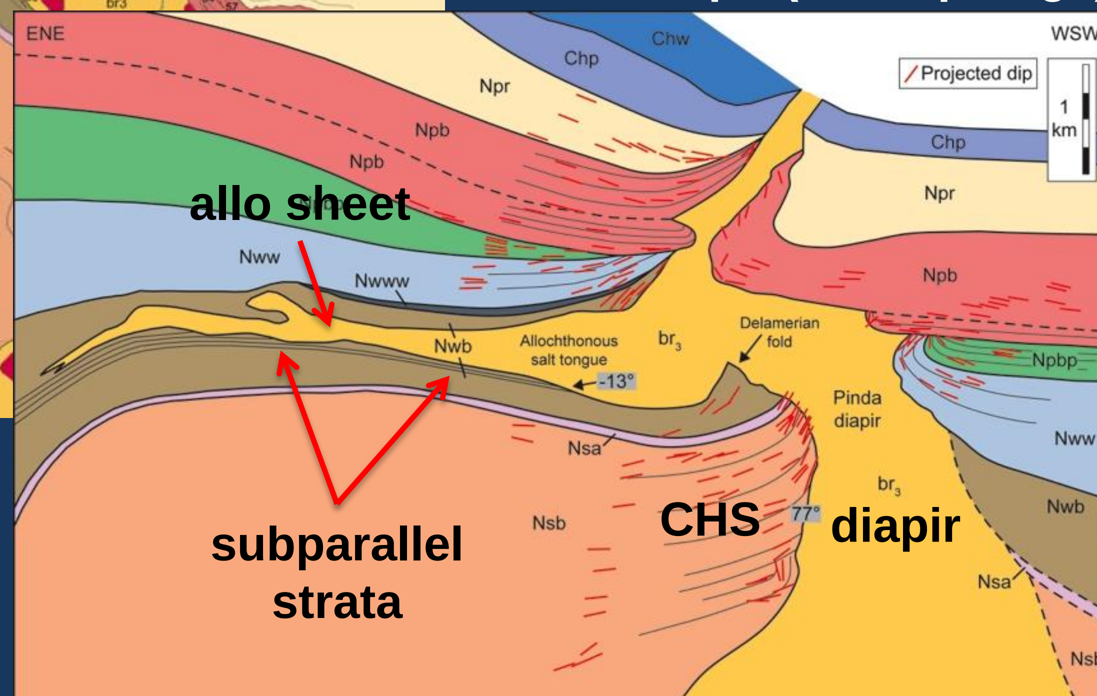
Composite Halokinetic Sequences

Secondary diapir > allo sheet example

Pinda diapir (map)



Pinda diapir (down plunge)



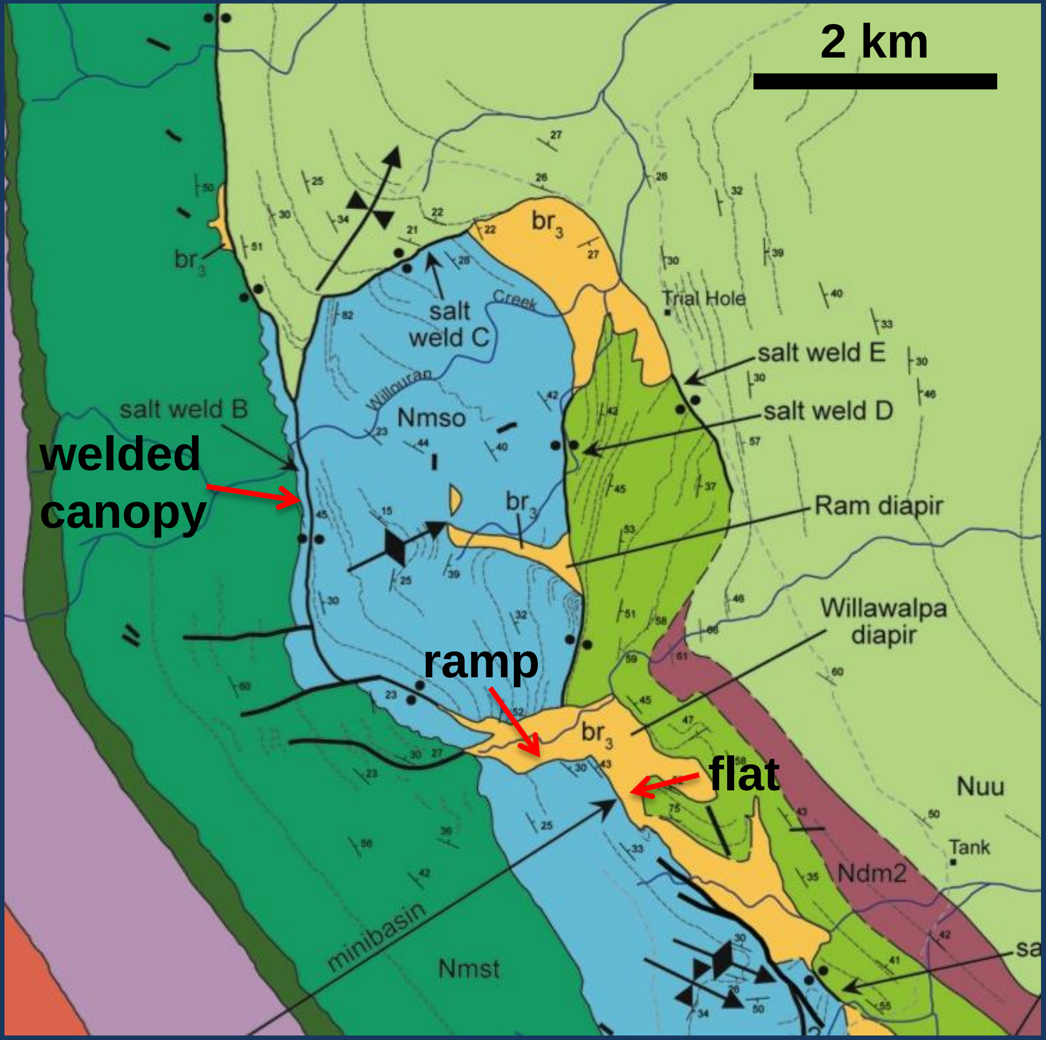
- **Tabular CHS**
- **Truncated roof at transition**

Hearon et al. (in press)

Unfolded Strata

High-angle stratal truncations

Eastern Willouran Ranges

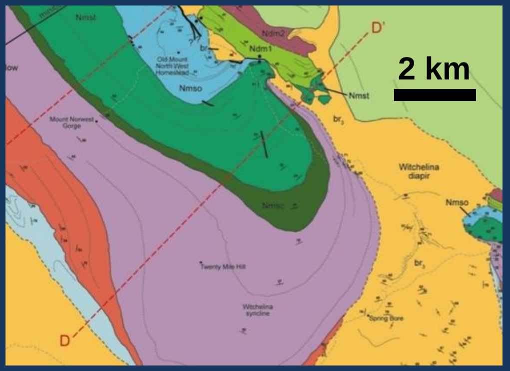


High angle truncations > salt flat

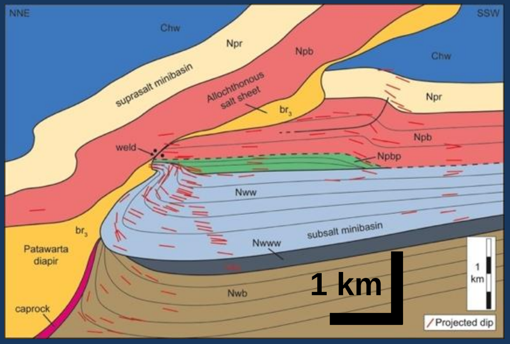
Summary of Data

- 13 examples of sharp transitions
  - Abrupt dip changes: 60° - 138°
- Presence and style of folding irrelevant
  - Megaflap, composite halokinetic sequences (CHS) & unfolded strata at transition
- 54% have roof; 46% do not
- BOS flats lack folds
- Absence of basal shear, thrust faults or rubble zones; rare MTCs

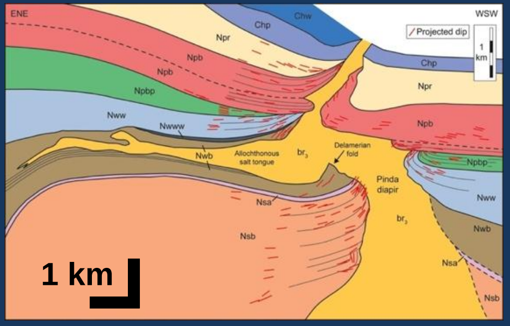
Eastern
Willouran Ranges



Patawarta diapir



Pinda diapir



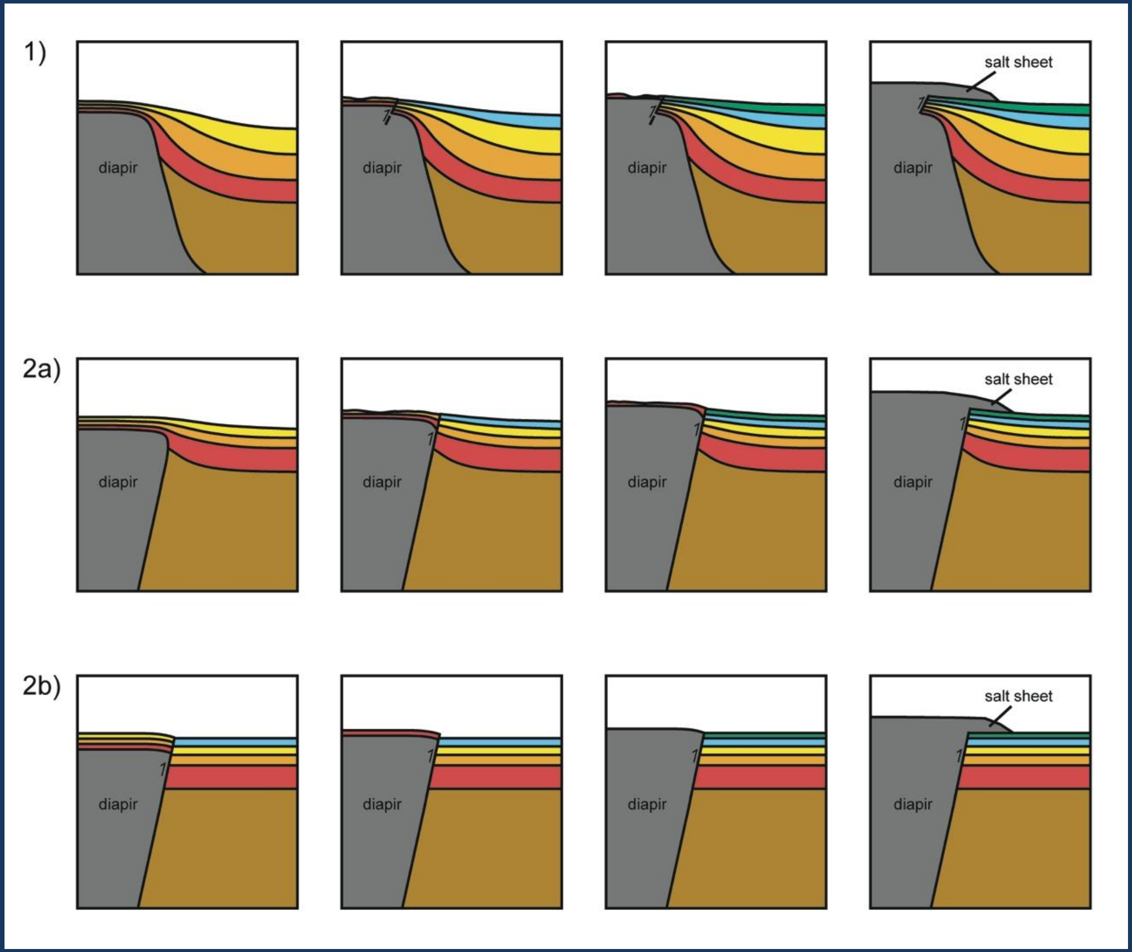
Hearon et al. (in press)

New models for allochthonous salt initiation and breakout

SALT-TOP BREAKOUT

SALT-EDGE BREAKOUT A

SALT-EDGE BREAKOUT B



Partially decapitated drape fold

Fully decapitated drape fold

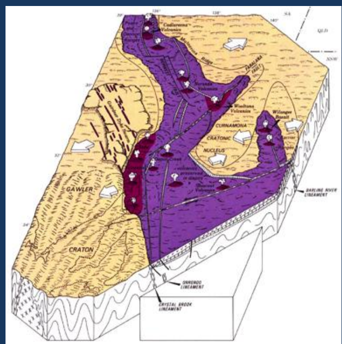
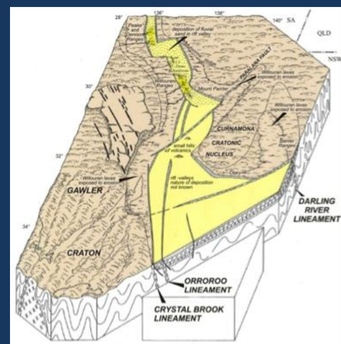
Long-lived Fault contact

- ***Explains variety of stratal truncations at diapir-allo salt transition***

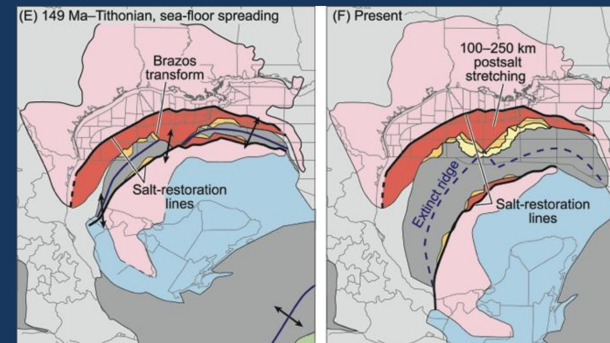
Hearon et al. (in press)

South Australia vs. Northern GoM

Failed rift

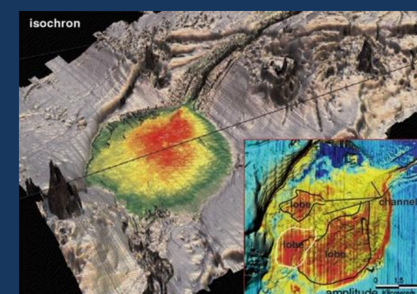



Passive margin

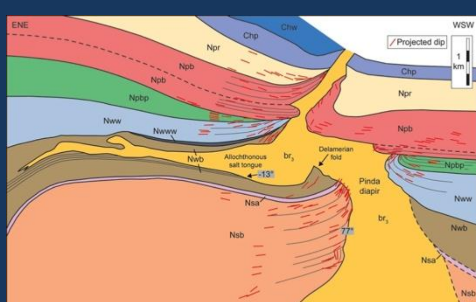


Shallow water environment
Thinner roof, dissolution

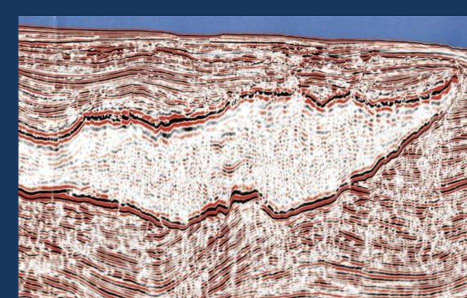

Predom. deepwater environment
Thicker roof, rare dissolution



Limited salt sheets



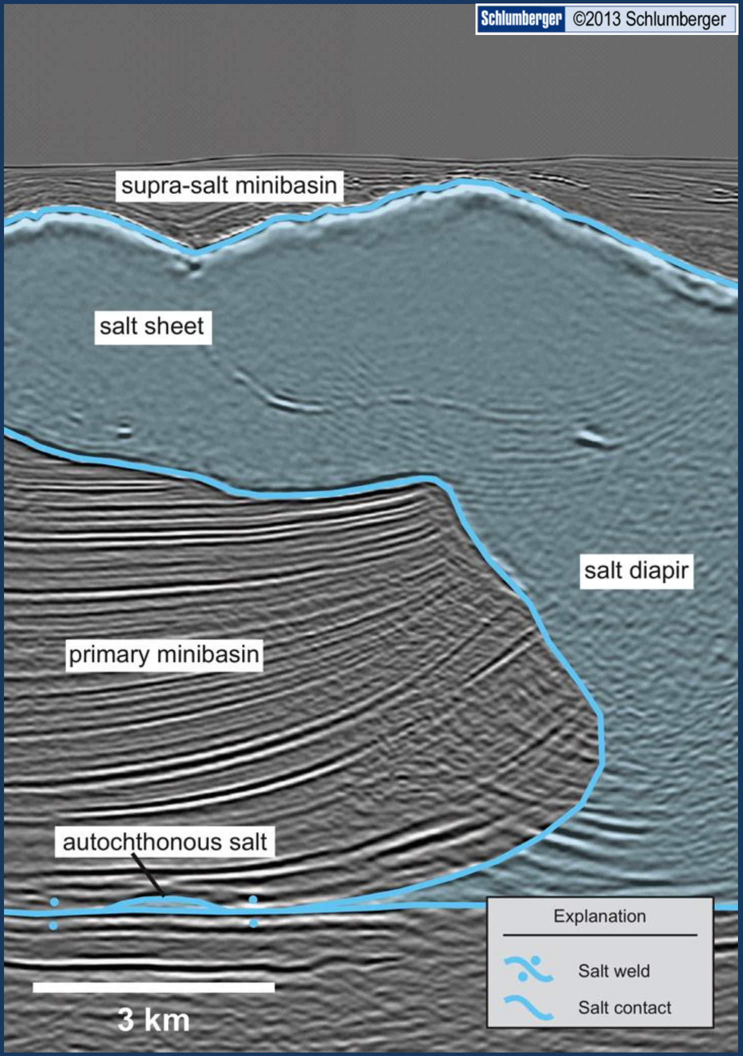
Extensive salt sheets & canopies



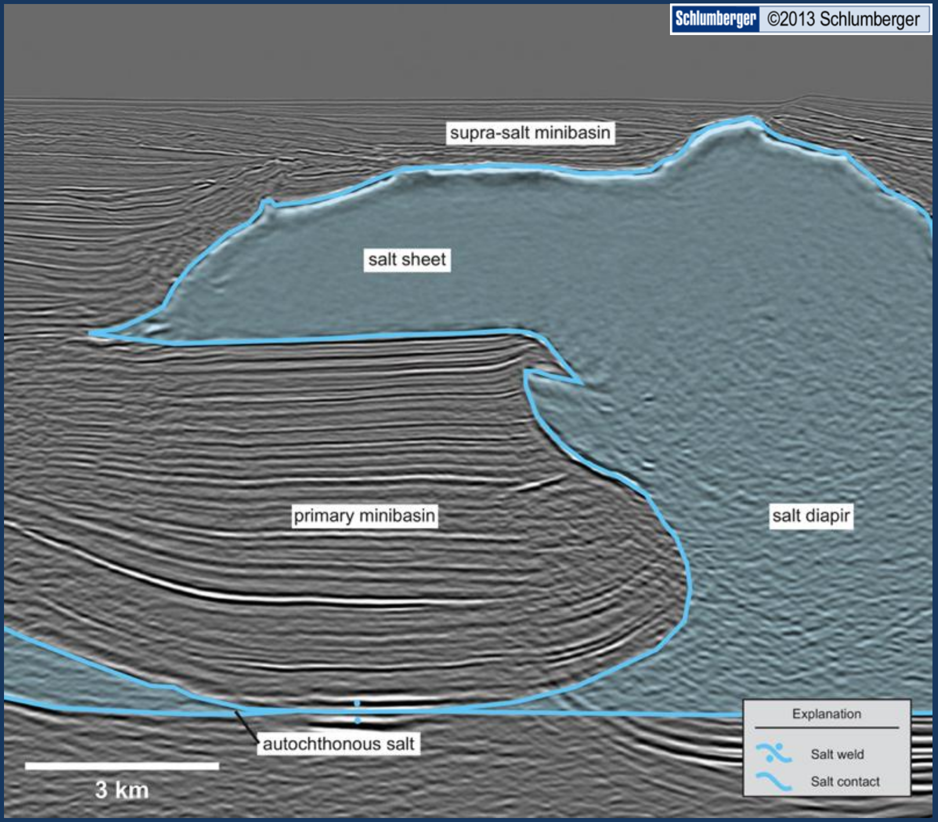
Despite the differences...

GOM Seismic Analogues

SALT-EDGE BREAKOUT



SALT-TOP BREAKOUT

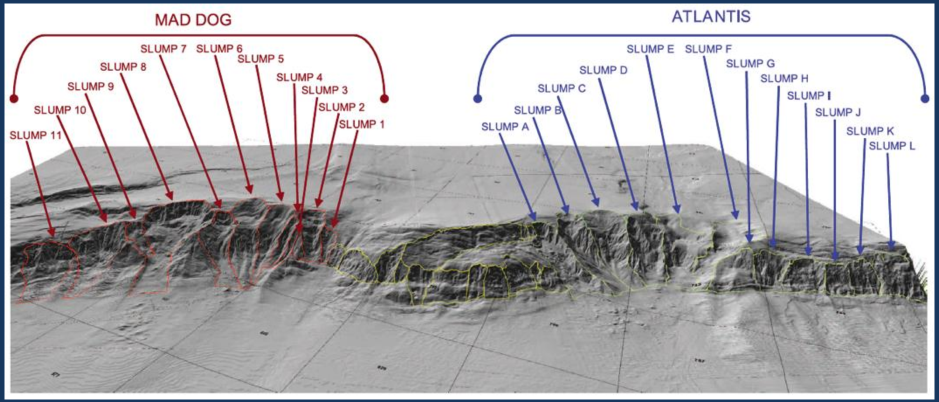


1:1 scale

Hearon et al. (in press)

Northern GoM Rubble Zones

- **75% of wells examined encountered rubble zone (Kilby et al., 2008)**



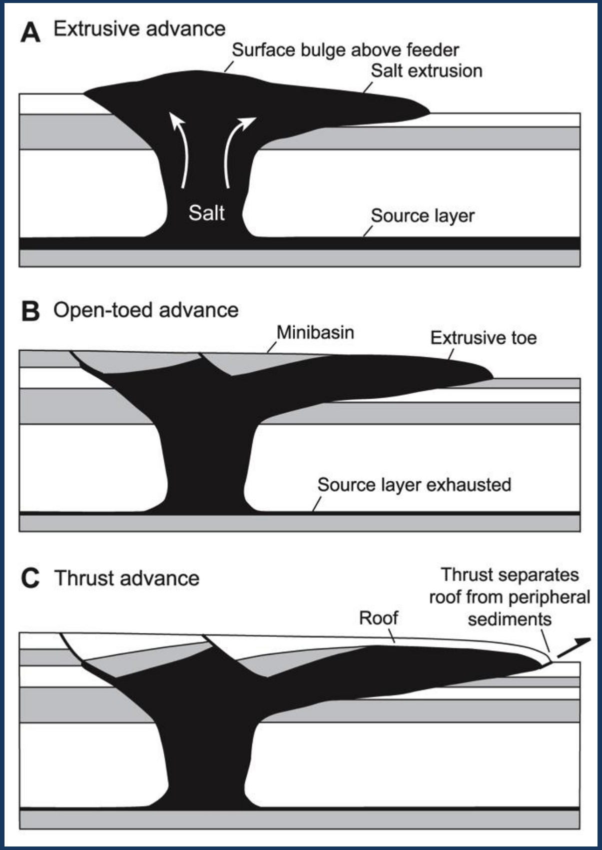
Orange et al. (2004)

Why no rubble in South Australia?

- **Thin roof (or lack of roof)**
  - Shallow water to subaerial depositional setting
- **Dissolution**
  - Exposure of salt without a roof
- **Lower relief**
  - Rare debris flow deposits in BOS strata

Advance vs. Initiation

Advance of allochthonous salt along ramp/flat trajectories

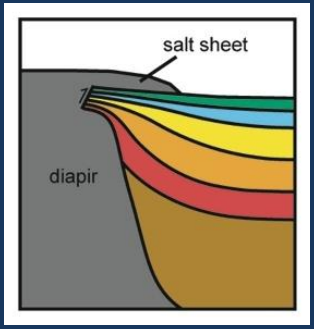


No evidence of basal shear, thrust faults or rubble zone along BOS in South Australia

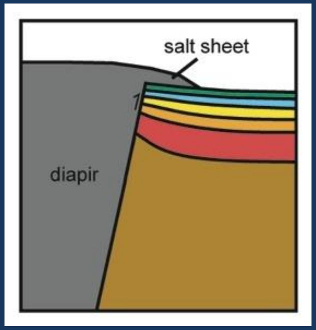
Hudec & Jackson (2009)

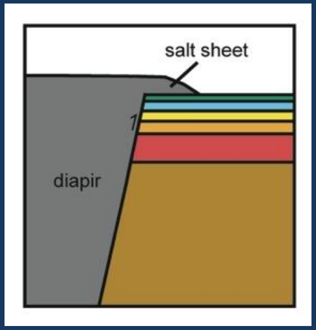
Transition from primary or secondary feeder to shallowly dipping allochthonous salt

SALT-TOP BREAKOUT



SALT-EDGE BREAKOUT





Partially to fully decapitated drape fold; Long lived fault contact

Hearon et al. (in press)

Allochthonous salt conclusions

Test models of allochthonous salt breakout and emplacement…

- Allochthonous salt breakout is abrupt; piston-like breakthrough of roof
- No correlation between presence/style of folding and breakout
- Geometry and process of allochthonous salt initiation similar between SA & GOM
- Two new allochthonous salt initiation/breakout models

- **Salt evolution**
  - Better understanding of processes involved during transition from steep diapirs to shallowly-dipping allochthonous salt
- **Range of geometries**
  - Megaflap, composite halokinetic sequences (CHS) & unfolded strata present at transition from diapirs and allochthonous salt