A Halokinetic Drape-Fold Model for Caprock in Diapir-Flanking and Subsalt Positions*

Kate Giles[1], Tim Lawton[2], Austin Shock[2], Rachelle Kernen[3], Thomas Hearon[4], and Mark Rowan[5]

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[1]University of Texas at El Paso, El Paso, TX (kagiles@utep.edu)
[2]New Mexico State University, Las Cruces, NM
[3]Shell Oil Company, Houston, TX
[4]Colorado School of Mines, Golden, CO
[5]Rowan Consulting, Inc, Boulder, CO

Abstract

Existing genetic models for diapiric caprock are largely based on observations from excavations or drill-hole data in near-surface or outcropping caprock developed on the crests of vertical diapirs. In these models, caprock develops in a top-salt position during a long-lived, relatively continuous accretionary process of halite dissolution by cross-flow of undersaturated waters, with concomitant anhydrite accretion by underplating and subsequent alteration of anhydrite to carbonate in the presence of anaerobic sulfate-reducing bacteria. Caprock in diapir-flanking and subsalt positions is typically interpreted to form by the same dissolution process, but with undersaturated waters flowing along the salt-sediment interface in a deeper subsurface setting.

The Neoproterozoic Patawarta salt sheet in the Flinders Ranges, South Australia, contains a laterally extensive (>10km) dolomite caprock assemblage preserved in both subsalt and suprasalt positions along the sheet margins. The caprock is 3-100 m thick and contains massive, laminated, and crackle breccia textures. The near-vertical to overturned subsalt caprock parallels steeply dipping strata of the Bunyeroo Formation in a tapered composite halokinetic sequence (CHS). The caprock terminates upward at an angular unconformity marking the upper boundary of the CHS. Basal strata of the overlying Wonoka Formation onlap the truncated caprock and contain conglomerates of caprock-derived detritus, indicating that the caprock formed in a suprasalt position prior to deposition of the Wonoka, which forms another CHS but without caprock. We observe similar relationships in caprock and adjacent Permian and Mesozoic strata flanking the Castle Valley diapir in the Paradox Basin, Utah.

Our model for flanking and subsalt caprock comprises 4 steps: 1) caprock develops in a crestal position by cross-flow waters; 2) continued diapiric rise and minibasin subsidence cause drape folding of roof strata and competent caprock, which detaches from the underlying halite-dominated diapir and rotates off the diapir top into a flanking position; 3) topography generated by diapir inflation as diapir-rise rates exceed

sediment-accumulation rates result in erosional thinning of the roof to create an angular unconformity that truncates the underlying CHS and flanking caprock; 4) increasing rates of sediment accumulation relative to diapir rise lead to onlap of the overlying CHS, which may or may not develop a new crestal caprock assemblage.

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Kate Giles (UTEP, kagiles@utep.edu)

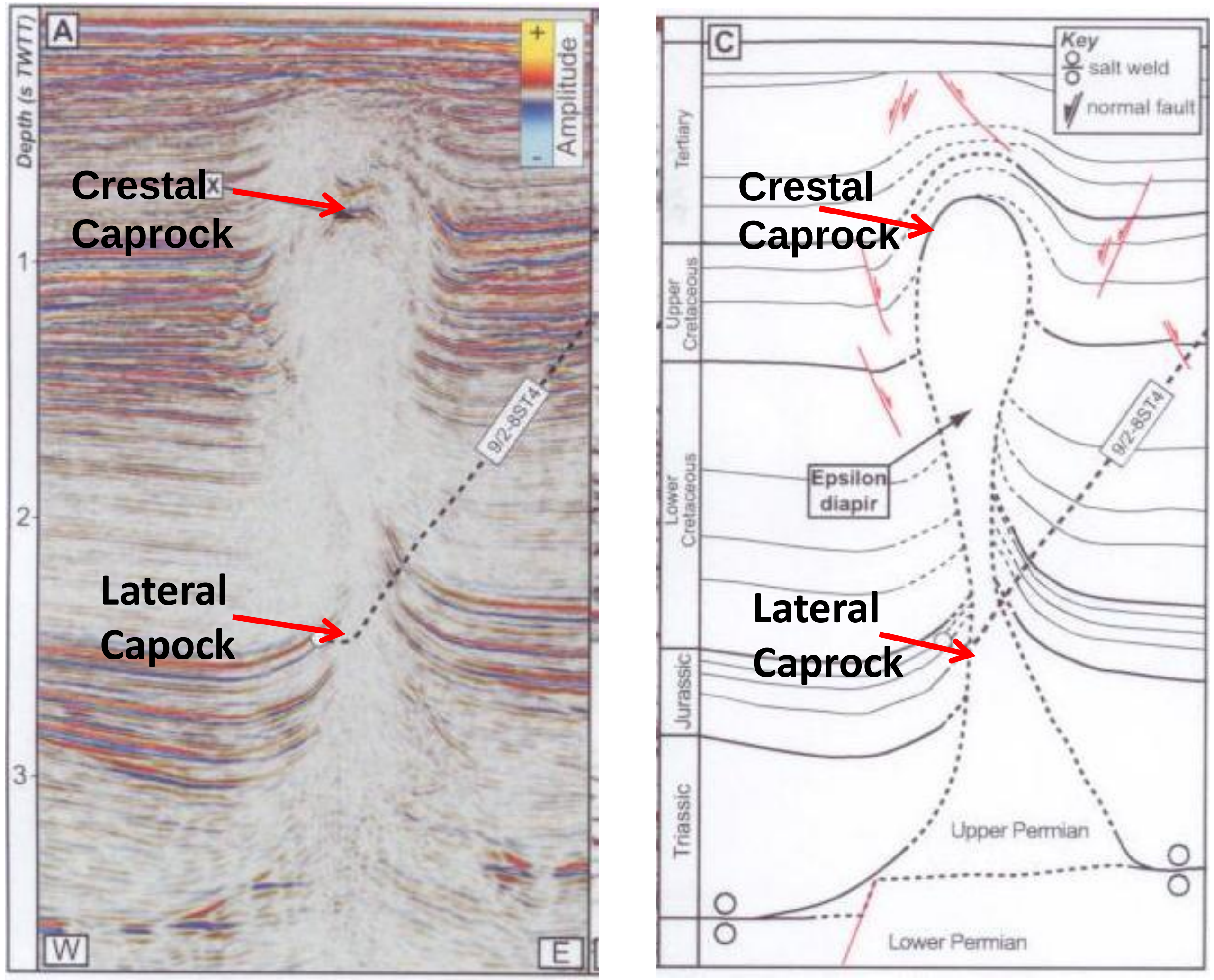
Tim Lawton & Austin Shock (NMSU)

Rachelle Kernen (Shell)

Thomas Hearon IV (CSM)

Mark Rowan (RCI)

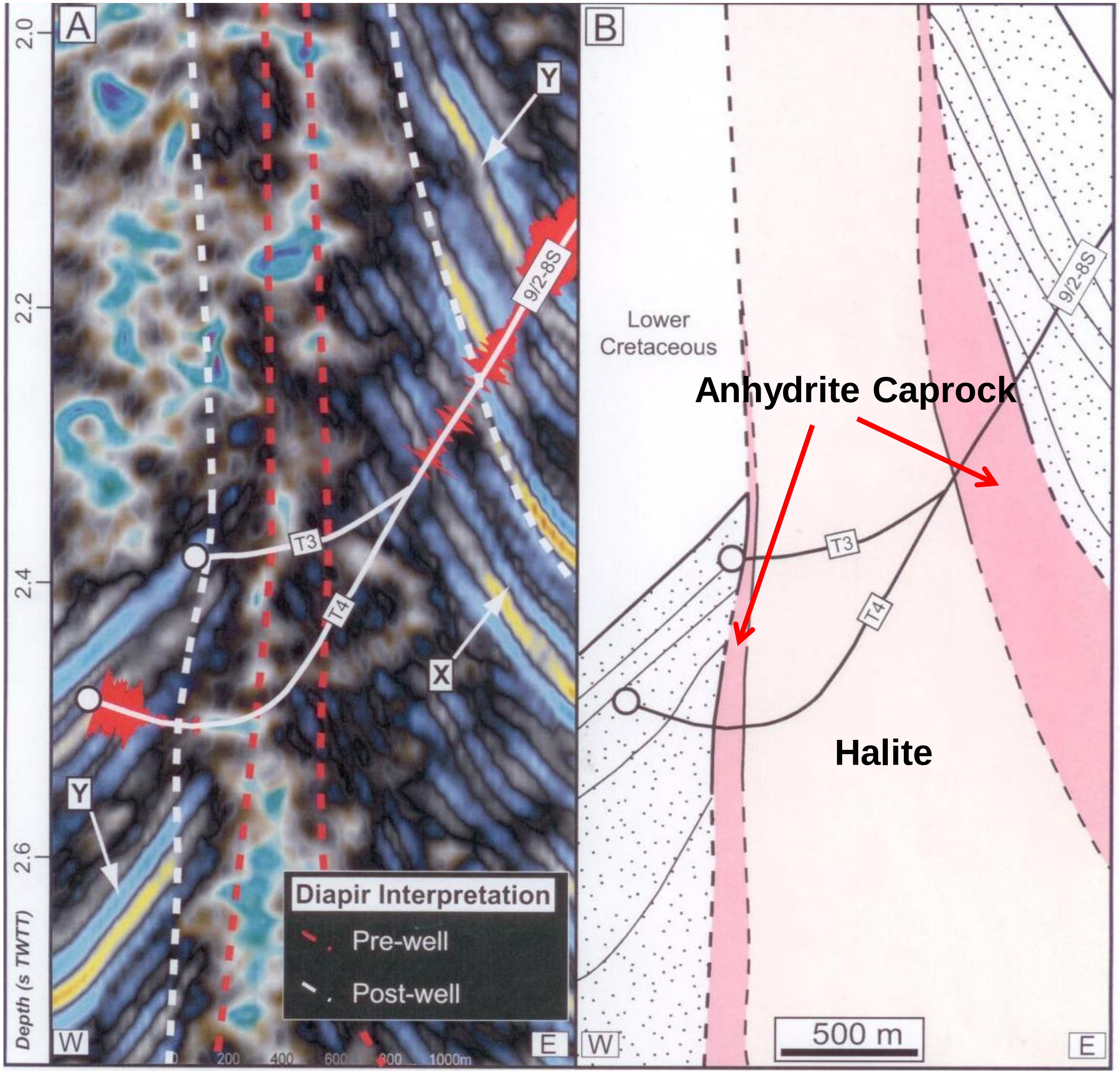
Subsurface "Lateral Caprock" Example
Epsilon Diapir, North Sea



Jackson, C. A. & Lewis, M.M., 2012, Borehole Calibration of Salt Diapir Lithology; *In press –Journal of the Geological Society of London*

Epsilon Diapir Lateral Caprock

Post-Drill Results



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Hypotheses for Lateral Caprock Formation

① Formed in situ in diapir-flank position in a steeply dipping attitude?

② Formed in diapir crest position in a horizontal attitude and was later displaced?

Why Should We Worry About How Lateral Caprock Forms?

1. Drilling Hazard?
2. Salt Flank Trap Integrity

    Reservoir? *Spindletop*

    Seal?

    Migration pathway?

*We need to understand the **process***

*to increase **prediction**!*

Common Caprock Lithologies

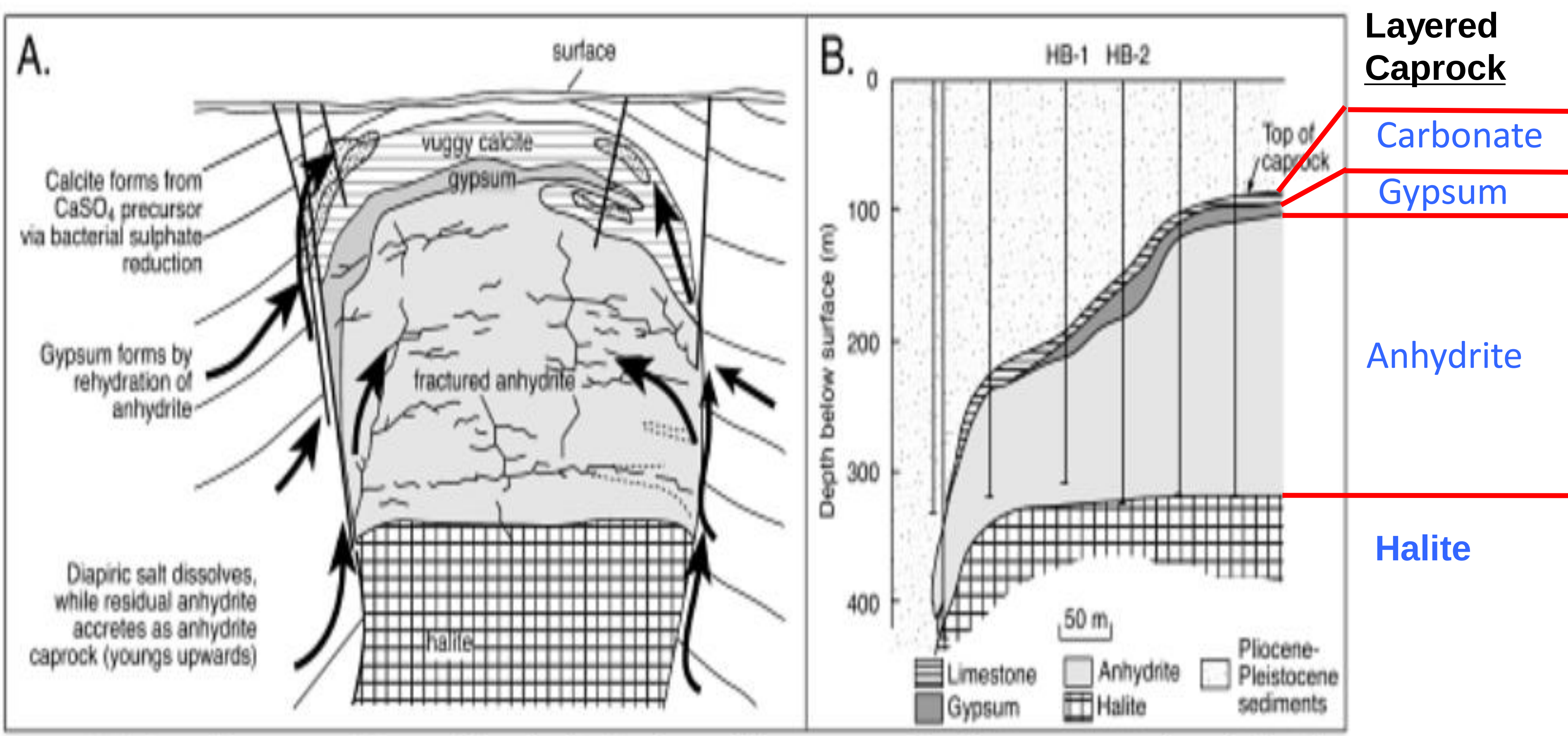
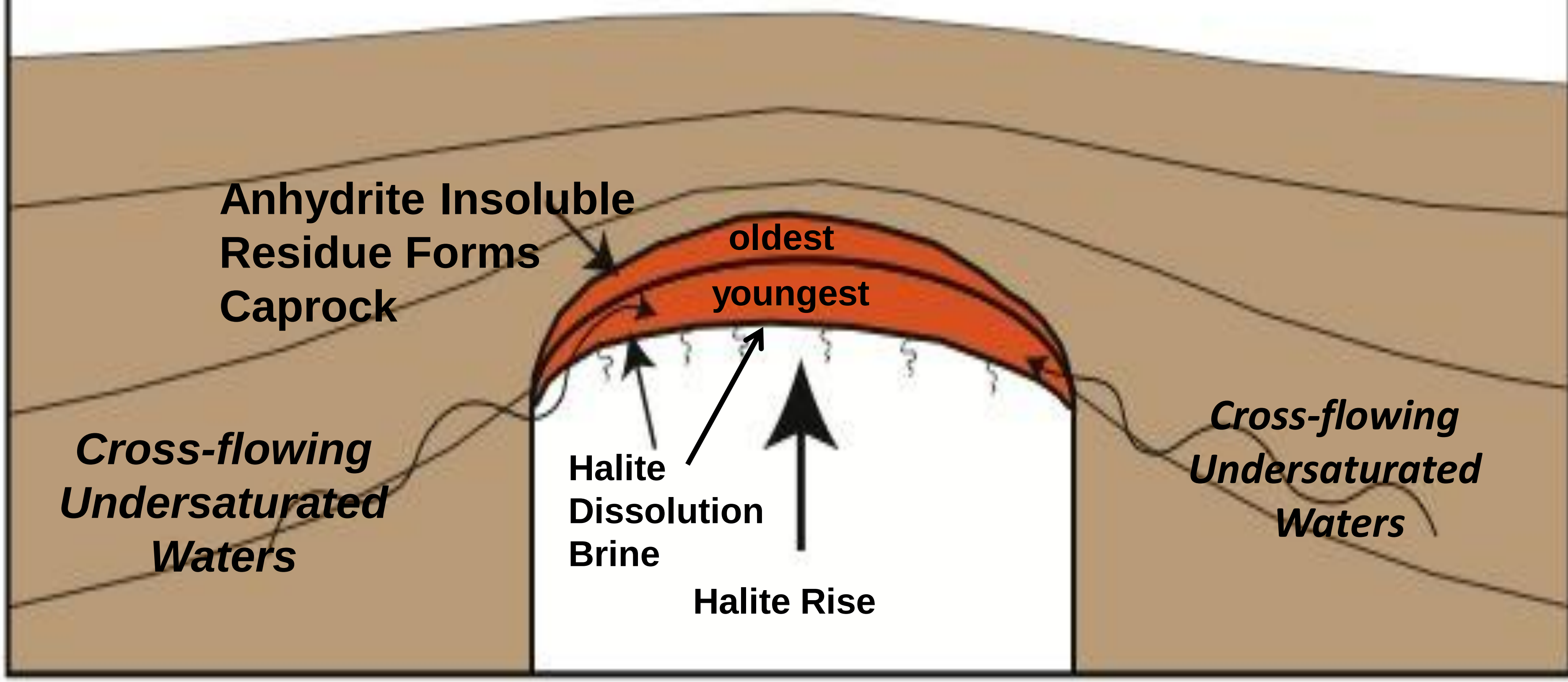


Figure 6.64. Caprock zonation. A) Caprock forms by the dissolution of the upper part of a salt structure once salt supply dwindles the rate of rise slows and it is flushed by undersaturated phreatic waters (black arrows). Dissolution of the halite leaves behind anhydrite that then accretes into an anhydrite caprock. The upper portion of the anhydrite unit rehydrates to gypsum that is then converted to limestone by bacterial sulphate reduction. B) Section of Hockley dome caprock showing relative thickness of the caprock zones and depth below the landsurface based on drilling (after Hallager et al., 1990).

Warren, 2006

Anhydrite Caprock Formation

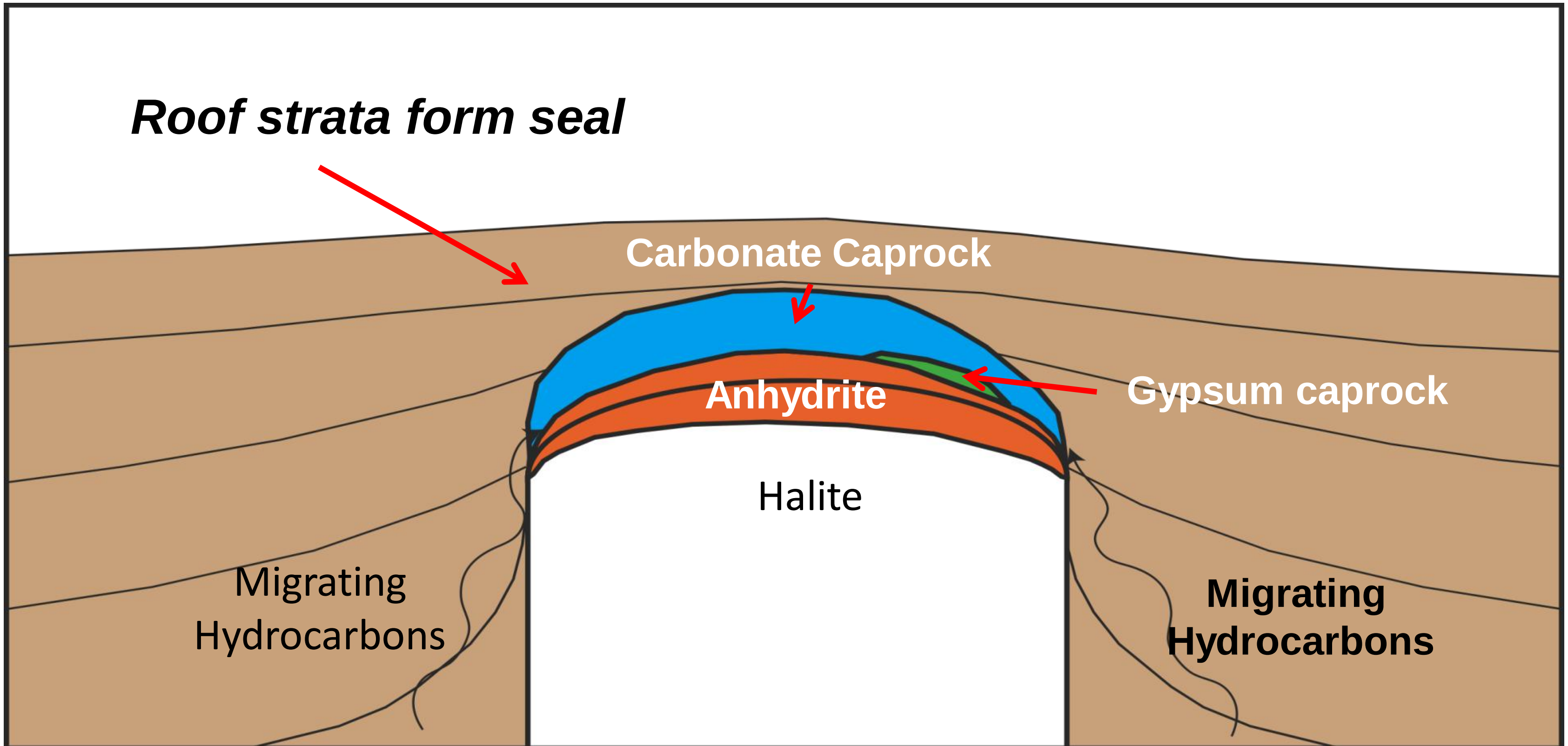
***Anhydrite insoluble residue accretes in cycles by underplating**
***Creates roughly horizontal coarse-crystalline bands in central part of diapir; inclined near margins**
*** GoM diapirs average 5% anhydrite**



Carbonate Caprock Formation

Biogeochemical Process:

1) **Anhydrite dissolution** $CaSO_4 \rightarrow Ca^{2+} + SO_4^{2-}$
2) **Sulfate reduction by anaerobic bacteria (SRB) in hydrocarbons**
   $SO_4^{2-} + CH_3COOH + 2\ H^+ \rightarrow HS^- + 2\ HCO_3^- + 3\ H^+$
3) **Carbonate precipitation**
   $2HCO_3 + Ca \rightarrow CaCO_3 + H + HCO_3$

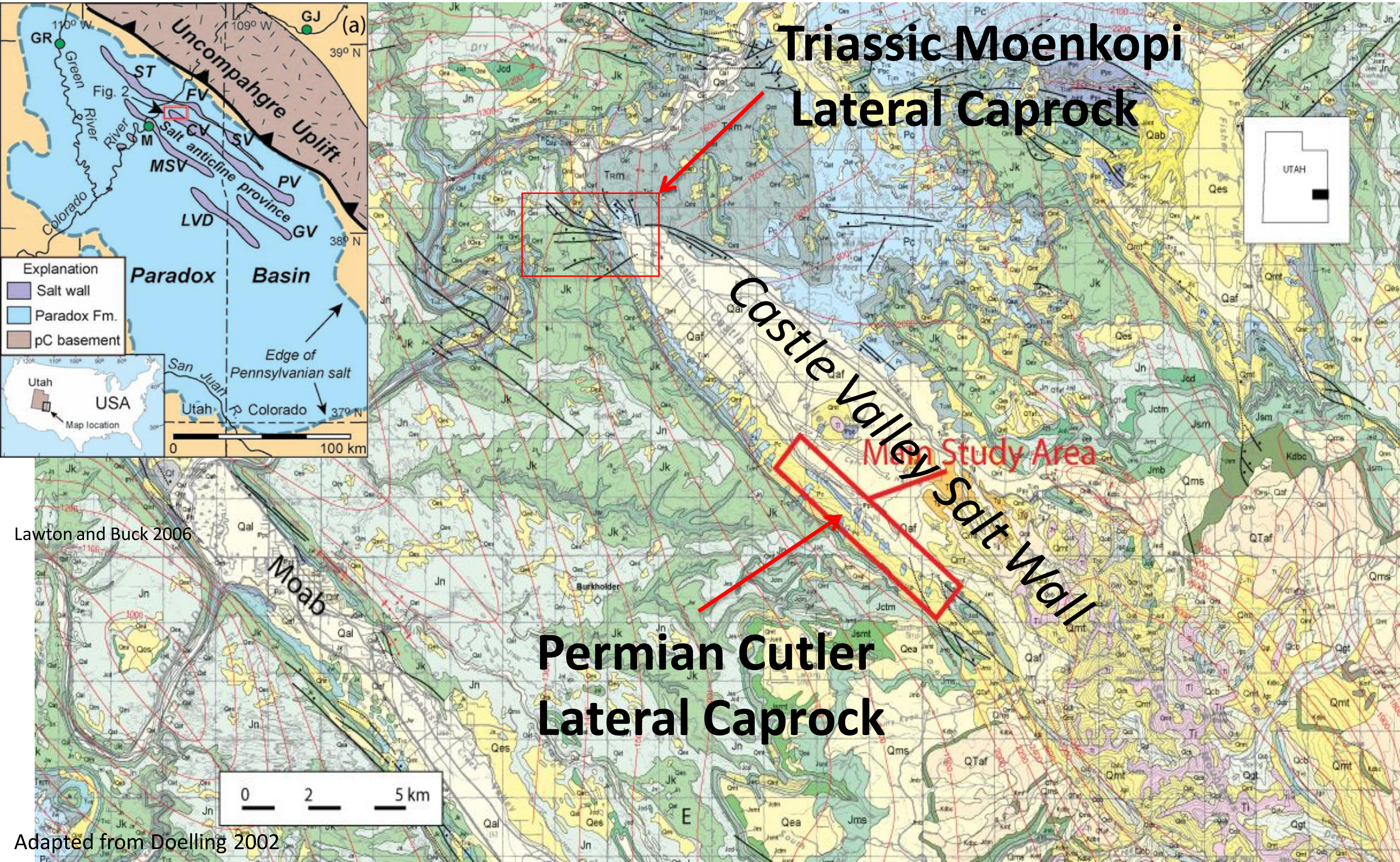


Carbonate Lateral Caprock Outcrop Studies

① Castle Valley vertical salt wall, Paradox Basin, Utah

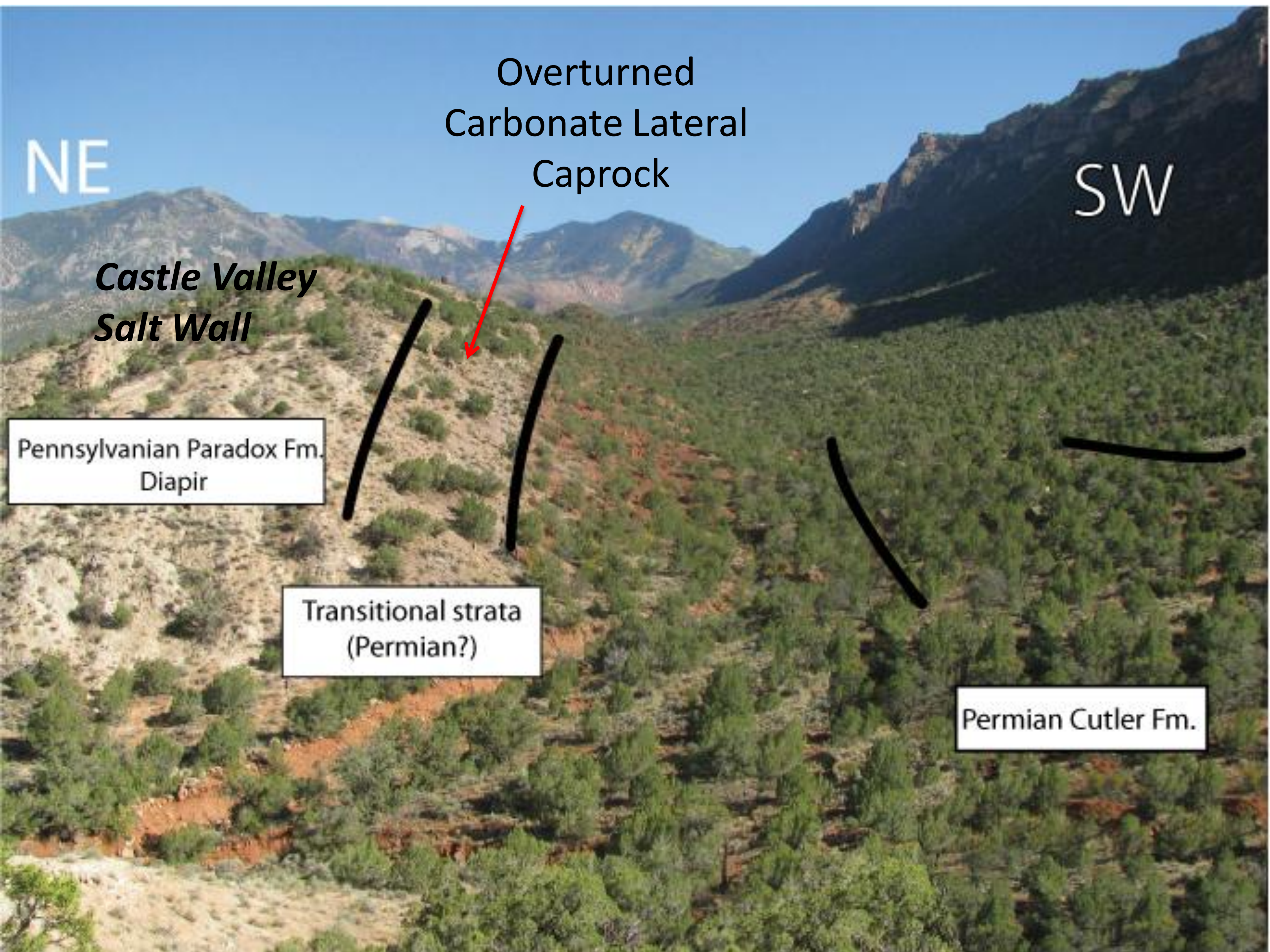
② Patawarta allochthonous salt sheet, Flinders Ranges, SA

Castle Valley Salt Wall, Paradox Basin, Utah
Lateral Caprock



Lawton and Buck 2006

Adapted from Doelling 2002

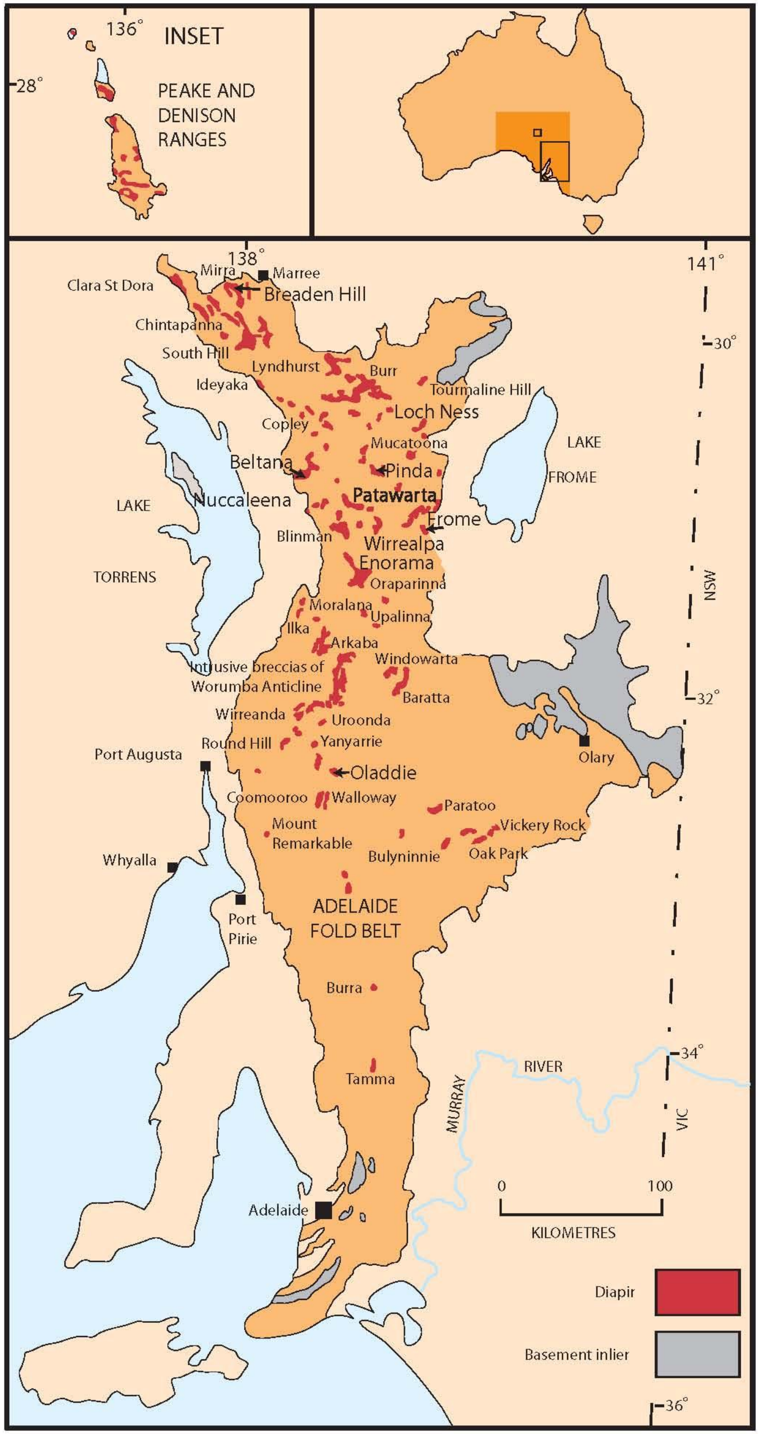

Overturned
Carbonate Lateral
Caprock
NE
SW
Castle Valley
Salt Wall
Pennsylvanian Paradox Fm.
Diapir
Transitional strata
(Permian?)
Permian Cutler Fm.

Fractured Dolomite Caprock

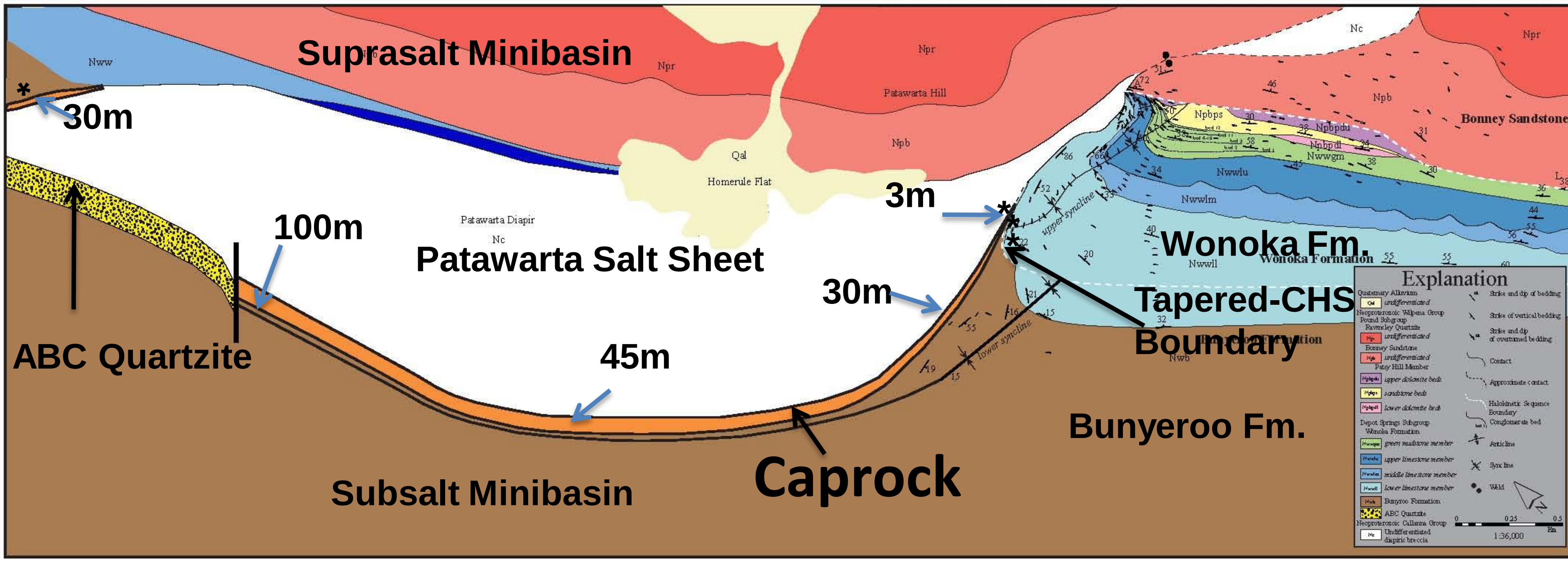
Permian Fluvial Cutler Channel with Diapir Roof & Caprock Clasts

Triassic Moenkopi Fluvial Channel with Diapir Roof and Caprock Clasts

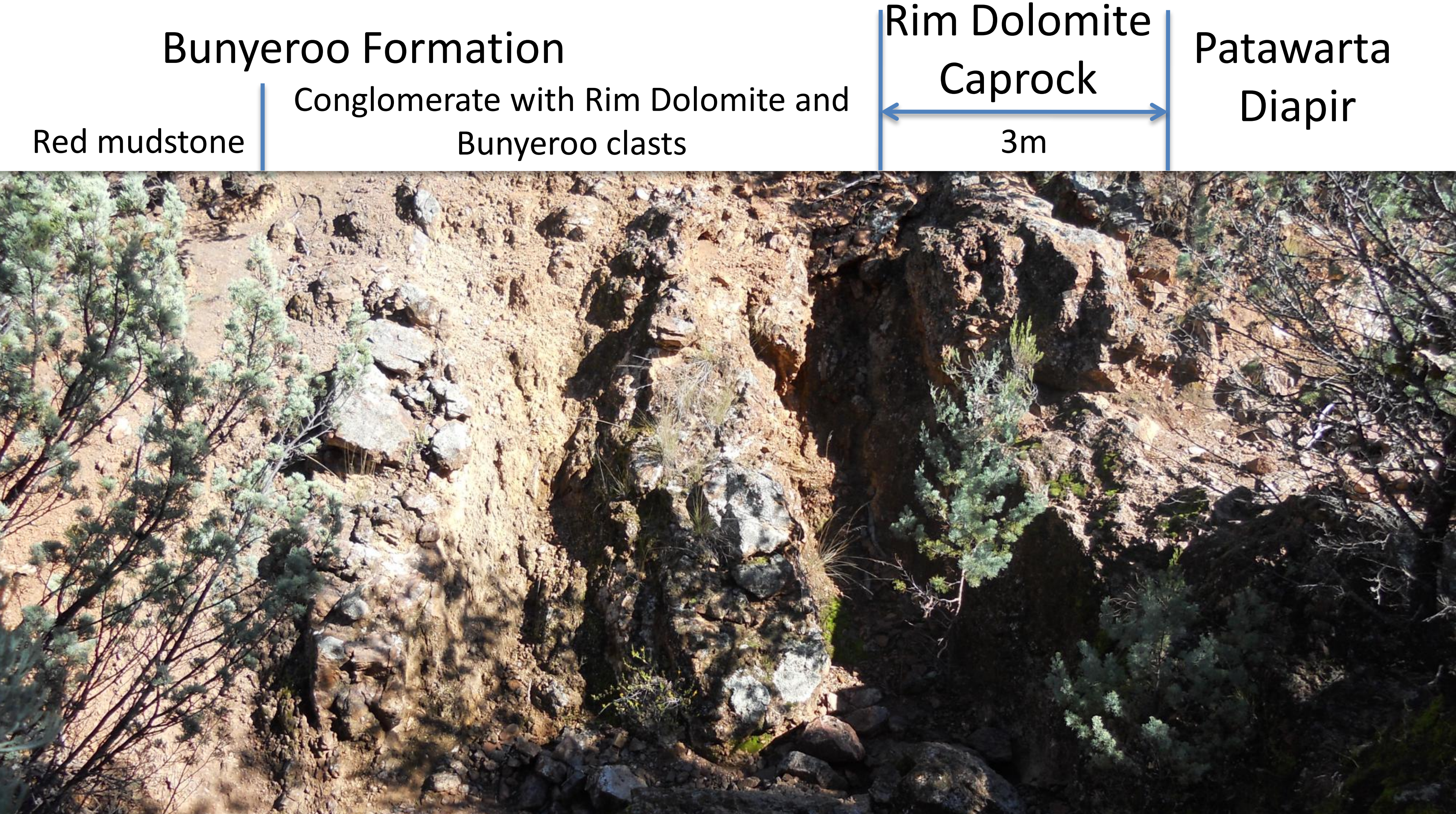
Patawarta Salt Sheet
Flinders Ranges,
South Australia



Patawarta Salt Sheet
Subsalt Carbonate Caprock



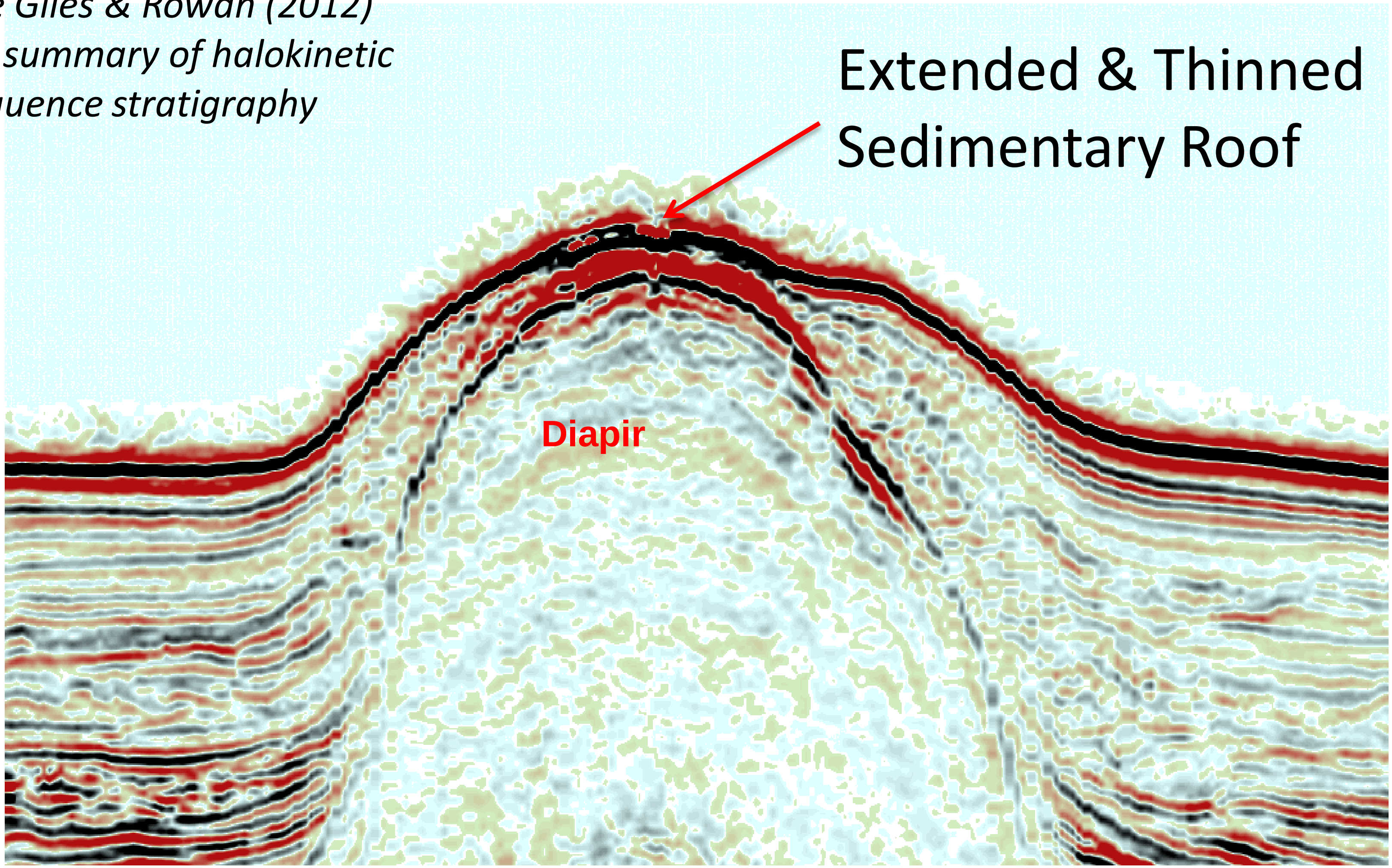
Rim Dolomite Caprock Truncated by Wonoka Tapered-CHS



Bunyeroo Conglomerate with Rim Dolomite Clasts

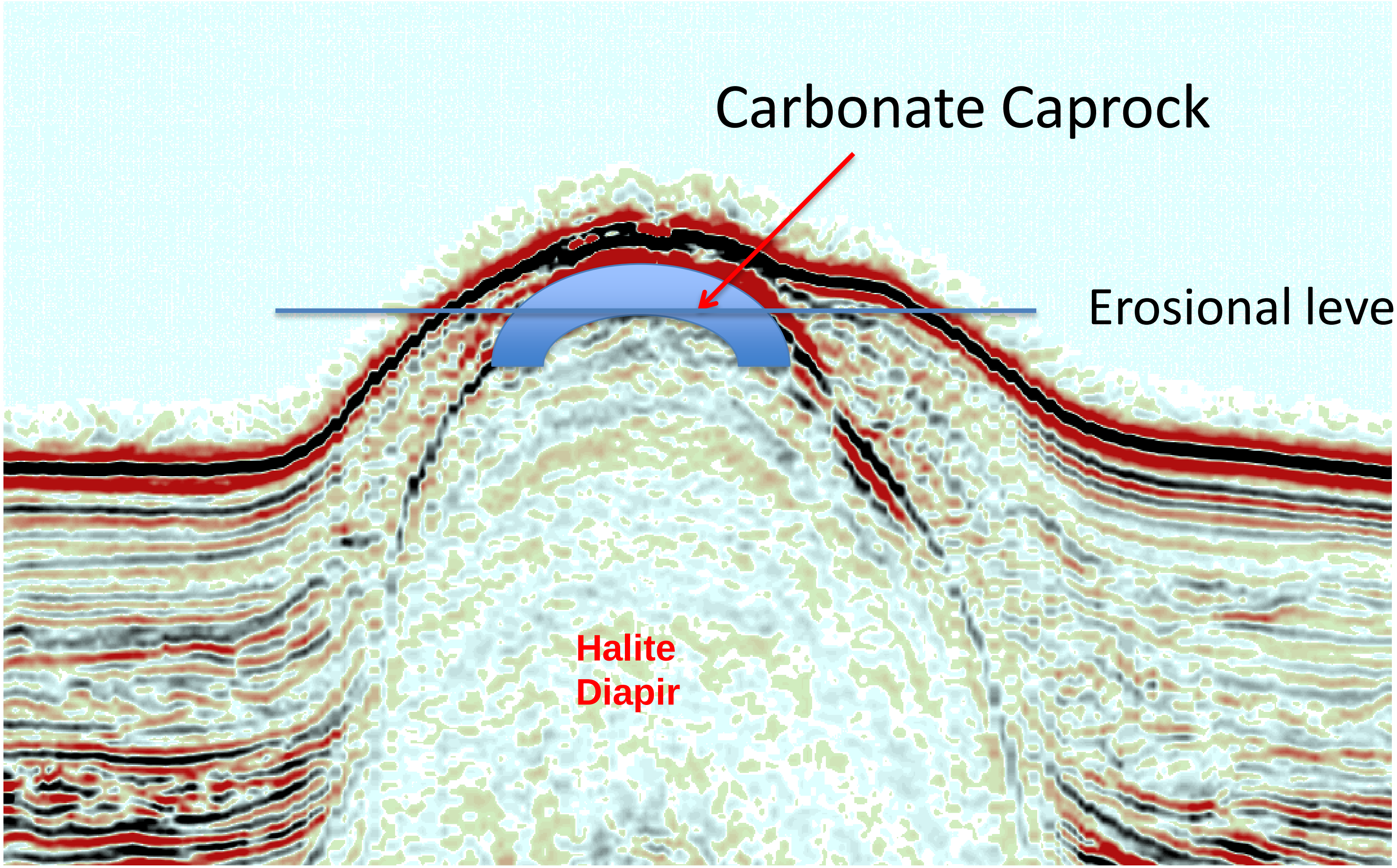
Halokinetic Drape-Fold Wedge

See Giles & Rowan (2012) for summary of halokinetic sequence stratigraphy



Data courtesy of C. Fiduk and CGGVeritas).

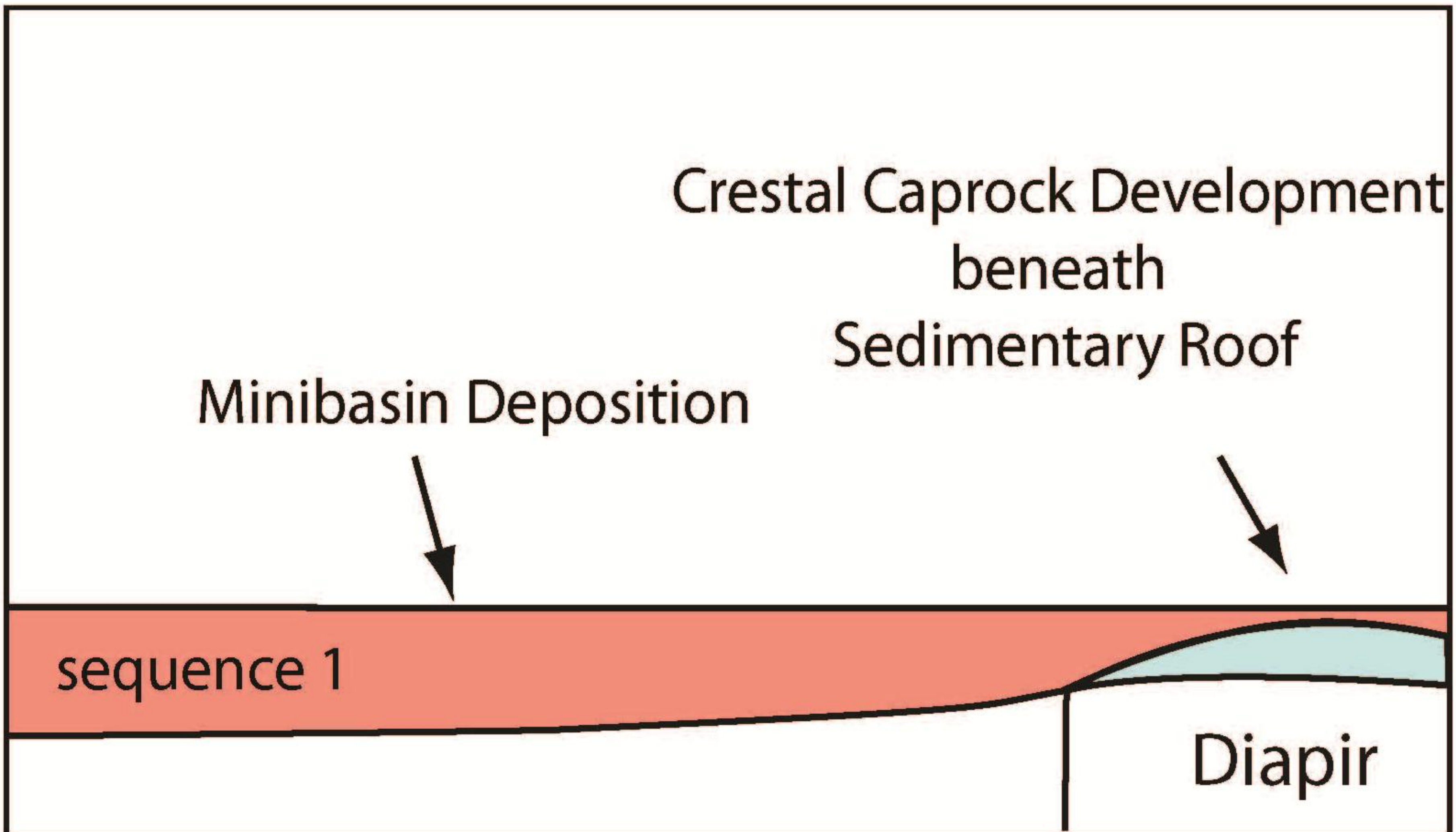
Halokinetic Drape-Fold Wedge



Top of diapir from the northern Gulf of Mexico showing draped wedge of overburden (data courtesy of C. Fiduk and CGGVeritas).

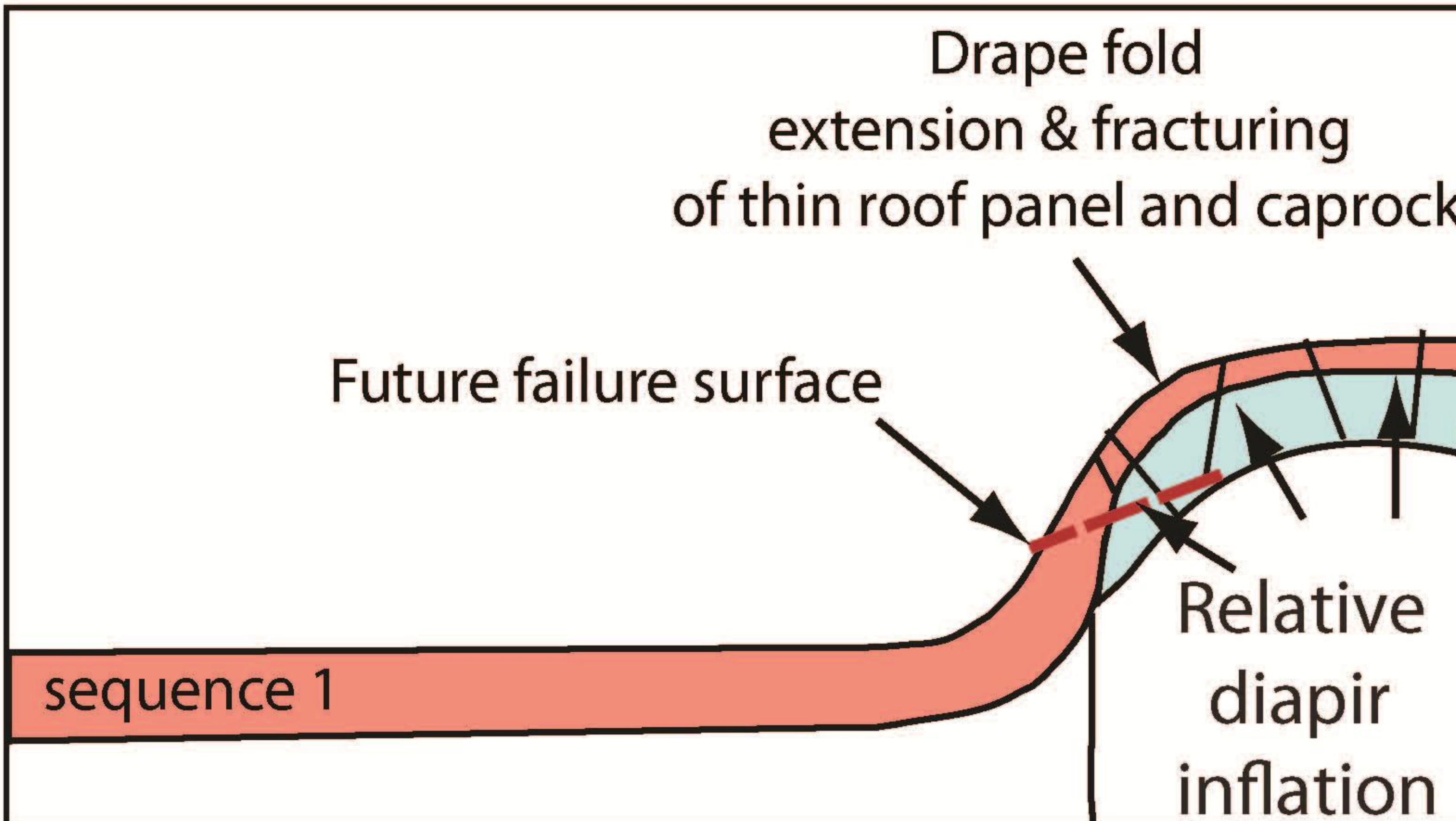
Halokinetic Drape-Fold Model

Step 1 Diapir Crest Caprock Formation



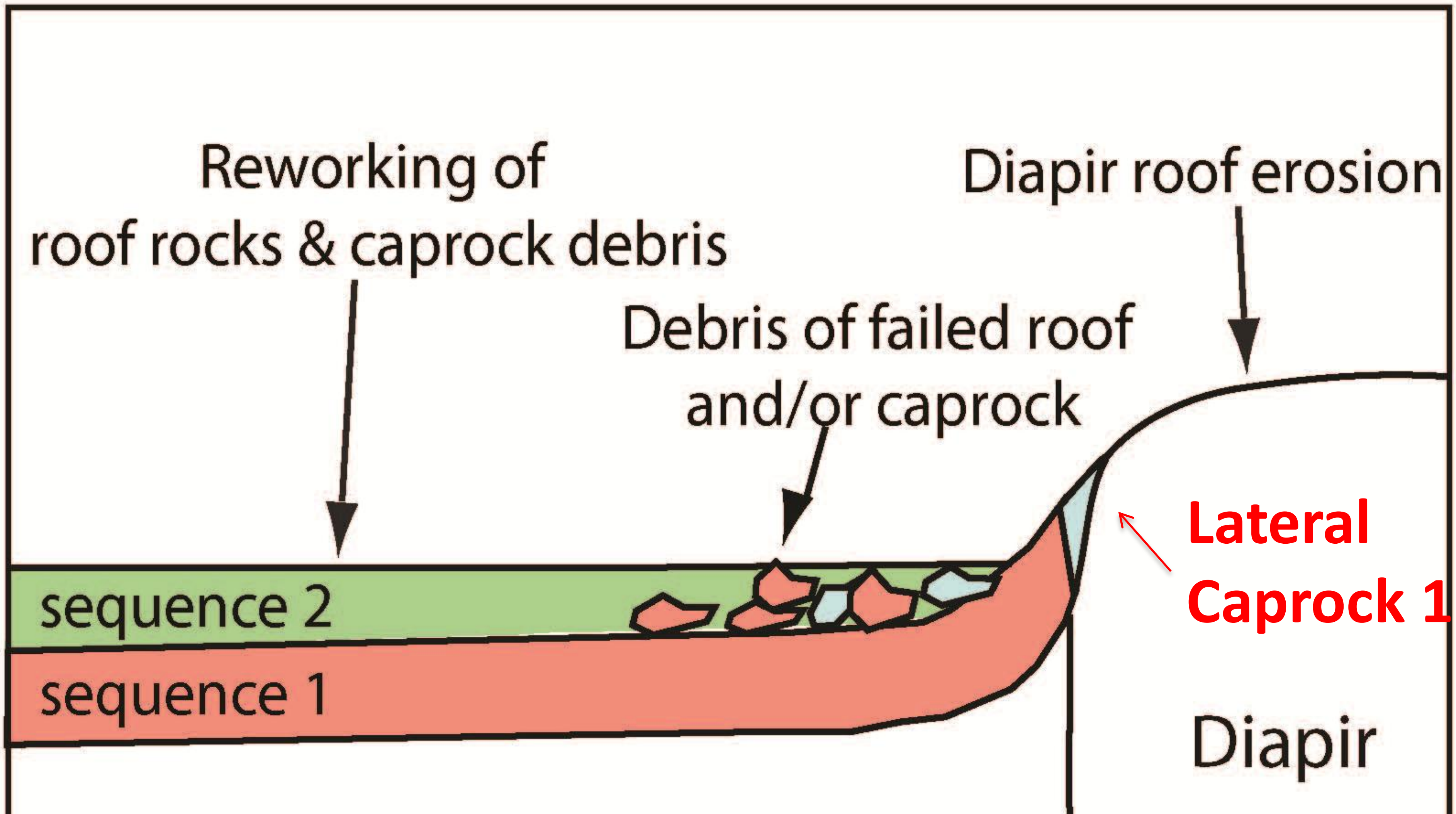
Halokinetic Drape-Fold Model

Step 2 Diapir Inflation & Drape-Folding



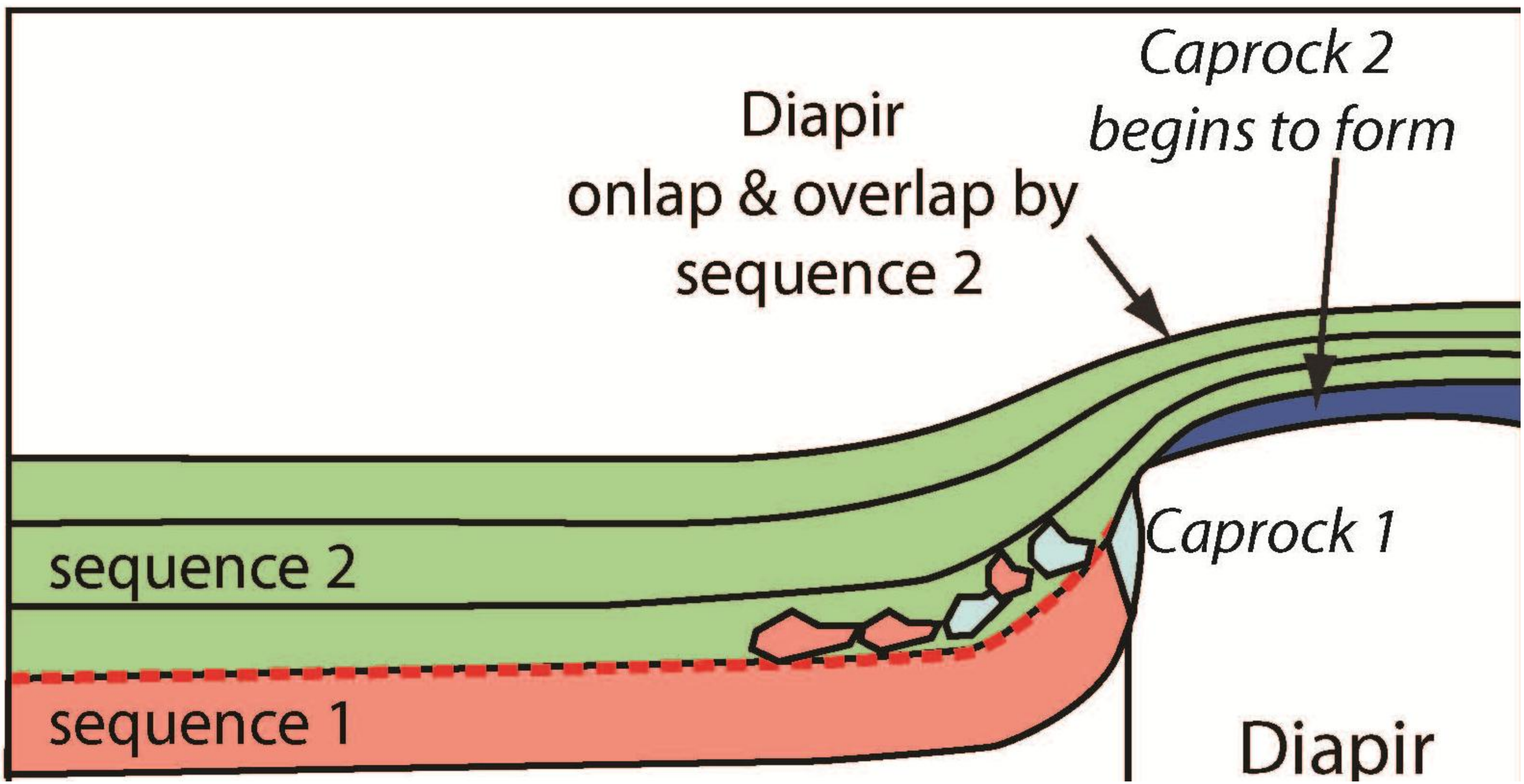
Halokinetic Drape-Fold Model

Step 3 Diapir-Roof Erosion

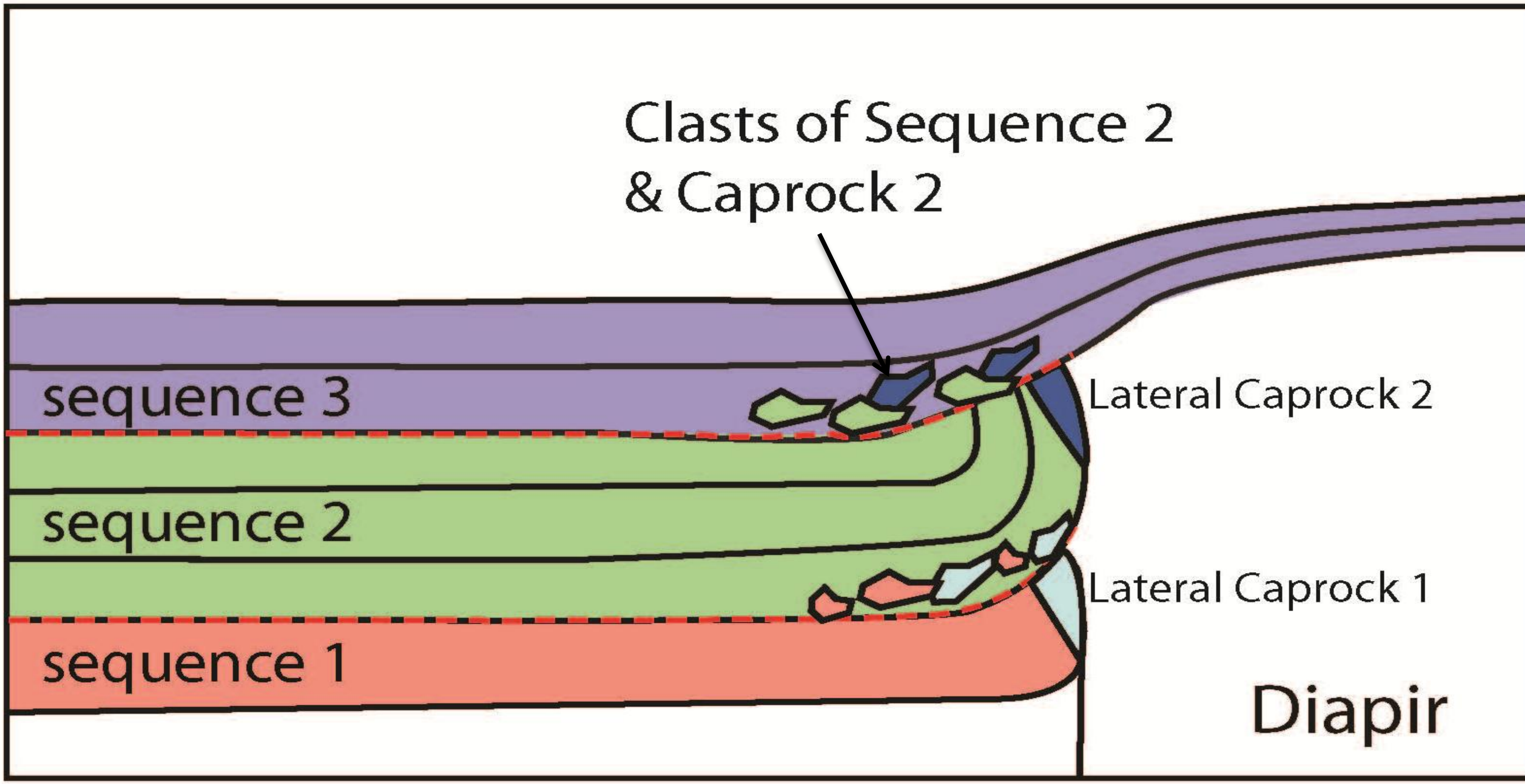


Halokinetic Drape-Fold Model

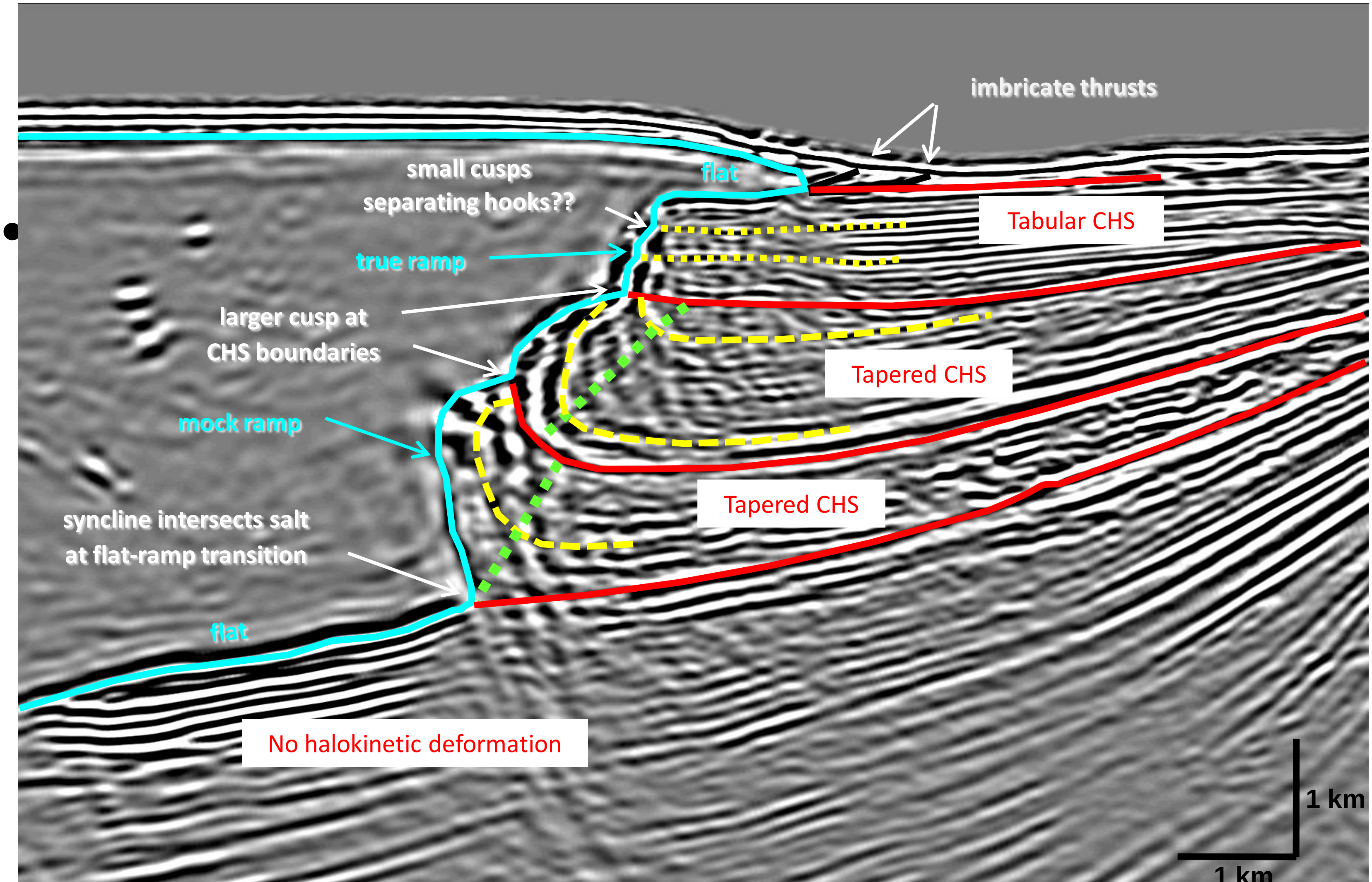
Step 4 Diapir Onlap & New Caprock "Event"



Lateral Caprock "Events"



Allochthonous Salt and Subsalt Caprock Events



Interpretation of allochthonous salt and adjacent halokinetic deformation (data courtesy of C. Fiduk and CGGVeritas)

Conclusions

- Lateral caprock forms in a diapir crest position and is rotated to a flanking or subsalt position by the process of halokinetic drape-folding.
- Lateral caprock forms as part of a halokinetic drape-fold “event” during passive diapirism and can be tied to the surrounding halokinetic sequence stratigraphy.
- A single diapir may have several “lateral caprock events”.
- “Carbonate caprock events” require hydrocarbon generation, migration, & trapping events to form.
- Caprock traps may be compromised with continued halokinetics.