Salt Shoulders*

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Abstract

A salt shoulder forms a zone at the margin of a salt diapir where the margin steps relatively abruptly inward. Strata above the shoulder may host hydrocarbon accumulations, especially when associated with salt dissolution-related anticlinal folds and normal faults. Utilizing outcrop and seismic data from salt shoulders formed on both salt walls and allochthonous salt sheets we summarize some basic characteristics of salt shoulders and relate them to processes associated with shoulder development. Salt shoulder strata display parallel to onlapping geometries and often overlie regional subaerial or submarine unconformities that truncated the crest of the diapir. The shoulder strata may be progressively rotated and upturned by drape folding as the inboard part of the diapir continues to rise. As this happens topography on the rising part of the diapir may confine sand-prone channel facies to the shoulder area resulting in stacked sand-prone reservoir facies in the onlapping shoulder strata.

In subaerial settings or if exposed with the lowering of base level the salt in the shoulder area may undergo dissolution, resulting in collapse folding and/or faulting of the overlying strata and concomitant caprock and/or karst collapse breccia development. In this scenario, the pre-shoulder outer edge of the diapir forms a pivot point (hinge) for collapse rotation of supra-shoulder strata down in-toward the new inboard diapir margin forming an anticline and tight syncline. The pivot point defines the outboard extent of potential down-toward-the diapir collapse faulting of supra-shoulder strata. The caprock and collapse breccia may provide substantial additional reservoir in shoulder traps. Shoulder formation is controlled by the interplay of lateral variations, from the diapir center to its margin, in salt-supply rate, salt-dissolution rate, and sedimentary roof and/or caprock thickness. Shoulders form when the salt rise rate near the margin of the diapir substantially decreases or stops relative the salt rise rate in the inboard central part of the diapir. This may be caused by differential salt dissolution and caprock formation from center to edge (i.e. higher dissolution and thicker caprock near the margin), differential erosion of roof strata from the center to the margin (i.e. more erosion or complete removal of the roof in the center while significant roof remains near the margin), or fault-related weakening of the roof in more central positions.
References Cited


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Shoulder Definition
Significance for Petroleum System
Database - Outcrop: Paradox Basin, USA; Flinders Ranges, SA
Database - Seismic: GoM, PriCaspian, North Sea
Summarize some basic characteristics of salt shoulders
Simple model of shoulder formation
Relate model to processes associated with shoulder development
A salt diapir margin geometry where the margin steps relatively abruptly inward.

Forms on both salt stocks/walls as well as allochthonous salt.
May host hydrocarbons in Shoulder Roll/Horn traps.

Especially if associated with anticlinal folds & faults.

Record of diapir-narrowing & minibasin expansion events.
Paradox Basin
Gypsum Valley
Salt Wall
Shoulders

- Defined on outcrop & 2D seismic datasets
- Supra-shoulder strata define minimum age of shoulder
- Multiple levels of shoulder development
- Progressive diapir narrowing & minibasin expansion
Shoulder Attributes: Size

Dimensions: width - 1 km     Length: highly variable 100m - 10’s km

- Gypsum Valley Chinle salt wall:
  300m-1km wide; >11km long

- GoM primary diapir:
  about 1km wide
Shoulder Attributes: Erosional Unconformities & Inboard Margin Halokinetic Sequences

- Deep Marine Example: Auger Diapir, GoM
Shoulder Attributes: Supra-Shoulder Strata

Geometries, Minimum age of shoulder, Inboard halokinetic sequences & Amalgamated stacked sand-prone channels

- Parallel
- Onlapping

Rowan et al., 2016

McFarland (2016)
Shoulder Attributes: Subaerial Settings

- Conglomeratic debris flows & lag deposits of diapir derived detritus
- Caprock – both gypsic & carbonate
- Karst & sinkholes
- Dissolution folding & faulting
Shoulder Attributes: Folding & Faulting

- Chinle Shoulder at Gypsum Valley
- Outboard anticline
- Inboard syncline
- Down-toward the diapir normal faults
Shoulder Attributes: Folding
South Australia Outcrop Example

- Shallow marine erosional base with no obvious lag or caprock
- Simple fold
- Forms just prior to allochthonous salt breakout
Halokinetic Drape Folding on Passive Diapir

Top of diapir from the northern Gulf of Mexico showing draped wedge of overburden (data courtesy of C. Fiduk and CGGVeritas).
Shoulder Model Step 1:

- Crestal Faulting & Differential Erosion Across Top of Diapir

Top of diapir from the northern Gulf of Mexico showing draped wedge of overburden (data courtesy of C. Fiduk and CGGVeritas).
Shoulder Model Step 2

- Continued, but inboard rise of diapir & progressive onlap & overlap of shoulder area

![Diagram of Shoulder Model Step 2](image-url)

- Shoulder
- New Inboard Margin
- Old Outboard Margin
- Onlapping sediments
- Halite Diapir
Shoulder Model Step 3

- Continued inboard rise of diapir & associated halokinetic sequences

Halokinetic drape-folded sediments at inboard margin
Halite Diapir

Drape-Fold Collapsed Shoulder

Fold Hinge

Drop-in Basin

Karsting +/- Caprock

Halite Diapir

Dissolution/salt evacuation drape-folding

- Drape-fold rotation of supra-shoulder strata toward inboard margin
- Fold hinge at outboard margin
- Forms diapir parallel anticline & inboard tight monocline/syncline
Shoulder Model Step 5

Dissolution/salt evacuation faulting

• Down-toward the diapir center normal faulting
• Synfolding or post-folding
Figure 21. Wide-azimuth, prestack depth-migrated 3-D seismic profile from the northern Gulf of Mexico showing a steep diapir that transitions upward to a low-angle allochthonous salt sheet, but with a short segment of roof preserved above a shoulder in the edge of salt (salt-top breakout). No vertical exaggeration. Data courtesy of Schlumberger.
Shoulder Formation Processes

Shoulder formation is controlled by the interplay of lateral variations, from the diapir outer margin inward, in:

- salt-supply rate
- sedimentary roof thickness
- erosional level
- fault-related roof thinning
- salt-dissolution rate
- caprock/karst breccia thickness
Conclusions: Salt Shoulders

• Provide an emerging new trap scenario on vertically rising salt diapirs
• Indicate periods of diapir narrowing & minibasin expansion events
• Have a predictable geometry and structural style that is seismic scale
• Are generated by variations across the diapir in relative salt rise rate and sedimentary roof thickness