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MODERN SALT TECTONICS

BOTTOM LINE

Recent developments in understanding of salt tectonics will facilitate oil and gas exploration and development in the Eastern Gulf Region.

PROBLEM ADDRESSED

Salt deformation plays a large role in the spatial and temporal distribution of reservoirs as well as hydrocarbon generation, migration, and entrapment. Breakthroughs in modern evaluation of salt tectonics include two basic concepts. First, differential loading drives salt tectonics and the process of diapirism is therefore more passive than had been believed. Second, lateral flow is locally important. A major component of salt tectonics is development of salt sheets, tongues, and allochthonous nappes. Passive diapirism, differential loading, extension, contraction, strike-slip faulting, and near-diapir faulting may trigger salt deformation.

KEY WORDS:
Allochthonous Salt
Diapirs/Diapirism
Extension/Contraction
Mechanics of Salt Deformation
Salt tectonics
Seismic Interpretation
Strike-Slip

TECHNOLOGY OVERVIEW

Different salt styles control trap styles in supra- and subsalt environments and have varying effects on sediment transport, deposition, and on hydrocarbon generation and migration. Better predictive models for reservoirs will be based on improved knowledge of mechanisms of salt (and overburden) deformation.

MECHANISMS OF SALT DEFORMATION

Rock salt forms a weak layer between other lithologies and deforms as a viscous fluid. The strength and brittle nature of overburden means that density contrasts play only a limited role in salt tectonics. Salt should be viewed as a pressurized fluid and it is differential fluid pressure that drives salt flow. Salt forms an excellent detachment surface into which faults sole. Several processes are known to thin or weaken overburden or create pathways and space for salt to move into. Processes include passive diapirism, salt movement triggered by differential loading, extension, contraction, strike-slip faulting, and the presence of allochthonous salt.

PASSIVE DIAPIRISM

Most diapirs grow primarily in a "passive" manner, with their crests essentially at the seafloor. Surrounding sediments subside into the source salt layer while the displaced salt moves into the adjacent diapir. Once the source layer is depleted, the diapir ceases to grow and is buried by further sedimentation. Salt geometries are primarily a function of the ratio of salt flow rates to sedimentation rates. When balanced, the diapir grows vertically; when sedimentation rate is relatively slow, the diapir expands.

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MOVEMENT TRIGGERED BY DIFFERENTIAL LOADING

Differential loading produced by emplacement of a depositional lobe induces a differential fluid pressure that drives salt withdrawal and minibasin formation. Salt moves laterally into flanking areas and a bathymetric high forms adjacent to the minibasin. A feedback process is created and the minibasin receives additional sediments. The process continues until the suprasalt minibasin touches down on the subsalt strata, forming a salt weld. At that time, minibasin subsidence ceases. Once the minibasin touches down, subsidence shifts from the center of the basin to the flanks, which are still underlain by salt. Both flanks subside, creating an anticlinal turtle structure. Subsequent depocenters form on both sides of the early depocenter.

MOVEMENT TRIGGERED BY EXTENSION

Extension is often closely associated with salt movement. Thin-skinned extension is caused by a combination of gravity gliding down a dipping salt layer and/or gravity spreading caused by a sloping surface. Rafts form when the hanging wall of a fault separates completely from the footwall and moves coherently along the salt detachment surface.

Extension-triggered diapirs may go through three evolutionary stages. These include reactive diapirism that occurs when regional extension thins the overburden. Graben formation at the surface is matched by development of an "inverse graben" at the salt-sediment interface. Salt fills the space in the inverse graben and forms a diapir that is triangular in cross section and has flanking growth faults that become younger toward the diapir crest. Active diapirism occurs when the overburden is thin enough for the pressure differential in the salt to break through to the surface. Passive diapirism occurs once the diapir reaches the surface. The diapir will continue to grow as long as there is adequate salt in the source layer.

MOVEMENT TRIGGERED BY CONTRACTION

Shortening of diapirs is a common and under-recognized process. Shortening is usually accommodated in salt-cored foldbelts near the toe of the salt layer or at the base of the slope. The close correlation between folds and diapirs can often be attributed to diapirs forming from salt-cored folds. Diapirs will localize the shortening strain and, as they are being squeezed, they will drive further salt extrusion. If the crest of a salt-cored fold is eroded or weakened enough by crestal faulting, salt may burst through as an active diapir. Once it reaches the surface, it can continue to grow as a passive diapir.

MOVEMENT TRIGGERED BY STRIKE SLIP FAULTING

Early compartmentalized downslope translation of overburden above salt creates a linked system of extensional, contractional, and strike-slip structures. Diapirs can be initiated along any of these structures. Releasing bends created by strike-slip movement creates drastic thinning of overburden. These are ideal locations for diapir initiation through reactive processes.

NEAR-DIAPIR DEFORMATION

Outcrop studies have shown that both radial and concentric faults occur around diapirs, and that the fault patterns are lithologically dependent. Modern data show that many fault patterns are approximately sub-radial due to the intersection of multiple fault trends. Many faults curve to become roughly tangent to the diapir face and produce cuspate salt outlines.

Deeper parts of many diapirs have partial halos of geopressured shale that are older and deeper-water facies than flanking strata. Modern interpretation is that these "sheaths" represent condensed section that were originally deposited on top of salt before the salt was remobilized into diapirs during passive downbuilding.

Another important form of near-diapir deformation is that produced by salt dissolution. The occurrence of cap rock on crests and upper flanks of many domes documents dissolution. Cap rock consists of insoluble residue, including calcite, anhydrite/gypsum, pyrite, and barite. Cap rock development is related to increased circulation of meteoric water at shallow depths. Therefore, cap rock thickness diminishes significantly with increasing depth to top of the diapir and cap rock is relatively absent in offshore environments.

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ALLOCHTHONOUS SALT

Allochthonous salt comprises sheet-like salt bodies emplaced above the evaporitive salt layer. End-member geometries include three basic components. Salt tongues form when a vertical or basinward-leaning diapir extrudes salt laterally. Evacuated bulb-shaped salt stocks have welds with central lows that ramp up in all directions. They may coalesce to form salt-stock canopies. Salt-nappe systems are distinguished from amalgamated tongues or stocks by their lack of local feeders. In salt-nappe systems, all the salt originates from the landward margin of the nappe and the base of the salt gradually climbs upward and basinward.

LESSONS LEARNED

Salt deformation is complicated, but the interpretation must be coherent, internally consistent, and compatible with accepted models. Interpretation guidelines include the following:

- Think regionally, in 3-D, and look deep. Clues that will constrain your prospect interpretation lie deeper. Lows below a regional average mark either salt withdrawal or normal faulting. Highs are caused by salt inflation or shortening/folding.

- Think time. Observed geometry is only one stage in an evolutionary model. Mentally restore your interpretation. All parts must fit at each stage.

- Consider processes and use realistic models of salt mobilization and associated deformation. Salt flow is driven primarily by pressure differential, not by density contrasts. Withdrawal salt must have some place to go. Salt sheets/diapirs usually grow near the sea floor with only a thin overburden.

- Map salt welds. Welds link salt bodies, serve as detachments, and mark earlier presence of salt.

- Use known salt/fault relationships. Growth/thrust faults usually sole into salt or equivalent welds and rarely cut through salt bodies.

- Because vertical exaggeration can be misleading, try to interpret seismic data at close to 1:1 scales.

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