Effect of Large-Scale Submarine Seafloor Slides on Hydrocarbon Exploration in NW Gulf of Mexico Basin

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The upper slope of the northwest Gulf of Mexico Basin (GOM) is replete with numerous seafloor and now-buried submarine slides of immense scale which adversely effect prospecting for hydrocarbons. Individual slumps and slides may cover hundreds of square kilometers and have generated thickened, repeated-section, chaotic rotated-blocks, and extentionally-related thinning over salt ridges. Several episodes of major slump systems may be stacked vertically within individual basins with active salt margins (Figure 1). These slumps pose two primary problems for hydrocarbon exploration: 1)subsurface imaging; and 2) seafloor and shallow subsea-drilling hazards. In addition, they are often confused with filled submarine "channels" in 2D profiles. The origin of these features is related to the interplay between salt-uplift land mass-wasting away from these highs, in a complex feedback loop. Several examples from the upper slope serve to illustrate the nature and scope of the problem.

The principle tool for hydrocarbon exploration in this region is amplitude or "bright spot" mapping, in trap, on 3D seismic data. Salt-withdrawal mini-basins are basically sediment traps surrounded by mobile salt, forming the familiar pothole-filled image of GOM seafloor physiography. Bright-spots along salt-basin margins are obscured when large-scale slumps and slides effect seismic imaging at depth. Velocity contrasts between slumped and autochthonous material, as well as within structurally complex slides, can disrupt seismic raypaths and degrade signal via absorption. Also, relative-amplitude strength is reduced when slumps allow salt to flow into the basin at the surface; these salt overhangs can completely wipe out the basin-margin image at depth. Lastly, the stacked slump packages themselves produce focusing and dispersion effects unique to each slumped event which can propagate through the entire section.

Fluid pressure prediction using seismic velocities and offset wells can be compromised when large-scale slumps dominate the shallow section below the mudline. Lithology prediction within shallow, rotated blocks (locally seismically-transparent) can be risky, given that flowing sands are a primary drilling hazard

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in the shallow part of upper-slope wildcat wells. Slump edges and internal structural boundaries locally give rise to fluid expulsion features at the seafloor, which can complicate spud location and/or drillship anchor patterns. Taken together, drilling risks through and near slumps are dramatically higher than normal.

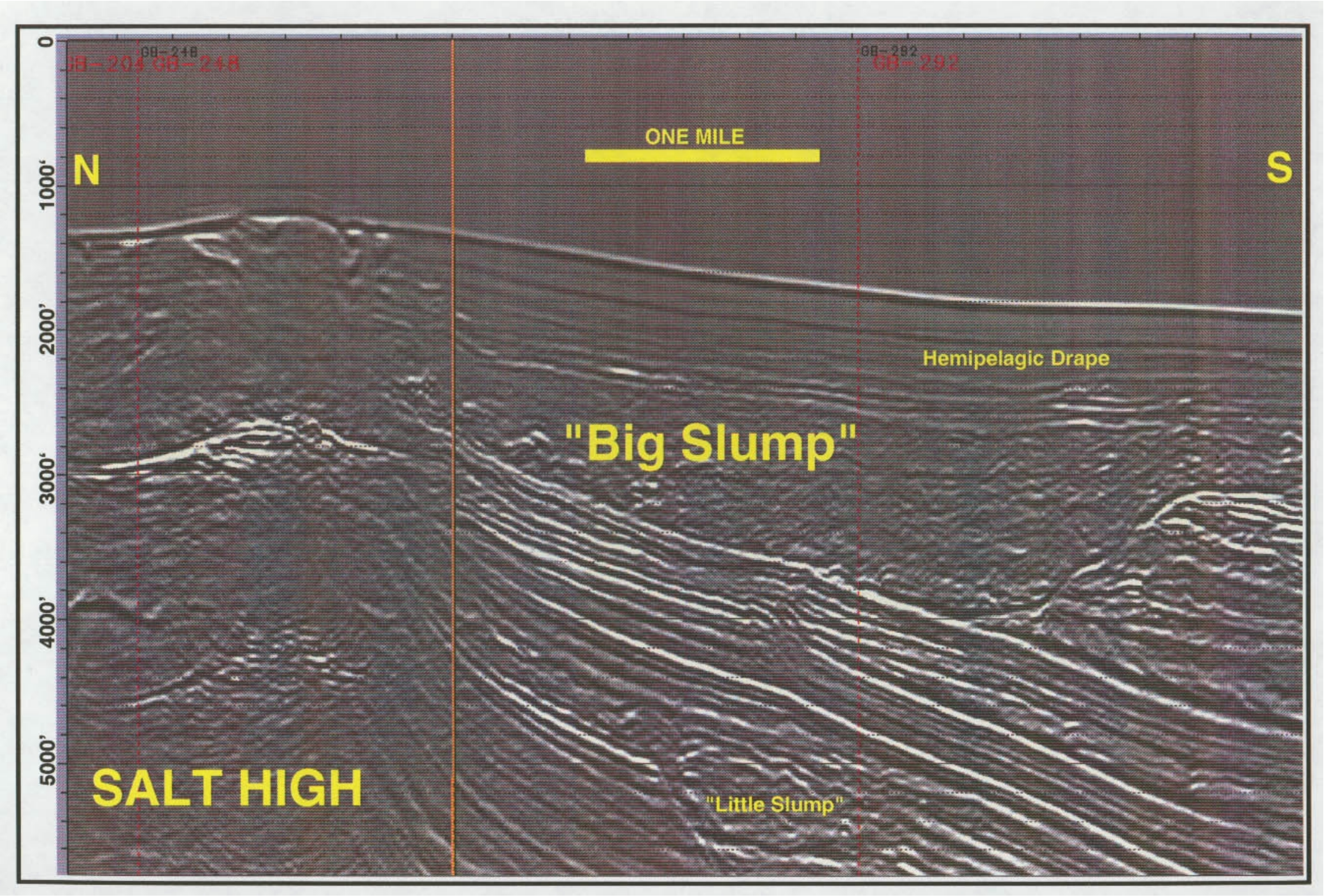
Adjacent to Auger basin in Garden Banks, a large scale, bow-shaped feature lies athwart a similarly-sized salt-high on the north-flank of a large salt-withdrawal basin (Figures 1 & 2) and illustrates the effect of shallow mass movement on seismic imaging at depth, both in terms of signal degradation and amplitude-dimming. The dip line of Figure 1 traverses the widest portion of the so-called Big Slump and shows a 1000 ft high frontal ramp almost four miles downdip of the salt ridge. The chaotic nature of the slump's internal reflectors is testament to the degree of deformation of the originally layered sequence seen outboard (to the right) of the slump. The detachment surface is clearly a prominent sequence boundary, parallel to underlying stratigraphy down to the ramp. The run-out from this slide is demonstrable across the entire withdrawal basin to the south and east. High-amplitude layered events on the footwall of the ramp are correlative with shallow-water flow sands penetrated in a recent Shell well to the south. The topmost 500 to 1000 ft of layered, low-reflectivity events are hemi-pelagic drape over the currently inactive slide. In mapview, the size and impact of this slide is even more readily apparent. The 1200 ms time-slice shows the gross outline of the Big Slump against high-amplitude, gently-dipping basinal events. The slump lies immediately downdip of a major culmination of the north-bounding salt ridge. The seafloor rendering of the area shows prominent seafloor expulsion features outlining the downdip edge of the slump (i.e. the ramp). Lastly, a background-gate of 500 ms from the seafloor down shows a strong contrast in high-amplitudes outboard of the quieter slump. Significantly, the internal structure of the slump is complex, with certain regions containing layered high-amplitude events. These regions are potential flow sands, and therefore are drilling hazards to be avoided by the bit.

Below the Big Slump is a second, much-smaller scale feature referred to here as the Little Slump (Figures 1 and 3). Although the Little Slump is spacially related to the same salt high as the Big Slump, its shape is long and narrow, as a long spoon. The map and profile of Figure 3 shows the narrow width (less than 1000 ft) of the minor slump relative to the overlying major feature which spans the entirety of the strike line. The geometry of the Little Slump and similar long, narrow features, can easily be mistaken for submarine channels; however, rotated blocks within the feature and careful mapping using flattened time-slices can help demonstrate its slump origin. Significantly, these types of slumps are not unique to this basin, but are found at all scales across the upper GOM slope.

Near Joliet field in Green Canyon OCS area, the complex nature of a seafloor slump is readily apparent

(Figure 4). Seafloor topography and illuminated renderings of sub-seafloor events show the bow-shaped, anastamosing patterns of a classic fold-and-thrust belt. In addition, the vertical profiles of Figure 4 show a complex internal structure: downdip thrust faults, repeated imbricate slabs, and updip extension are seen on the dip line, whereas the strike line shows high-angle lateral footwall ramps located updip of the toe thrust faults. Incidentally, this example illustrates the main benefit of using 3D seismic data to elucidate slump kinematics– the strike-line could easily be misconstrued as a dip-profile if this were the only 2D section available, but it is, in fact, perpendicular to the true transport direction.

In a more regional context, this slump is spacially associated with a salt high immediately updip; also that the slump and the salt high are the same width. The slump transport direction is toward the bathymetric low to the south, which is now the sight of a salt tablet currently at the seafloor. This association (*salt high/ slump/basin low/ salt tablet*) can be observed all across the upper slope and constitutes a major archetype for salt-related slumping. Figure 5 schematically illustrates a two-step model for large-scale, upper-slope slump formation. In the GOM, older salt canopies loaded in the Plio-Pleistocene form salt-bounded withdrawal basins all across the slope; salt walls form via downbuilding as turbidites fill the basins. More recently, when sediment supply was either diverted or shut-off altogether, the salt-sediment wedge of the entire slope relaxed via downbuilding as turbidites fill the basins. More recently, when sediment supply was either diverted or shut-off altogether, the salt-sediment wedge of the entire slope relaxed via gravity -spreading, thus triggering salt diapirism via extension. This diapirism can form seafloor tablets where salt reaches the seafloor at topograghically-low extensional graben, and may also actively oversteepen adjacent basin flanks closer to the shelf. Large-scale shallow-slumping is spacially associated with these relatively oversteepened flanks, which transport themselves toward the salt tablets on the seafloor into topographic lows. This model can explain many salt-related features visible on the seafloor today as well as explain certain slumped horizons in older stratigraphy. Correctly applying this model can help constrain reservoir and trap elements in these more deeply-buried examples.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S
Hemipelagic Drape
"Big Slump"
SALT HIGH
"Little Slump"

Figure 1

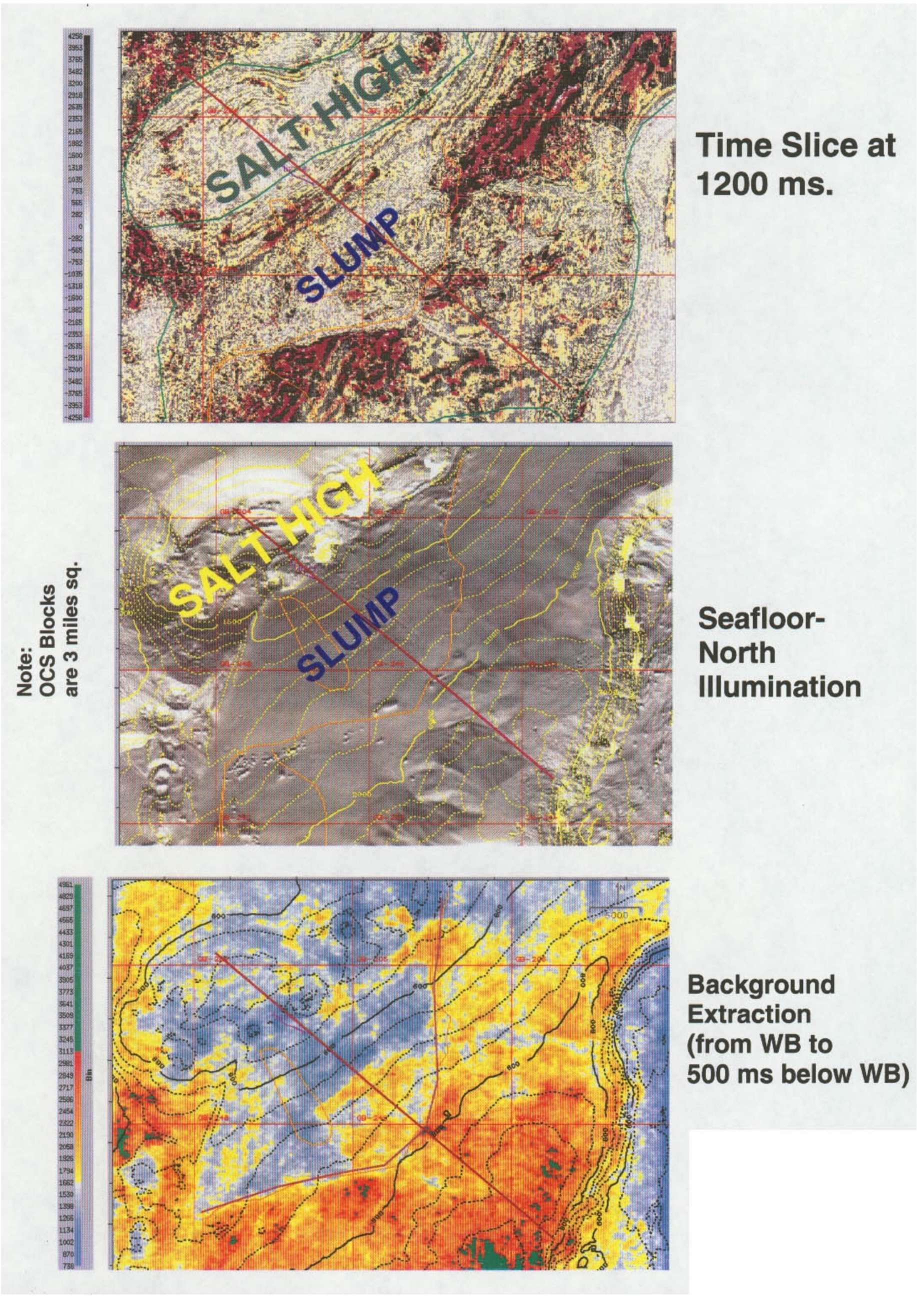
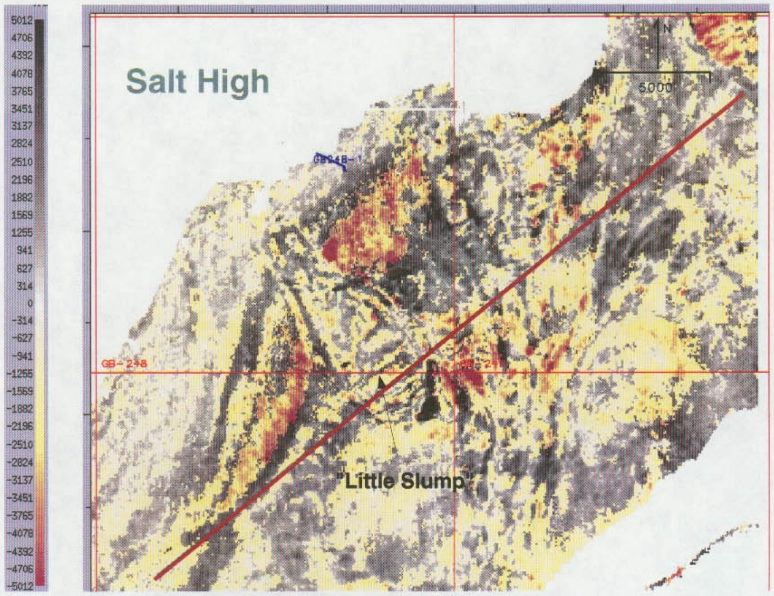
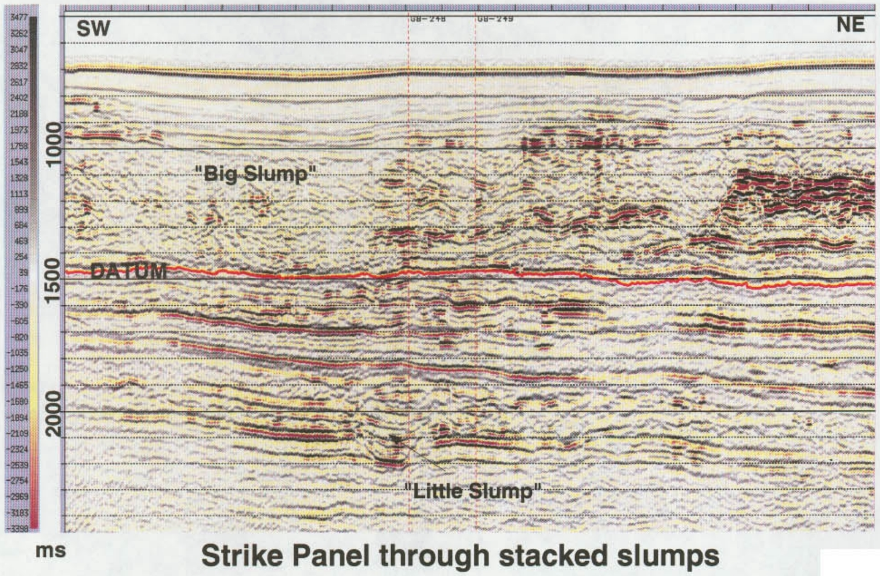

SALT HIGH
SLUMP
Time Slice at 1200 ms.
SALT HIGH
SLUMP
Seafloor- North Illumination
Note: OCS Blocks are 3 miles sq.
Background Extraction (from WB to 500 ms below WB)

Figure 2



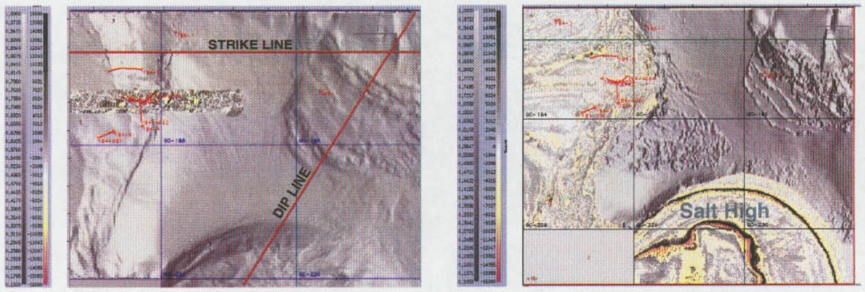
Flattenned Amplitude Slice at 540 ms below DATUM
through spoon-shaped slump



Strike Panel through stacked slumps

Figure 3

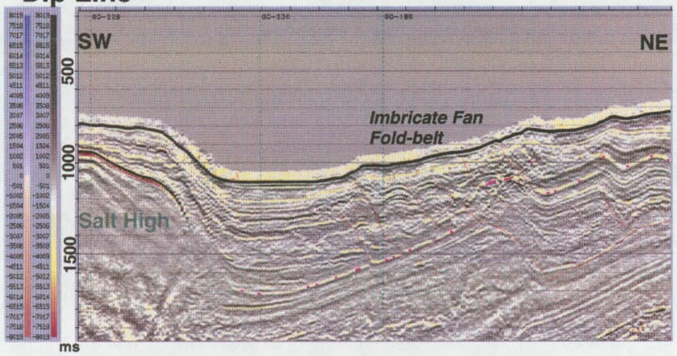
Seafloor Slump Adjacent to Joliet Field (Green Canyon)



Seafloor- East Illumination

Horizon within slump- East Illumination

Dip Line



Strike Line

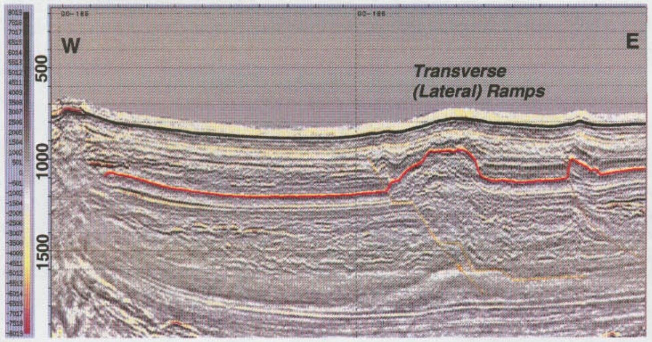


Figure 4

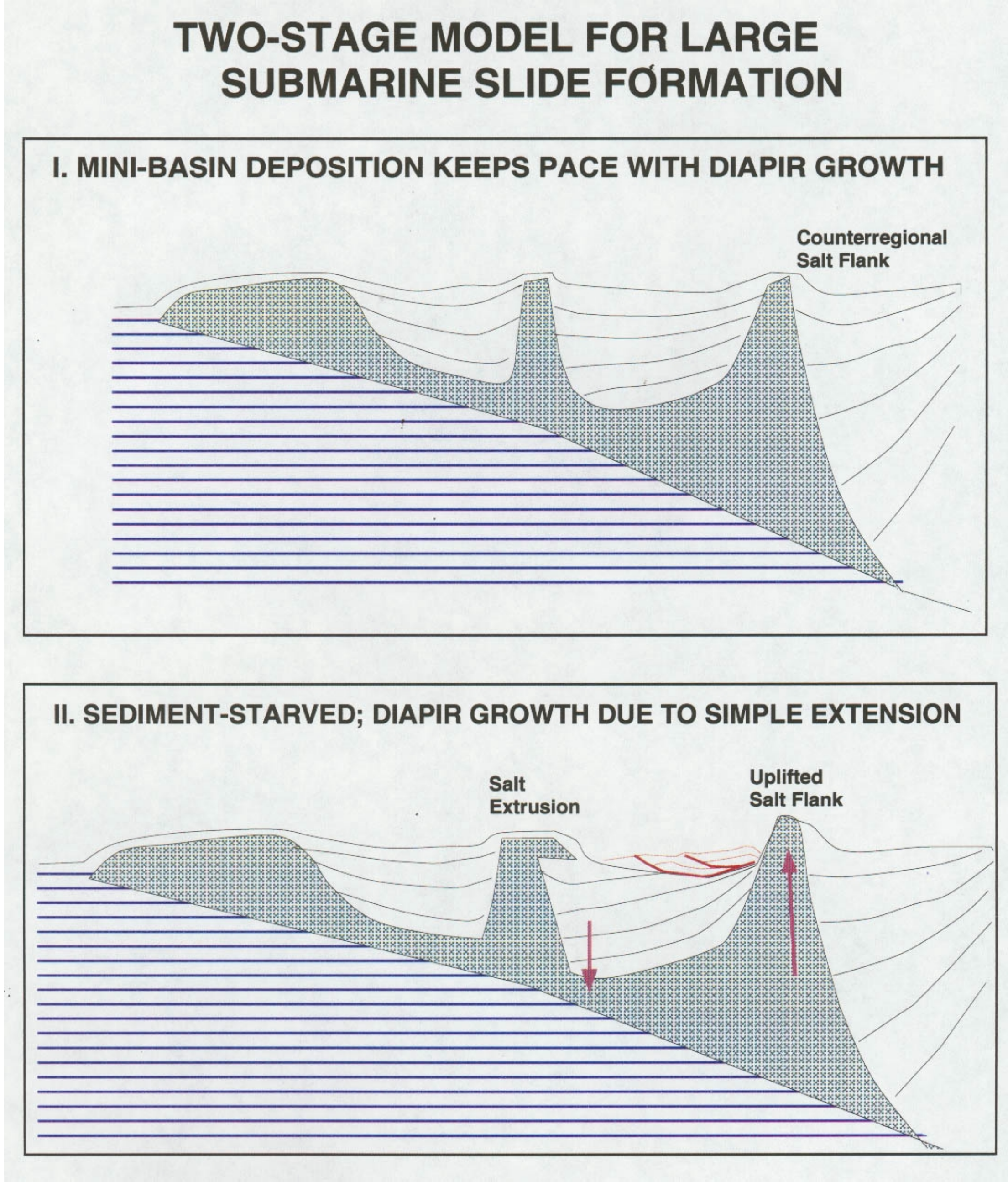

TWO-STAGE MODEL FOR LARGE SUBMARINE SLIDE FORMATION
I. MINI-BASIN DEPOSITION KEEPS PACE WITH DIAPIR GROWTH
Counterregional Salt Flank
II. SEDIMENT-STARVED; DIAPIR GROWTH DUE TO SIMPLE EXTENSION
Salt Extrusion
Uplifted Salt Flank

Figure 5