Initiation and early evolution of salt withdrawal mini-basins

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Salt withdrawal sedimentary basins, termed mini-basins, that are characteristically 10–20 km in diameter and up to 10 km deep are common features of rifted continental margin salt tectonic provinces. In the Gulf of Mexico, for example, they occur as clusters in which the planiform subcircular basins are bounded and divided by salt ridges and diapirs. The most dramatic examples populate the salt canopy region landward of the Sigsbee Escarpment. Their development is generally attributed to buoyancy driven flow in which sinking denser overburden displaces lower density salt which rises into adjacent highs, an example of a Rayleigh-Taylor (R-T) instability. However, this mechanism will not work when the average density of the compacting overburden in the basins is less than that of the salt. This situation typically prevails for clastic sediment until its accumulated thickness is approximately 3 km. An alternative mechanism must therefore be found to initiate the mini-basins and foster their development until the R-T instability can take control. This mechanism has remained a mystery.

We propose a three-component mechanism that initiates and grows mini-basins. It involves the early sedimentation onto the salt layer, the lateral flow of sediment and salt, and the isostatic response of the salt to the sediment load. The key process that is required is early-stage localized convergence (ΔV ~ cm/yr) among laterally translating regions of thin sediment (m's thick, km's radius) resting on the (~km thick) salt layer. This laterally convergent flow typically occurs in the unstable toe of continental slope regions. The convergent zones behave much like pressure ridges between ice floes except that the material that fills the ridges is the salt, not overburden. The dynamical height of these salt ridges controls the whole process. Where the lateral motion of the overburden is uniform it drags the salt in an underlying uniform Couette channel flow.

In the convergent regions, where the velocity changes, excess salt accumulates and is either pumped vertically into the pressure ridges or expelled laterally in the salt layer as a Poiseuille channel flow. The maximum dynamical height of the ridges is determined by the lateral differential pressures they generate. As the ridges grow vertically, progressively more of the accumulating salt is pumped laterally and they achieve their maximum height when all additional salt is expelled in this way. However, the lateral pressure gradient and associated Poiseuille flow are reduced by sedimentation that fills the accommodation (the nascent mini-basins) between the pressure ridges. Sediment loading therefore leads to a positive feedback mechanism when sedimentation keeps pace with the upward pumping of the ridges because the ridges can continue to grow vertically and create more accommodation.

Lubrication theory, an approximation commonly used in mechanical engineering, can be used to understand the mechanics of this system and leads to a governing equation for the maximum height of the pressure ridge and corresponding depth of the mini-basin,

$$\Delta h = \frac{3\eta \Delta V L}{(\rho_s - \rho_o) g h_c^2}$$

where, η is the salt viscosity, ΔV is the change in velocity of the overburden across the pressure ridge, L is the average half-length (radius) of the adjacent mini-basins, h_C is the thickness of the salt layer, g is the acceleration due to gravity, and ρ_S and ρ_O are the salt density and the average density of the compacting sediment overburden. If the system can achieve a $\Delta h \sim 3$ km, the average density of the compacted sediment exceeds the salt density and the process continues via the buoyancy driven R-T mechanism.