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Discussion

Salt tectonics at passive margins: Geology versus models – Discussion

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ABSTRACT

Brun and Fort (2011) use mechanical analysis, experimental models, and geologic data to suggest that deformation in passive-margin salt basins is dominantly a result of gravity gliding rather than gravity spreading. They claim that only seaward tilt of the salt layer is effective in driving basinward translation of the salt and overburden and that differential loading alone requires extreme conditions that do not occur in nature. In this Discussion, we refute many of their arguments and conclusions. We show that: i) a more thorough mechanical analysis indicates that gravity spreading is effective if the proximal overburden is at least three times thicker than the distal overburden, a common occurrence on passive margins; ii) more realistic analogue models also demonstrate that extreme thickness variations are not necessary for gravity spreading; iii) their analysis of structures or structure associations is sometimes misleading; and iv) there is abundant evidence that gravity spreading is dominant on some margins. In particular, modern data from the northern Gulf of Mexico confirm traditional interpretations that Cenozoic failure was mainly due to downslope movement driven by sedimentary loading, not SW-directed gliding driven by tilt of the deep salt as claimed by Brun and Fort (2011). We conclude that both gravity gliding and gravity spreading are common processes which may vary spatially and temporally in any one salt basin.

1. Introduction

A recent article in this journal by Brun and Fort (2011) challenged established paradigms for the tectonics of salt-involved passive margins in general and for the northern Gulf of Mexico (GoM) margin in particular. We are in favour of critical reexamination of conventional wisdom, particularly where new data or experimental and numerical models have become available. However, we disagree with many of the key assertions of Brun and Fort (2011), including the following.

1. Gravity spreading in salt-floored passive-margin stratigraphy requires boundary conditions that are rarely achieved in nature and is a process difficult to reconcile with geological evidence.
2. Gravity gliding is the only mechanically viable process on passive margins.
3. Various structures and structure associations are diagnostic of spreading vs. gliding. In gravity spreading, for example, distal contraction occurs only at the toe of the sediment wedge and migrates basinward over time.
4. Salt withdrawal minibasins do not result from subsidence under the weight of sediments.
5. Salt tectonics of the central Northern GoM margin was dominated by persistent SW-directed movement, in contrast to the conventional interpretation in which movement during the Tertiary was directed primarily down the seafloor slope.

While we fully agree with the importance of gravity gliding on many passive margins, especially early in margin history, we believe that dismissing the commonly dominant role of gravity spreading is a mistake. In this Discussion, we will argue that: i) critical arguments and algebraic analysis made in support of these assertions are invalid; ii) the assertions stem from selective or unsound evaluations of existing data; and iii) a significant body of geological evidence exists demonstrating that the assertions are incorrect. We will first address the theoretical, analytical, and modeling aspects of the issue and then discuss real examples where the evidence for gravity spreading is overwheming.

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2. Analysis of gravity gliding and gravity spreading

Gravity gliding and gravity spreading are two end-member modes of gravity tectonics, and both result in a decrease in gravitational potential energy (Ramberg, 1981). In gravity gliding, the driving energy causes motion parallel to the basal surface and downdip along that surface (Fig. 1A). Gliding does not require internal deformation of the translating body, but a moving body with internal flow parallel to the basal slip surface is a variant of gliding. The bottom surface must have a component of dip in the movement direction, whereas the dip of the top surface is not diagnostic of gliding: it may have no overall dip (Fig. 1B) or it may dip counter to movement (Fig. 1C).

In gravity spreading, the driving energy causes motion of the material toward the basal surface (Fig. 1D), requiring deformation of the spreading body. Parts of the upper surface must have components of dip in the movement direction, but the dip of the basal surface may be opposite to motion (Fig. 1D), horizontal (Fig. 1E) or in the same direction as the motion (Fig. 1F).

2.1. Mechanical analysis

By means of simple equations, Brun and Fort (2011) predicted values of stress and mechanical conditions of failure for models of gravity spreading and gravity sliding. We suspect that readers may have some difficulty in following the analyses because the authors have not been clear in: i) defining parameters, ii) choosing reference axes, iii) distinguishing between horizontal and vertical components of stress, iv) distinguishing between total stress and effective stress, and v) taking account of porosity. After going through their analyses carefully, we have come up with somewhat different results.

Let use consider first the equations for gravity spreading (Brun and Fort, 2011, p. 1128). Their equation (1) is correct, but for vertical effective stress. To use this equation for horizontal stress requires an assumption, for example, that the state of stress in the thicker sediment is lithostatic or that the thicker sediment is collapsing in horizontal extension. Their equation (2) is for total stress, but only if the thin lyaer of sediment is dry and impermeable. Equations (3) are correct for Mohr-Coulomb failure, but only if the material has no cohesion. Equation (4) is incorrect, because it results from confusing effective and total stresses. This means that their remaining equations (5) and (6) are also inaccurate. We therefore question the implications for wedges in nature and experiment and offer instead our own analysis in two dimensions for gravity spreading (Fig. 2A).

Let ρ_s be the density of the solid particles and ρ_f be the density of pore fluid. The effective vertical stress (σ'_{zz}) increases linearly with depth in each layer: $\sigma'_{zz} = kz$. Here, $k = g(\rho_s - \rho_f)(1 - \psi g)$ being the acceleration of gravity, $(\rho_s - \rho_f)$ the effective density due to buoyancy, and ψ the porosity. If the sediment fails according to a Navier–Coulomb criterion (yet has no cohesion), we agree with Brun and Fort (2011) that the principal stresses at failure will be proportional: $\sigma'_1 = K\sigma'_3$, where $K = (1 + \sin\phi)/(1 - \sin\phi)$, ϕ being the angle of internal friction. However, this expression involves effective stresses, not total stresses. Let us assume that layer B fails in horizontal compression, while layer A fails in horizontal extension. The horizontal effective stress is therefore $(\sigma'_{xx})_A = Kkz$ in layer A and $(\sigma'_{xx})_B = (1/K)kz$ in layer B. By integration with respect to z, the total horizontal force in the sediment is $(f_x)_A = Kk(H_A)^2/2$ for layer A and $(f_x)_B = (1/K)k(H_B)^2/2$ for layer B. For equilibrium of forces along x, if shear stress is negligible in the salt, $(f_x)_A = (f_x)_B$ and therefore $H_A/H_B = K$. This result is simpler than that of Brun and Fort (2011) and it should be valid for material that is either dry or wet. For example, if $\phi = 30°$, $K = 3$; whereas if $\phi = 20°$, $K = 2.04$. However, if there is overpressure, leading to seepage forces, the vertical stresses may become very small or even vanish. Small variations in thickness or in other properties may then lead to instability. Brun and Fort (2011) noted that, for a flat base (Fig. 2A), the water depth $(H_A - H_B)$ will be unrealistically large. However, if each of layers A and B is long enough to produce local isostatic compensation within the asthenosphere, the base of the salt will subside differentially (warp) and the lateral variation in water depth may then be five or six times smaller than for a model having a flat base.

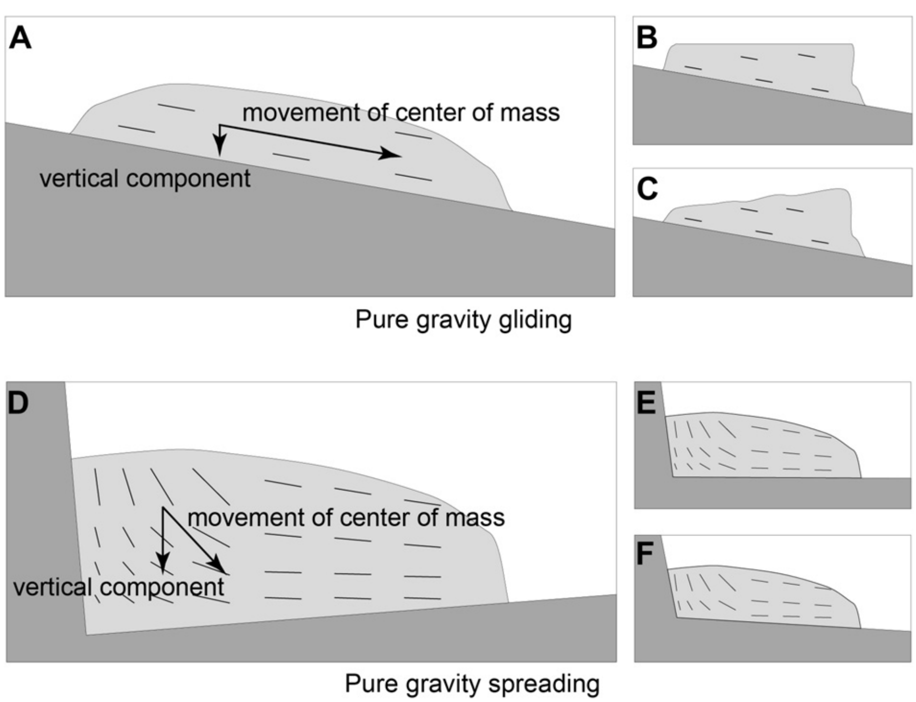

Figure 1. Definitions of gravity gliding and gravity spreading.