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Laboratory investigation of coupled deformation and fluid flow in mudrock: implications for slope stability in the Ursa Basin, Gulf of Mexico

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Integrated Ocean Drilling Program (IODP) Expedition 308 was dedicated to the study of fluid flow, overpressure, and slope stability in the Ursa Basin, on the continental slope of the Gulf of Mexico. In this location, turbidite channel levees deposited a wedge-shaped body: the deposition rate in the thick part of the wedge exceeded 12 mm/yr. This rapid deposition of fine grained sediments generated excess pore pressure observed near the seafloor. IODP drilling focused on three Sites: U1322, U1323, and U1324, along the steepest slope (2º) on the eastern section of the Ursa Canyon levee deposits. In this study, we conducted a suite of deformation experiments on samples from Site 1324, to understand the stress-strain behavior and stress history of the recovered core material. Our samples were taken from depths of 30-160 meters below seafloor, and are composed of ∼40% silt and ∼60% clay, with porosities ranging from ∼42-55%. We first conducted uniaxial consolidation tests to determine pre-consolidation stresses and define deformation behavior due to simulated vertical loading. In a subset of tests, we subjected the samples to undrained shearing following consolidation, to define the friction angle and define relationships between stress state and deformation.

We find that the lateral effective stress during uniaxial compression is 56-64% of the vertical effective stress (avg. K_0=0.6). Pre-consolidation stresses suggest that pore pressure is hydrostatic to 50 mbsf (meters below seafloor), and is overpressured below this, with excess pressures up to 70% of the hydrostatic effective vertical stress (λ^*=0.7) at 160 mbsf. The time coefficient of consolidation (c_v) in these experiments is ∼2.2x10^{-8} m^2/s. Undrained shear tests define a failure envelope with a residual friction angle (ϕ) of 23º and zero cohesion. In our shearing tests, we observed no pore pressure change during initial (primarily elastic) shear deformation, but note a monotonic increase in pore pressure during the later plastic shear deformation, possibly due to re-organization of sediment grains. Our consolidated undrained tests suggest that the slope in the study area should remain stable during sedimentation, despite the high overpressure (λ*=0.7). However, this stress condition could be affected by gravitational and seepage forces that cause horizontal extension along the slope. In this case, a reduction in horizontal confining stress would render the slope sediments unstable (drive them to active failure) as defined by the Coulomb criterion. If shear strain during slope failure leads to plastic deformation of the sediments, this would also induce a pore pressure increase, further decreasing the factor of safety (FS) for landslides. For the landslides of the slope (i.e., FS=1.0), the overpressure rate λ^* should reach 0.92 for the given slope (2º). However, active normal faulting takes place at lower values of λ^* (0.2-0.8). Our analysis suggests that the instability of the slope may arise more likely from normal faults dipping stiff (45º+ϕ/2) than from landslides slipping on a plane parallel to such a gentle slope of seafloor.