How Pressure, Stress, and Column Height Interact to Control Secondary Migration Within Geopressured Strata

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Overview

Oil pressures at the peak of the Lentic sand in the south Eugene Island 330 (EI-330) Field converge on the minimum principal stress of the bounding cap rock. We interpret that this system is dynamically constrained by the stress field present. We present a simple model to describe the distribution of pressure in sands and shales which are rapidly buried. We compare this model with observations of pressure and stress within the Lentic sand. We interpret that elevated pore pressures induce flow along permeable fractures. The analysis both suggests that secondary migration is controlled by the stress field within overpressured strata and provides a method of estimating trap integrity.

Pressure Distribution Due to Rapid Sediment Loading

Consider a sand, initially horizontal at the surface of the earth, which is rapidly buried by impermeable shales (Figure 1). Pressures within the sand body will follow the hydrostatic gradient and pressures within the shale will follow the lithostatic gradient (Figure 1). In this simple example, where the sand subsides in a linear manner, the pressures of the sand and shale will be equal at the midpoint of the sand. At the peak of the structure the sand pressure exceeds that of the shale while at the low point, the shale pressure exceeds that of the sand.

Figure 2 illustrates the actual pressure distribution in the shales and sands of the Lentic horizon. Pore pressure estimates within the shale (dark circles) show that the pore pressure within the shale is parallel to the overburden gradient and reaches approximately 85% of the overburden gradient (Figure 2). We interpret these shales to be undrained and overpressured due to rapid sediment loading. The pore pressure of the sand is approximately 500 psi greater than that of the overlying shale (~95% of the lithostatic gradient).

Paper presented at the AAPG Hedberg Research Conference, "Integration of Geologic Models for Understanding Risk in the Gulf of Mexico," September 20–24, 1998 (Galveston, Texas).

These observations are compatible with the sediment loading model presented in Figure 1.

Stress vs. Column Height

The minimum principal stress of the shale caprock (S_{hmin}^{sh}) lies between the shale pore pressure and the overburden stress (Figure 2). The pore pressures of the underlying Lentic sand (P_p^{ss}) are within 200 psi of the fracture gradient of its caprock (S_{hmin}^{sh}) (Figure 2). We interpret that the Lentic oil column is dynamically constrained by the stress field present. Any larger oil column will elevate pore pressures at the peak of the reservoir and induce fluid flow by fracture permeability within the caprock either by hydraulic fracturing or frictional failure

Implications

In rapidly loaded basins such as the deep water Gulf of Mexico the pore pressure in sands and shales are decoupled because of extremely low permeability within the shale. This allows the pore pressure within the underlying sands to converge on the minimum principal stress of the cap rock. If the pore pressure and the minimum principal stress can be estimated ahead of the drill bit, it is possible to place an upper bound on the column height present in an exploration target. In addition, the sediment loading model provides insight into why lost circulation is common within shales in overpressure. As mud weights are raised to overcome the pore pressure in reservoir sands, the minimum horizontal stress of the bounding shales may be exceeded.

References

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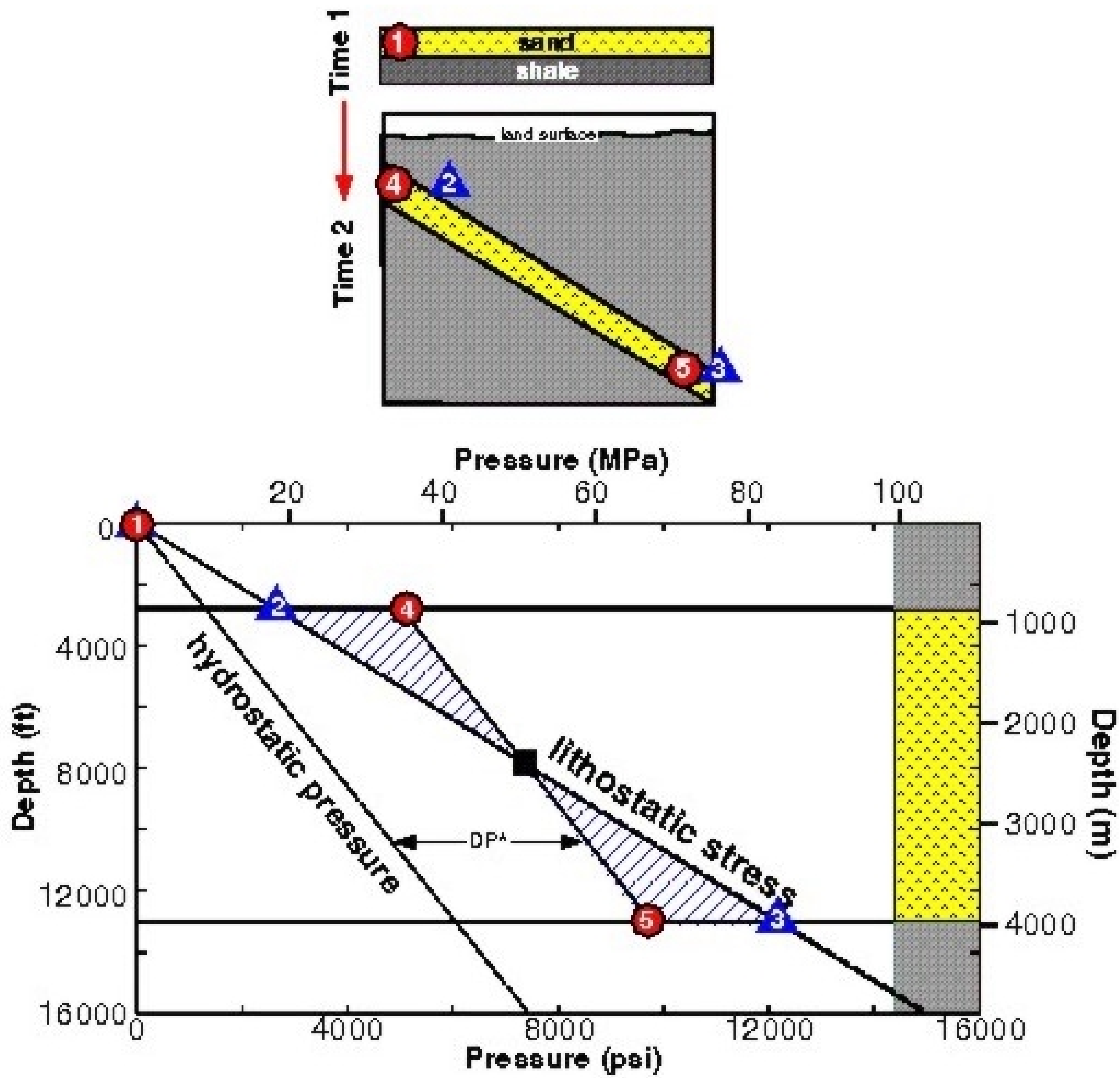

Figure 1 Pressure distribution that results from instantaneous loading of a permeable sand body by impermeable shales. (Modified from Stump et al. (1998).

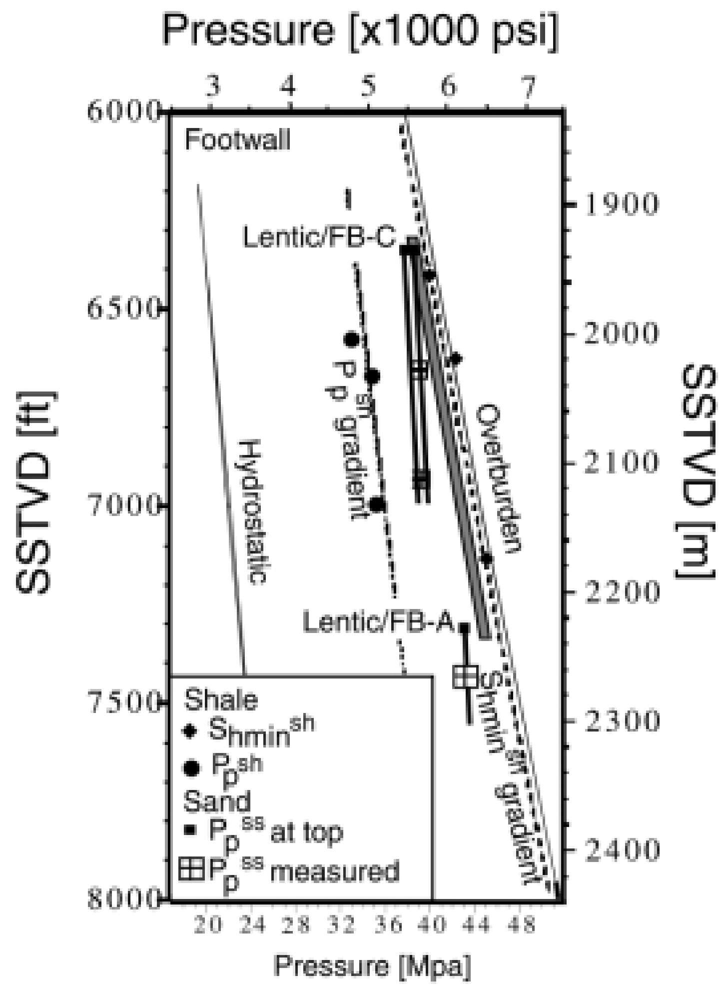

Figure 2 Pressure and stress state of the Lentic sand in the EI-330 Field, Gulf of Mexico. Least principal stresses in shales (S_{hmin}^{sh}) are from leak-off tests (LOT). Shale pore pressures (P_p^{ss}) are calculated using porosity-effective stress method. The black squares represent the reservoir pore pressure at the top of the structures. In Fault Block C, the reservoir pressure is within 200 psi of the fracture gradient and is 500 psi greater than the pressure within the overlying shale. (Modified from Finkbeiner et al., in review