"Basin scale" versus "localized" pore pressure stress coupling – implications for trap integrity evaluation

R. Mourgues (1)*, J.B. Gressier (1), L. Bodet (1), D. Bureau (1), A. Gay (2)

(1) L.P.G., CNRS UMR 6112, University of Maine, 72085 Le Mans, France
(2) Géosciences Montpellier, CNRS UMR 5243, 34095 Montpellier cedex 5, France

* corresponding author: Regis.Mourgues@univ-lemans.fr

Abstract

In petroleum industry, the difference between pore pressure (Pₚ) and minimum horizontal stress Sₘ is of major consideration. It is often assumed to represent how close a system is to hydraulic failure and thus the maximum hydrocarbon column height that can be maintained (Gaarenstroom et al., 1993). While Sₘ and Pₚ are often considered to be independent parameters, several studies in the last decade have demonstrated that Sₘ and Pₚ are in fact coupled (Addis, 1997; Breckels and Eekelen, 1982; Engelder and Fischer, 1994; Hillis, 2001; Tingay et al., 2003). However, the nature of this coupling remains poorly understood. In this study, we explore the influence of the spatial pore pressure distribution on Sₘ/Pₚ coupling. Assuming undeformable lateral boundaries for the sedimentary basin, the Sₘ/Pₚ coupling (ΔSₘ / ΔPₚ ) varies from (1 - k) for fluid overpressure distributed in the whole basin to 0.5(1 - k) for localized overpressure (Rozhko et al., 2007) (fig.a). We also underline that a pore pressure/vertical stress coupling appears (∆Sᵥ / ∆Pₚ ≠ 0) when the pore pressure is localized around a pressure source (overpressured sandy reservoir or at top of a fault that conducts fluids). We apply these pore pressure/stress coupling to predict the failure pressure of an overpressured sealing formation around a localized source of pressure (fig.f).

In order to verify our analytical predictions, we conducted some hydraulic fracturing experiments on granular analogue material submitted to distributed and localized pore fluid overpressures. Our apparatus consisted of an Hele-Shaw like cell, 1m long and 70 cm high (fig.e). Following Mourgues et al., 2009, we used air to control the pore pressure field. At the base of the model, a reservoir of compressed air applied a constant basal pressure which simulated the effect of an overpressure distributed at basin scale. Within the model, an air injector, 2mm large, superimposed a second pressure field to simulate a localized increase of pore pressure. To ensure a good control of pore pressure distribution in the material, we used diatomaceous earth as an analogue of sediment. This powder was permeable and cohesive.

For experiments with no central injection (fig.d2), horizontal fractures opened within the model in response to the increasing overpressure as it was predicted by Cobbold et Rodrigues (2007). For such laterally homogeneous pore pressure field, there is an high Sₘ/Pₚ coupling ratio and tensile failures can not open without stress inversion that occurs for lithostatic pore pressure. For experiments where a central injection superimposed a second pressure field within the model, hydraulic fractures opened from the injector (fig.d1). We measured the pressure required to initiate failure at the injector (λₗ_clusters) for various values of distributed pore fluid overpressure (λₗ_clusters) and we compared them with our analytical predictions. The best correlation occurs for Poisson's ratio ν = 0.35 (fig.f). In overpressured sediments, our experiments demonstrate that supralithostatic pore pressure that can be locally sustained without fracturation of the cover.

Applied to trap integrity evaluation, our study shows that hydraulic fracturing and seal breach probably occurs for fluid pressure greater than would be predicted from conventional retention capacity that does not take into account Sₘ/Pₚ coupling.
figure: (a.) Results of numerical and analytical predictions on the coupling between pore pressure and stresses for various distributions of pore fluid overpressure in a basin. Predictions are made assuming elastic rheology and no deformation on the lateral boundaries of the model. (c.) Evolutions of the effective stress Mohr circle during pore pressure increase for various sizes of the overpressured zone (w) represented on figures b. (e1.) Experimental apparatus for hydraulic fracturing. The model is built with diatomite powder between two glass walls. Air is injected at the base to provide a constant basal pore pressure that simulates "basin scale overpressure" ($\lambda_{basin}$). The localized pore pressure field is generated by a central air inflow ($\lambda_{loc}$). (d1.) Vertical hydraulic fractures initiated at the central injector. (d2.) Horizontal hydrofractures created by "basin overpressure". They result from the stress inversion occurring for $\lambda_{basin} > 1$ (fig.c3). (f1.) Results of fracturing
tests. Failure pressures measured at the central injector are plotted as a function of "basin fluid overpressure"($\lambda_{\text{basin}}$). Experimental data fit well with our analytical models for $\nu = 0.35$.

References


