In Situ Stress and Overpressures of Brunei Darussalam

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Abstract

This thesis analyses in situ stress and overpressure throughout Brunei. The resultant in situ stress and pore pressure data is applied to establish the neotectonic evolution of the Baram Delta province and resolve a variety of current geomechanics issues affecting petroleum exploration and production in the region.

A database of pore pressure information was compiled for 157 wells in 61 fields throughout Brunei. Overpressures are observed in 54 fields in the underlying pro-delta shales and the inner shelf deltaic sequences. Porosity-vertical effective stress plots from 31 fields reveal that overpressures are primarily generated by disequilibrium compaction in the pro-delta shales but have been vertically transferred into the inner shelf deltaic sequences. Sediments overpressured by disequilibrium compaction exhibit different physical properties to those overpressured by vertical transfer and hence, different pore pressure prediction strategies are required depending on the overpressure generation mechanism. Sonic and density log data detects overpressures generated by disequilibrium compaction and pore pressures are accurately predicted using an Eaton exponent of 3.0. Sonic log data detects vertically transferred overpressures, even in the absence of a porosity anomaly, and pore pressures are reasonably predicted using an Eaton exponent of 6.5.

The present-day stress tensor in Brunei displays a range of unique characteristics as a direct result of the tectonic setting of the Baram Delta province. The area exhibits the greatest variation in vertical (overburden) stress gradient ever described. The vertical stress gradients in 24 fields vary from 18.3

24.3 MPa/km in the hinterland at 1500 m depth. This vertical stress variation represents a variation in bulk density across the delta of 2.07-2.48 g/cm^3 in the top 1500 m of sediment. Breakouts and drilling-induced tensile fractures observed in 19 wells indicate that the maximum horizontal stress is oriented margin-normal (NW-SE) in the proximal parts of the basin and margin-parallel (NE-SW) in the distal region. The margin-normal maximum horizontal stress direction is perpendicular to the strike of Miocene-Pliocene normal growth faults in the delta. Hence, there has been an approximately 90° rotation of the maximum horizontal stress direction over time in

the inner shelf. The present-day and temporal stress rotations and the variation in vertical stress yield a 'snapshot' of a delta that is inverting and self-cannibalising. The proximity of the northwest Borneo active margin has resulted in uplift of the hinterland and successive inversion of normal-faults in a basin-ward direction, reflected in the present-day by the high vertical stress magnitudes and the margin-normal maximum horizontal stress in the inner shelf. The region of deltaic growth faulting is also 'prograding' as demonstrated by the margin-parallel maximum horizontal stress direction and active growth faulting in the outer shelf.

The minimum horizontal stress gradients in normally pressured sequences in 18 fields vary from 13.8 MPa/km in the Late Miocene-Quaternary Baram Delta system up to 17.0 MPa/km in the Middle-Late Miocene Champion Delta system. The higher minimum horizontal stress magnitudes are the result of a greater degree of basal attachment in the Champion Delta system. The minimum horizontal stress magnitude increases in overpressured sequences and decreases in depleted sequences with a pore pressure-stress coupling ratio ($\Delta\sigma_{hmin}/\Delta P_p$) of 0.58. Pore pressure-stress coupling results in the likely mode of overpressure-induced rock failure being tensile failure oriented NW-SE (rather than reactivation of existing faults) in the inner shelf.

The maximum horizontal stress magnitude determined in four fields reveals that a normal faulting stress regime ($\sigma_v > \sigma_{Hmax} > \sigma_{hmin}$) exists in normally pressure sequences of the Baram Delta province and hence the region is currently tectonically 'relaxed'. The full stress tensor is applied to resolve several petroleum geomechanics issues in the Baram Delta province. Planned underbalanced and shallow wellbores are more mechanically stable, with respect to compressional and tensile failure, if deviated towards the minimum horizontal stress direction. However, proposed fracture stimulation in mature fields can be more easily undertaken in boreholes deviated towards the maximum horizontal stress direction. Current exploration prospects in the western outer shelf region are typically bounded by growth faults. However, the bounding-faults are optimally oriented for reactivation and hence, fault seal breach is a significant exploration risk in the western outer shelf region.