Fault-seal Prediction in the gulf of Mexico: Empirical Data

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Fault-seal prediction is a long-standing risk of both exploration and production. Faults of course may trap hydrocarbons, subdivide fields into separate pressure compartments and well drainage areas, or appear completely transparent to hydrocarbons. In the GOM, Shell Offshore Inc.'s extensive and longstanding leasehold and production databases, coupled with streamlined fault-seal analysis software, have made it possible to compile empirical characteristics of well-constrained sealing and non-sealing faults. The results show that many of the common assumptions regarding fault seals are, in fact, not well justified. Accurate assessment and prediction of fault seals cannot be done using these assumptions, but can be done from empirical databases.

The main cause of sealing faults and sealing portions of faults is generally assumed to be cross-fault juxtapositions of shales with reservoir sands, which are characterized in terms of Allan maps and juxtaposition diagrams (Allan, 1989; Knipe, 1997). The sealing capacity of those presumably few sand-on-sand fault contacts which do seal is thought to be due to the seal capacity of the gouge, which can be described by either of two types of equations. One type of equation, typified by Shell'' Clay Smear Potential, describes the gouge'' seal capacity in terms of a physically continuous, wedge-shaped smear of clay or shale. The smear'' seal capacity is related to the length and continuity of the smear, which in turn are directly proportional to the overburden pressure and thickness and viscosity of shale, and inversely proportional to the magnitude and rate of displacement (e.g., Bouvier et al., 1989; Fulljames et al., 1996).

The second type of equation, typified by Linsay's Shale Smear Factor (Lindsay et al., 1993) or Badley's Shale Gouge Ratio (Yielding et al., 1997), describes the gouge's seal capacity in terms of a homogeneous mix of the sands and shales. In this type of equation, the seal capacities thought to be inversely proportional to the sand/shale ratio of the faulted rocks. Faults cutting high net/gross sections are though to have proportionally sand-rich gouges, and hence have little pressure-sealing capacity.

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Even though the two types of equations represent fundamentally different physical processes, recent but limited comparisons of the two have suggested that they yield equivalent results (e.g., Yielding et al., 1997; Handschy & Alexander, 1998). Both types of equations, however, require empirical calibration in order to relate actual fault-seal capacity (in terms of cross-fault differential pressures or hydrocarbon column heights) to either clay smear potential numbers, shale smear factors, or shale gouge ratios. Until recently, the efforts required to compile such calibration sets were simply too overwhelming to justify their collection.

Shell Oil Co. has developed proprietary software which greatly expedites these efforts. It directly incorporates all available well and 3D seismic data, enabling construction of highly constrained fault-plane maps. The results show that it is essential to collect data only from fault sets where the structure and stratigraphy are highly constrained by both well and 3D seismic control. Moreover, where fluid pressure gradients exceed hydrostatic, calculations of fault-sealed pressures must be constrained by measured formation pressures, or at least mud weights, on both sides of the faults.

The actual results of such data-intensive studies show that pressure-sealing faults in the Gulf of Mexico commonly include significant areas of sand-on-sand contact. Sealing sand-on-sand fault contacts occur in both hydropressured and geopressured reservoirs, and in at least one case, along an apparently long-lived and currently active fault. Conversely, traps formed by san-on-shale fault contacts are commonly underfilled with respect to the structurally highest possible sand-on-sand cross-fault leak point. Thus juxtaposition diagrams alone do not constrain fault-seal risks.

Comparisons of the two types of gouge equations with the *in situ* cross-fault pressure differences, show that one equation correlates well with the observed pressures in most cases, while the other does not.