GEOMECHANICAL AND MICROSTRUCTURAL PROPERTIES OF SILICICLASTIC FAULT ROCKS AND THEIR IMPACT ON PREDICTION OF FAULT REACTIVATION

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Fault seal prediction has become one of the most important considerations in petroleum exploration in recent years. This has been the result of intensive research from seismic to core to micro scale and has resulted in such developments as robust fault juxtaposition analysis diagrams and an understanding of the microscale processes that result in fault rock development. Well constrained lithological and juxtaposition data tied to seismically observable fault zones can provide good estimates of seal potential along faults and uncover regions along a fault zone where potential leak windows exist. However, while such analyses can define the sealing potential of faults that have been inactive since hydrocarbon charge, they cannot incorporate the potential for seal breach due to fault reactivation subsequent to charge.

The likelihood of reactivation can be assessed given knowledge of the stress field, fault orientation and the failure envelope for the fault rocks, assuming the current in situ stress field is representative of the stress field during reactivation. The relationship between these variables also dictates the likely mode of failure the fault will undergo. Morris et al. (1996) defined slip tendency as the ratio of shear stress to normal stress acting on a fault surface. Ferrill et al., (1999) defined dilation tendency as the normal stress acting on a fault plane normalised by comparison with the differential stress. Calculations of slip and dilation tendency were used to assess the likelihood of fault reactivation at the proposed high-level radioactive waste repository site at Yucca Mountain, Nevada. However, neither of these methods incorporates rock properties into their calculations resulting in relative estimates of shear and extensional failure. The relative risk between slip and dilation tendency cannot be determined and mixed mode failure (extensional-shear) is not considered at all. Wiprut and Zoback (2000) determined the increase in pore pressure required to induce reactivation of a previously inactive normal fault in the Visund Field, northern North Sea, assuming cohesionless frictional failure. These and related studies of the relationship between stresses and fault reactivation/permeability assume that the failure envelopes for pre-existing faults are described by a cohesionless Byerlee (1978)-type friction law. However, frictional sliding experiments on cohesionless joints or saw-cuts through rocks of the type summarised by Byerlee (1978) do not describe the failure envelopes for cemented fault rocks which may exhibit significant cohesion. This paper presents failure envelopes for microstructurally and petrophysically characterised fault rocks. Further, given that cohesionless friction relations do not describe the failure of these fault rocks, and that the methods outlined above require separate calculations to assess the risk of shear and tensile failure, an alternative approach to assessing the risk of fault reactivation and associated seal breach is presented and applied to a case study in the Otway Basin. This technique combines laboratory derived failure envelopes for fault rocks with in situ stress conditions to allow the risk of tensile and shear failure to be assessed using a single method.

The results of natural and laboratory-induced fault behaviour from wells in the Otway Basin are compared with sample material from a producing Carnarvon Basin field where rocks from a fault zone have been cored. Capillary pressure, microstructural and juxtaposition data obtained from these fault rocks indicate a capability to hold back gas columns in excess of 100m, yet many fault closures are found to contain only palaeo-columns. Trap failure is usually attributed to reactivation of trap-bounding faults, often during Miocene-Recent times in these basins. Faults susceptible to reactivation can be predicted by geomechanical methods involving the determination of the in situ stress field and the orientation and dip of faults with respect to that stress field. Failure envelopes of fault rocks have been determined to estimate reactivation potential in the present day in situ stress field. This approach works well where fault rocks are weaker than the host reservoir sandstone but may not be applicable where fault rocks are stronger.

We consider scenarios where fault rocks are stronger than the surrounding reservoir sandstone and consider the implications of this for geomechanical prediction of fault reactivation. Results from the study of faults and their associated damage zones in the Australian Carnarvon and Otway Basins show that some cataclasites and phyllosilicate framework fault rocks that have undergone post-deformation healing can exhibit high cohesive strengths (up to 17 MPa) and thus cannot be adequately described by a cohesionless frictional failure model. In fields where fault rocks are stronger, intact hydrocarbon columns are present, irrespective of whether faults are optimally oriented for reactivation. This indicates that the assumptions of zero cohesive strength and constant friction coefficient for predicting the reactivation potential of fault rocks may not be completely reliable.

References

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