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The Use of Structural Modelling in the Simulation of Naturally Fractured Reservoirs: An Example from the Tarija Basin, South American Andes as an Analogue for Algerian Atlas Uplift Reservoirs

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Naturally fractured reservoirs account for an ever-increasing proportion of operator portfolios. The derivation and understanding of fracture attribute data is complex with fractured reservoirs having many additional barriers to correct examination. Examples of such difficulties are summarised by Nelson (2001) and include: a lack of in-depth quantitative approaches to describing and characterising fractured reservoirs and overly simplistic approaches to describing fracture network geometry. Three-dimensional structural modelling can provide insight and quantitative results applicable to simulation models of naturally fracture reservoirs. An Andean example from the Tarija Basin, Argentina is used to illustrate the modelling techniques that can be applied to Algerian Atlas Uplift Reservoirs in order to resolve uncertainty in fracture networks. A clear understanding of the origin and type of fractures likely to be encountered in the subsurface is critical before the fracture network fluid flow properties can be assessed (Price and Cosgrove, 1990) and optimal exploitation strategies adopted.

Fractures in natural systems form as a result of geological processes; therefore a reproduction of the deformation history can provide insight into understanding the genesis of fracture systems. Three-dimensional structural modelling allows exploration of geological processes that have contributed to the generation of fractures. Using this approach the geologist can reconstruct the structural geohistory of the reservoir, (e.g. removing the effects of sediment compaction, folding and faulting). Furthermore, with regard to modelling fracture networks, a combination of forward and reverse kinematic modelling allows the prediction of strain recorded in the rocks. These modelling techniques yield strain tensors, which assist characterisation of the fracture network for the entire reservoir. Such strains sometimes correlate with fractures observed at outcrop and in wells (e.g. Hennings et al., 2000; La Pointe et al., 2001).

In order to be able to model these fracture systems accurately we need to understand their genesis. The generation of such fractures can come about via a combination of events. However their genesis can typically be summarised by two hypotheses; syntectonic or pre-tectonic fracturing.

In the syntectonic model most fractures are formed during tectonic macro-deformation. In cases of significant tectonic deformation observations show that rocks record significant strain during their geological history, in a manner dependent upon the rock properties and boundary conditions. Under brittle deformation conditions in the upper crust (the default conditions for petroleum reservoirs), reservoirs form fractures predominantly by yielding after the elastic strength of the rocks is exceeded. This can be due to bending of strata or pervasive shearing; as such fracturing accommodates the strain of the material through time. Areas with high bulk strain are therefore expected to have more intense fracturing than areas with low strain. Based on these assumptions, strain analysis and curvature analysis (Lisle, 1994) can be used to model fracture systems with the help of structural restoration and forward modelling techniques.

The pre-tectonic hypothesis supposes that most fractures are formed prior to a main tectonic deformation. During the build up of stress prior to major tectonic release, fractures are formed in the rock. These fractures are oriented according to the stress regime, while the fracture intensity is expected to be nearly constant over large areas, and largely a function of rock properties, implying mechanical homogeneity. This model has often been used to explain natural fracture systems in areas with low tectonic deformation. During tectonic movement (such as thrust-sheet emplacement), the pre-existing fracture networks are mostly passively transported and only a minor amount of the tectonic strain is accommodated by the fracture network. Fracture intensity is thus mostly controlled by rock properties and is not expected to show much variation over the reservoir scale. Such fractures can be modelled stochastically, or forward modelled from stress calculations based on an assumed initial geometry.

In reality both end members may be present to varying degrees, depending on the geological history, the intensity and style of deformation and the rock properties. Additionally, other fractures may be formed in the upper-crustal layers due to exhumation, thermal expansion or contraction, or hydraulic processes. As such, a clear understanding of the geological and structural history, combined with feedback from well information, will decide which proxy is most appropriate to model fracture intensity and orientation fields.

Workflows are presented for the kinematic restoration of 3D geologic models to their pre-deformation states. Techniques used to determine geometric parameters such as curvature are illustrated and the results compared to finite and incremental strain recorded from tectonic movements derived by forward modelling of surfaces and volumes. The Tarija Basin case study illustrates how such modelling techniques can be applied directly to Atlas Uplift reservoirs as proxies for fracture locations. The resulting Discrete Fracture Network (DFN) models enable the generation of virtual fractures for comparison with well data and export to field-scale reservoir simulation models. The approach described can reduce exploration and development risk and enhance production.

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