The Impact of Fault Properties on Reservoir Production Behaviour

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Faults are important elements in the production behaviour of hydrocarbon reservoirs. Recently, compartmentalisation of deepwater reservoirs has become an important issue and faults have been identified as one of the key contributing factors. Also, compartmentalisation was identified as a key strategic theme because it is considered to be an important contributor to surprises encountered in recent development projects.

Faults are represented conventionally in production flow simulation models using transmissibility multipliers to capture the fault rock properties. The transmissibility multiplier, single number between 0 and 1, is a function of all the physical variables that combine to baffle flow between fault-offset cells. Whether hydrocarbons will flow at significant rates across faults will influence well counts, well placement, and ultimate recovery.

In the context of fluid flow, the most important features of a fault are the throw, the fault thickness, the permeability reduction inside the fault, and the increased entry pressure for the non-wetting phase. The transmissibility of the flow connections across the fault is based purely on the geometry and the properties of the host rock. To get a geologically consistent description of the effect of the fault on fluid flow, the thickness of the fault zone and the impact on permeability and entry pressure are incorporated in consistent, systematic ways, in order to isolate their impacts on production behaviour.

Accurate characterizations of the faults have yielded more realistic and more economic highly deviated and horizontal wells across faults, robust field development plans with clear economic advantages, and successful history matches.

Insights into the Genetic Controls on Production Performance of Deep-water Reservoirs; Analogies from Quaternary Case Studies

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During the 1990s, exploration for hydrocarbon reservoirs in deep-water basins resulted in the discovery of numerous significant new fields (GoM, offshore Nigeria and Angola). Spurred by this activity, a great deal has been learned about turbidite-dominated deep-water reservoirs. However, observations made during the development of these fields has tested conventional wisdom and indicate there is much more to learn about deep-water depositional systems and depositional controls on performance behavior. Early production and 4D seismic monitoring data from many of these fields indicate heterogeneities near and below seismic resolution are common and are important controls on fluid flow. The depositional processes responsible for the formation of these heterogeneities are poorly understood and therefore, difficult to predict and to represent in geologic and reservoir simulation models.

One source of information bearing on the problem(s) comes from case studies of Quaternary systems. Detailed case studies of the Congo, Var, Amazon and Corsican fans are here used to better understand and illustrate fundamental geologic processes impacting reservoir characteristics. From these studies, significant progress has been made on a variety of relevant topics including: channel sinuosity and lateral migration, channel-fill heterogeneities, confining levees and terraces, channel-levee transition zones, channel avulsion processes and related deposits and distal, terminal lobe deposits. These insights, when integrated with knowledge gleaned from 3D and 4D seismic images, well logs, cores and production information from subsurface settings provide a process-based understanding of deep-water reservoirs and their production performance.

Reservoir Development, Surveillance and Management in Deepwater Slope Systems – Reservoir Architecture, Heterogeneity and Connectivity Learnings from the Zafiro Field, Equatorial Guinea

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With long construction lead times, relatively short field life and the high cost of many deepwater field developments, ongoing multidisciplinary integration is essential for development plan implementation and continuous improvement of reservoir depletion plans. The phased development of the Zafiro Field provides an excellent example of how this can be achieved and demonstrates the impact of multiple, hierarchies of reservoir heterogeneity and connectivity on fluid flow over the productive life of a deepwater field.

The Zafiro Field, Equatorial Guinea, was discovered in 1995 and contains over 20 Pliocene age deepwater slope channel complexes. The field was developed using a staged approach and includes both subsea and platform wells. High-resolution 3D, 4D seismic log and pressure data from 100 reservoir penetrations, over 3500ft of conventional core and 10 years of production data have been integrated to create very accurate geologic and reservoir simulation models. In addition, staged development and continuous drilling has allowed the ongoing collection and integration of log and pressure data from stacked reservoirs. This has helped evaluate well interference/conformance, identify reservoir baffles and barriers, confirm relative permeability differences, and allowed differentiation of primary from secondary gas caps, and perched water from zones swept by injection. When integrated with reservoir surveillance data, the high resolution hierarchical seismic stratigraphic framework, combined with detailed depositional environment interpretation and 4D seismic analysis has allowed a more complete understanding of the spatial and temporal changes in fluid saturation, reservoir pressure and the movement of fluid contacts.

Dynamic Palaeo-fluid Flow within Giant Gas Fields from the Browse Basin, Australia

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An investigation of the fluid flow history of reservoir sandstones from a series of giant gas fields in the Browse Basin has revealed significant changes in the palaeo-hydrology of the basin through time. Salinity measurements on aqueous inclusions within diagenetic quartz document substantial changes in formation water salinity involving ingress of highly saline waters that have become progressively diluted with time. Fluid inclusions with the highest palaeo-salinities (>200,000 ppm) have the lowest trapping temperatures whilst inclusions with salinities that are closer to the current formation waters (generally <20,000 ppm) have trapping temperatures that are similar to the current reservoir temperature. These data imply that formation water salinity decreased throughout a period of continuously increasing burial and temperature probably reflecting flow of the denser, more saline fluids into the deeper parts of the basin and replenishment by waters of lower salinity.

Hydrocarbon charge consisted of an early oil charge, filling only the crestal parts of these structures before being displaced or absorbed by a volumetrically more significant gas charge. A subset of fluid inclusion salinity measurements collected on inclusions that contain both oil and formation water have a much narrower salinity range (25,000–35,000 ppm) than those that are purely water filled, but are more saline the current formation waters. These oil-water inclusions have trapping temperatures that are consistent with trapping prior to the subsequent gas charge. The reservoirs complex charge and fluid flow history has major implications for irreducible water salinity, the accurate estimation of Rw and ultimately reserves.

Dual Hydraulic Behaviour of Basin Boundary Fault Systems in the Dutch Part of the Southern North Sea Basin: Results of Integrated Analysis of Pressure, Temperature and Hydrochemical Data

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The Carboniferous-Cenozoic sedimentary sequence of the Netherlands North Sea contains a great variety of proven hydrocarbon plays. Understanding of fluid flow behaviour of faults is of critical importance for the petroleum exploration, appraisal and production. This paper provides results of an integrated study to assess the 3D permeability framework of the North Sea area and focusses on the results with respect to the hydraulic role of major basin boundary fault systems. Hydrodynamic methods were applied combining information from recently completed stratigraphic and structural maps, studies of the sedimentological and tectonic development and burial history simulations, with pressure, temperature and salinity data from 500 wells.

The Cenozoic sequence in the Netherlands unconformably covers nine Mesozoic Basins that rest on the Southern Permian Basin, which in turn overlies the Variscan foreland Basin. The post-Variscan history has been influenced by the older Variscan geological and structural configuration of the area. Many of the faults have been reactivated multiple times and shaped the Mesozoic basinal structure. Present-day patterns of hydraulic head revealed that basin boundary fault sytems may act as barriers for lateral flow and separate the pressure and flow systems in the basins from adjacent platforms; in some areas flow is towards the fault zone suggesting it is also acting as a conduit for vertical flow. Trends of relatively high salinity in different reservoirs along fault zones and temperature anomalies suggest that these fault zones have acted as preferential flow zones.

We show examples of this dual hydraulic behaviour of basin boundary fault systems.