Sensitivity analysis of the influence of faults on oil production from shallow marine reservoirs

T. Manzocchi[1], J.A. Strand[1], J. Matthews[2], A.Skorstad[3], J. Carter[2], J. Howell[4], K.D. Stephen[5]

[1] Fault Analysis Group, Dept. of Geology, University College Dublin, Dublin 4, Ireland.
[2] Department of Earth Science and Engineering, Imperial College, London SW7 2AZ, UK.
[3] Norwegian Computing Center, Postbox 114 Blindern, N-0314, Oslo, Norway.
[4] Department of Geology, University of Bergen, Allegt. 41, N-5007, Bergen, Norway.
[5] Institute of Petroleum Engineering, Heriot-Watt University, Edinburgh, EH14 4AS, UK.

We describe results from the multi-partner, EU-supported SAIGUP project, the principal purpose of which is to quantify objectively the influence of geological complexity on production forecasts in progradational shallow marine reservoirs. The approach used has been to build realistic synthetic reservoirs with combinations of geological factors and to flow-simulate a 30-year production history using four different production plans on each. Formal statistical as well as more physically or geologically based, often curiosity-driven, analyses of the 20,000 sets of simulation results are used to determine the influence of geological characteristics on total oil production, recovery factor, and discounted reservoir value.

Sedimentologically, the models range from comparatively simple, parallel, wave-dominated shorelines through to laterally heterogeneous, lobate, river-dominated systems with abundant low-angle clinoforms. One or more stochastic realizations of each of 81 parametrically distinct sedimentological models are placed within 10 structural cases of our datum reservoir; a typical three-way dip-closing tilted fault block containing post-depositional normal faults. Three distinct fault systems (a strike-parallel, a strike-perpendicular and a compartmentalised fault case) are sampled at three strain levels to give 9 faulted versions of each reservoir. Each fault system merges into a common unfaulted reservoir at zero strain; this defines the 10^{th} structural case. The largest faults in the highest strain versions have throws slightly lower than the total 80m thick reservoir sequence, and realistic populations of sub-resolution breached and unbreached fault relay zones are included in some models. Up to 9 fault-rock permeability predictors, defined using the fault surface Shale Gouge Ratio as a permeability-proxy, are applied to each faulted sedimentology. The well locations in the four development plans are based on the unfaulted and three faulted structural end-members.

We focus on the effects of the faults on the value of the model reservoirs. Fault juxtaposition effects can reduce the reservoir value by up to 30%, with the greatest losses observed in models with lower sedimentological aggradation angles and, paradoxically, faults striking parallel to water-flood direction. Fault-rock has a greater effect than juxtaposition only in the compartmentalized reservoirs and only when the permeability predictor is towards the more sealing cases of published SGR/permeability relationships. Except when the flow direction is parallel to the faults, moderately sealing faults can increase the value of reservoirs. These results, often counter-intuitive, arise from the dependence of reservoir value on both sweep efficiency and production rate: although flow rates are lower if the waterflood direction is perpendicular to lower permeability faults, the permeability anisotropy imparted by these faults results in more optimally disposed flow paths, and hence in more efficient sweep. Conversely, faults parallel to flow direction have little effect on flow rate but can significantly reduce sweep efficiency. Simple analytically derived predictors of (a) fault juxtaposition and fault-rock quality in a sequence stratigraphic context, and (b) reservoir permeability anisotropy as a function of fault system compartmentalization and anisotropy, allow estimation of likely ranges in production rate and sweep efficiency as a function of faults in reservoirs with different structural and sedimentological characteristics. These can, in turn, be used to estimate their value, dependent on the production plan. Although tested only within the suite of synthetic models described, these predictors are generic, and might therefore serve as tools for estimating the effects of faults on ultimate reservoir value early in the production or appraisal period of faulted, shallow marine reservoirs.