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TITLE : Incorporation of fault properties in hydrocarbon migration models

PROJECT CO-ORDINATOR : SINTEF Petroleumsforskning AS (IKUNO.BMD)

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Objectives and Introduction:

A major shortcoming of existing modelling systems for basin-scale hydrocarbon migration is that they do not take account of the effects of faults. The primary Infami objective was to add functionality to an existing migration modelling software system (Semi) to incorporate both the negative and positive effects of faults on migration and accumulation in multiple carrier/reservoir intervals offset by seismically mapped faults. Additional project objectives were to improve understanding of the factors controlling fault seal capacity both by basic research approaches and by attempting to replicate known hydrocarbon distributions using the newly developed software.

Semi is a computational modelling system designed to investigate migration and entrapment of oil and gas from source rocks to traps, and thereby provide explorationists with quantitative estimates of the amounts of hydrocarbons in (undrilled) traps, and the most likely phases to expect in them. Oil migration is modelled by the ray-tracing method where oil migrates upwards due to buoyancy forces beneath the top surface of a carrier interval. Three types of fault seal behaviour are of concern: 1) juxtaposition seal due to the across-fault juxtaposition of sealing units against carrier units; 2) across fault 'membrane' seal where carrier units are juxtaposed across the fault; and 3) migration along faults. The seal capacity in case 1 is a function of the geometry of the fault carrier unit(s) and seal capacities in cases 2 and 3 are controlled the by the threshold pressures of the fault rocks. The key objective was to define methodologies for defining fault threshold pressures and incorporate these three behaviours in single and multiple carrier Semi simulations. The assumptions made at the outset of the project which formed the basis for fault seal calculation were 1) fault seal capacity is defined by fault rock threshold pressures, i.e. static rather than dynamic seal and 2) fault rock threshold pressures are related to the percentage shale in the faulted sequence i.e. the Shale Gouge Ratio (SGR).

Results

Software development:

The Semi single carrier software has been modified to provide accurate calculation of fault seal parameters (SGR) by the inclusion of functionality to:

- Derive vshale distributions for the model area based on available well data. The vshale within an individual well may be assigned to particular fault blocks, interpolated between wells or a combination of these approaches. In either case vshale distribution is guided by mapped horizons.
- Variation in seal capacity due to changes in hydrocarbon phase and density.
- Account for differences in fault throw between the base and top carrier horizons due to erosion and/or fault movement during deposition of the carrier interval.

Fault threshold pressure distributions along faults are calculated primarily as a function of SGR. A look up table allows complete freedom of definition of SGR to threshold pressure relationships in addition to predefined relationships including a relationship based on published laboratory fault property data. Different threshold pressures can be defined for oil and gas. Changes in phase and hydrocarbon fluid densities together with fault threshold pressure define variations in fault seal capacity during a model run. A Monte Carlo approach to the assignment of fault seal properties has been developed for the single carrier version of the simulator. A series of parameters, defined within user specified ranges, modify an input 'seed' SGR to threshold pressure relationship to define multiple realisations of these relationships. This approach allows for rapid calibration of SGR to threshold pressure relationship against known hydrocarbon columns within a study area.

For the multiple carrier system a faulted horizon grid and a series of isopach maps define several carrier unit and associated sealing unit pairs. The software computes leak-points and entry-pressures for cross-stratigraphic flow across and along the fault planes defining all potential flow paths between carrier units on either side of each fault. Multiple map windows allowing simultaneous inspection of hydrocarbon distributions and flow in each carrier interval, and three dimensional viewing provides a means for inspecting the complex flow in stacked carrier units.

Migration modelling:

The application of the single carrier modelling technique to good quality data has been demonstrated to be capable of producing close matches to known hydrocarbon distributions in the subsurface. An inability to replicate known hydrocarbon accumulations points to poor model definition, in particular inaccurate fault throws, or a lack of understanding of fault seal processes. In the latter case, modelling provides an opportunity to improve understanding.

The new methods when applied to high quality datasets provide a means of estimating faults seal envelopes (e.g. SGR to threshold pressure relationship) which is significantly faster and more robust than standard methods. In this method seal capacities for individual traps do not just constrain the SGR to threshold pressure at a single assumed across fault leak point but provide constraints on best fit relationships as they require not only that oil must be trapped to a particular level but also that hydrocarbons can access the trap. These additional requirements provide more stringent constraints on a fault seal envelope than the single point derived in standard fault seal calibration.

A close match to the modelled multiple carrier case was not achieved. This is thought to be mainly due to difficulty in definition of throws of small faults. Given the very complex and tortuous migration arteries involved in multiple carrier models it would perhaps have been surprising if a good match was obtained at the first attempt.

Other aspects:

Outcrops of minor faults were studied in three dimensions
by cutting closely spaced serial sections through faulted unlithified sediments. The faults demonstrate the complexity of fault zone structure which arises from the propagation of faults through soft sediments. Significant areas of faults comprise multiple slip-surfaces onto which fault displacement is partitioned. Branchlines between two slip-sufaces are ares of increased clay smear, but more importantly from a fault seal viewpoint, sand smear continuity and thickness. Continuous sand smears were observed where the fault displacement was as much as five times the thickness of the sand layer. Discontinuous clay smears at low ratios of fault displacement to clay layer thickness (~3) occur in faults formed close to the surface and are attributed to a sand/clay competence inversion at low burial depths.

Two dimensional DEM modelling applied to the growth of normal fault zones in cross-section, offsetting alternating sand/shale sequences has been shown to reproduce many of the features characteristic of such faults in nature. The models indicate fault zone structure and shale smear distribution in fault zones is controlled by the complex interplay between confining pressure, or depth of burial, and the relative thicknesses and strengths of sandstones and shales.

Considerations based on capillary theory have indicated that the trapping potential of faults should be influenced by changes in across-fault aquifer pressure, where seal capacity is reduced for hydrocarbon columns on the high pressure side and increased on the low pressure side. The magnitude of this effect can be calculated as a function of the relative water transmissibilities of the seal and the trapped oil column. However collated data relating across-fault aquifer pressure variations to buoyancy pressure due to trapped hydrocarbons do not demonstrate a correlation between these measures and so the results of these analyses are inconclusive.

Applications:

The newly developed software functionalities provide a means for incorporating theoretically derived fault seal prediction algorithms into migration modelling and to test these predictors against known hydrocarbon distributions. The software therefore provides a link between theory and known hydrocarbon distributions opening a new avenue of fault seal research.

The migration modelling methodology will enhance exploration capability in both mature and immature provinces. The anticipated improvements in industry practice arising from the methodologies developed and implemented within the project, will contribute to continued efforts to secure sustained hydrocarbon reserves and to ensure a stability of energy cost within the EU.