THE IMPACT OF FAULT SEAL PROPERTIES ON HYDROCARBON MIGRATION MODELLING OF THE OSEBERG-SYD AREA, VIKING GRABEN.

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The sealing capacity of faults is known to have a major control on hydrocarbon distribution and accumulation. Seal analysis of faults which bound known accumulations is standard practice within the oil industry and empirical datasets comprising the results of several analyses provide the basis for risking undrilled fault- dependent prospects. However fault seal capacity predictors based on these empirical datasets are not generally incorporated into migration modelling. Incorporation of predicted fault seal properties into migration modelling provides a stringent test of predictive methods and the empirical data on which they are based. The requirement in migration modelling is to replicate the complete hydrocarbon distribution, including known filled and unfilled traps and the trapped phases. This procedure provides a powerful tool for testing and increasing our understanding of fault seal processes. Results from multiple model realisations with different predicted fault seal capacities provide a means for conducting sensitivity analysis and therefore lead to improved prospect risking. Inability to model precisely known hydrocarbon distributions may indicate shortcomings either of the data (e.g. seismic mapping, sequence definition) or of the geological understanding of the processes incorporated in the models (e.g. fault seal processes). In addition, migration modelling of the entire migration network of spill-points and migration arteries, allows us to distinguish fault- dependent traps which are unfilled because they do not lie on a migration pathway from those where the bounding faults are not sealing and therefore complements existing methods for fault seal calibration.

Here we describe a method for incorporating predicted fault seal capacities into migration modelling and illustrate its application to the Oseberg-Syd area, Viking Graben. The method has been implemented within Semi migration modelling software (Sylta 1991). Semi employs a ray tracing modelling approach which assumes that hydrocarbons migrate along the top of a permeable carrier bed and upwards along the steepest dip governed by buoyancy. Hydrocarbon charge may be from a source layer within the model area or from injection points at the edges of the model at locations defined from regional migration studies. Burial history, hydrocarbon maturation, expulsion and secondary migration are calculated at user defined timesteps.

Fault sealing potential is considered to be related to the percentage shale within the part of the sequence which has moved past a point on the fault surface; termed the Shale Gouge Ratio (Yielding, 1997). In the approach adopted here a vertical profile of SGR values at a point on a fault trace is calculated from the lithological sequence, defined by a vshale curve, and the fault throw (Fig. 1a & b). SGR values are converted to fault rock capillary threshold pressures using equations constrained by available calibration data to give a curve of fault threshold pressure versus depth (Fig. 1c); sensitivity analysis can be performed for a range of SGR/threshold pressure relationships. The threshold pressure curve is used to determine the seal capacity at the point on the fault trace for particular fluid densities and capillary properties i.e. contact angle and interfacial tension. Where the carrier interval is self-juxtaposed then the fault seal capacity is determined by the intersection of the capillary pressure profile, due to the buoyancy of the hydrocarbon column, with the fault rock threshold pressure curve

(Fig. 1c). Where the carrier interval is self-separated, i.e. the fault throw is greater than the carrier interval thickness, the fault seal capacity is the maximum threshold pressure of the portion of the fault between the upthrown and downthrown carrier interval. Fault seal capacities are calculated along the length of each seismically mapped fault and the ray-tracing method automatically locates the leak point of each fault during the model run.

The vshale curves used to calculate SGR values are derived from the available well data. Individual wells may be assigned to particular areas of the map, e.g. individual fault compartments, or may be interpolated between wells to give a continuously varying sequence over the model area. The interpolation routines honour changes in thickness of the carrier interval across faults. The software also allows for temporal variation in trapped phase so that the sealing capacities of faults may change during a model run depending on the trapped hydrocarbon type.

The modelling approach has been applied to the Oseberg Syd area of the Viking Graben (35 x 22km area). The majority of the known hydrocarbon accumulations in this area are at least partly dependent on fault seal and a correlation between SGR and fault seal capacity has been previously demonstrated (Fristad et al. 1997). Hydrocarbons occur in the Traissic, Statfjord Formation and within the Ness and Tarbert Formations of the Middle Jurassic Brent Group. Here we have modelled migration and accumulation within the Tarbert Formation. Faulting within the area initiated during the time of deposition of the Tarbert sequence so there are thickness changes in the modelled carrier interval across some faults, and the depth of burial of the carrier at the time of faulting was up to a few hundred metres. The model area is generally shallower than the hydrocarbon generation window and hydrocarbons are sourced mainly from kitchen areas to the west and the south; hydrocarbons are injected into the model at points determined from regional migration studies.

The Oseberg Syd model output, in terms of migration pathways and hydrocarbon distributions, is highly sensitive to the input threshold pressure relationship as illustrated in Fig. 2. Two different migration arteries are identified in Fig. 2(a). The first of these (shown white) connects three traps A, B and C which are separated by two sealing faults; traps B and C are known to contain hydrocarbons, while A is an undrilled prospect. Trap A is sourced from the east and leaks to the north, into the structurally higher trap B, when the sealing capacity of the bounding fault is exceeded. B in turn spills into C where the bounding fault forms a branchline with a second fault bounding trap C. For the higher fault seal case (Fig. 2b) the sealing capacity of the fault bounding A to the east is not reached and hydrocarbons spill close to the southern tip of the fault to merge with the second migration artery (shown white with black line). Similarly trap B spills ~4km to the south of the crest of the structure where the bounding fault has a branchpoint with a minor fault. For this fault seal case trap, C is not charged. The precise fault seal relationship chosen can therefore strongly control not only the magnitude of trapped hydrocarbons but also whether individual fault blocks are charged or not.

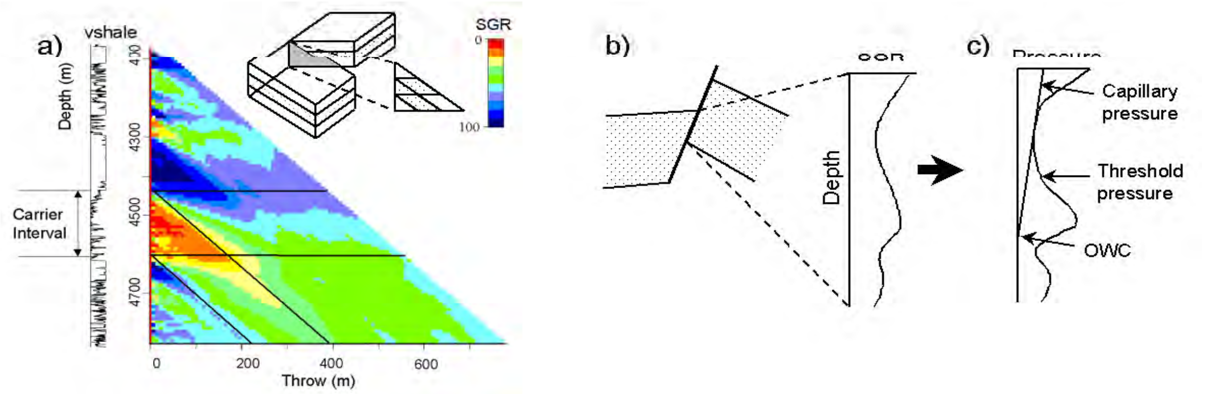

Fig. 1. Schematic diagram illustrating the method of calculation of fault seal capacity. (a) Sequence-throw juxtaposition diagram constructed for the vshale curve on the left of the figure (TVD in metres) and contoured for SGR. The horizontal and diagonal lines are the top and base of the carrier interval on the upthrown and downthrown side of the fault, respectively. The diagram construction is illustrated in the inset. In the inset, the stippled area represents the carrier interval. The SGR versus depth curve for the relevant fault trace segment (b) is converted to a threshold pressure curve (c). The depth of the oil-water contact is determined by the minimum capillary pressure due to buoyancy required to intersect the fault threshold pressure curve.

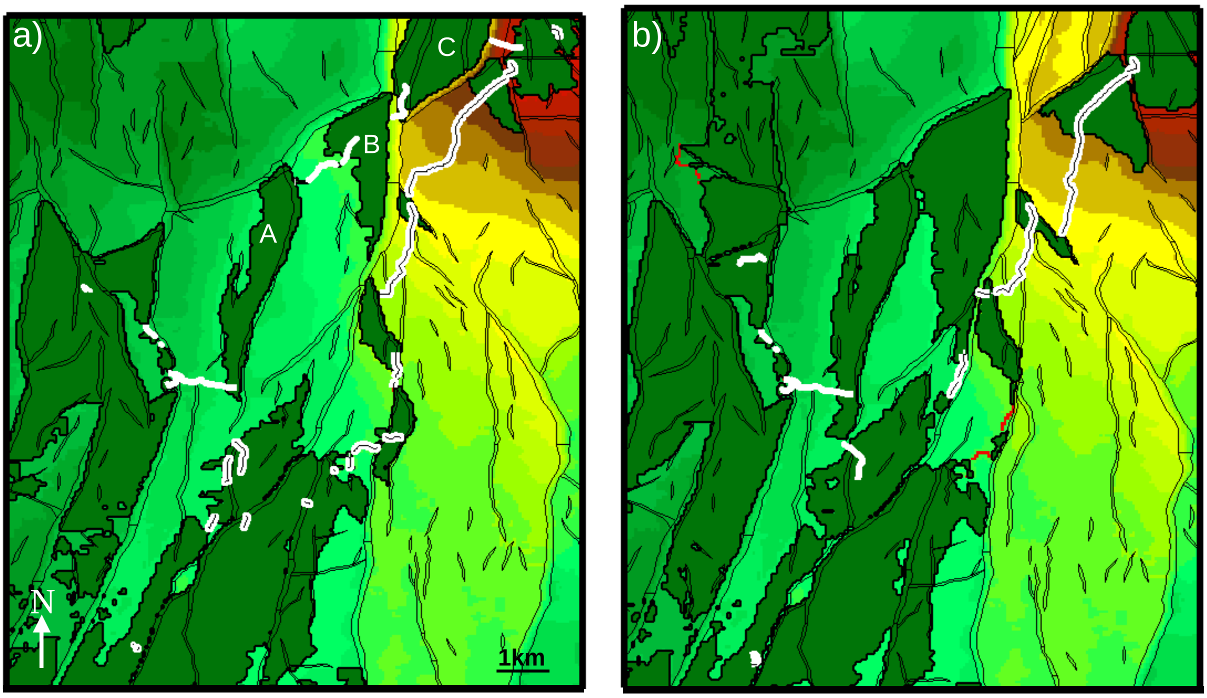

Fig. 2. Top carrier structure contour map of part of the Oseberg Syd area. The regional carrier dip is towards the west. Dark green areas outlined in black are model hydrocarbon accumulations. A, B and C are progressively higher accumulations discussed in the text. Two migration arteries are highlighted in white and white with a black line; the flow direction is generally from the SW to NE. Fault seal capacities calculated for a) are lower than those for b) i.e. lower fault threshold pressures for a given SGR value.

Hydrocarbon distributions within the model are dependent not only on the fault threshold pressure relationship but also on the vshale distributions over the model area. The approach used here allows sensitivity analysis of both these parameters to be conducted giving an improved risking of prospects. Accuracy of fault mapping is also an important factor. While multiple realisations of seismic mapping are generally not available, migration modelling highlights those parts of the study area which are critical to the overall migration scenario and which should be the focus of increased mapping effort. Within the Oseberg Syd area the known hydrocarbon distribution can be reasonably well matched but uncharged fault bounded blocks where hydrocarbons are known to exist point to errors in the seismic mapping, inadequacies in the geological definition of the model (e.g. spatial variation in vshale) or an additional fault seal process not incorporated in the modelling.

References

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