A novel adaptive gridding approach to hydrocarbon migration modelling

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Abstract

New approaches to basin scale hydrocarbon migration modelling may enable more accurate estimates of flow pathways, oil and gas losses and volumes trapped in undrilled prospects. These computer based methods may aid in constraining uncertainties and reducing exploration risk

Most sedimentary basins include complex and dynamic geological features such as faults and salt bodies that may be best represented as non-regular mesh elements in computer simulators. Hydrocarbon migration flow patterns evolve through geologic time and we therefore propose to use dynamic meshes where each element in the mesh represents a section of a migration flow-path.

The width and length of the individual hydrocarbon flow elements may typically be 30m and 200m, respectively. The hydrocarbon flow mesh is placed within a regular or non-regular structural mesh that represents the stratigraphic section during burial. The non-regular parts of the structural mesh are typically located along fault planes and salt domes.

The stratigraphic mesh is subdivided vertically into flow-units in order to achieve a more realistic representation of flow in e.g. thin carriers and seals. This allows for using a Darcy flow approach with relative permeabilities and capillary pressures as functions of oil and gas saturations in the calculations of migration velocities, hydrocarbon saturations, column heights and migration losses within each migration flow-path.

The oil and gas flow-patterns within a subsiding basin can be studied in a 3D view as flow-rates for each modelled time-step. Highlighting migration arteries may be an efficient technique for focusing exploration efforts, e.g. more detailed seismic mapping towards the prospective areas. Overall statistics of migration losses versus e.g. carrier permeabilities are useful for assessing the migration efficiencies at the basin level.predictions should become possible if the seal is sufficiently well characterised.

Content:

•Objectives
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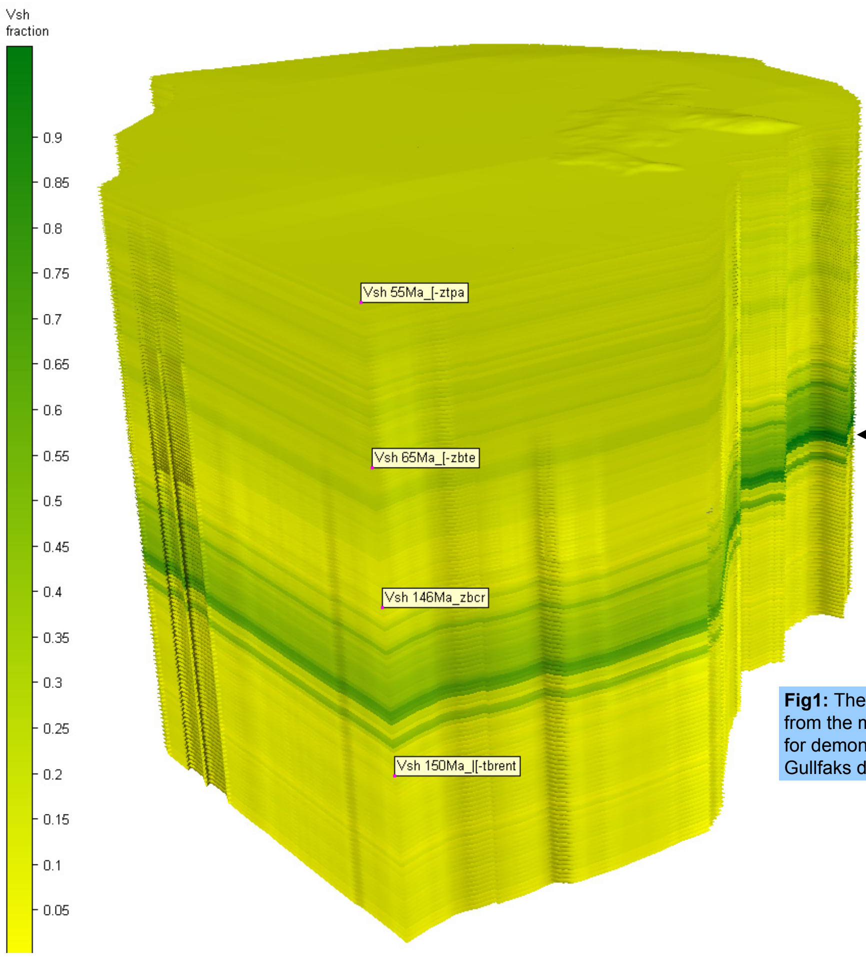
•Vertical description
•Flow modelling
•Flow patterns
•Results
•Further work
•Conclusions

Objectives

Hydrocarbon migration modelling is a tool that can be used to increase our understanding of the migration process and help in the description of oil and gas flow patterns through geological time. Geological risks can therefore be studied using these techniques.

We outline a novel approach to migration modelling and show how It can be applied to the basin-scale migration of oil and gas in a multi-carrier system.

We show some of the new properties that can be plotted in order to gain insights into the process of hydrocarbon migration at basin scales. We concentrate on lateral migration in this poster.



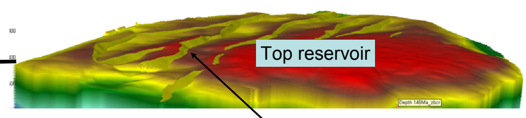


Fig1: The distribution of shale content (Vsh - %) in a stratified basin with faulting from the main carrier below a regional seal. “Basin” is synthetic and will be used for demonstration purposes only. Strucural model is modified from a published Gullfaks dataset from StatoilHydro.

Lateral Meshes

Most sedimentary basins include complex and dynamic geological features such as **faults** and salt bodies that may be best represented as **non-regular mesh** elements in computer simulators (Fig 2).

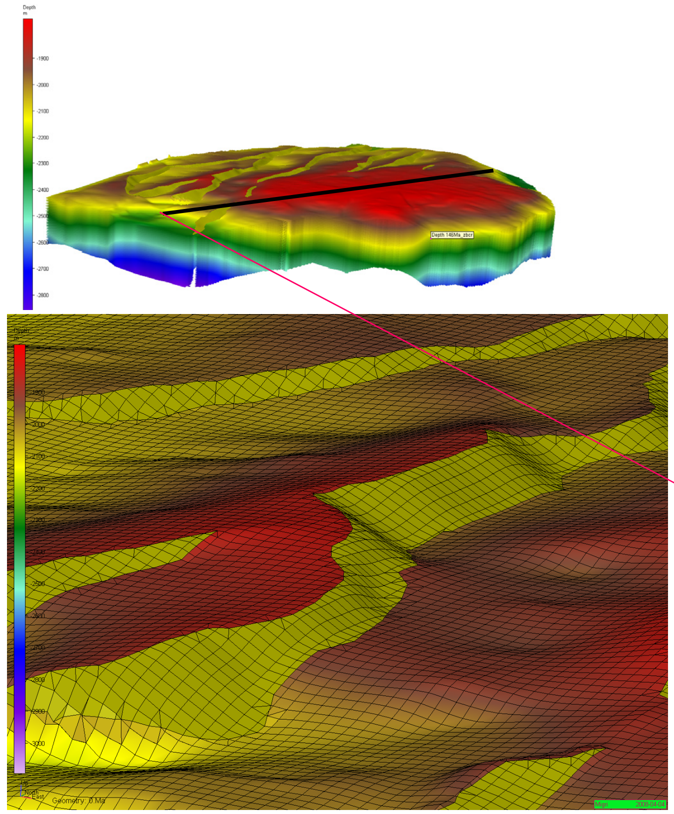


Fig 2. Top of faulted carrier with non-regular meshes shown. Yellow fault planes.

Hydrocarbon migration flow patterns evolve through geologic time and we therefore propose to use dynamic meshes where each element in the mesh represents a section of a migration flow-path (Fig.3, right)

The width and length of the individual hydrocarbon flow elements may typically be 30m and 200m, respectively. The hydrocarbon flow mesh is placed within a regular or non-regular structural mesh that represents the stratigraphic section during burial. The non-regular parts of the structural mesh are typically located along fault planes and salt domes Figs 2, 3). All structural mesh elements that experience lateral flow are automatically split into a number of flow elements. The flow elements are oriented along the flow-path direction of the carrier. This direction can be detemined from carrier dip, lateral entry pressure variation and overpressure changes within the carrier system. See next Plate (left) for a more detailed description.

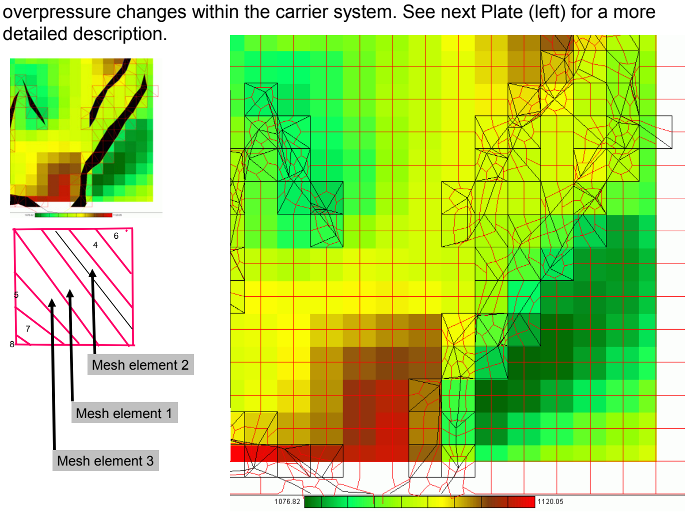


Fig 3. Faulted surface with red outlines of non-regular mesh elements (upper left). Black mesh outlines and red mesh connections (right).
Nine flow elements within a single regular structural mesh element (lower left)

Vertical subdivision

The stratigraphic mesh is subdivided vertically into flow-units (Fig 4) in order to achieve a more realistic representation of flow in e.g. thin carriers and seals. This allows for using a Darcy flow approach with relative permeabilities and capillary pressures as functions of oil and gas saturations in the calculations of migration velocities, hydrocarbon saturations, column heights and migration losses within each migration flow-path (see next plate).

We use a high-resolution Vsh log to define the vertical stratigraphy of the basin (Fig 5). The stratigraphy is subdivided into a series of layers, and this constitutes the structural mesh. Each layer is further subdivided into a series of sub-layers, which means that each structural mesh element is vertically subdivided into flow-units. All lateral flow within each layer is treated as sub-parallell by the simulator.

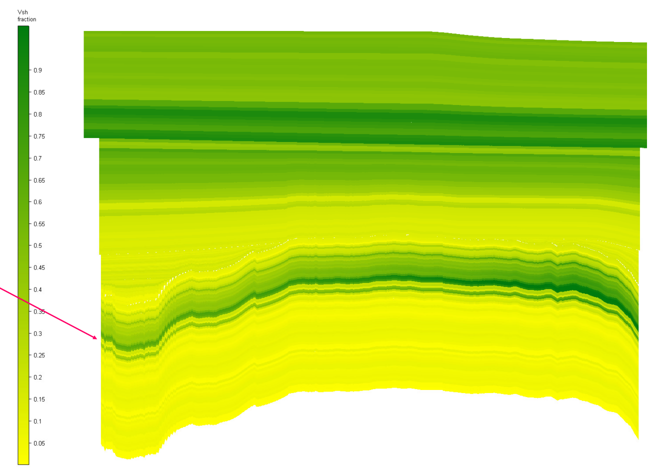


Fig 4. Vsh plotted along cross-section of basin along profile shown in Fig 2 (top). Each separate Vsh colour represents a separate flow unit. This model contains 6 layers, each with 36 sub-layers (see also Fig 5)

The vertical Vsh stratigraphy is used in the calculation of flow properties for the sublayers together with average values of each property for the layer. The latter can be loaded from basin simulators, such as Petromod3D.

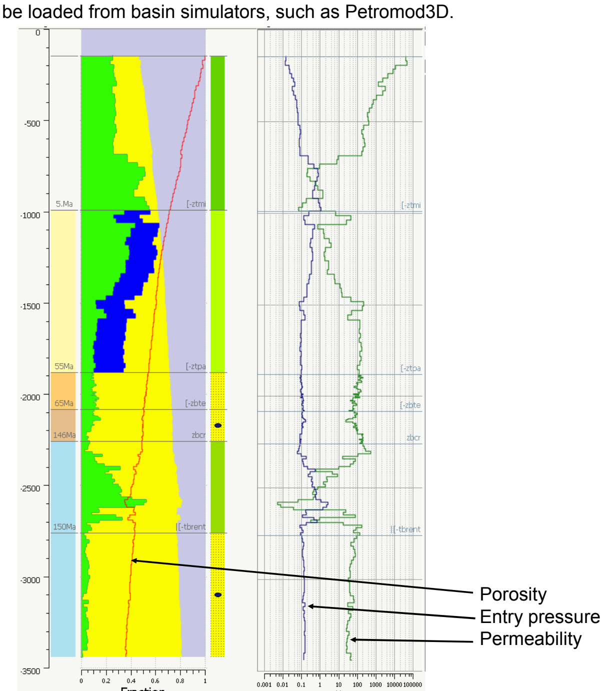


Fig 5. Stratigraphy (left), lithologies and derived parameters from Vsh (right). Red curve is porosity. Blue and green curves (right) are Pe and Kr, respectively. The 6 layers in the model are colour-coded in the middle bar. A total of 36 sublayers modelled within each layer in this case. Layer horizons are annotated with name at 5, 55,…Ma

Flow modelling

Dynamic flow meshes where each element in the mesh represents a section of a migration flow-path are used. The shapes and directions of the flow meshes change dynamically during burial, both laterally and vertically.

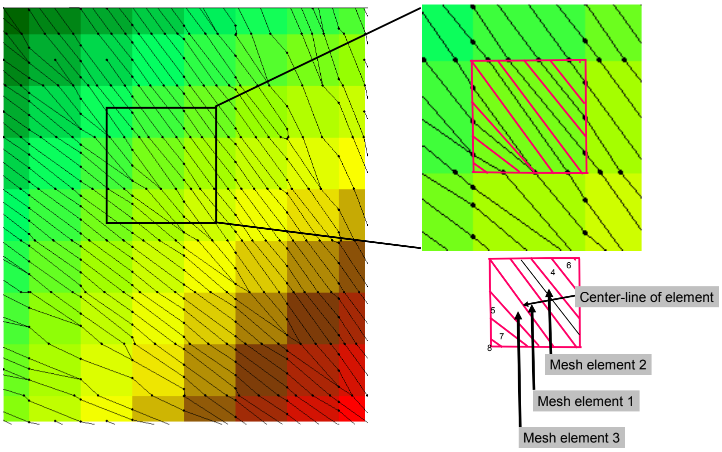


Fig 4. Top of carrier with center-lines of flow elements (left). Center-lines and flow element outlines for one single structural mesh element (red, upper right). There are a total of 8 flow elements within this single structural element (lower right)

Process description highlights:

- •Variable saturation within structural mesh element.
- •Focused migration within structural mesh element.
- •Darcy dynamic relative permeabilities and capillary pressures.
- •Account for lithological variation (Vsh and K description).
- •Complex geometry accomodated.

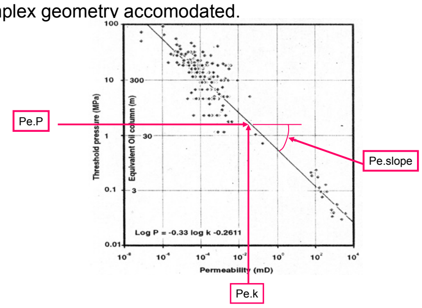


Fig 5. Entry pressure calculated from permeability of each layer: 3 parameters describe the relationship.

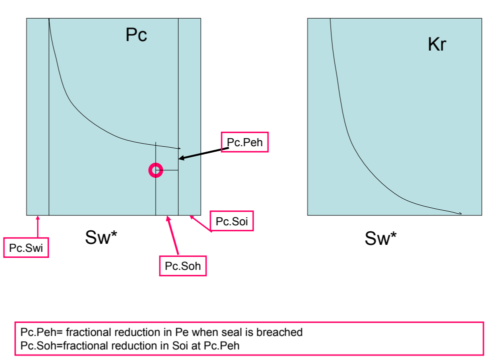


Fig 6. Capillary pressures (left) and relative permeabilities (right) description for each layer. Red point indicates end-point for vertical migration hysteresis (cap-rock seal potential can be reduced when the seal is breached).

The simulator tracks hydrocarbons components from flow element to flow-element while calculating flows of oil and gas phases within each flow-element using a simplified and fast PVT-calculation method. Flow is tracked while calculating dips, permeabilities end entry pressures and solving for column heights and hydrocarbon saturations. Migration losses can then be subtracted from flow before passing the components to the next flow element.

This process is repeated for each time-step modelled.

Flow patterns

The oil and gas flow-patterns within subsiding basins can be studied in a 3D view as flow-rates (Fig 7) for each modelled time-step. Highlighting migration arteries (Figs 8,9) may be an efficient technique for finding areas where exploration efforts can upgrade the quality of prospects by e.g. more detailed seismic mapping efforts. Flow-paths selected in Fig 7 (right) become visible when we remove the top reservoir horizon to reveal migration stringer properties (Fig. 8)

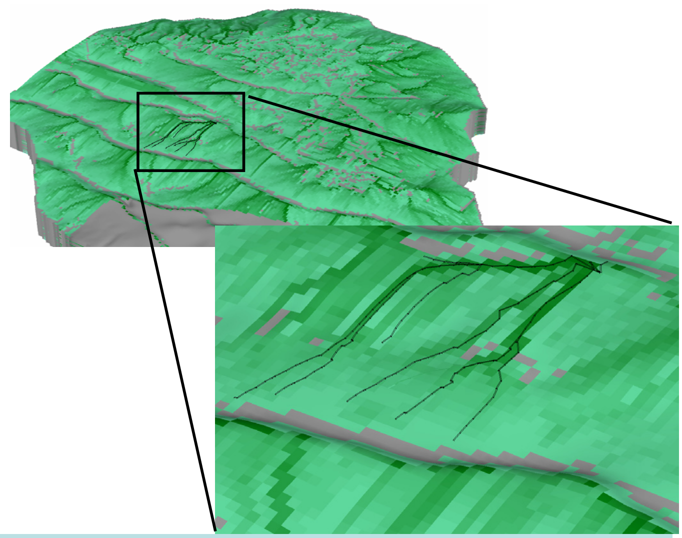


Fig 7. Basin scale lateral flow (upper left) below vertical seal with darker green for higher flow-rates. A close-up with 7 selected flow-paths is shown in lower right (thin black lines show migration flow-paths)

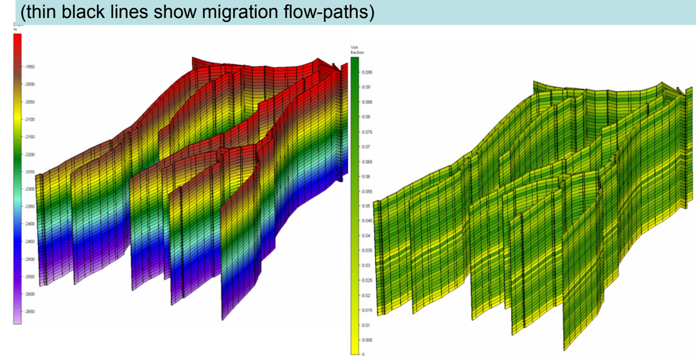


Fig 8. Same flow-paths as in Fig 7: Depth (left) and Vsh (right).Yellow indicates more sand in Vsh plot.

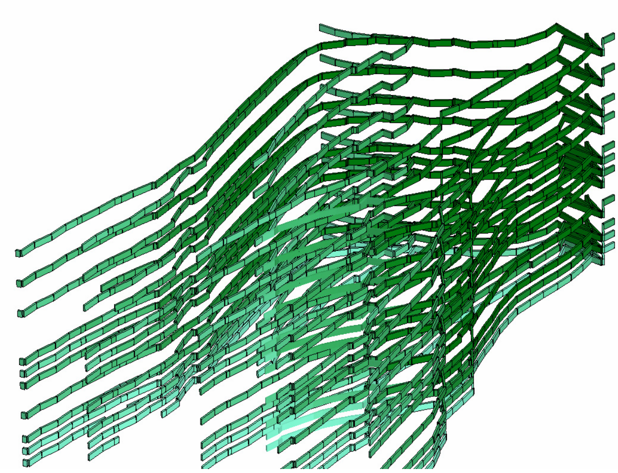


Fig 9. Lateral flow-rates in migration stringers along selected flow-paths of Figs 7 and 8. Same colour scale as in Fig 7. Note how focusing of flow-paths increases flow-rates. Only carriers with flow included here (see more details in next plate).

Results

The average flow within a structural element (Fig10, left) is a sum of all the flow-paths migrating through that node in all sublayers. Flow within a single structural element is represented by 8 flowpaths * 11 migration stringers = 88 active flow elements in this basin.

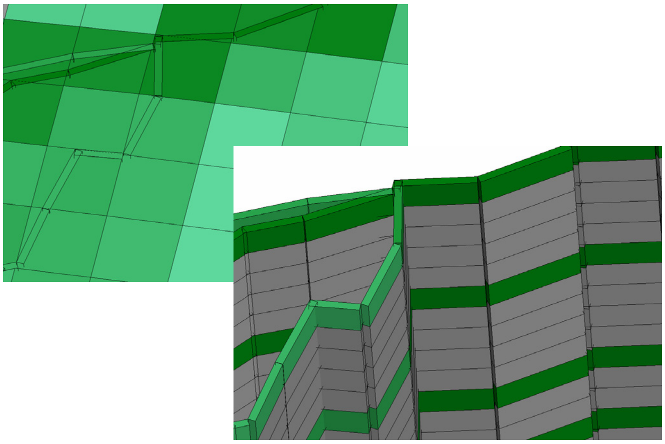


Fig 10. Lateral flow in migration stringers along three selected flow-paths from Fig 7. Note change to darker colour (more flow/area) where flow-paths merge.

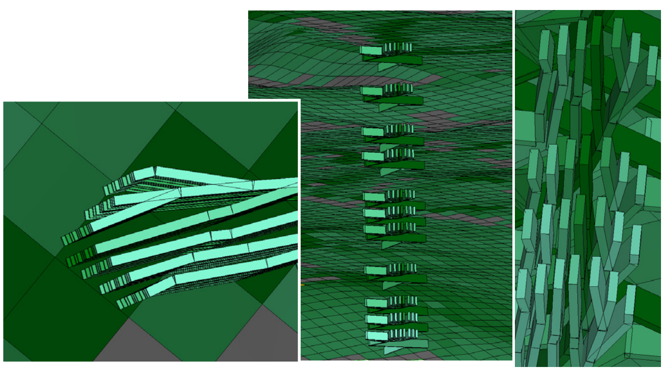


Fig 11. All active migration stringers within a single structural element seen from below (left) and from the south (middle). Flow-rates of lowermost migration stringers are lower than further up (lighter green colours, right). Most of the flow seems to be modelled within the center flow-path, which may result in a very heterogenic distribution of migration losses within this computing node.

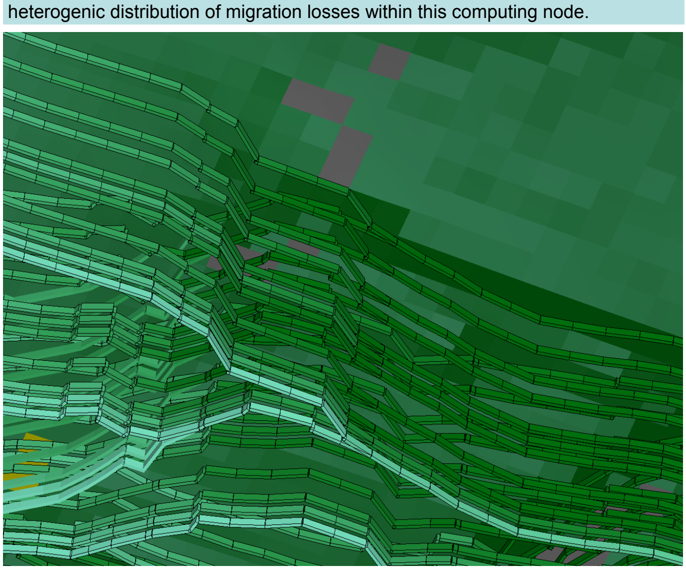


Fig 12. A series of migration stringers plotted below the average flow-rates along the top of a carrier (layer). Notice how all migation stringers within each structural element of this layer is modelled to be sub-parallel (flowing in the same direction). When this condition is not met by a layer, it has to be split into 2 or more layers for flow to be modelled accurately.

The distribution of the flow elements can help us gain insight into where oil and gas are likely to flow. By plotting the number of active flow elements within each structural element for each layer (Fig13) and each sub-layer (Fig 14) we can outline areas with many flow-path elements (warm colours) and areas with relatively few active flow elements (cold colours).

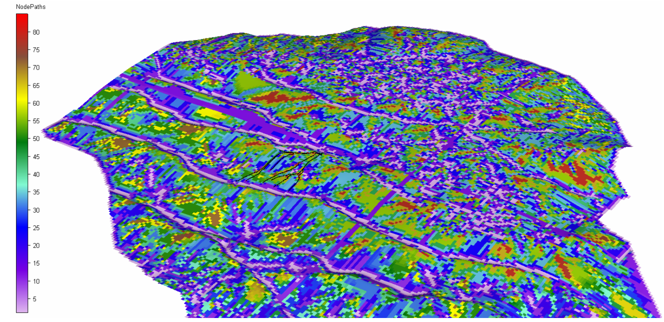


Fig 13. Number of active migration stringers within each layer structural mesh element (ranges from 0 to 88).

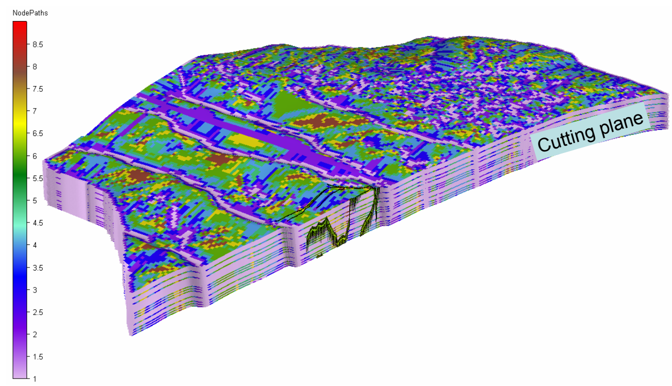


Fig 14. Number of active migration stringers within each sub-layer mesh element (ranges from 0 to 8). Cutting plane used to highlight vertical variability.

Further work

Attempts to apply the method to large-scale basin systems are underway. The methods have not yet been proven to work for such large systems, but preliminary testing on dual-core computers suggest that increasing the size of the modelled geological systems to multi-million node systems may result in linear rather than exponential scaling of CPU times. The method should also be well suited for parallell computing on multi-core CPUs.

Conclusions

An adaptive gridding approach to hydrocarbon migration modelling has been implemented. This approach allows for a rigorous computation of hydrocarbon saturations, column heights and velocities during migration. This poster shows how the method works for shale/sand sequences with mostly lateral migration (secondary migration) and with short-distance vertical migration from inter-layered shale source rocks.

Visual analysis of migration stringer patterns can assist in understanding the complex patterns of hydrocarbon flow in sedimentary basins.

Attempts to apply the method to large-scale basin systems are underway. The method has not yet been proven to work for such large systems, but preliminary testing on dual-core computers suggest that the upscaling to multi-million node systems may be closer to linear than exponential CPU time scaling The method may also be well suited for parallell computing on multi-core CPUs.

Acknowledgements

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