PS New Tools for New Challenges: Petroleum System Modeling of the Kurdish Foothills*

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Abstract

Fold and thrust belts are typical regions where classic basin modeling tools do not accurately manage the combination of lateral and vertical tectonic displacements. These complex areas where hydrocarbon expulsion from source rocks is prior or simultaneous to compressive tectonics require more accurate modeling approaches integrating active faulting, folding, and fluid flow. The basin burial and geometry reconstruction, fault connectivity and fluid movements should thus account for the actual horizontal deformation through time, which is impossible with a regular backstripping approach.

We here introduce a 2D kinematic tool specifically designed to meet this objective. Starting from present day section digitalization, it aims at producing rapidly consistent geological scenarios for basin modeling purposes. The first challenge of this approach is related to the number of restoration steps to provide as basin modeling requires a detailed kinematic scenario with, at minimum, a basin geometry at the end of each simulated layer deposition. Combining several geometrical and mechanical methods, the tool thus focuses on ergonomics to enhance productivity and afford multiple scenarios testing. The second challenge is linked to the mesh preservation through time that we believe essential for mass balance. In this regard, a new meshing technology has been developed to track sediments deformation while being compatible with a simulator able to take advantage of an accurate description of the basin evolution through time. Running on unstructured meshes and accounting for lateral displacement, this basin simulator uses the produced kinematic scenario for the forward simulation of heat transfer, pressure, hydrocarbon generation, migration, and accumulation. Faults impact on fluid flow is assessed through an implicit modeling of the gouge and damage zones properties through time.

An application case from the Kurdish foothills illustrates the applicability of these new technology and workflow. Preliminary structural reconstruction work detailing the four main deformation phases of the area is used to guide the complete kinematic scenario made of more than

twenty steps. Forward basin simulation is then run. The model, calibrated to available well data, allows testing the impact of thrusting on maturation, migration pathways, and hydrocarbon charge and quality. Several scenarios are elaborated, contributing to reduce the exploration risk.

Reference Cited

Vilasi, N., J. Malandain, L. Barrier, J.-P. Callot, K. Amrouch, N. Guilhaumou, O. Lacombe, K. Muska, F. Roure, and R. Swennen, 2009, From Outcrop and Petrographic Studies to Basin-Scale Fluid Flow Modeling: The Use of the Albanian Natural Laboratory for Carbonate Reservoir Characterization: Tectonophysics, v. 474, p. 367-392.

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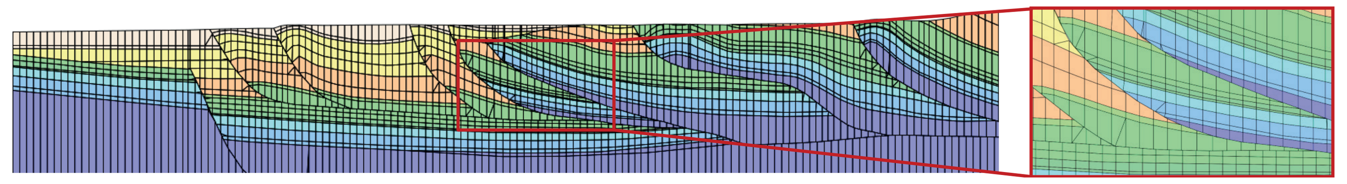
Bridging the Gap between Structural Geology and Basin Modeling

The Challenges of Modeling Complex Tectonics

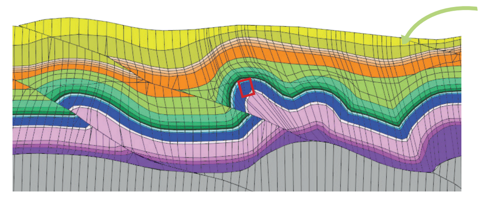
When it comes to assessing tectonically complex basins such as fold and thrust belts, conventional basin modeling tools do not accurately manage the combination of lateral and vertical tectonic displacements and often involve major simplifications on present day geometries and tectonic history. More accurate modeling approaches integrating active faulting, folding and fluid flow are required, especially when hydrocarbon expulsion from source rocks is prior or simultaneous to compressive tectonics. It implies a new workflow involving a real structural restoration rather than the regular backstripping approach, and also new technologies able to account for model complexities in terms of geometries through time and thus simulation meshes which become unstructured.

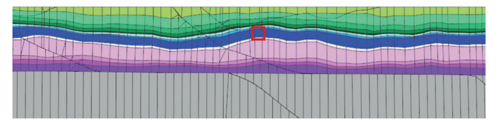


Example of cross section from the Albanides, adapted from Vilasi et al., 2009 - The geology complexity can be captured by an unstratured mesh

A New 2D Kinematic Restoration Tool for Basin Modeling Purposes

KronosFlow™ has been specifically developed to rapidly produce consistent geological scenarios for basin modeling purposes. Unlike existing balancing and structural restoration packages, it allows an easy restoration of the numerous steps required for basin modeling with, at minimum, a basin geometry at the end of each simulated layer deposition. Combining several geometrical and mechanical methods, the tool thus focuses on ergonomics to enhance productivity and afford multiple scenarios testing.





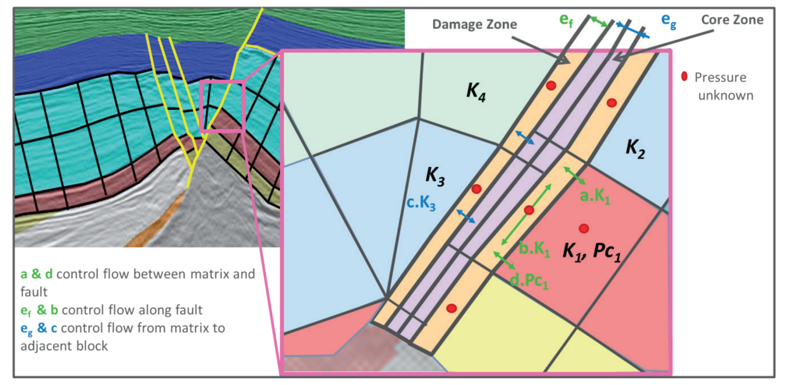
Mesh preservation and deformation through geological time

The second challenge adressed by the tool is the mesh preservation through time that is essential for mass balance considerations. A new meshing technology has thus been developed to track sediments deformation while being compatible with an innovative simulator able to handle this type of environment.

A Specific Basin Simulator

Running on unstructured meshes to properly capture geometries and accounting for sedimentation, erosion, and lateral displacements, the new *TemisFlow*™ basin simulator uses the produced kinematic scenario for the forward simulation of heat transfer, pressure, non-compositional and compositional hydrocarbon generation, migration and accumulation.

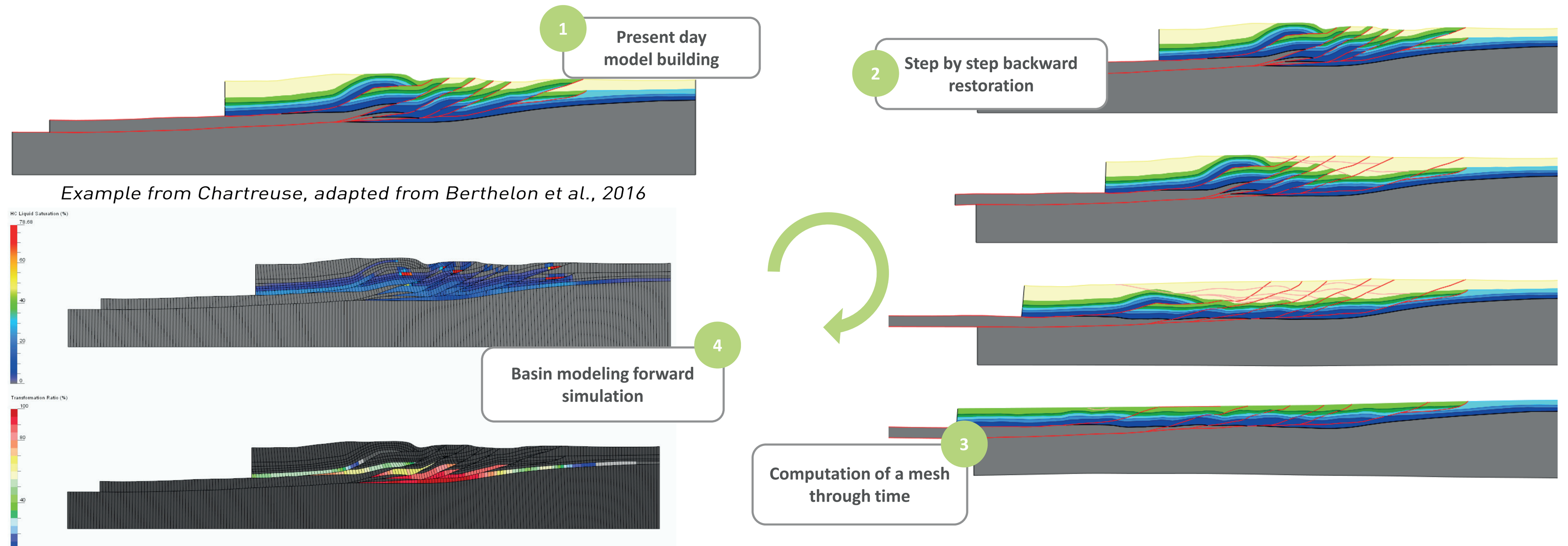
Faults impact on fluid flow is assessed through an implicit modeling of the core and damage zones properties through time.



Co-refining of adjacent meshes to represent the fault core and damage zones and simulate water and hydrocarbon flow accross and along fault planes

A Four Step Worklow

In the end, a four-step workflow allows honoring both strutural geology and basin modeling constraints for efficient and reliable petroleum system assessment studies in complex geological settings.



A 4 step workflow combining KronosFlow™ (steps 1 to 3) and TemisFlow™ (step 4)

References:
- Vilasi et al., 2009, From outcrop and petrographic studies to basin-scale fluid flow modelling: The use of the Albanian natural laboratory for carbonate reservoir characterization, Tectonophysics 474, 367-392
- Mackertich et al., 2015, History of hydrocarbon exploration in the Kurdistan Region of Iraq, GeoArabia, 2015, v. 20, no. 2, p. 181-220
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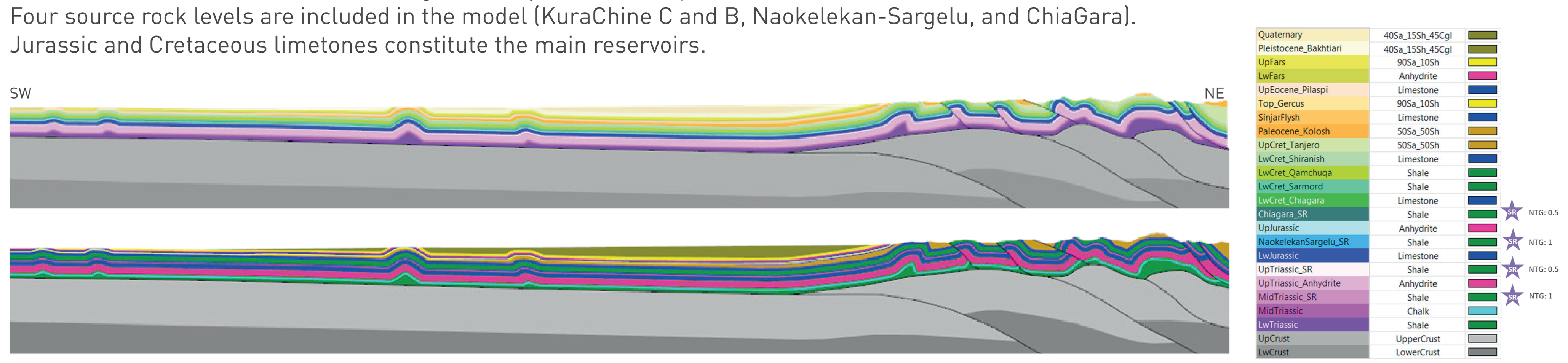
Application to the Foothills Region of Kurdistan

This worflow has been applied to the Kurdish foothills on a NW-SE section of approximatively 210km across the Zagros fold belt and NW of the known Kirkuk field. Four nearby wells with thermal and maturity data were available for model calibration as well as virtinite reflectance outcrop measurements.

Stratigraphy, Lithologies and Petroleum System

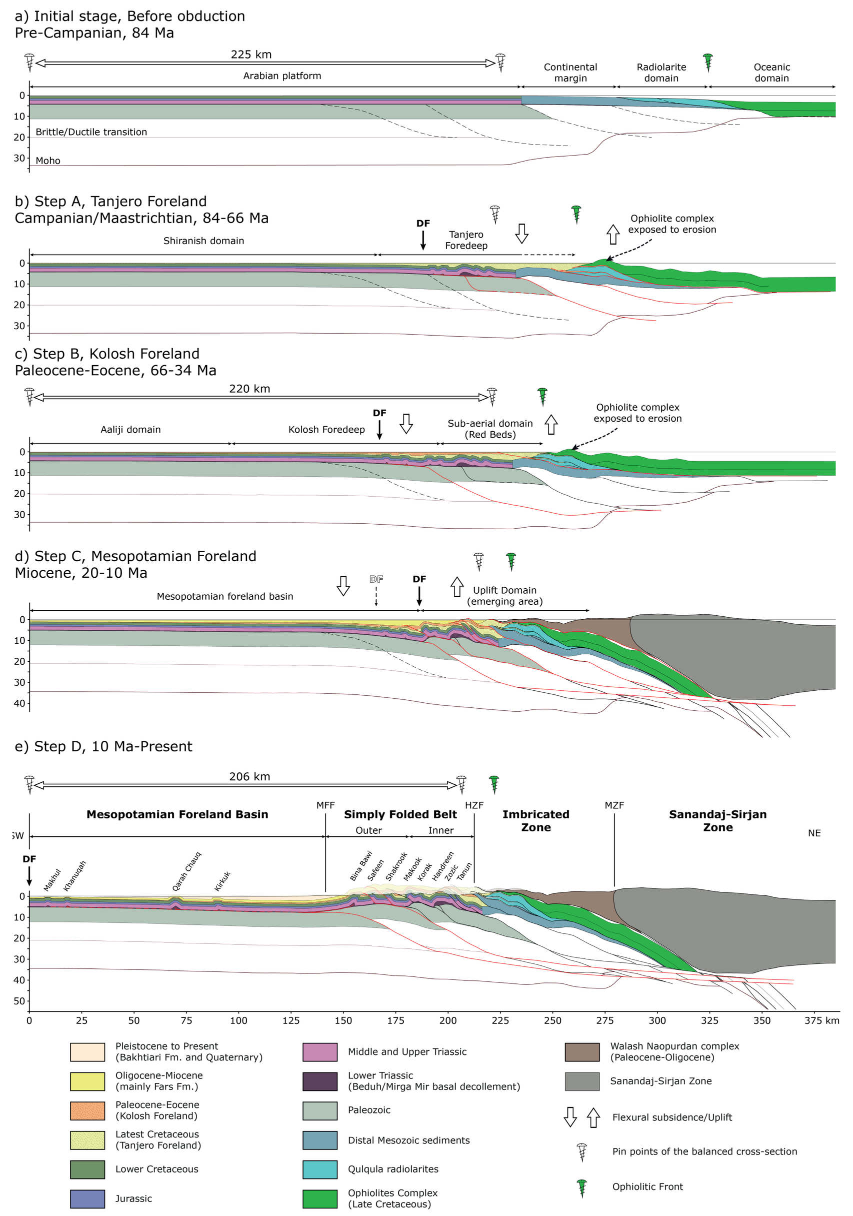
The section was digitized from a previously balanced cross-section and refined in 23 units. Three main phases of sedimentation are identified:
1) The Mesozoic passive margin, from Lower Triassic to Lower Cretaceous, with the deposition of shales, evaporites and carbonates;
2) The proto-foreland basin, from Upper Cretaceous to Paleocene-Eocene, with the deposition of clastics (Tanjero, Kolosh) followed by an alternation of carbonates, sands and evaporites;
3) The collision foreland basin, from Oligocene to present, mainly made of clastics.

Four source rock levels are included in the model (KuraChine C and B, Naokelekan-Sargelu, and ChiaGara).
Jurassic and Cretaceous limetones constitute the main reservoirs.



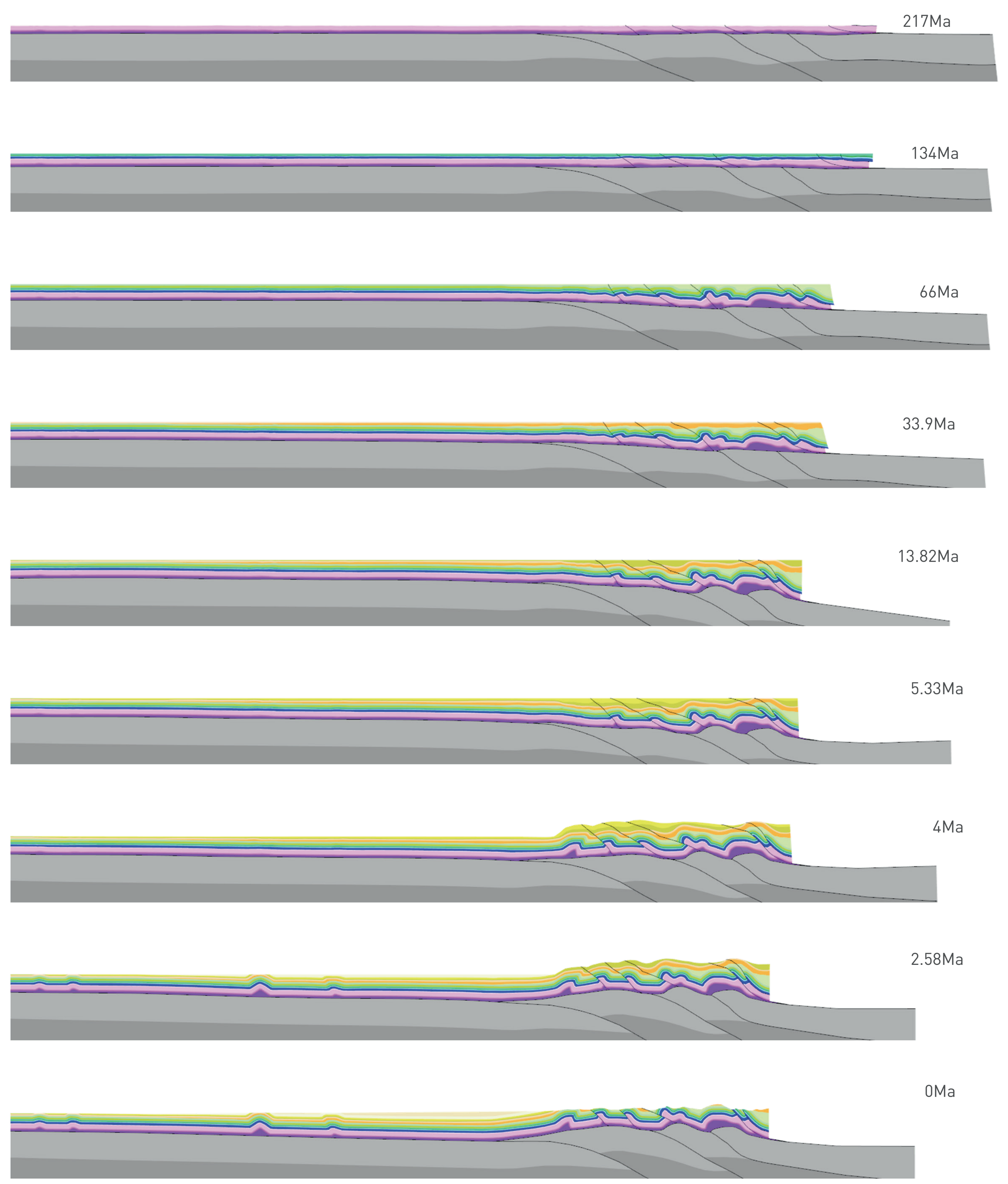
Deformation History

Preliminary structural reconstruction work detailing the four main deformation phases of the area was used to guide the complete kinematic scenario made of 24 steps. Erosion was estimated from structural restoration and field vitrinite measurements. The scenario was then meshed with a single grid following deformation through geological times.



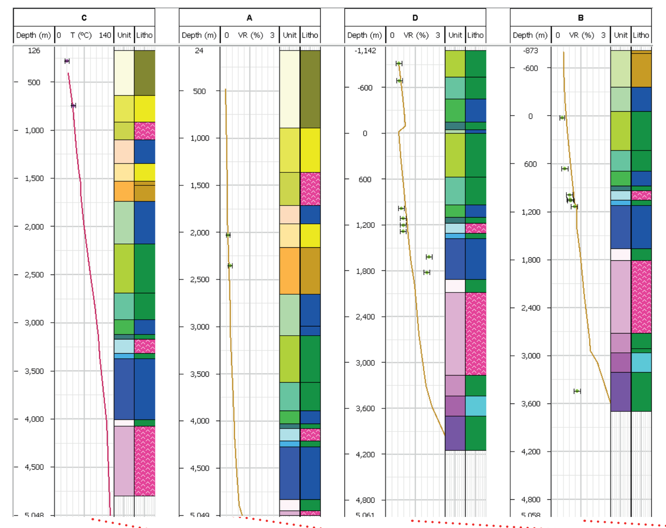
Crustal-scale evolution in 4 main steps, Le Garzic, 2018, in prep.

(a) Pre-Campanian initial stage. (b) Step A, Campanian-Maastrichtian, development of the Tanjero flexural basin during Neo-Tethys oceanic obduction event. (c) Step B, Paleocene-Eocene, foreland wards propagation of the deformation and concomitant sedimentary depocentre. (d) Step C, Miocene, Fars deposition with the continental collision dominated by thick-skinned tectonic. (e) Step D, Bakhtiari and younger deposition with thrusting beneath the Mountain Front Flexure and the thin-skinned propagation of the deformation in the Mesopotamian foreland basin.

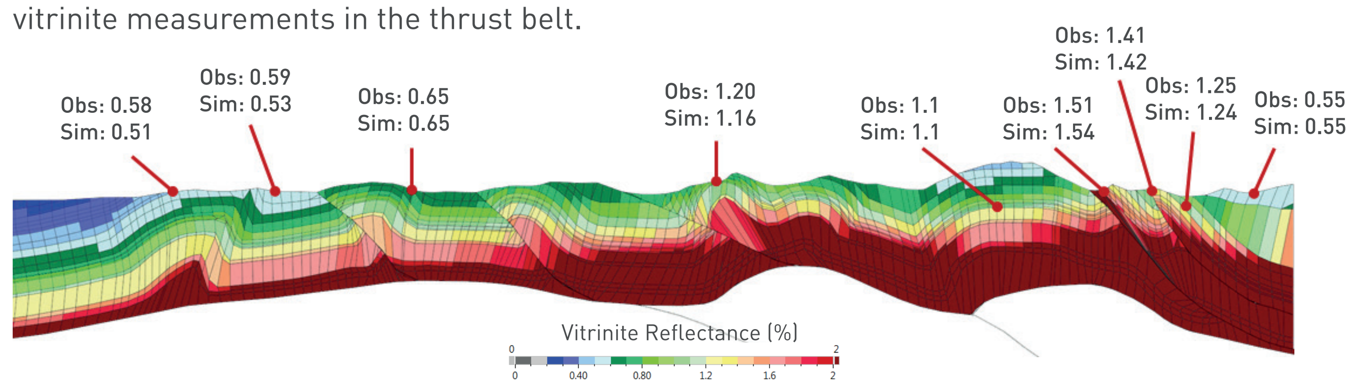


9 out of the 24 steps of the kinematic restoration - total shortening of 27km from Cretaceous to Present day

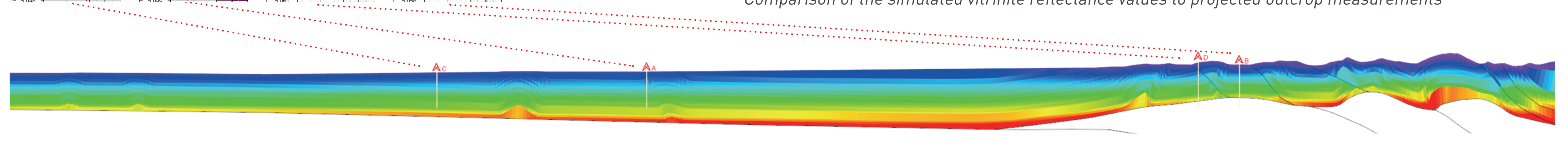
Model Calibration and Results



A simple lithospheric model with a constant temperature of 1330°C at the Upper Mantle base was used and surface temperatures were set according to the section localization and topography. The model is calibrated to wells vitrinite reflectance and temperature data, as well as outcrop vitrinite measurements in the thrust belt.



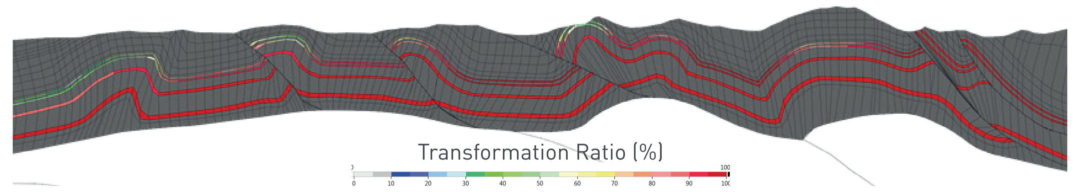
Comparison of the simulated vitrinite reflectance values to projected outcrop measurements



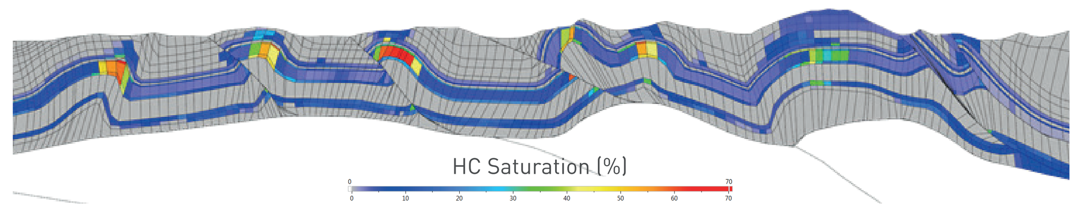
Temperature ditribution at present day (5°C/purple to 200°C/red) and calibration to 4 available wells projected along the section

Source Rock Maturity, HC Expulsion Timing and Migration

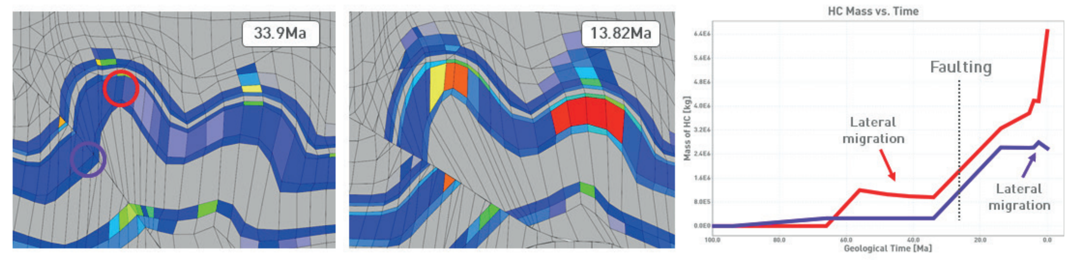
Source rocks are all mature in the thrust belt. Transformation ratio of the deepest source rocks is high (>90%), shallowest ones show local lower values linked to early folding of structures in Late Cretaceous. Hydrocarbon generation also starts from Early to Late Cretaceous depending on source rock levels.



The model shows that the main play (Lower Jurassic Limestones) is charged by the Upper Triassic source rock, while the hydrocarbons generated by the deepest Mid Triassic source rock remain trapped below the anhydrites. The later expulsion from the Upper Jurassic and Cretaceous source rocks contributes to minor accumulations in the above limestones (Chiagara formation). Known HC accumulations are reproduced.

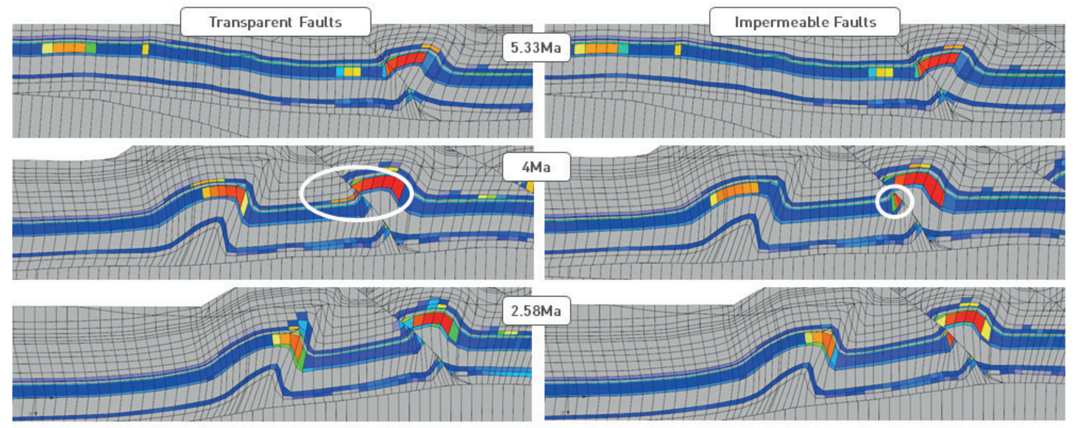


Faults are considered transparent and just act as juxtaposition interfaces between sediments of different nature, with no specific fluid flow behavior



Cell history extractions highlight the impact of faulting on hydrocarbon migration and accumulation

Faults play an important role on hydrocarbon accumulation as their development in Miocene prevents further fluids migration from the footwall to the hangingwall of the different structures. Jurassic limestones are particularly sealed by the Triassic anhydrites. It leads to fault trapping in the footwall and restricts the hydrocarbon source of the main accumulations to the hangingwall.



Sensitivity tests on faults permeability show it has a moderated impact on present day hydrocarbon accumulation. Main difference is the appearition of fault traps in the Jurassic limestones in the case of impermeable faults. This is notably explained as faulting occurs in the last 30My, once folded structures are already in place and most of the hydrocarbons have reached the reservoirs.
However, differences in migration history can be observed locally depending on faults behavior. Transparent faults connect different reservoirs and allow HC migration through the faults plane, whereas impermeable faults totally seal the reservoirs leading to fault trapping in the Jurassic limestones, as mentionned above.

Conclusions and Perspectives

This work introduces a new 2D kinematic restoration tool specifically designed to meet basin modeling requirements: it allows the quick generation of the numerous paleogeometries needed for accurate petroleum system assessment with a single mesh deformed through time. Associated to an innovative simulator, this approach allows accounting for folding, faulting and extension/shortening in basin models within an acceptable timeframe, which is mandatory to meet the industrial constraints.
An application to the foothills region of Kurdistan highlights its operational use. Through an efficient integration of a realistic structural interpretation and reconstruction, as well as outcrop and well data, it allows the generation of a complete and complex model to simulate the petroleum system evolution of the area and understand and test the impact of faults on hydrocarbon generation, migration and trapping. This approach offers new perspectives for the petroleum system evaluation of structurally complex basins.