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# EXPERT SYSTEMS AND MACHINE LEARNING TECHNIQUES FOR EFFECTIVE PETROLEUM SYSTEM RISK ASSESSMENT AND MODEL UPDATE

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## Abstract

Numerical modeling is a powerful and every time more vital tool for exploration as it is naturally multi-physics, multi-disciplinary and allows for sensitivity analysis and scenario testing. However, its potential is underemployed for risk assessment, which is often poorly or even not performed, due to required time and experience. Therefore, we developed a new methodology based on machine learning techniques and expert systems to overcome these stumbling blocks and to increase the efficiency of numerical modeling projects during exploration and production phases. One of the first aspect of our approach was to bring back the focus on the petroleum system itself. For that we implemented an expert system which allows to integrate efficiently geological experience in the definition of the uncertainty on the elements and on the processes involved. In a second step, machine learning techniques are used to understand the global behavior of the petroleum system, given the defined uncertainties, in a format compatible with most common play analyses such as CRS mapping and in a timing consistent with operational studies. The Levant Basin, in the Eastern Mediterranean, is used as an application case study. The results show that by better defining uncertainties on the petroleum system and by working on maps for play analysis, we allow explorationists to access fast and meaningful risk assessments. Moreover, sensitivity analysis and model update are greatly simplified using this methodology.

**Keywords:** Petroleum, Exploration, Production, Petroleum system, Machine learning, Expert system, Numerical modeling, Risk assessment, Play Analysis, Source rock, Levant Basin.

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## 1. Introduction

Petroleum exploration is becoming more and more technological for companies to maintain competitiveness. Numerical methods such as petroleum system or stratigraphic modeling, formerly exclusively accessible to major oil and gas companies, are now part of common exploration workflows in most exploration teams. However, as these powerful simulation techniques require expertise and time to be fully effective, and as many of the exploration experts will retire in the next few years, companies are facing the problem of keeping expertise while reducing cost and increasing effectiveness. On the other hand, risk analysis and update of petroleum system interpretation, which are ones of the main progresses that these numerical techniques should bring to companies, are hardly performed or remain complex due to technicality and required time.

Therefore, we developed a new methodology to increase the effectiveness of these highly technological simulation methods based both on an expert system, which enhance and guide the determination of the risk related to the studied petroleum system, and on machine learning techniques, for providing maps of risks at exploration scale. This methodology can also be used for model updating when more calibration data or knowledge are available on the basin of interest, what can save significant amount of time.

## 2. Methods

Understanding and being able to quantify the uncertainties during petroleum system assessment are the keys to deliver pertinent and in-depth analysis for relevant decision-making. However, as basin modelling englobes a range of geological disciplines, used to describe the formation and evolution of sedimentary basins, current methods are often either based on gut-feeling and best versus worse case scenarios or on very time-consuming Monte-Carlo methods. These latter involve dozens of physical parameters in a workflow providing high-quality statistical results but low-value petroleum system interpretation.

Therefore, our first objective was to solve the gut-feeling problem by building an expert system which helps explorationists define and quantify uncertainty on the main elements (source-rock, reservoir, seal…) and processes (maturation, expulsion, migration…) involved in the accumulation of hydrocarbons as illustrated in the figure 1. Instead of working with extreme scenarios or multiple parameters, the methodology identifies the key-elements of the petroleum system and guide the user in the estimation of their uncertainty based on the geological context and on the geological rules coming from literature or expertise (Hacquard, 2018).

For instance, source rock richness and nature (controlling its reactivity), which involve several simulation parameters, are estimated based on analogs, source-rock type, TOC/IH relationship and laboratory pyrolysis when available. This would normally require a strong geochemical expertise that our method makes available for every explorationist while reducing the number of uncertain parameters to be handled (richness and nature) and making easier the interpretation of results.

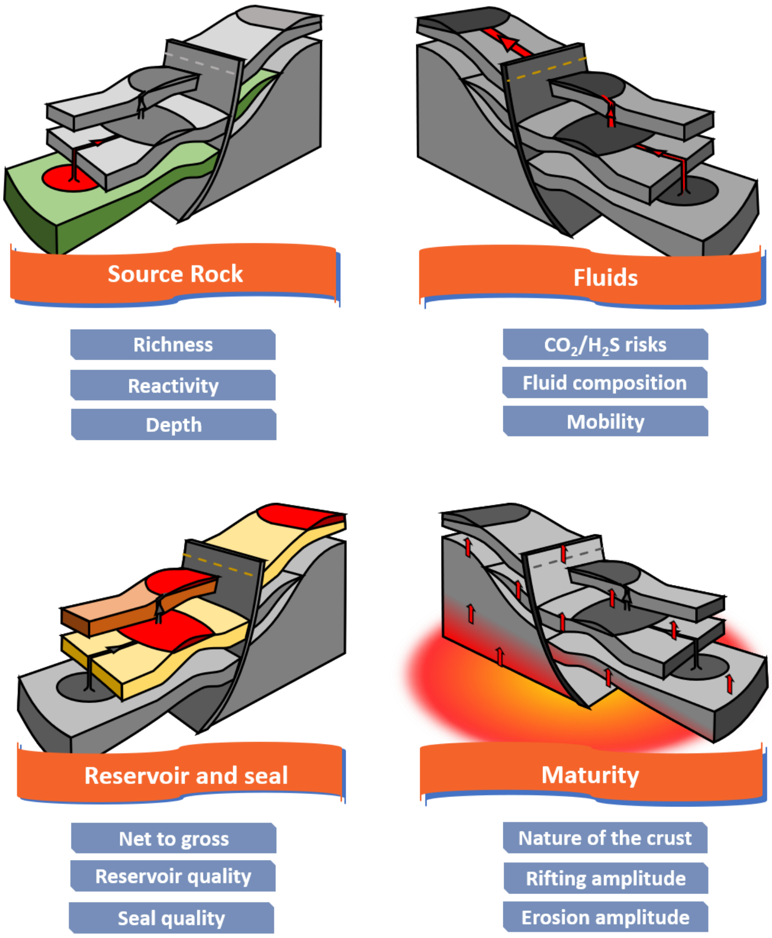


Figure 1. Description on the main elements and processes considered by the expert system for the definition of the uncertainties related to the petroleum system (modified from Hacquard, 2018).

In a second step, we aimed at providing risk analysis in an adapted format for petroleum system assessment (maps), in a timeframe which remains consistent with operational projects while preserving rigor. Therefore, we used the geologically meaningful uncertainties previously identified and integrated them into a workflow for risk analysis using machine learning methods. This results into a significant reduction of the required time to perform robust and rigorous sensitivity and risk analysis compared to Monte Carlo techniques.

We propose to apply a methodology based on an extension of the proxy models approach, initially used in meteorological modeling, that is well suited to spatial outputs such are map based results (Marrel and Perrot, 2012). It uses several machine learning techniques such as regression, principal component analysis or clustering, to learn the main aspects of the petroleum system, reduce time required for the study and provide results giving access to meaningful geological interpretation (Gervais *et al.*, 2018).

Lastly, update of petroleum system assessment can be easily achieved when new data are made available without the need to perform additional simulations. This is made possible by weighting risk analysis output using likelihood measurements (comparison between calibration data and simulation results) to extract more likely results.

## 3. Application case study: the Levant Basin

The Levant Basin, in the Eastern Mediterranean, is a frontier hydrocarbon province with recent major gas discoveries. To date, no significant hydrocarbon accumulations were encountered, and a deep thermogenic petroleum system remains speculative. The lack of data and a complex geodynamic history still challenge the exploration and basin scale investigation of petroleum systems. Numerical models, such as those illustrated in figure 2, are well suited for assessing the risks related to these high risk - high reward frontier basins as they can integrate all the knowledge and uncertainties associated to the petroleum systems.

As a biogenic petroleum system has already been proven with the large gas discoveries, one of the main unknown of the basin relies on the existence and maturity of source-rocks for a potentially deeper thermogenic petroleum system. In order to assess the risks related to the source-rocks we used a previous study of the Levant Basin performed by Bou Daher *et al.*, 2016 and by Barabasch *et al.* (submitted) combined with the previously presented methodology to define uncertainties on source rock richness, reactivity and depth as these elements can have strong effect on the source rock efficiency.

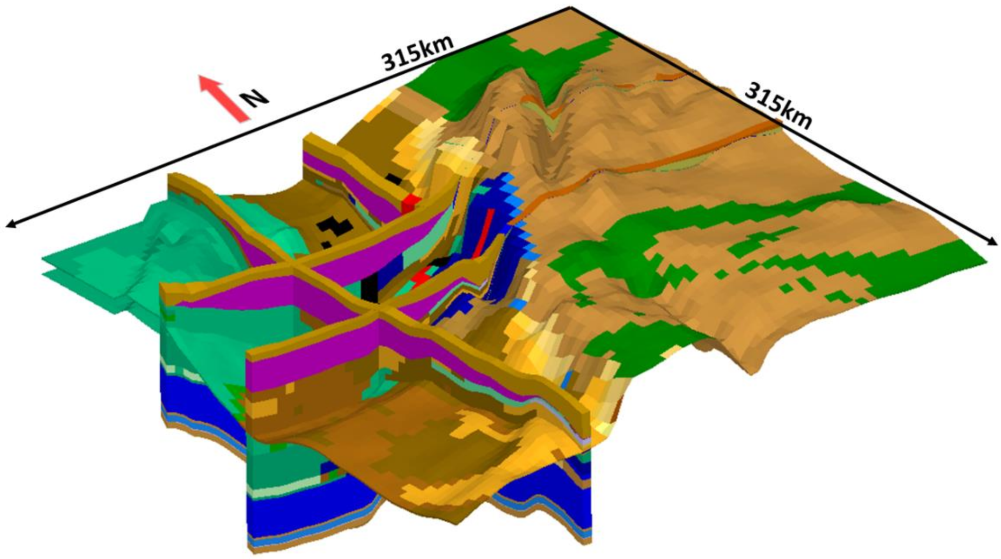


Figure 2. Illustration of the 3D numerical used to study the petroleum system of the Levant Basin. Modified from Barabasch *et al.* (submitted) and Bou Daher *et al.* (2016)

Uncertainties were automatically defined based 1/ on concepts recently published on organic matter sedimentation and preservation which links the petroleum potential of a source rock to the bathymetry of deposition and to the sedimentation rate (e.g. Chauveau et al., 2016; Bruneau et al., 2017), 2/ on kinetics concepts for the source rock reactivity (Ducros, 2016; Hacquard, 2018) and 3/ on uncertainty concepts for time to depth conversion to define uncertainty on the depth of the source rocks (Hacquard, 2018).

## 4. Results and discussion

Based on the uncertainties automatically defined using our geological expert systems for source rock richness, reactivity and depth, we generated simulations on which to learn the "basin behavior" through artificial intelligence. Then we were able to compute some results of interest to evaluate the risk on the maturity of the source-rocks of the Levant Basin: classical results such as percentiles, illustrated in figure 3 for transformation ratio of the Kimmeridgian source-rock but also, more interestingly, the probability that a given source rock reached a high level of maturity, as illustrated in figure 4. These kinds of results can then be directly used in CRS mapping approaches for play assessment.

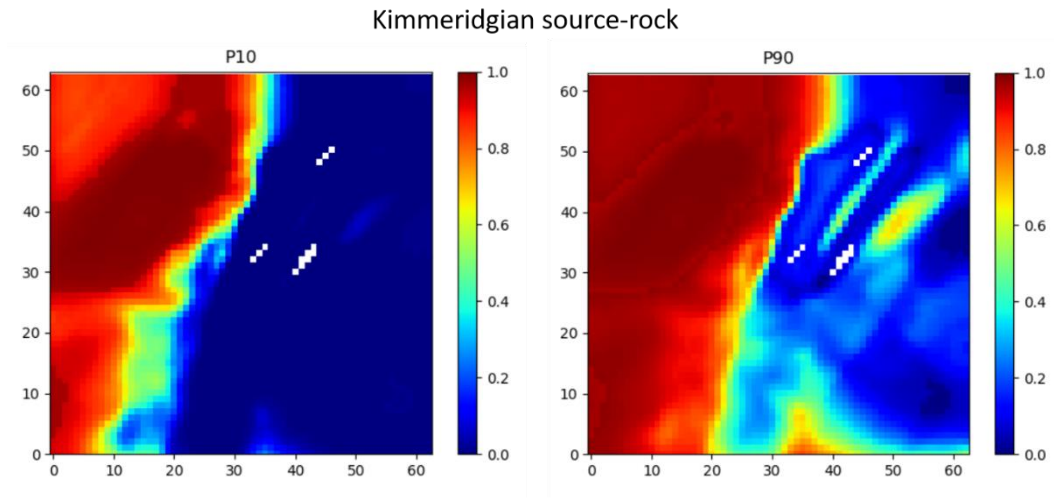


Figure 3. Percentiles of transformation ratio (%) reached by the Kimmeridgian source rock of the Levant Basin according to the defined uncertainties on source-rocks properties. (North is upward)

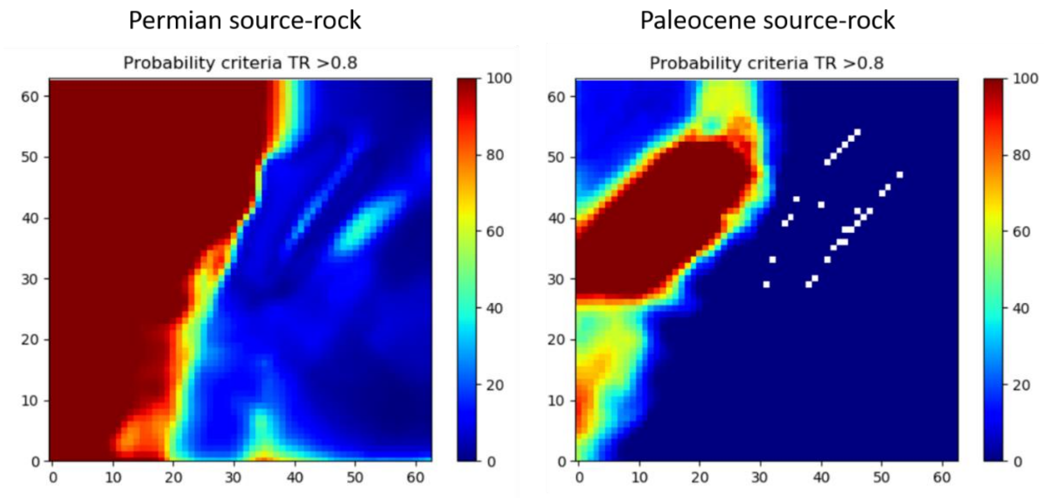


Figure 4. Map of probabilities (%) that the Permian (left) and the Paleocene (right) source-rocks reached a transformation ratio higher than 80%. (North is upward)

Finally, the methodology also helps to decipher the contribution of each of the uncertain elements in the variability of the result of interest, what can help driving the efforts in the right direction in the process to reduce exploration risks. Figure 5 shows the contribution of the uncertainty of the three source-rock properties on the variability of the mass of petroleum expelled from the Kimmeridgian source-rock. For instance, it appears that, in the case of the Kimmeridgian source-rock, the uncertainty on the reactivity has a major effect on the quantity of expelled oil along the Lebanese Margin, which corresponds to more interesting zones (cf. figure 5 bottom right) while the TOC is the major contributor on the variability in the deep basin which is expected to be in the dry gas window (cf. figure 3). The uncertainty on the time-to-depth conversion seems to have a much lower effect, limited to the margin and to the offshore parts as the deep basin is always overmature (cf. figure 3).

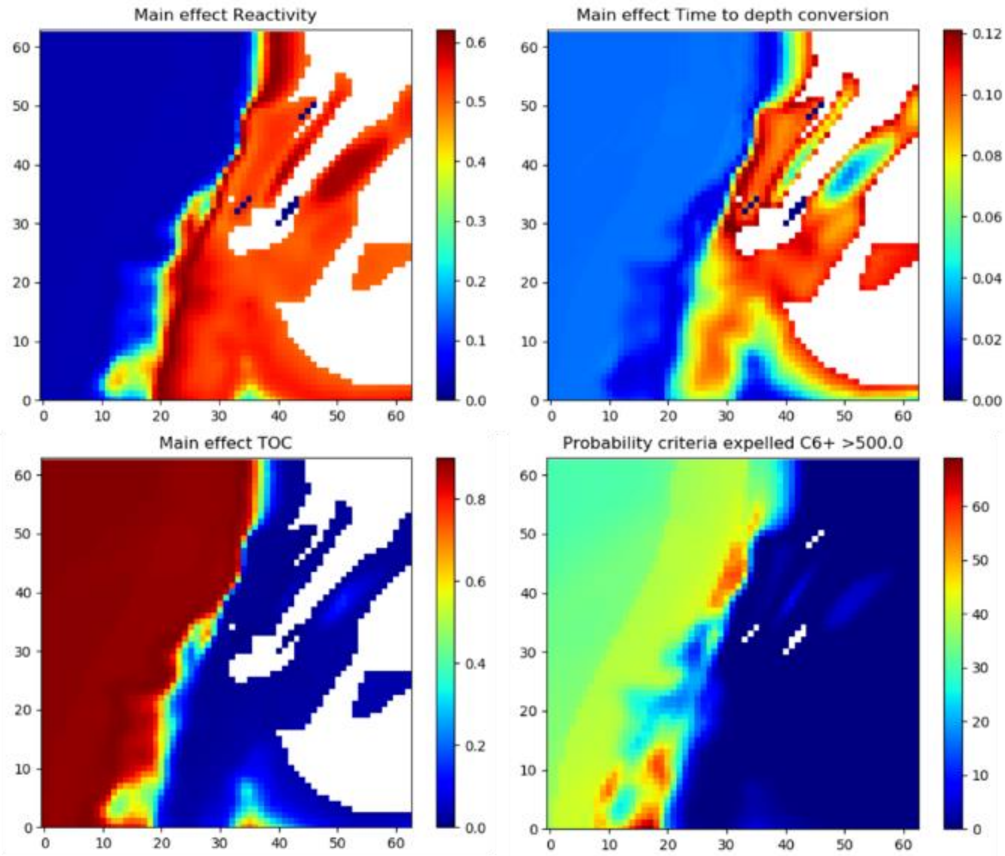


Figure 5. Maps of property contributions (%) to the variability of the expelled mass of oil from the Kimmeridgian source-rock and map of probabilities (%) that the expulsion of oil from the same source-rock is higher than 500kg/m² (bottom-right). The most prospective zones lie along the margin (bottom-right) which correspond to areas where the source-rock reactivity has a strong contribution to the uncertainty (top-left).

## 5. Conclusion

Three expert systems were used to better assess the risks related to the source rocks of the Levant Basin. They allowed to account for the uncertainties on the richness, the reactivity and the depth of a source-rock based on geological and geochemical knowledge and expertise.

The complete methodology was tested on the natural case study of the frontier Levantine Basin for the assessment of its deep petroleum system. It proved to be time effective and robust. It provided highly valuable results for the exploration of this still poorly known but promising basin by giving access to the identification of sweet spots and to clues on how to further reduce the risks.

By using our new methodology for petroleum exploration in sedimentary basins, modelers can save time and gain experience through expert systems guiding them in identifying major exploration risks. Workflow outputs, in map format, make easier the interpretations which can be made with powerful, but still complex, basin modeling tools. They are also very convenient for sharing results with other colleagues involved in the basin exploration and help decision-making based on CRS mapping.

## 6. Acknowledgements

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