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Hydrocarbon exploration risk evaluation through uncertainty and sensitivity analyses techniques

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Abstract

The evaluation of the exploration risk in the oil industry is a fundamental component of the decision process related to the exploratory phase. In this paper the two basic components of the exploratory risk: trap *geometry* and trapped hydrocarbon quantities (*fluid*), are compounded in a single coherent uncertainty and sensitivity approach. The results clarify that the model geometry influences each Petroleum System Modeling step and that the geometric uncertainty is correlated with the fluid uncertainty. The *geometric* uncertainty evaluation makes use of geostatistical techniques that produce a number of possible realizations of the trap geometry, all compatible with available data. The evaluation of the fluid uncertainty, through a Monte Carlo methodology, allows us to compute the possible quantities of oil and gas, generated in a basin and migrated from the hydrocarbon source location to each single trap. The final result is the probability distribution of oil and gas for each trap in the basin, together with other useful indicators like: the hydrocarbon filling probability map, the closure probability map, the drainage area probability map, the spilling paths probabilities, the trap-filling scenarios.

Keywords: Hydrocarbon exploration; Petroleum system modeling; Uncertainty; Sensitivity; Risk evaluation

1. Introduction

In the hydrocarbon exploration activities the main goal is to find traps where oil and/or gas were accumulated and retained in quantities that are greater than a variable economic threshold. Neglecting all the economical variables that come into play, the basis of any drilling decision is associated with the presence/absence of hydrocarbons (hydrocarbon risk) in the potential traps of the basin. This evaluation is the result of the joint efforts undertaken by a team of geologists, geochemists, geophysicists and engineers, in trying to get the best picture of the prospects that may be potentially drilled.

This study can be schematically split into two components: the *geometric* one and the *fluid* one. The first one is the object of Basin Modeling (BM)[1] activity, that gives a 4D (in space and time) description of the basin status and evolution. The *fluid* one is the objective of the Petroleum System Modeling (PSM), that produces the history of the geologic processes that led to generation and accumulation of hydrocarbons in the current traps.

2. Methodology

Modeling geological processes is subjected to uncertainty because input data are scarce and imprecise and also because the algorithms used for modeling are an approximation of

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[1]Historically the term "Basin Modeling" has been used with slightly different meanings. In this paper it is used to describe the rocks properties distribution in space and evolution in time. In practice this is strictly correlated to the fluid properties distribution and evolution and therefore a clear distinction between BM and PSM is partially subjective.

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the true geological processes. This observation implies that a probabilistic approach is needed to account for the lack and imprecision of knowledge, enabling us at the same time to compute the "hydrocarbon risk" for each trap of a basin.

Regarding BM, geostatistical techniques can be used to model the uncertainties of both geologic layer geometries and facies[2] properties. *Geometric uncertainty* arises from the process of converting interpreted seismic time reflections into depth reflectors, as this process relies on *uncertain seismic propagation velocities*. The evaluation of the uncertainty of facies properties distribution refers both to seismic data attributes and to sedimentological interpretation. In this paper we are considering only geometric uncertainty, as the methodology to take into account facies uncertainty is quite complex to set up, at basin scale.

As the PSM is an inverse problem and the data available is scarce and uncertain, we have to deal with multiple possible "realizations" of the basin model as well as of the petroleum system evolution. Even if all the "realizations" are fitted to known available data, this calibration process just reduces the space of possible solutions but it is unable to justify by itself the choice of a unique, or most probable, or optimal solution.

Each of the phases of the PSM (including BM) contributes to the overall uncertainty and can be explored with a sensitivity approach. As shown in [1], where a brief summary of the different approaches is presented, almost all the papers deal with the uncertainty evaluation of only some of the phases of PSM. In fact, besides the great amount of CPU time needed, the main difficulty in applying Uncertainty and Sensitivity Analyses (UASA) to the entire PSM is given by the complex management of the complete workflow.

Another great source of uncertainty is given by the assumptions (the conceptual model) that are practically needed in the inversion of the scarce data available. These alternative conceptual assumptions, or geological hypotheses, are dealt with by means of scenario variables [2]. To drop a scenario, or one of the combinations of different scenarios, means to hide a component of the uncertainty and thus to increase the risk of biased choices.

Our approach consists of considering all possible combinations of scenario variables and producing, for each scenario, as many realizations as needed for uncertainty and sensitivity analyses. With regard to uncertain input variables these can be numerical (continuous or discrete) or categorical (e.g. a set of functions or maps).

Moreover the nonlinearities hidden in the modeled geological processes are such that there are threshold values of some variables or combination of variables that may trigger one event (e.g. generation of gas, etc). For this reason the use of UASA approaches that assume linearity or continuity hypotheses need great caution, so that, in our opinion, it is preferable to use a Monte Carlo approach to the extent that is allowed by hardware constraints.

2.1. Basin and petroleum system modeling

A general introduction to BM and PSM techniques can be found in many books (see for example [3], while a more quantitative analysis of basin evolution is given in [4]), in the following only the main modeling steps are mentioned and the workflow that has been applied is described (see Fig. 1).

The BM (for the purposes of this paper) consists of: the shape definition of the geologic structures; the spatial distribution of the geological properties of interest for each geologic layer in the basin model; the structural evolution of the basin during geologic time (in this study only vertical compaction of sediments due to overlying sediment load was taken into account); the definition of the history of the heat flow at the basis of the sediments (coming out from the basement, in the earth upper crust).

The PSM can be grossly subdivided into: the description of the evolution of the Pressure & Temperature (P&T) fields in the sediments; the history of the Generation & Expulsion (G&E) of the hydrocarbons (oil and gas, in the simplest case) from source rocks; the migration of hydrocarbons from source rocks to reservoirs and the preservation of trapping conditions of the hydrocarbons throughout the evolution of the basin (M&T).

2.1.1. Basin modeling

At the basin scale the depth model is suitably built using the *layer-cake* vertical depth conversion method from

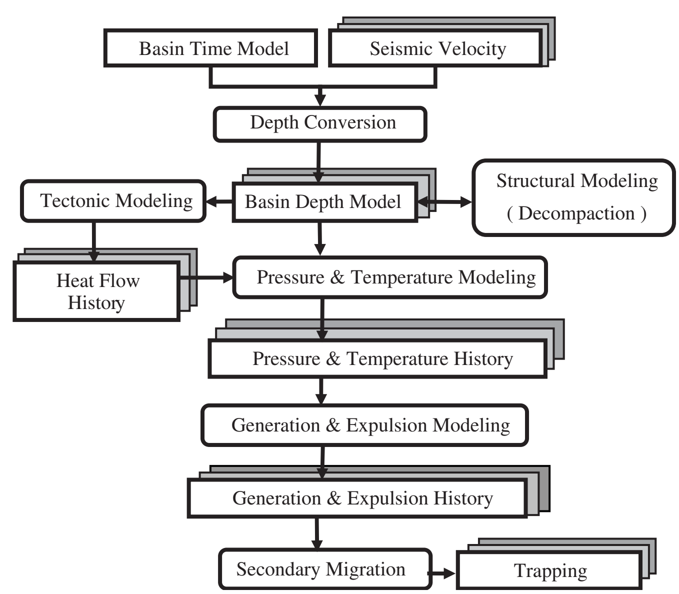

Fig. 1. Workflow of the Basin Modeling and Petroleum System Modeling applied in this study. Boxes with rounded corners represent modeling steps. Rectangular boxes represent input/output data. Repeated shadowed rectangular boxes represent simulation results of input/output data.

[2]A "facies" is a rock layer that differs from the others (as in composition, age, etc) because of its formation.