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Reservoir geo-modeling and uncertainty management in the context of geo-energy projects

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Keywords: Geological Modelling, reservoir, uncertainty, risks

Abstract
Reservoir geo-modeling is a fundamental step of the multi-phased geo-energy maturation journey. It allows the description and quantification of the subsurface static and dynamic parameters, which will largely determine the success or failure of exploration, development and management of geo-resources. The geo-modeling exercise, based on careful data quality check and use of a-priori knowledge, is typically performed at the early stage of a geo-energy project and it is used both to test ideas on development strategy and quantify the economic aspects. From the quality and correctness of a geo-model therefore will depend important business decisions that will have a long-term impact on the overall geo-energy development journey. Inaccurate or wrong understanding of the subsurface at the early stage of a project will have a persistent negative impact on the destiny of the entire project, which very seldom will be improved by high-quality execution practices. In order to reduce the risks of failure of any geo-energy project, subsurface uncertainty identification, quantification and management will need to be considered. Fit-for-purpose models, able to represent different possible subsurface configurations and respond to a variety of project objectives and business questions, will need to be implemented. A reliable deterministic representation and quantification of the subsurface parameters can be thus obtained by a set of geo-models (subsurface realisations) aimed at capturing the full possible range of both geological and fluid behaviour characteristics. These will be a solid basis for planning the development strategy, defining economic forecasting and moving in to project execution while providing a realistic description of the associated risks.

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1 Introduction

The reliable quantification of subsurface geo-energy resources represents one of the major challenges during their exploration, development and management phases, regardless whether the project deals with hydrocarbons, geothermal energy (heat or hot water), storage of gas (methane or carbon dioxide), storage of heat or subsurface repository of nuclear waste deposits.
Over the last 25 years a variety of geo-modeling tools have been developed in the petroleum industry, service companies and academia to address this complex task using either deterministic or stochastic approaches (Williams et al. 2004, Perrin & Rainaud 2013, Zakrevsky 2011). Regardless the approach, the quality of representation of the subsurface by a model is intrinsically dependent on the amount and quality of available data that seldom will have sufficient extension to ensure a complete understanding of the full variability of the subsurface geological characteristics (Fig. 1).
Understanding the subsurface uncertainties and capturing these in the modeling is therefore a critical task prior any modeling exercise that needs to be performed in a timely manner and several times within the geo-energy project life-cycle.
This paper intends to provide some considerations regarding the general importance of different geo-modeling approaches and the management of the uncertainties intrinsically related to them in the framework of a geo-energy journey and highlight the criticality of these tools in supporting project decision-making and in determining, at an early

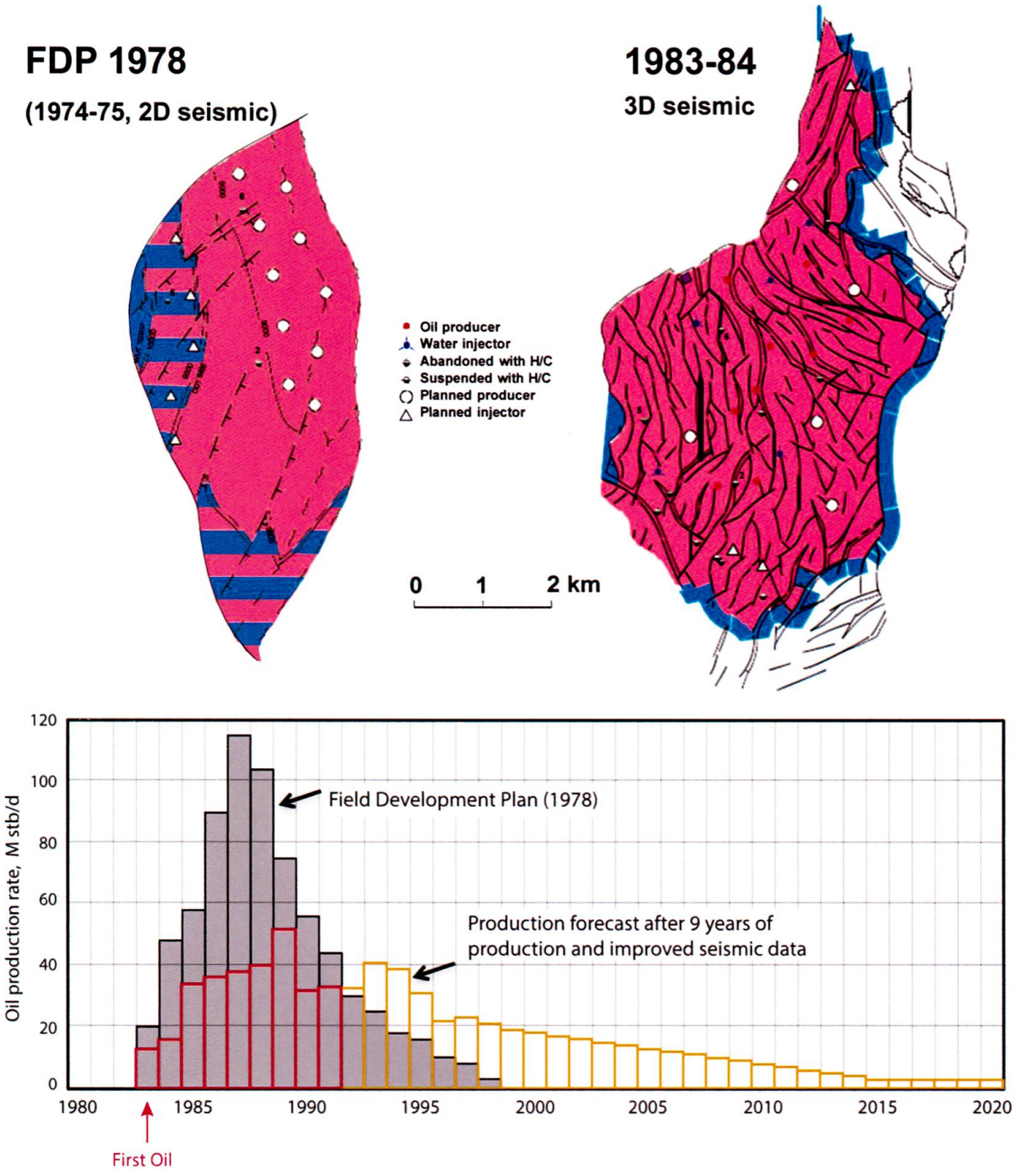


Fig. 1: The prediction capability of a geological model in support of any geo-energy resource development it is strongly depending on quality and amount of the subsurface data which almost by definition will be incomplete, discontinuous and often unreliable. Handling these uncertainties is therefore key for any subsurface geo-model to be able to manage project risks. The first geological model of the Cormorant field (Northern North Sea, UK) based on few well penetrations and 2D seismic which was used to plan the field development plan (FDP) yielded a largely inaccurate production forecast which at that time did not take into account the possible complex reservoir compartimentalisation as it was revealed by the 3D seismic survey acquired in 1983–84 (modified after Lim 2002).

phase of each individual projects, their destiny in terms of technical and economic success.

2 The context

A geo-energy journey from value creation to value realisation, passes through a series of well defined phases (Fig. 2). In the initial phase the technical and economic feasibility of pursuing a subsurface opportunity is identified and assessed. It is the initial and preliminary phase where the geological data are collected and studied in the context of a both regional and specific screening aimed to set the basis for future more detailed work. This feasibility study is followed by a second phase leading to the selection of the technically and economically most attractive opportunity (i.e. choice of prospect(s), of most attractive development strategy and related recovery mechanisms, etc). It is in this phase that the detailed geo-modeling is performed aimed at capturing all the critical information which serves to represent the subsurface complexity and related uncertainties and thus deliver a reliable range of key parameters such as static volumes, recoverable volumes, degree of reservoir compartimentalisation and connectivity, etc. It is during this phase that the most important choices are made regarding the static and dynamic subsurface properties (e. g. size, permeability and connectivity), which will have a fundamental impact on the overall future of the project, despite the good or poor execution (see later).

The combination of these two phases, which require an integration and coordination of several disciplines and expertise (Fig. 3) ranging from geophysics, reservoir sedimentology, petrophysics and reservoir engineering (e.g. Cosentino 2001, Le Ravelac et al. 2014), will indeed lead to describe in full the reservoir complexity and understand and quantify both static (e.g. size and shape of sand bodies, porosity and permeability dis-

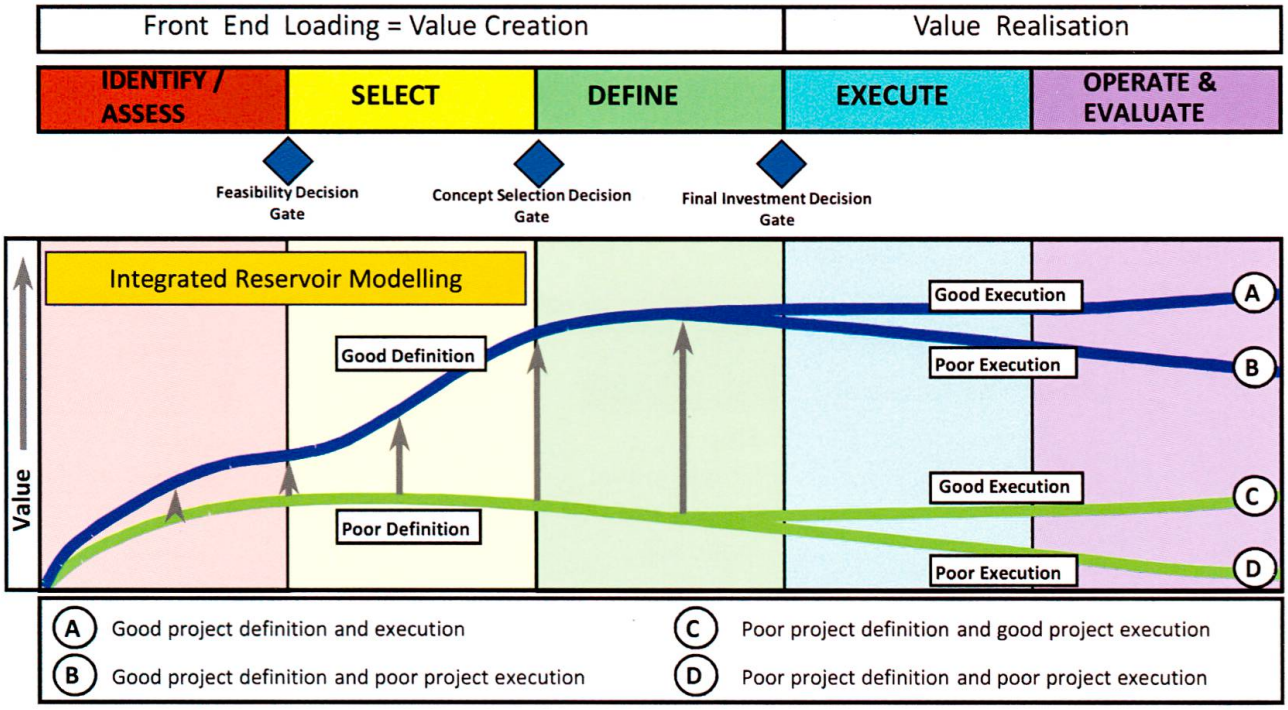


Fig. 2: The geo-energy journey, aimed to create and realize value from a geo-resource in the subsurface can be described in five distinct phases which range from the identification/assessment and selection of the opportunity, definition of the project, followed by execution and concluded by the operation/evaluation. The most reliable assessment of the real value of a given opportunity is generated at the beginning during the selection and definition of the steps displayed in the graph.

tribution, orientation and spacing of fault and fracture network, fault transmissibility, etc.) and dynamic (e.g. effective flow properties and flow behaviour) parameters.

Following the «Select» phase, the implementation continues with the definition of the projects where the operational and effective technologies and approaches (i.e. drilling and development concepts) are discussed and defined. In the «Define» phase a detailed economic and commercial evaluation is performed to check the ‹financial health› (e.g. economic returns) of the project. This in turn will lead to the project execution phase during which the first wells are drilled and the first results are obtained. These will allow the check and validation of the subsurface model proposed in the earlier phase. This important feedback loop between the subsurface reality and the predictive model continue throughout the full lifecycle of a geo-energy development (Fig. 4), especially during the production phase when new knowledge of the reservoir (i.e. static and dynamic data) becomes available. New data interpretations will be most likely requiring an update of the model and subsurface uncertainties. The better the data interpretation and quality assessment, and the faster the new learning obtained during the execution phase is integrated in to the overall understanding of the subsurface, the better the uncertainty ranges of critical parameters will be handled and possibly reduced (see later).

A the end of each subsurface opportunity realization project, a full evaluation of the entire geo-energy journey will enable all interested parties (i.e. geoscientists, engineers, etc.) to reflect on several aspects of

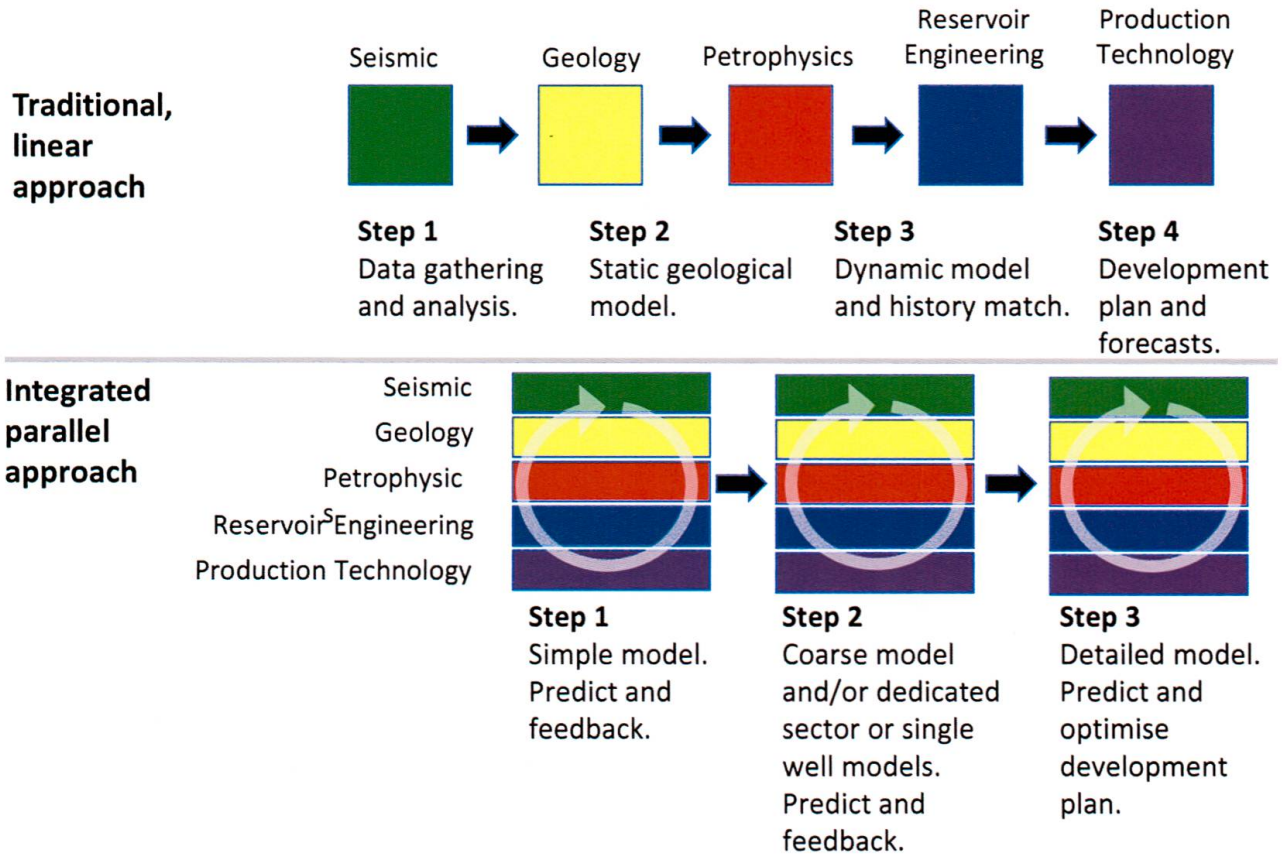


Fig. 3: Comparison between the traditional and integrated modeling approaches. The traditional linear approach consists of discrete phases where individual disciplines contribute to the modeling effort separately with distinct tasks and deliverables.
The integrated parallel approach implies a multidisciplinary and concerted effort from the beginning of opportunity through to the maturation phase, working on and delivering increasingly more detailed, though fit-for-purpose, models.

the project ranging from subsurface prediction capability to execution performance. This step represents an invaluable learning opportunity whose lessons learnt can be applied to improve and steer future geo-energy projects.

During the lifecycle of any multi-phased project, as it could be the case of a complex hydrocarbon development (Fig. 5), several fit-for-purpose models may be constructed to evaluate and assess the subsurface response to specific development techniques which can follow each other over time in order to maximize geo-energy recovery and hence project value. In this case, building and maintaining a field database from which geo-models can be built quickly to support specific decisions may have more business value than maintaining a single, complex field model (Ringrose & Bentley, 2015).

3 Criticality of the geo-modeling phase

The «Identify/Assess» and «Select» phases represent critical steps in the geo-energy project. Good prediction capability of a geo-model can determine the future of the overall opportunity and value realization. A project selection based on a well defined and realistic quantitative description of the subsurface (geo-model), and combined with the most appropriate development concept («Define» phase) will be able to maintain and sustain throughput for the entire journey and be affected only marginally by poor execution and operation performance (Fig. 2).

On the contrary, a poor understanding and definition of the subsurface during the first two phases of the geo-energy journey will prove an incorrect assessment of the real

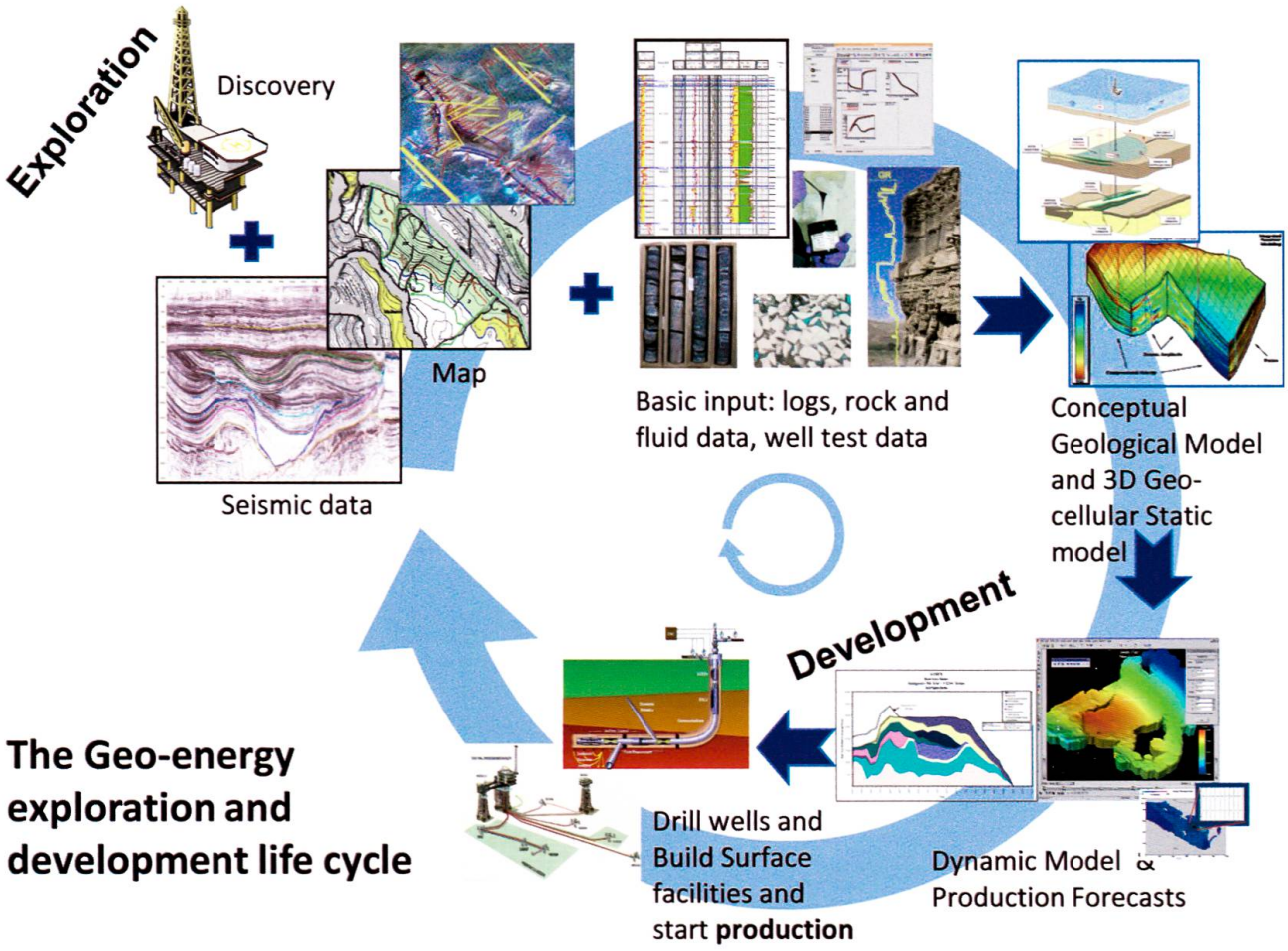


Fig. 4: The geo-energy project life-cycle from exploration and development. Data and reservoir static and dynamic parameters will need to be integrated in geo-models to obtain reliable reservoir behaviour prediction and geo-energy production forecasts. Learning from project execution needs to be integrated and used to validate model prediction and allow adjustments «on route» where is required.

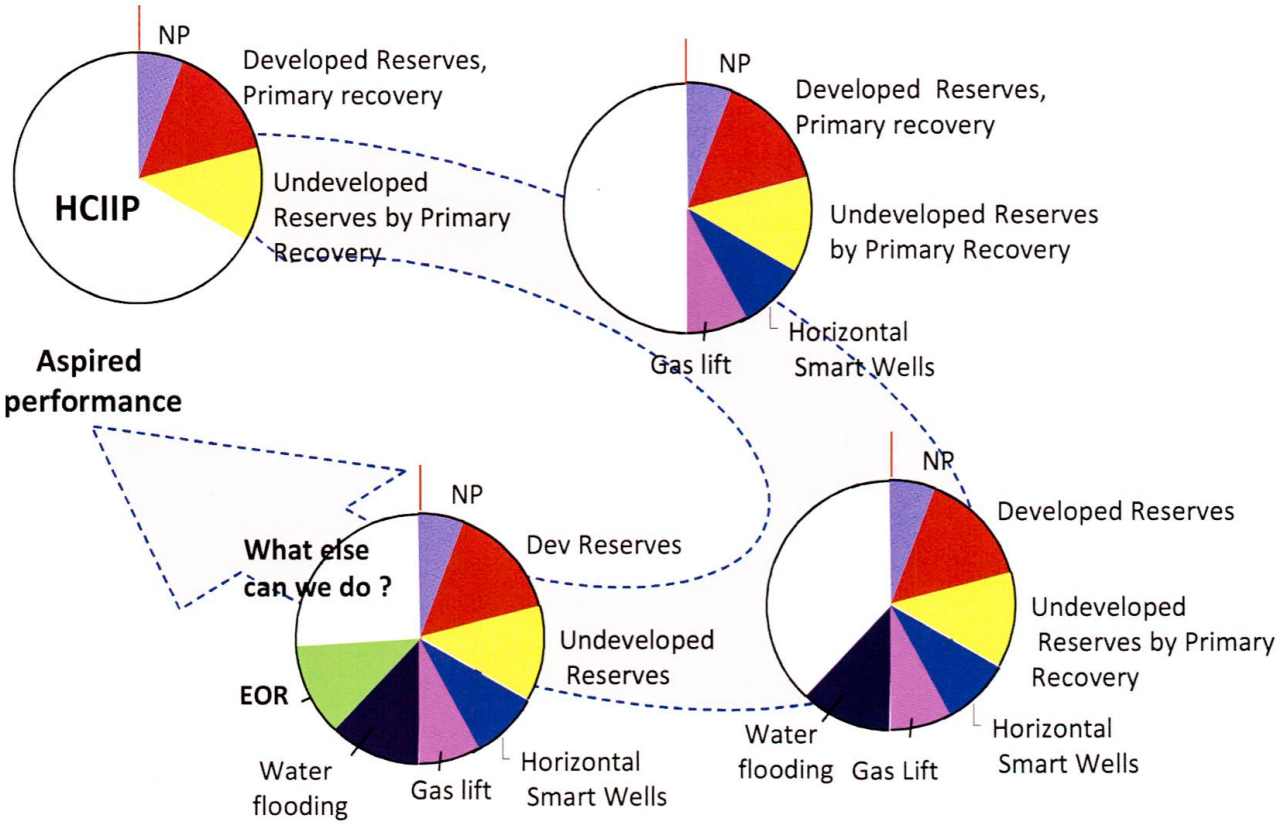


Fig. 5: Maximising project value by addressing recovery mechanisms throughout the field development life-cycle to attain the best aspired project performance, requires the support of fit-for-purpose geo-modeling approaches able to respond to a variety of questions regarding the static and dynamic behaviour of the reservoir at full field, reservoir or well scale. The circle represents the total hydrocarbon initially in place (HCIIP) and individual coloured wedges, the amount of hydrocarbon, which has been produced (NP: net production) or will be recovered with different development technology (horizontal wells, gas lift, water flooding, EOR: enhanced oil recovery). The white wedge represents the yet unrecovered resources, which may be addressed by future innovative technology.

value associated with the opportunity. This cannot be improved even by a good project execution and operation (Fig. 2).

This highlights the critical importance of developing during these two first phases of the geo-energy project a sound understanding of the subsurface by analyzing, quality checking and integrating all available static and dynamic data. Access to 3D seismic, well velocity data and parameters describing reservoir properties and continuity are especially important to build a correct structural framework. Cores and extended well tests allow the population of the subsurface model with the correct geological data and predict flow behaviour.

The lack of good quality data and/or a low level of representativeness of the subsurface complexity at this early stage of the geo-energy journey may be addressed by either dedicated data gathering campaigns or by ensuring that the description of the subsurface (geo-models) captures the full range of uncertainties in the most accurate way.

4 The geo-modeling steps

The description and quantification of subsurface geology through a three-dimensional model requires a systematic approach, which overall is not dissimilar to any other modeling effort leading to predictive capabilities (e.g. weather and economic forecasts). As mentioned above, the impact of an inadequate geo-model at early stage in a geo-energy maturation journey can determine the under-performance or failure of a project. This risk can be minimized by the implementation of thorough model building

processes consisting of well structured and ordered steps. Prior to embark on the merely mechanical geo-cellular construction phase, the first task is to define the purpose of the model (step 1). In this step the technical and commercial boundary conditions of the modeling exercise need to be identified together with the definition of main uncertainties and drivers (e.g. maximising production, quantification of aquifer strength, identify bypassed oil, etc.). At this stage the choice of resources and tools, the modeling approach and the resolution of the model are decided (e.g. sector model vs. full field, size of the overall model and grid blocks, etc.). Step 2 is to perform an integrated data analysis where all data will be examined and used. For instance, understanding and interpreting the pore system and its geometries both at core and log scale will allow the definition of pore types leading if necessary to their classification based on morphology and/or genetic criteria usually inferred by the position, size and shape of the pore relative to the components of the rock mass. Integration of petrographical and petrophysical data is typically required for this purpose. On the inter-well to reservoir scale the definition of geobodies as quantifiable volume of rock with a set of characteristic geometry, fabrics, textures or properties related to a particular genetic origin, needs to be pursued. Usually, this includes the identification of relevant depositional, diagenetic and structural processes with associated geometries also assisted by the use of data from analogue situations where the subsurface is better known. This step leads to the definition and drawing of a conceptual geological model (CGM) and the identification of the critical parameters controlling the reservoir architecture connectivity properties, etc., all of which are affected by high level of uncertainties. Step 3 focuses on the definition of the model architecture with the aim of representing the pore system and its geometries. Ultimately, modeling aims at representing the porosity/permeability system and its geometries. Discrete rock types are thus defined at both core and log scale which allow the description of different bodies of rock with defined flow properties, comprising a characteristic set of pore types, with a distinct genetic origin. The integration of a stratigraphic correlation scheme, with fault and fracture data and facies, petrophysical, and production data will help identify flow units at the inter-well and reservoir scale. These are body of rock characterized by flow properties that contrast with adjacent flow units and will determine the dynamic behaviour in the subsurface. Once this is achieved the CGM can be implemented in a geo-cellular environment using the most appropriate and/or available software tools and approaches depending on the scale of interest and size of model (Fig. 6).

5 Handling uncertainties in geo-modeling

Modeling the subsurface to support the assessment, definition and execution of geo-energy projects necessarily needs to address issues such as subsurface uncertainty management, distribution of expectation volumes and production forecast scenarios. Uncertainty management and modeling (Corre et al. 2000, Caers 2011), in particular is a somewhat controversial subject that can receive different types of approach in academia and industry depending often on both knowledge of the subsurface and company cultural background. Stochastic or geostatistical approaches aimed to quantify uncertainties around a reference (or base) case model and at quantifying the impact of these uncertainties on gross-rock volume, resource-in-place or production profiles through probability distribution functions contrast with other approaches where the geostatistics are unable to represent the true variability of the subsurface in an organised manner (Davies et al. 2009). For

this reason geostatistic approaches could have an intrinsic risk of under or over-estimating the uncertainties. Thus a scenario-based approach is preferred to the stochastic one. In other cases, often in cases of well-established knowledge of production performance in mature geo-energy projects, the rule-of-thumb estimates of uncertainties based on the company's accumulated experience over many past case studies is often deployed.

Regardless the approach one decides to implement, geological processes vary strongly in temporal space, posing a great challenge in terms of subsurface modeling. Understanding the subsurface micro and macro textural and heterogeneous properties of varying rock formations is crucial to developing appropriate geo-modeling concepts and techniques, particularly for analysis at scales ranging from kilometres to the nanoscale. Deciding how to build a subsurface geological model is therefore not a trivial task. The lack of direct observations, the discontinuity and incompleteness of data require the development of conceptual model to imagine and thus describe the distribution and variability of the subsurface parameters in the three-dimensional space. The approach to handle uncertainties may vary

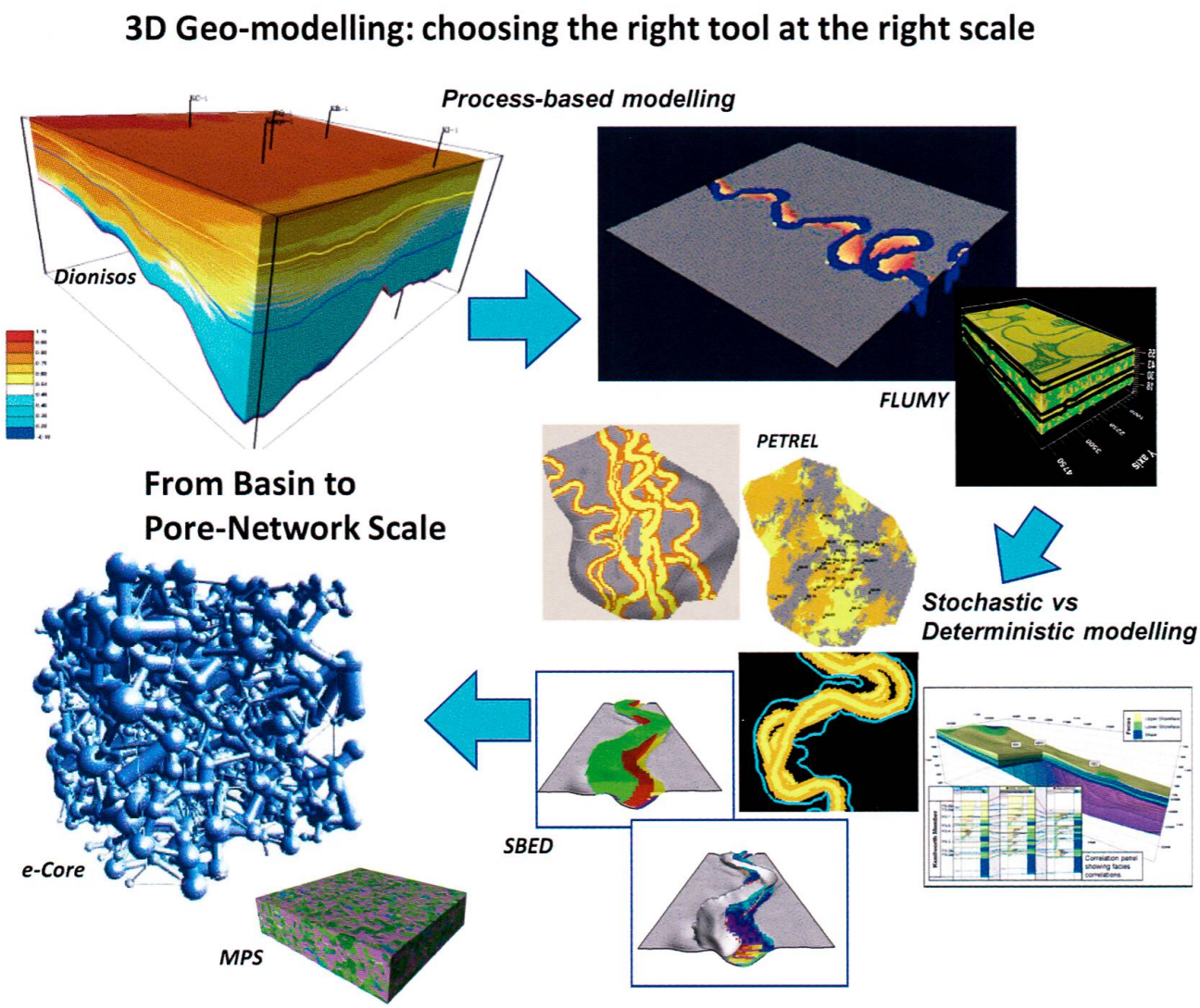


Fig. 6: 3D Geo-modeling: choosing the right tool at the right scale. Several geo-modeling techniques exist which offer the ability to describe quantitatively natural geological environments at different scale. Choosing the right tool is critical to ensure fit-for-purpose and reliable results. Images on this figure are from a variety of proprietary tools such as Dionisos (Institut Français du Petrole Energie Nouvelles), Flumy (Ecole des Mines de Paris) Petrel (Schlumberger), SBED (Geomodeling Technology Corp.), MPS (multi point statistics developed by Ephesia Consult SA) and e-Core (Numerical Rocks).

greatly in the industry and there is no single receipt to perform this task in a simple and standardized way. The perception and awareness of project risks may determine the ultimate approach with which uncertainties are handled (Fig. 6). In any case, the effectiveness of a geo-energy project depends heavily on the CGM attempting to describe the subsurface. Its quality and reliability therefore can vary greatly as it depends both on the available data and, to a large extent, on the overall level of knowledge, experience and ability of the individuals or teams predicting the «true» geology. Even in the most fortunate case (e.g. large data sets) different degrees of unknowns will remain, which will result in the identification of key parameters, both associated with static and dynamic subsurface characteristics for which limited understanding is characterized by a variable degrees of uncertainty (Fig. 8).

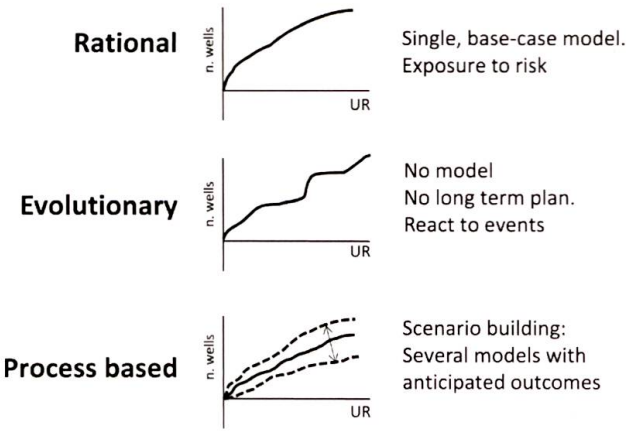


Fig. 7: Uncertainties associated with a geo-energy project can be handled in different ways depending on the overall understanding and awareness of impact of different subsurface parameters and effectiveness of development scenarios. These will determine the attitude towards the exposure to risks. The three graphs showing the relationship between predicted ultimate recoverable (UR) volumes vs. number of wells explains the different approaches. The rational approach will consider one base case model and will be intrinsically highly exposed to failure/risks if the predicted model is not correct. The evolutionary approach typically refers to a situation where there is no prior understanding of the subsurface due to lack of planning and a short sight attitude. The process based approach, allows the development of a range of anticipated outcomes through building different models and development concepts (scenarios).

Research projects aimed at studying reservoir outcrop analogues (e.g. Flint & Bryant 1993, Moscariello et al. 2013, Howell et al. 2014) focus on substantially improving the understanding of the nature and architecture of specific geological environments (Fig. 9), and how they function and evolve over time. This knowledge is used to reduce fundamentally the uncertainties of predicting their geometry and composition and modeling the same geological environments in the subsurface, where only limited data based on borehole and seismic observations are available. A sound understanding of the subsurface anatomy based on geological analogues and a deep knowledge of genetic processes help defining the best modeling strategy for the creation of realistic reservoir architecture in sub-surface models (Davies et al. 2009). Without this background knowledge, probabilistic models constructed using a minimum of geological input can result in the poorest comparison to reality, with an unrealistic, disorganised scatter of sediment bodies. For reservoir scale models, these can be considerably improved when a] a high-resolution deterministic framework of time-lines is introduced; b] geological trends are used to capture the broad-scale architecture of the reservoir; c] body shape and size are deterministically constrained (Davies et al. 2011, and Fig. 9).

At a smaller scale, modeling pore network can be performed by deployment of innovative technologies, such as quantitative evaluation of composition and texture by scanning electron microscopy (e.g. QEMSCAN [Quantitative Evaluation of Minerals by SCANning electron microscopy], Moscariello et al. 2013) combined with modeling approaches such as direct sampling, transition probability, multi-point geostatistic simulations and texture synthesis (Kessler et al. 2013, Mariethoz & Caers 2014), are key to address the challenges of capturing the

complexity of geological environments at different scales, quantify and validate the modeling outputs. In this case the innovative direct sampling technique involves the use of complex stochastic algorithms permitting the establishment of three-dimensional geometries from partial images and/or datasets of a defined area which can range in size from a sedimentary basin to a pore in a shale rock. The multi-point simulations build upon classical methods of interpolating data and quantifying uncertainty by modeling spatial probability patterns in the subsurface based on training images – images depicting the theoretical geological heterogeneity at a given point (Fig. 8). These techniques complement the texture synthesis approach, which also utilises training images to assemble realistic graphical textures which can be applied at different scales (e.g. Kessler et al. 2013; Mariethoz et al. 2014).

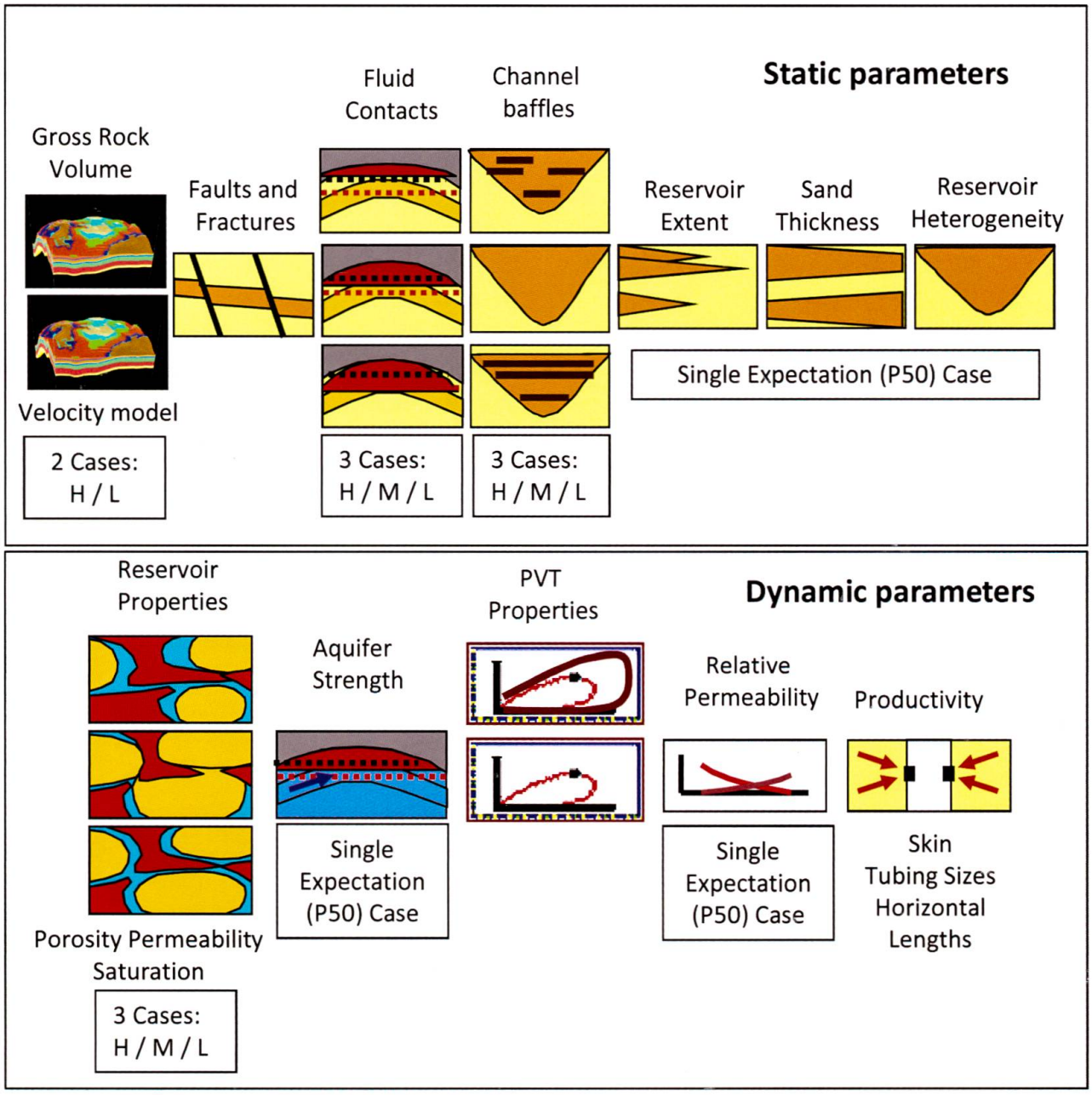


Fig. 8: Examples of key subsurface parameters whose understanding and examination in the modeling effort are considered critical to describe the static and dynamic characteristics of the subsurface. Not all subsurface parameters have a large range of uncertainty to be handled by the modeler. However, all of them need to be considered to produce a full range of realistic possible outcomes. These parameters will be also listed in the risk and uncertainty register as illustrated in Fig. 10.

Capturing and quantifying uncertainties at different scales becomes therefore an important and critical aspect of geo-modeling exercises. Depending on how well are understood and managed, these multiple scales can determine the success or failure of a geo-energy project (see Fig. 1).

Whether a geo-model will be constructed using a stochastic or a deterministic technique or a combination of the two, managing uncertainties efficiently requires the construction of a range of geo-models each of which will represent a different and realistic combination of subsurface parameters (Fig. 10). This approach will produce a number of «subsurface realisations» with specific subsurface characteristics (e.g. reservoir geometry and connectivity, etc.) and values (e.g. gross rock volume, average porosity, volume in place, etc.). In this context, a deterministic approach by choosing the combination of parameters to be used in the geo-modeling exercise has the advantage of producing auditable and explainable results. If a fully geostatistical approach would be used instead, such specific «manageable» results are not straightforward.

Besides enabling the representation of the subsurface, the geo-cellular geological models are critical tools allowing the quantification of uncertainties. The use of geo-cellular models allows the evaluation and ranking based on impact on the overall project values (e.g. connectivity, recoverable volumes, net present value, etc.). Standard sensitivity analysis tools such as Pareto charts and sensitivity plots (Fig. 11) can enable the visual comparison of effects of changing variables in the various cases, identifying the most critical variables which have the highest

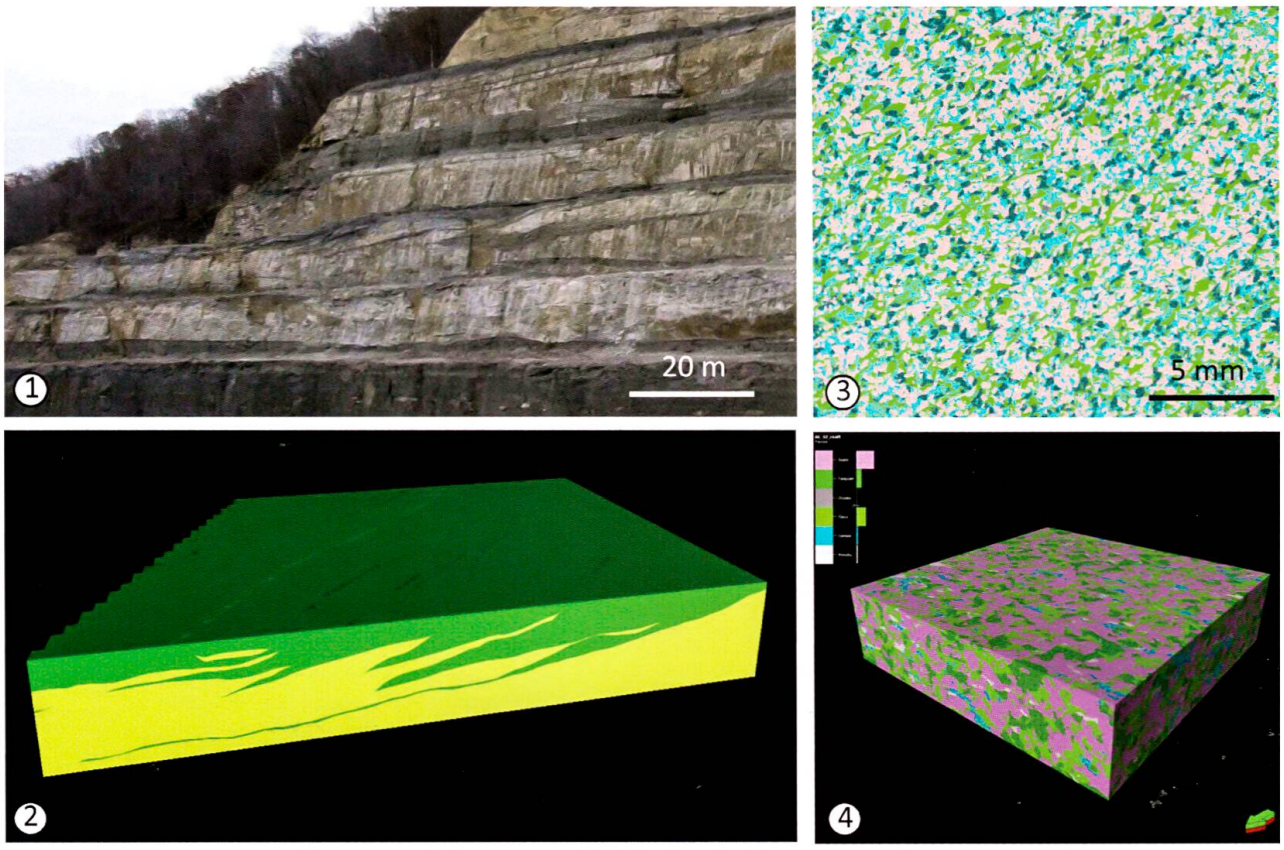


Fig. 9: Geo-modeling of different geological environments requires adequate tools able to capture their natural complexity. [1] Clinoform geometry at decameter scale from Upper Carboniferous fluvio-deltaic sandstones well exposed in Eastern Kentucky are modeled with a deterministic approach [2]. The micro-texture of a sandstone reservoir [3], analysed by QEMSCAN quantitative automated petrography in two-dimensional environment (thin section) is modeled with multi-point statistics and the knowledge transferred in the three-dimensional space [4]. Modeling images courtesy of Aymeric Le Cotonnec, University of Geneva and Tatiana Chugunova, Total SA.

impact and establish a confidence level in the estimation of input data. Such an approach will lead naturally to developing a register of the key project risks which will need to be taken into account in the project planning and execution phase.

6 Geo-modeling follow-up

The outcomes of the geo-modeling exercise and the generation of multiple subsurface realizations will enable to build a cumulative probability curve (Fig. 12) by either applying probabilistic simulation methods (e.g. Montecarlo simulation) or assigning a change of success to each individual subsurface model, based on experience, production data in nearby analogue fields, etc. In this curve two neighbouring volumetric values (e.g. hydrocarbon in place or reserves, volumes of connected geothermal aquifer, storable CO_2 volumes, etc.) may refer to very different subsurface circumstances (e.g. geological models) and therefore may pose different challenges for the geo-energy development project (e.g. different location of porous sand and thickness of reservoir and fault compartmentalisation). Each individual subsurface realization will be the basis for elaborating the development concepts in which the various drilling, production technology and facility engineering aspects will be considered. At this stage, fit-for-purpose models aimed at screening the dynamic responses of the subsurface to different recovery technology (e.g. ranges of pressure depletion, fracking, water injection, gas lift, etc.) can be useful to check the viability of the development concept. For each individual subsurface realization, therefore, there will be potentially distinct development concepts

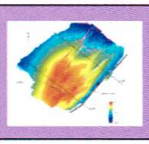
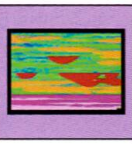
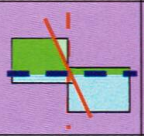
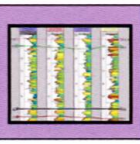
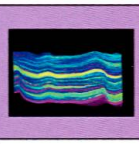
	Gross Rock Volume	Reservoir Geology			Pore Volume			HC Volume
	(Structure, Velocity, Thickness)	Correlation	Facies	Fault modelling	Porosity	HC Saturation	Gas Water Contact	Permeability
Subsurface Realisations and Key Subsurface Parameters								
Subsurface parameter variability	T/Z sensitivity + %		Fluvial dominated		From logs			
	3D Seismic 2008	Well picks	Aeolian Dominated	Verticals	From logs with co-kriging using Impedence cube	Phi-dependent and height on GWC	2912.5	Phi dependent
	T/Z sensitivity - %	Seismic picks	No facies	Sloping fault	Impedence Cube	K-dependent and height on GWC		V clay dependent
Level of uncertainty	Medim	Low	Low	Medium	Low	High	Medium	Medium
Impact of uncertainty	High	High	Medium	High	Medium	High	Low	High
Associated risk	large variations in volumes than expected	high vertical/lateral heterogeneity	higher heterogeneity than expected	loss of volumes	worst reservoir than expected	impact on volumetrics	possible impact on volumetrics	V clay underestimate volumetrics
Is there anything we can do to reduce the uncertainty ?	drill well to the south	check offset wells	investigate nearby wells/fields	acquire BHI	acquire modern e-log suite	perform SCAL	examine regional data	analyse SCAL data
Comments	to be included in the FDP reccomendation	none	none	to be included in the FDP reccomendation	none	none	check with exploration team	none

Fig. 10: Deterministic subsurface realisations are constructed by selecting specific combination of parameters which have been previously identified as critical in describing the subsurface. The subsurface parameter variability is also described along with the level and impact of the uncertainty associated with each of them. This summary table also captures possible solution to address the uncertainty and associated risks that may be considered in a later stage of the modeling phase or project life-cycle.

including, for instance, different number of wells, well locations, recovery mechanisms and different evacuation methods, facilities and routes. The combination of a subsurface realization and a development concept represent a development scenario (Fig. 12). Each individual development scenario will be associated with recoverable volumes, production forecasts, costs and overall economic values (net present value, capital or operational costs, etc.). The latter will be one of the most critical parameter which will decide the future of a geo-energy project determining its level of attractiveness (Fig. 12). However, the final selection may be based on other value drivers, which in a particular historical, economic and political situation are considered more important (e.g. geo-political situation, local government objectives, company strategic choices, country entry strategy, etc.).

7 Conclusions

Reservoir geo-modeling represents a fundamental step for describing and quantifying the subsurface in the context of geo-energy exploration, development and management. The geo-model therefore represents a synthesis of the understanding of the subsurface at the time of the model building exercise and reflects key choices that the team, preferably formed by experts in different disciplines, have made concerning the subsurface static and dynamic parameters. These choices, made at early stage of the geo-energy journey, will have an important impact on the project maturation and implementation. The geo-modeling exercise is therefore a very delicate and critical process where a series of steps needs to be ensured in order to design and implement the most efficient approach. The construction of a fit-

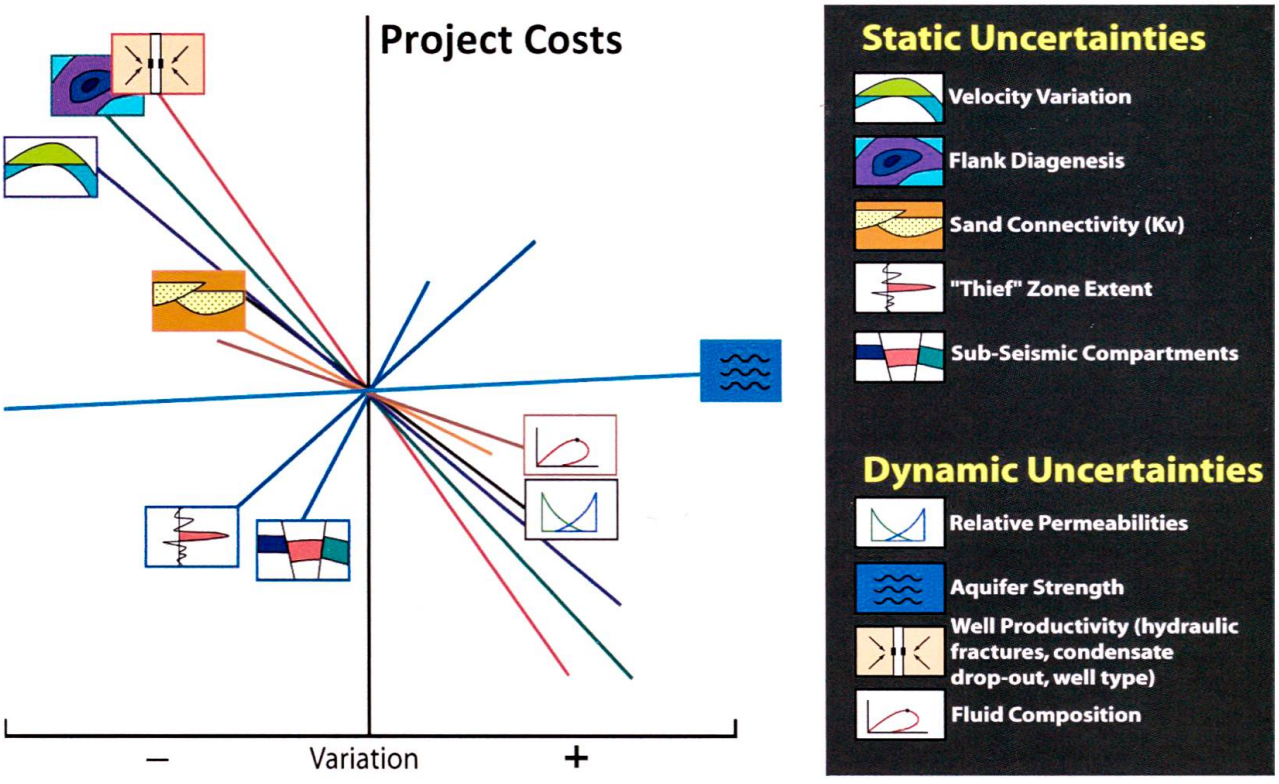


Fig. 11. Sensitivity plots enable the visual comparison of effects of individual subsurface parameters and identify the ones that have the largest impact on the project values. In this example well productivity, flank diagenesis and velocity variation have the largest effect on project costs while even possible large variations on aquifer strength will not affect the project economics. Parameters which most affect the project values are the ones which will need to be addressed in detail in the modeling exercise and, if possible by new data gathering efforts.

for-purpose model will need to take into account all critical data and related uncertainties and risks that may determine the success or failure of a geo-energy project. Model data inputs and choice of modeling approach are particularly critical, as they will have strong effect on the outcomes. The latter concept is well summarized in the industry jargon by the expression: «rubbish in - rubbish out».

The full understanding of key parameters controlling the geo-energy resources distribution is the base for a reliable quantification of the subsurface which will need to be represented by a set of models (i.e. subsurface realisations), capturing the full range of volumes and associated key uncertainties.

Within a full life-cycle of a geo-energy project the subsurface modeling exercise is intrinsically a never ending task: the improved knowledge coming from new subsurface data acquired during production or analogue projects will require a continued effort to update and improve the model. Each geo-model can therefore be seen not as a final product but as a starting point for supporting exploration, development and management of subsurface energy resources. Each geo-model will be, in fact, continuously challenged by the reality of facts and updated as long as the project will carry forward. A necessary task, which will last throughout the life-cycle.

Finally, the geo-model is a useful communication tool that allow the subsurface team to

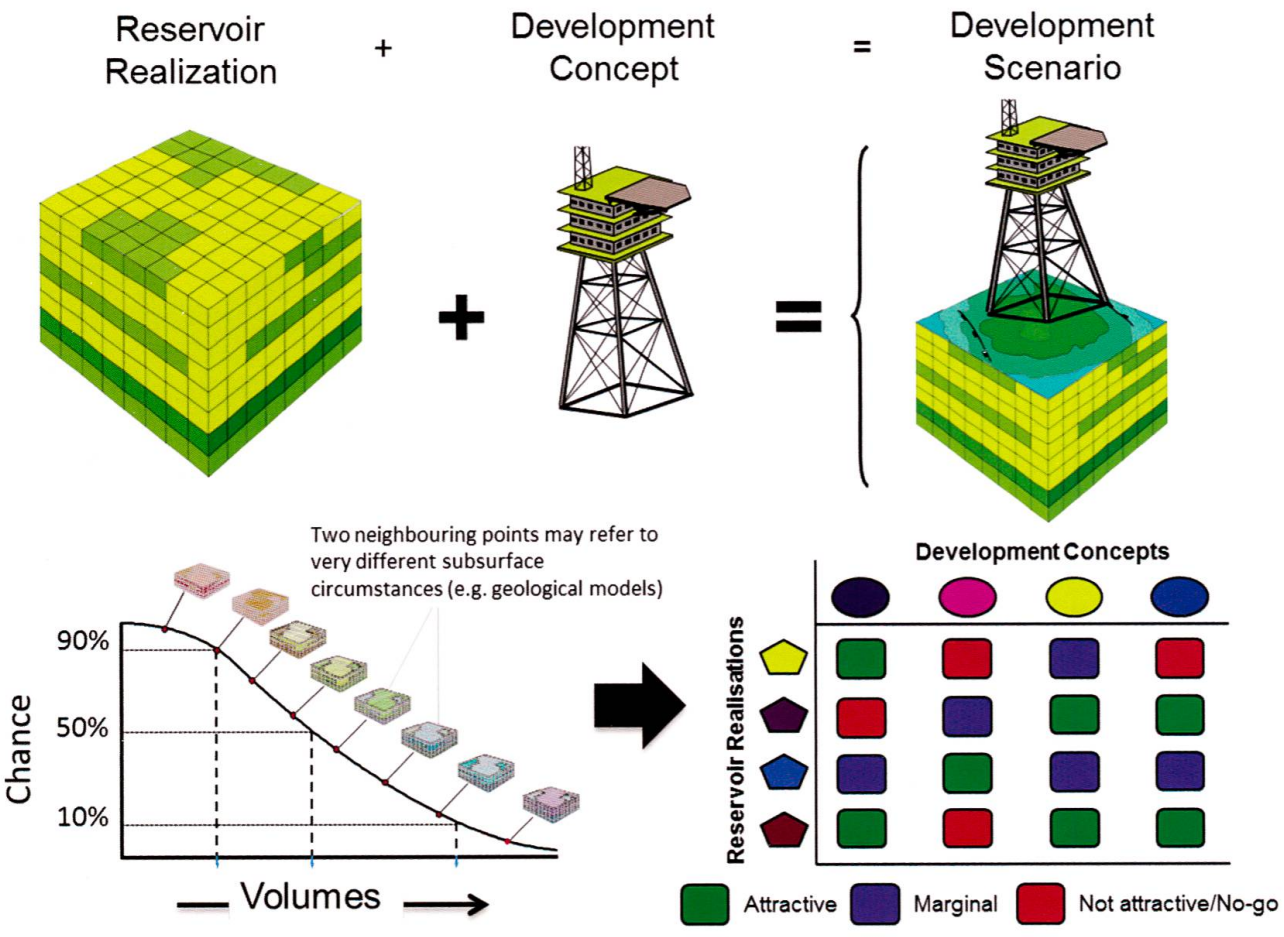


Fig. 12: A development scenario is the combination of individual subsurface realizations and development concepts (i. e. number and type of wells, production facilities, etc.). The combination of volumes from different geo-models plotted in a cumulative probability curve show the full range of variability of values and the probability associated with each of them. The final selection of development scenarios, often based on a matrix plot, will be determined by what value driver is most important, which is not always necessarily the profitability of the project (NPV). Typical value drivers can be: Capital expenditure (Capex), Operating expenditure (Opex), Net Present Value (NPV), Production Forecast, Unit Development Costs, Unit Technical Costs, local government objectives, company strategic choices, etc.

transfer knowledge about opportunities and risks to decision makers. The risks of unconsciously constructing a wrong model because of non-representative data or their incorrect interpretation, can potentially lead to severe business, technical and human consequences (e.g. blow out). For this reason, a solid understanding of reservoir geosciences, based on strong basis of geophysics, sedimentology, petrography, structural geology, petrophysics and fluid dynamic, is deemed necessary before embarking in any geo-modeling effort.

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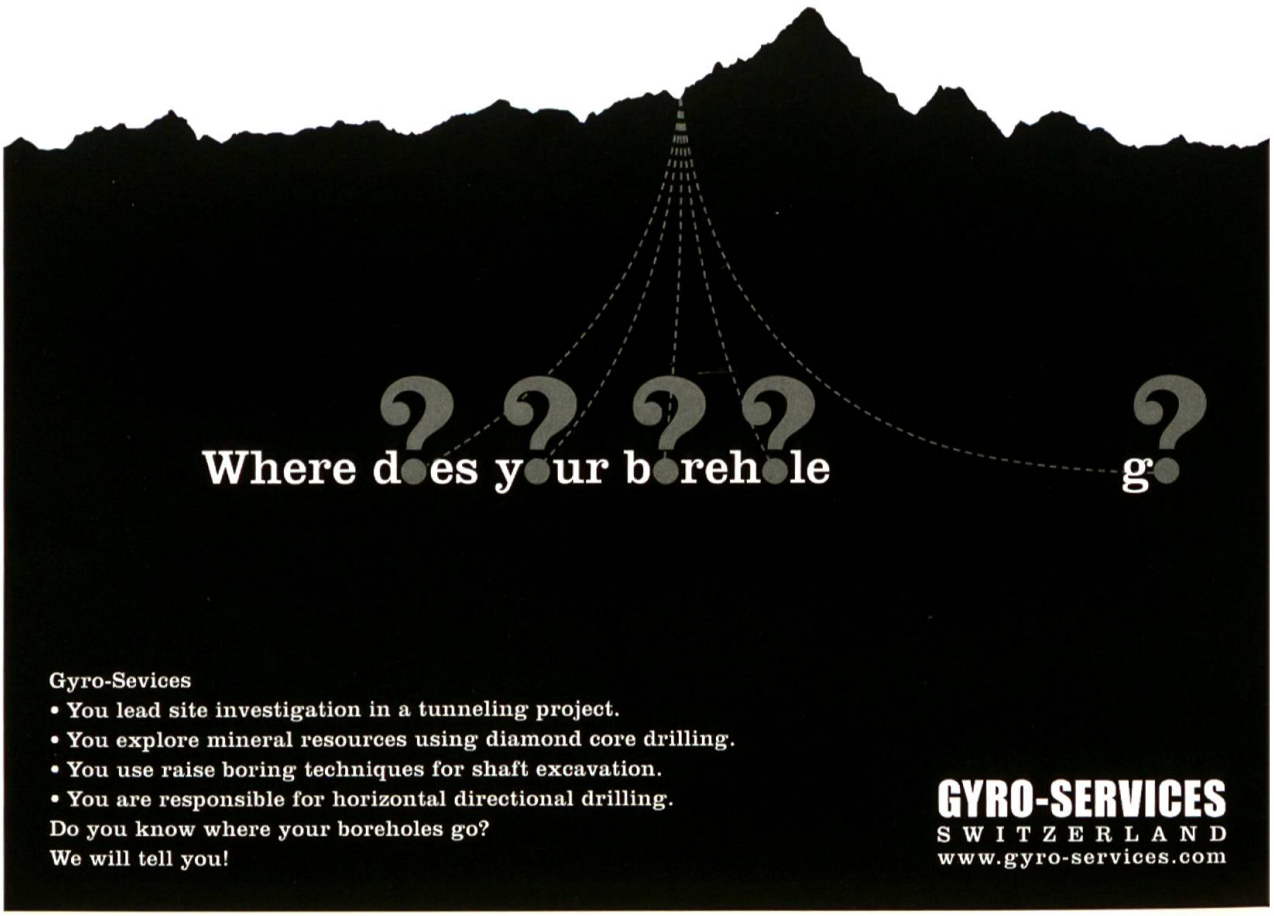
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