VAŽNOST ODABRANIH GEOLOŠKIH VARIJABL
U KARAKTERIZACIJI ODABRANIH LEŽIŠTA
UGLJIKOVODIKA

THE IMPORTANCE OF SELECTED GEOLOGICAL
VARIABLES IN CHARACTERIZATION OF MATURE
HYDROCARBON FIELDS

Tomislav Malvić, INA d.d. Zagreb, SD Naftaplin, RGN fakultet Sveučilišta u
Zagrebu, Davorin Balilić, INA d.d. Zagreb, SD Naftaplin

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depositional environments, sandstones.

Sažetak

Geološka karakterizacija zrelih ležišta ugljikovodika standardan je proces, s dobro
poznatim dijagramom teka i geometrijskim podlogama kod svih ležišta
ugljikovodika u čijoj je proizvodnji pređen maksimum. Pad proizvodnje opisan je
krivuljom predviđanja s obzirom na vremensko razdoblje u kojemu je još uvijek
ekonomski pozitivna. Odlučuje se sve većim omjerom vode u količini
proizvedenih fluida te primjenom različitih sekundarnih i terciarnih metoda
teriranja ležišta (zavodnjavanje, utiskivanje različitih plinova) kako bi se ostvario
što veći konačni iscrp. Povećanje ukupne količine proizvedenih rezervi
ugljikovodika ovisi o pravilnom stavljanju u međuodnosi veličina koje se nazivaju
ležišnim varijablama (poroznost, propusnost, zasćenje, dubina, debljina), a većina
od njih su ujedno i geološke varijable koje svoje vrijednosti temelje uglavnom na
dekametarskoj skali i osnovu su za postavljanje geološkog modela ležišta.
Međutim, ulaskom u zrelo razdoblje pridobivaja najčešće raste broj točkastih
podataka s tim vrijednostima te dolazi do ponovne izrade detaljnijeg geološkog
modela te izračunavanja preciznijih odnosa između proizvodnosti i navedenih
geoloških veličina. Takav napredak posebno je moguće ostvariti unutar
homogenih pješčenjačkih ležišta, tj. unutar središnje kanaonal zone masivnih,
debelih (nekoliko desetaka metara) pješčenjaka te ga zatim ekstrapolirati u rubna
međukanalna područja ili područja poplavne ravnice u facijesima tankih
pješčenjačkih slojeva (do nekoliko metara) ili laporovitih pješčenjaka. U tim
slučajevima posebno je važno uspostaviti odnose:

(a) između vrste taložnog okoliša, litofacijesa i njihovih presječnih debljina,
(b) utjecaja kompakcije obzirom na dubinske razlike na smanjenje poroznosti te
(c) broja podataka i odabira najpristupačnije metode interpolacije za gore
navedene točkaste podatke.
Abstract

Geological characterisation of mature hydrocarbon reservoirs is standard procedure, with well-known workflow and geomathematical basis in all cases where decline of production is observed. Such production decreasing is described with decline curve where is clearly stated period of still economical positive recovering. Also, declining period is described with progressively higher share of water in total recovered fluids and consequently application of secondary and tertiary methods of reservoir stimulation (water flooding, gas lift) with goal to increase total recovery. The increasing of total produced hydrocarbon reserves depends on right calculation of inter-dependence among reservoir variables (porosity, depth and thickness). The most of them are also geological variables that mostly do not change their measured values in decametre scale. They are the base for the geological model creation. However, in the period of field maturation it most often means progressively higher number of point data. This new, larger dataset is a base for calculation of newer, more detailed geological model and calculation more precise relations between production rate and mentioned geological variables. Such progress is especially possible to realize in homogenous sandstone reservoirs, i.e. inside central channel zone with thick (several tens meters) sandstone facies. Obtained values then can be extrapolated in marginal, inter-channel or levee-bank areas, i.e. in facies of thin sandstone layers (several meters) or facies of marly sandstones. In such cases, there is need to establish:

(a) relations among depositional environment type, lithofacies and their average thicknesses,
(b) influence of compaction regarding depth differences and reflectance in porosity decreasing and
(c) number of data and selection of the most appropriate interpolation method for mention point data.

1. Introduction

The beginning of use of the geomathematical methods in describing of mature reservoirs started in the early 1980s. That was period when well logging included a lot of new logs, and reservoir mapping begging to perform with geostatistical methods. From then, application of statistics in data processing for exploration and production of hydrocarbons is crucial (e.g. Jensen et al., 2000). Classical disadvantages in hydrocarbon reservoir modelling had been noticed in describing reservoir in inter-well area. There interpolated values often were not confirmed, in acceptable errors, with new wells.

Geological rules, as part of natural laws, are mostly described deterministically, but it is reason for limitations in their application in subsurface conditions, because all reservoirs (Figure 1) variables have more or less stochastical properties (Malvić, 2009a). Clastic sedimentation of any type, and evenly
biogenic deposition, are the result of numerous processes that lasted for long periods and are responsible for the texture and structure of reservoir (e.g. granulometry and sorting of clastics). Any numerical approach in modelling of petroleum, hydrogeological or other geological systems led to regularities expressed through the statistical values or numerical algorithms for mapping (e.g._andrićević et al., 2007; Malvić, 2008). Using “enough” data geological model can be upgraded in a detailed object-based model, describing reservoir architecture and/or distribution of reservoir variables. The mapping of reservoir variables is the most important outcome of geological modelling, when mapping methods, especially geostatistical, using algorithms how to reach as precise as possible outcome from representative dataset (e.g. Malvić and BAlić, 2009). The term “representative” means the dataset with certain statistical properties, e.g. with standard deviation +/- 5%, using as low as possible number of data.

Figure 1. Using of deterministic and stochastic approaches in geostatistical reservoir mapping (from: Malvić, 2009a)

The variable (Figure 1) can be predicted deterministically and stochastically. According this statement, any reservoir system can be described as deterministic if for the same input it always gives the same output. Oppositely is the case of completely random system where the same input always give a different outcome. Such system can be regarded only theoretical, because in the subsurface is no any completely random reservoir system. Stochastical system is located between determinism and randomness, because any estimation of reservoir variable inside them will be accompanied with uncertainties around estimated points. The application of more appropriate estimation method can (Figure 2):
(a) Led to better know margins of uncertainties in each grid point for selected reservoir variable;
(b) To decrease margins of uncertainties using the mathematically more advance methods (this usually asks for more input data, what is characteristics of mature stage of hydrocarbon production).
Any approach to modelling of reservoir variables need to be set, according to Jensen et al. (2000), on the type of analysed reservoir:

1. **Deterministical reservoirs** where inter-well area is clearly and certainty described and correlated in metre scale using e-logs and cores. Structural framework and lithologies of lithostratigraphic beds are well-known. Such reservoirs can represent more than 50% of large to medium hydrocarbon pools in mature petroleum provinces (like the Pannonian Basin of the northern Adriatic Sea), i.e. belong to mature stage of the hydrocarbon field, which several decades produced hydrocarbons.

2. **Stochastical reservoirs** are those where “some” uncertainties in estimation of reservoir variables remained. Geological model is not optimized, but allows possible production. Variable uncertainties remained partially significant in the inter-well area. The majority medium to small existing hydrocarbon reservoirs is just of such kind, even in mature provinces. The reason is quantity of proven reserves, not enough large to drill several tens of wells and decrease uncertainties in inter-well area so low that reservoir can be classified as deterministical.

3. **Random reservoirs** are generally rare, and can be described only in the exploration phase, i.e. when only 1-5 exploration wells and laterally distanced seismic sections exist. The any reservoir variable is only assumed in wide range (like volume, thickness, petrophysics...) and approximated using Monte Carlo. Any hydrocarbons are classified as possible reserves or P10 (according SPE&WPC style). Numerical modelling (except random sampling) can not be applied due to lack of analytical data, only analogy.
2. Improved characterisation of reservoir variables

The critical moment in modelling of any reservoir is defining “typical static model” as a base for production prognosis with several scenarios. Using stochastics there can be reached several such “static” outcomes, where only changeable variable through the period of production is hydrocarbons-water contact. Each static model is often applied in estimation of Probability Of Success (abbr. POS) of new hydrocarbon discovery/volume in existing or new play, prospect or reservoir. Such calculation are based on geological variables, which can be estimated or calculated easily in mature pool, using deterministical tables (Figure 3) of different geological categories and events (Malvić and Rusan, 2009). In some calculation procedures can be improved with stochastics for variables that are characterised with such properties (Malvić, 2009b), like porosity (Figure 4).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
<th>Probability</th>
<th>Suitability</th>
<th>Example</th>
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<tr>
<td>Sandstone</td>
<td># of sandstone</td>
<td>0.50</td>
<td>Good</td>
<td></td>
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<tr>
<td>Shale</td>
<td># of shale</td>
<td>0.50</td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>Porosity</td>
<td># of porosity</td>
<td>0.50</td>
<td>Good</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3. The example of geological categories and events with values as support for reservoir variables and POS deterministical calculation (from: Malvić and Rusan, 2009)
Figure 4. Example of stochastical approach in deterministical calculation. Represented are minimum, median and maximal reservoir volumes (all equiprobable) for Badenian clastics lithofacies. (Porosity scale is in colour, the red is 0%, and the blue is about 5%) (from: Malvić, 2009b).

Application of well-known deterministical procedure (POS) in combination with stochastical approaches in obtaining several equiprobable realization (using for example sequential Gaussian simulations, SGS) can be right approach for the most of the hydrocarbon fields in the mature petroleum provinces. The most of hydrocarbon fields in provinces like the Pannonian Basin include several tens to hundred wells and some net of seismic sections. In the “average” case regarding data availability (e-logs, DST measurements, cores, seismic sections interpreted in depth domain distanced laterally hundred or so meters), such fields can be classified between deterministical and stochastical reservoirs.

So “combined” approach can be the most appropriate in the reservoirs with up to 20 wells and heterogeneous reservoir lithology (e.g. Smoljanović and Malvić, 2005), where two improvements had been proved (case in the Drava Depression):

1. Kriging advantages (minimizing of variance) is proven, if this technique (Ordinary Kriging) is compared with results of Inverse Distance Weighting;
2. Stochastically obtained porosity maps can lead to several realization of Original Hydrocarbon In Place (abbr. OHIP), clearly depicted the minimum and maximum ranges of possible reservoir volumes. The most appropriate can be easily checked after any of selected production period (so called “history match”).
In any case, there are several proves and papers presenting maps (Figure 5) from clastic reservoirs from the Croatian part of Pannonian Basin (e.g. Balić et al., 2008) where is shown that Kriging techniques (the most often Ordinary Kriging) have always advantages compared with interpolation methods of simpler algorithms.

![Figure 5. Comparison of porosity maps interpolated with Inverse Distance Weighting (upper-left), Moving Average (upper-right), Ordinary Kriging (lower-left) and Nearest Neighbourhood (lower-right) (from: Balić et al., 2008). The Kriging approach was proved as the most appropriate (visually and using cross-validation).](image)

Interestingly, there is one deterministical approach that include stochastic in output maps, using several maps of different probabilities connected with chance that mapped variable reached at least (or maximal, depends on program) selected value. It is Indicator Kriging technique, often used in mapping of reservoir lithofacies, like it was presented e.g. in the Sava Depression (Novak et al., 2010).

Five such Indicator Kriging maps are presented on Figure 6, for the porosity values in the Lower Pontian sandstone reservoir in the Kloster Field.
3. Conclusions

Selection of geological variables for characterisation of the mature hydrocarbon fields is crucial for later outputs. The very first task is selected appropriate values for variable, removing at least (a) outliers, (b) data with known measurements error. The next is collected at least 20-30 point data for selected variable or two variables that can be correlated.

The collected dataset of geological variables can be analysed independently for each variable dataset, making its own statistics and maps. However, sometimes variables can be significantly correlated and data applied together (like in cokriging mapping). How geological variables are measured on different geographical and physical scales, often is only appropriate correlations of ranks. It means that linearity and regression can not be always “key tool” for establishing connections between reservoir geological variables.
The mapping is crucial process in reservoir characterisation, what means that each selected geological variable would need to be mapped. For variable with enough point data, deterministical geostatistical approach is recommended (kriging). If correlation is observed between two variables deterministical approach, numerically “dependant”, is advised (cokriging).

However there are some variables, which in reality do not have enough large sampled dataset to be characterised with “representative” statistics (variance, average, variogram...), i.e. statistics valid for population of variable. Those are usually variable that representate petrophysical or depositional properties of reservoir (like porosity or thickness). In such case, geostatistical stochastic mapping (sequential Gaussian simulation, sequential indicator simulation) is welcome improved of deterministical geological model.

References