Stochastical approach in deterministic calculation of geological risk - theory and example

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PRESENTATION FROM SCIENTIFIC AND EXPERT GATHERINGS

Calculation of geological risk (or Probability Of Success; abbr. *POS*) of hydrocarbon discovery in existing or new play or prospect in the Drava depression has been done using well-known deterministical procedure. Such approach, with slightly modifications, can be used in almost all reservoir lithologies in any hydrocarbon basin or depression. This calculation, although already an old-fashion tool, represent reliable tool and it is why it is still applicable in many oil and gas companies or consulting firms.

Analysis is performed in the youngest part of reservoir (which encompasses four lithofacies) in the Stari Gradac-Barcs Nyugat field. It is represented by coarse-grained sediments of Badenian age. This field is selected regarding there are already done some estimations of existence of additional hydrocarbon reserves in the žsubtle' traps, but also numerous geostatistical analysis with porosity data taken from all reservoir's lithofacies. Of course, the youngest and the shallowest lithofacies included the most such measurements, and also it is (together with the next, deeper lithofacies) reservoir's part with the largest hydrocarbon reserves.

Deterministical approach in *POS* calculation had been improved in deterministical-stochastical, by using geostatistical porosity maps, where this variable is expressed through three possible realizations (minimal, median and maximal) for analysed Badenian lithofacies.

Total *POS* remained the equal as such value calculated only deterministically (*POS*=0.375). It is because average porosity in analysed Badenian clastics varying in narrow interval, and its selection from stochastical results did not have influence on estimation of probability of new hydrocarbon reserves existence. But, in deeper lithofacies, where lithology is more heterogeneous and/or more cataclised, variations in porosity are significantly higher. In such case, introducing of deterministical-stochastical approach could result in changes in *POS* values, depending on which stochastical realization had been selected as representative.

Key words: geological risk, determinism, stochastic, porosity, Pannonian basin

1. Introduction

Calculation of geological risk is well-established tools for estimation of possible reservoir in new or existing plays, prospects or reservoirs. This procedure is well described in many papers; in the areas of the Drava depression such tool and evaluation of play and prospects is published in papers referenced as.[1, 2, 3, 4, 9] In paper[1] also some areas in the Sava depression are evaluated. It is useful to define area where such calculation is performed. In such case, 'play' is generally defined as an operational unit and 'prospect' as an economic unit. Each play can be characterized by several prospects and/or fields having similar geological features and history.[5,7] In this paper the term 'play' is used as a substitute for stratigraphic interval(s) within which the economic volumes of hydrocarbon reserves are discovered.

Mathematically, it is simple deterministical multiplication of several geological categories and final result is *estimation* of hydrocarbon existence. Such estimation can be more or less subjective, depending if the each single category value is evaluated from engaged professional or taken from official probability tables.

On the other hand, many geostatistical estimations are more and more performed stochastically (instead of deterministically), especially estimations of reservoir petrophysical variables. It is because natural phenomena (or geological processes) are situated between deterministical and chaotical models, i.e. in the 'realm' of stochastic.

Porosity is always one of variables that are estimated as part of category 'Reservoir' (Table 1), in the calculation of geological risk. It is why can be observed as one of two subcategories in mentioned category. Just this variable can be (favourable) estimated stochastically, through a set of realizations (minimum, median, maximum etc.) and consequently statistics of this variable can be obtained from hard and simulated data together. It is why here is considered how stochastical estimation of porosity can be incorporated in deterministical geological risk calculation. Finally, it resulted in hybrid-type of geological risk calculation what is described in the following chapters.

2. Short theory of geological risk, deterministical equaion and stochastical realizations

Calculation of geological risk is well-established tools for estimation of possible reservoir in new or existing plays,

Table 1. This is an example of relevant database prepared for the Bjelovar subdepression and can be mostly unchanged applied in all the Drava depression (after [2, 3])

TRAP	RESERVOIR	SOURCE ROCKS	MIGRATION	PRESERVATION OF HYDROCARBONS	
Structural	**Reservoir type**	**Source facies**	**HC shows**	**Reservoir pressure**	**'p'**
Anticline and buried hill linked to basement	Sandstone, clean and laterally extended; Basement granite, gneiss, gabbro; Dolomites with secondary porosity; Algae reefs with significant secondary porosity, due karsting or other subaerial processes exposure	Kerogene type I and/or II	Production of hydrocarbons	Higher than hydrostatic	1.00
Faulted anticline	Sandstones, rich in silt and clay; Basement with secondary porosity, limited extending; Algae reefs, filled with skeletal debris, mud and marine cements	Kerogene type III	Hydrocarbons in traces; New gas detected >10%	Approximately hydrostatic	0.75
Structural nose closed by fault	Sandstone including significant portion of silt/clay particles, limited extending;	Favourable palaeo-facies organic matter sedimentation	Oil determined in cores (luminescent analysis, core tests)	Lower than hydrostatic	0.50
Any "positive" faulted structure, margins are not firmly defined	Basement rocks, including low secondary porosity and limited extending	Regionally known source rock facies, but not proven at observed locality	Oil determined in traces (lumin. anal., core tests)		0.25
Undefined structural framework	Undefined reservoir type	Undefined source rock type	Hydrocarbon are not observed		0.05
Stratigraphic or combined	**Porosity features**	**Maturity**	**Position of trap**	**Formation water**	
Algae reef form	Primary porosity >15% Secondary porosity >5%	Sediments are in catagenesis phase ("oil" or "wet" gas-	Trap is located in proven migration distance	Still aquifer of field-waters	1.00
Sandstones, pinched out	Primary porosity 5-15% Secondary porosity 1-5%	Sediments are in metagenesis phase	Trap is located between two source rocks depocentres	Active aquifer of field-waters	0.75
Sediments changed by diagenesis	Primary porosity <10 Permeability <1x10**(-3) micrometer**2	Sediments are in early catagenesis phase	Short migation pathway (<=10 km)	Infiltrated aquifer from adjacent formations	0.50
Abrupt changes of petrophysical properties (caly, different facies)	Secondary porosity <1%	Sediments are in late diagenesis phase	Long migration pathway (>10 km)	Infiltrated aquifer from surface	0.25
Undefined stratigraphic framework	Undefined porosity values	Undefined maturity level	Undefined source rocks		0.05
Quality of cap rock		**Data sources**	**Timing**		
Regional proven cap rock (seals, isolator)		Geochemical analysis on cores and fluids	Trap is older than matured source rocks		1.00
Rocks without reservoir properties		Analogy with close located geochemical analyses	Trap is younger than matured source rocks		0.75
Rocks permeable for gas (gas leakage)		Thermal modeling and calculation (e.g. Lopatin, Waples etc.)	Relation between trap and source rocks is unknown		0.50
Permeable rocks with locally higher silt/clay content		Thermal modeling at just a few locations			0.25
Undefined cap rock		Undefined data sources			0.05

LEGEND:

- Category (orange)
- Sub-Category (blue)
- Geological event (two colors are used only becasue of visibility) (yellow / white)
- Probability for particular geological event (light grey)

prospects or fields. This procedure is more or less subjective, because each single category could be evaluated:

(a) from engaged professional (geologist),

(b) taken from official probability tables or

(c) using benchmark test, respecting new well data.

Generally, the hydrocarbon plays or prospects are deterministically analysed by several independent geological categories, like: (1) structures, (2) reservoirs, (3) migration, (4) source rocks and (5) preservation of hydrocarbons (e.g. references [2, 3, 7]). The most categories can be evaluated using well-files, well logs, seismic, cores, stratigraphic interpretations, information from typical geological sections and other relevant laboratory analyses. Many of these data can be simple determined using internal or published tables of geological probabilities for different basins and depressions. Such database for Croatian part of Pannonian basin is published in references[2, 3] and shown on Table 1.

It needs to be noted that presented table is valid for typical lithological sequences for Pannonian basin. In the broad sense it can be applied in three different types of reservoir stratigraphy; starting from the oldest these are: (1) Palaeozoic interval (mostly represented by gabbro and metamorphics), (2) Middle Miocene (mostly breccia and conglomerates of Badenian age) and (3) Upper Miocene (reservoirs are represented by sandstones).

Such defined values from Table 1 make possible to calculate geological risk or Probability Of Success (*POS*) for any consider play of prospect by using Equation 1:

$$POS = p\text{ (structures)} \times p\text{ (reservoir)} \times p\text{ (migration)} \times p\text{ (source rocks)} \times p\text{ (preservation)} \quad (1)$$

where are:

POS — *final value of geological risk (or probability of discovery),*

p (structures) — *probability of existence of structure in reservoir, and estimated from relevant column in Table 1 (i.e. from the values available for this category in table),*

p (reservoir; migration; source rocks; preservation) - same procedure as for p (structure).

The *POS* and 'p' are deterministical calculation of probability values in range 0-1. Let us now to consider the subcategory *porosities* under category *reservoir* (Table 1). Porosity is the most often analysed through porosity maps and finally to expressed as mean value belonging to the map. Such porosity map can be interpolated deterministically using methods like kriging, cokriging, inverse distance weighting etc. or stochastically (using simulation like sequential Gaussian simulation or others). The other way, i.e. conditional simulation, gives the set of realizations that are different, but all are equiprobable. It means that all such maps are possible and variations in inter-well areas are result of uncertainties allowed by interpolation algorithm, also honour input data (so called hard data). If such approach is introduced in deterministical calculation of *POS* (Equation 1) it implies that porosity probability [p(porosity)] could be selected from Table 1 several times, and each selection can result in another probability values.

Applied stochastic tool is defined as SGS (Sequential Gaussian Simulation) methods that are kriging based (kriging map is zero realization) and where unsampled locations are sequentially estimated in random order until all unsampled cell are not estimated. SGS were used because the reservoir space can be considered as a space of apparent randomness, especially in the case of petrophysical parameters. Regarding randomness in reservoir space, it would be more precise to state that "*...at any scale there is a single true distribution of reservoir properties in a reservoir, although some of the depositional and diagenetic processes forming of reser-*

Fig. 1. The location of Stari Gradac-Barcs Nyugat field
Sl. 1. Smještaj polja Stari Gradac-Barcs Nyugat

voir properties are not well understood because the lack of knowledge about the initial and boundary conditions. That is why we applied many stochastic approaches in estimating deterministic attributes." (personal communication and valuable opinion of Prof. Dr. János Geiger, 2009). Simulation made possible to scope a whole set of uncertainties, while interpolation method (even kriging) give us a smoothed picture of reservoir properties which is appropriate for visualizing trends but not always for describing reservoir heterogeneities.

3. Case study – stochastical porosity variations in clastics lithofacies of Badenian age from reservoir of the Stari Gradac-Barcs Nyugat field

Let consider as example very interesting heterogeneous reservoir of the Stari Gradac-Barcs Nyugat field. This gas- condensate field is located on the Croatian-Hungarian border (Figure 1), along the Drava river, approximately 150 km east from Zagreb.

3.1. Short geological settings of the analysed field

The field is situated in the northwestern part of the Drava depression. This depression is southern branch of the Pannonian basin system. The reservoir is of massive type, trapped with combined structural-stratigraphic closure. Lithology of the reservoir is very complex, divided in four lithofacies (but all connected in single hydrodynamic unit):

(a) Clastites of Badenian and (possibly) Upper Triassic age;

(b) Dolomites of Lower Triassic age;

(c) Quartzites of Lower Triassic age;

(d) Metavolcanites of Permian, Devonian and (possibly) Carboniferous age

The variation in calculation of geological risk, improved with stochastical analysis of porosities, had been applied for the youngest lithofacies of coarse-grained clastics of Badenian age. This part of reservoir is located in the youngest (Neogene age) part (Figure 2) of buried hill, which is mostly formed in the rocks of Mesozoic and Palaeozoic ages.

The porosity, in Badenian clastites, as the variable analysed stochastically had been firstly interpolated deterministically using improvement of the Ordinary Kriging instead of the Inverse Distance Weighting method. These two methods are also compared by cross-validation and kriging showed the significant lower error (kriging=3.914 vs. inverse distance=5.279).

3.2. Geostatistical mapping of porosity

The kriging interpolation was based on anisotropic variogram model with principal axis striking 120-300° and subordinate axis on 30 - 210° direction. These are also structural axes of the field. The principal range is 3 500 meters and subordinate 1 200 meters (ref. [6]). It is important that input dataset comprised only 15 hard-data, and modelling of subordinate axis was mostly done from experience from other fields. Kriging map was base (or zero-realization) for stochastical modelling. But, limited input dataset strongly forced using of stochastical approach, which can better modelled and show uncertainties.

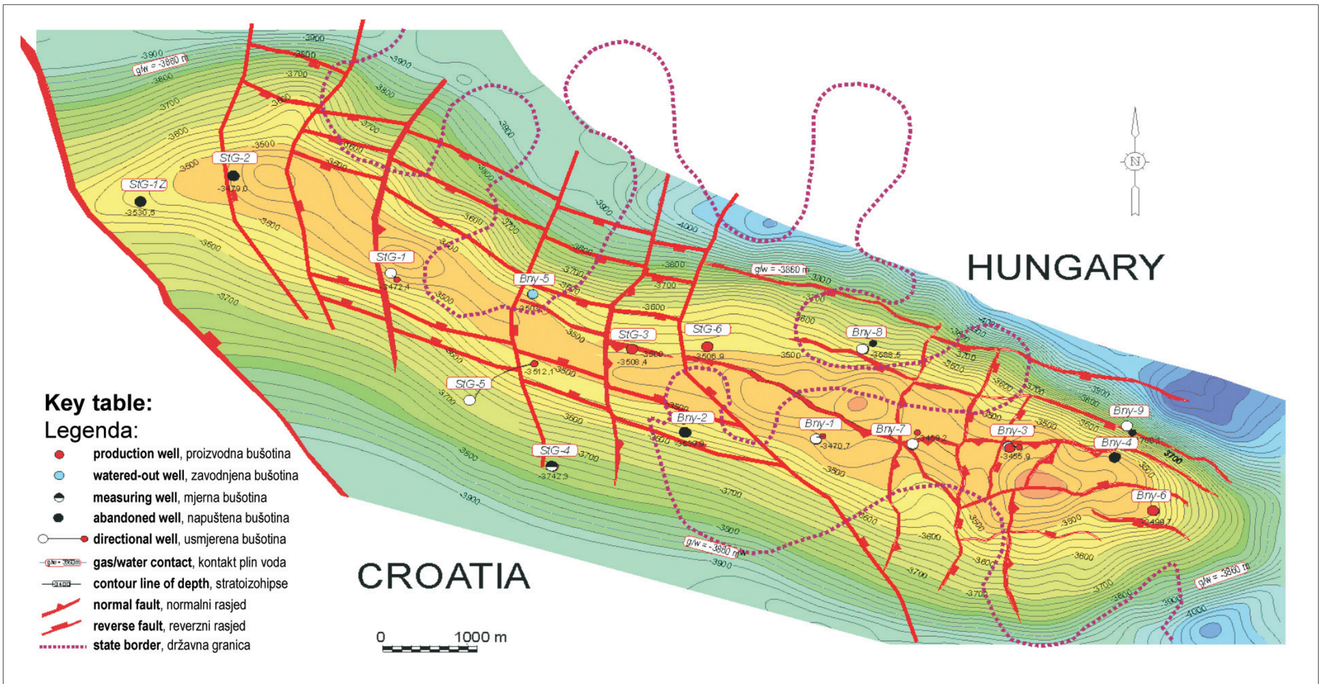

Fig. 2. Structure map of top of lithofacies Clastites (after reference [8])
Sl. 2. Strukturna karta po krovini litofacijesa badenskih klastita (iz rada [8])

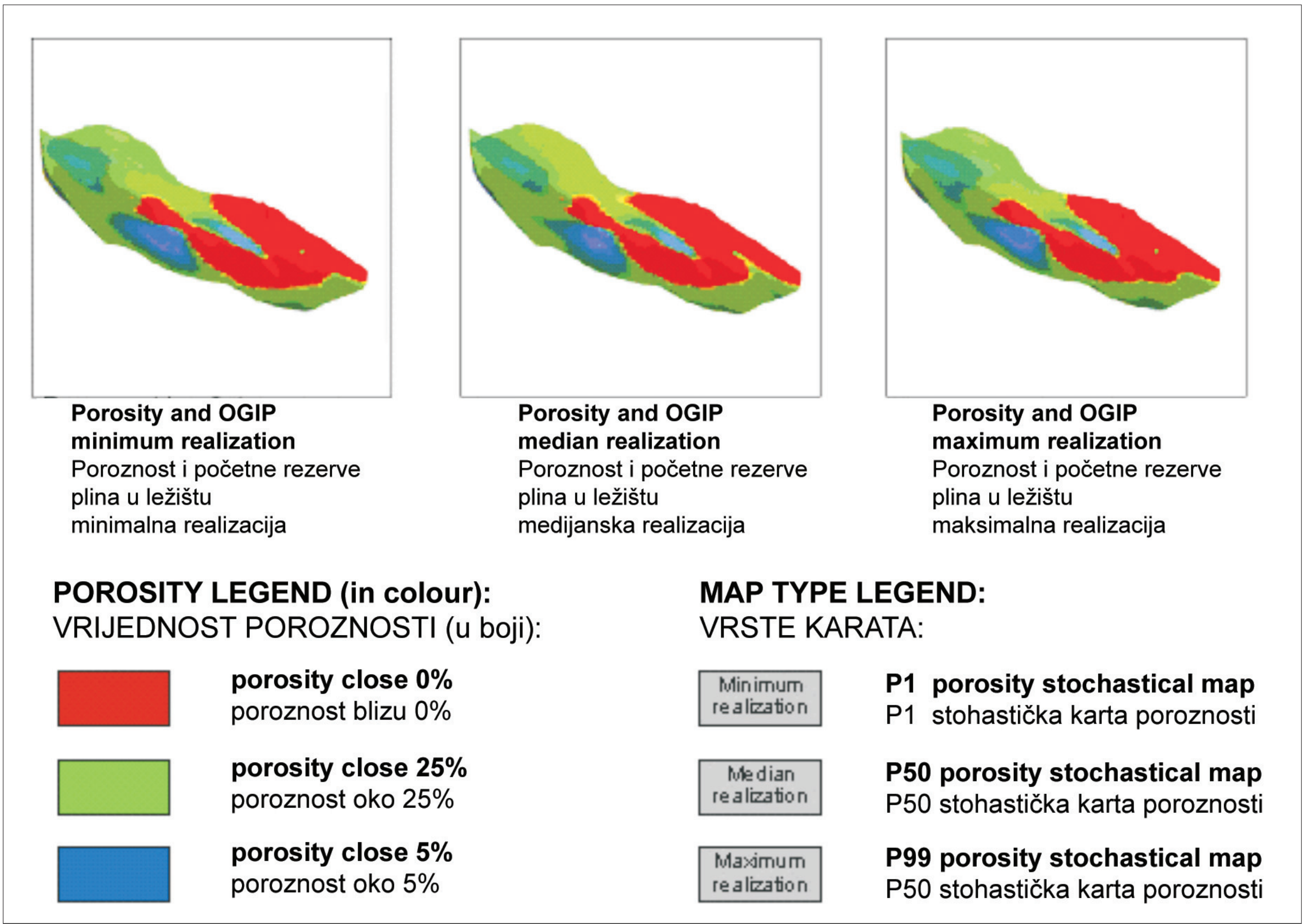

Fig. 3. Minimum, median and maximal reservoir volumes (all equiprobable) for clastics lithofacies. Please, observe difference in red and blue areas borders. Porosity scale is in colour, the red is 0%, and the blue is about 5%.

Sl. 3. Minimalan, medijanski i maksimalan volumen ležišta (svi jednako vjerojatni) za klastični badenski litofacijes. Molim pažnju obratiti na razlike u granicama crvenih i plavih zona. Skala poroznosti je u boji, gdje crveno označava 0 %, a plavo oko 5 %.

Number of 100 simulations was performed for each lithofacies. Interesting realizations were chosen from OGIP (Original Gas In Place) histograms marking minimum, median (P50 quantile) and maximum volumes. We assumed that it is the simplest and fair ranking criteria. It could be interesting to look at results that are presented through complex stochastical map (multiplication of *variable* porosity and *several constants* named as gross pay, net/gross and hydrocarbon saturation maps; Figure 3).

3.3. Deterministical calculation of POS

All categories are evaluated deterministically (after Table 1 and Equation 1). The Badenian reservoir is characterized with following values:

(1) Structures:

Trap is faulted anticline (p=0.75);

Quality of cap rock is regionally proven (p=1.00);

(2) Reservoir:

Coarse-grained sandstones (p=1.00);

Primary porosity<5% (p=0.50);

(3) Source rocks:

Kerogen type II (p=1.00);

(4) Migration:

Proven production (p=1.00);

Position of trap (p=1.00);

Trap is older than mature source rocks (p=1.00);

(5) HC preservation:

Higher than hydrostatic (p=1.00);

Still aquifer (p=1.00).

Total Probability of Success (*POS*) is multiplication of probability of porosity (0.5) and all other categories (0.75), i.e. *POS*=0.375.

3.4. Deterministical-stochastical calculation of POS

Average porosity values for selected realizations had been 3.1%, 3.2% and 3.53% respectively. This value could be considered as three possible inputs for subcategory porosity, and calculation of three possible *POS* values. Let us again consider the values from Table 1.

The Stari Gradac-Barcs Nyugat field is proven gas- condensate field, with proven reservoirs, production and known location of source rocks as well as migration pathways. It means that all categories can be evaluated as follows:

(1) Structures:

Trap is faulted anticline (p=0.75);

Quality of cap rock is regionally proven (p=1.00);

(2) Reservoir:

Coarse-grained sandstones (p=1.00);

Primary porosity three values 3.1; 3.2; 3.53<5% (p=0.50); (this subcategory had been stochastically estimated by minimal, median and maximal values, i.e. P1, P50 and P99 realizations)

(3) Source rocks:

Kerogen type II (p=1.00);

(4) Migration:

Proven production (p=1.00);

Position of trap (p=1.00);

Trap is older than mature source rocks (p=1.00);

(5) HC preservation:

Higher than hydrostatic (p=1.00);

Still aquifer (p=1.00).

The total *POS*=0.5 x 0.75 = 0.375. Of course, the field area is consider as the mature petroleum zone and obtained *POS* can be used as descriptive value for chance to find additional by-passed or satellite gas or condensate volumes inside field polygon or very adjacent areas structurally connected by the field structure.

It is easy to observe that in both cases, i.e. in deterministical and deterministical-stochastical calculation, are obtained equal values of 0.375. It indicates on several statements:

(a) Methodology had been correctly applied, and results has not been changed although stochastics is introduced;

(b) Significant difference between deterministical and deterministical-stochastical results would probably appeared due to weak estimation of average porosity;

(c) Furthermore, it is obvious that interval where porosity varying in analysed lithofacies can fluctuate around the mean, respecting statistical rules (i.e. standard deviation), in relative narrow borders. It indicates on relatively homogeneous distribution of this variable in analysed reservoir;

(d) This methodology is successfully tested and it can be expected that, in lithologies where porosity ranges are wider, it probably would result in different *POS* value if it is calculated by deterministical-stochastical approach.

4. Conclusion

Reservoir space is always characterised with uncertainties, and permanent problem is how to express them. It could be done using several deterministical values, based on experience collected in observed basin or depression with hydrocarbon reservoirs, but sometimes also applying stochastics in such regions.

In both case reservoir parameters in geological risk calculation are parameters that could be varied numerically using appropriate mathematical tools. Majority of geological categories are strictly based on laboratory or well test result and can be shown only by single deterministical value.

But two categories can be stochastically analysed in each field. These are

(a) '*Reservoir*' regarding porosity and

(b) '*Preservation*' through reservoir depth.

It described case analytically is confirmed that in category 'Reservoir':

1. Porosity has values in the range 3.1 (minimum), 3.2 (mean) and 3.53% (maximum);
2. It was not change in *POS* value in any approach (deterministical or deterministical-stochastical), because all porosity values belong to the same geological event in subcategory 'Porosity features', shown in 2nd column on Table 1 (i.e. case that primary porosity is less than 10%, and permeability less than 10^{-3} μm^2);
3. However, it indicate that the youngest part of reservoir (Badenian clastites) is mostly characterised by homogeneous porosity distribution, i.e. average values calculated from measured and simulated values is located in relatively in narrow interval;
4. In such case applying of deterministical-stochastical approach in *POS* calculation did not yield any changes in result, but its using proved correctness of the methodology, which than can be applied in older lithofacies (rocks) in analysed field or other fields with similar lithologies, where can be expected higher variations in porosity values (whether primary or secondary);
5. Presented methodology can be applied in all types of hydrocarbon reservoirs in the Drava depression, especially in clastics facies (sandstones, breccia and conglomerates).

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