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Preliminary communication

Deep mapping of hydrocarbon reservoirs in the case of a small number of data on the example of the Lower Pontian reservoirs of the western part of Sava Depression

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Abstract

Production of hydrocarbons from Lower Pontian reservoirs of Sava Depression is in "mature" stage, which involves the application of secondary methods (formation water injection). Due to the small number of injection wells, mapping methods have been applied in this paper are: the nearest neighbourhood and the inverse distance. Both methods have been applied on Lower Pontian reservoirs of oil-gas field "A" (Western part of Sava depression), which is in the secondary phase of hydrocarbon production. The mapped parameter is the amount of injected brine water and its spatial distribution in reservoir "L".

Keywords: Inverse Distance Weighting, Nearest neighbourhood method, Sava Depression, Croatia

1. Introduction

The production of hydrocarbons from the Lower Pontian reservoir of Sava Depression is in "mature" stage. Oil and gas fields in Sava Depression are in the secondary or tertiary stage of production. The most effective secondary method of recovery is injection of formation water for reservoir pressure support. Injection systems consist of a small number of injection wells, and thus a smaller set of data for the mapping. Previously applied deterministic methods for mapping of Lower Pontian (Kloštar-Ivanić formation) reservoirs were (e.g., **Balić et al., 2008; Husanović & Malvić 2014**): inverse distance weighting, moving average, nearest neighbourhood, kriging and cokriging (with cross-validation of models). The methods used for a large number (more than 20) (e.g., **Balić et al., 2008; Husanović & Malvić 2014**) of input data were: kriging and cokriging (with cross-validation of models). For the application of the above mentioned methods, requires a reliable variogram model, which in the case of small input data set, is not applicable. The most suitable methods of mapping for small input data number (less than 15) are: nearest neighborhood and inverse distances (e.g., **Husanović & Malvić 2014**). The paper describes the geological characteristics of the study area, the mapping methods and the application on the injection wells of oil-gas field "A".

2. Geological characteristics of study area

The oil-gas field „A" is located in the western part of Sava Depression, in Croatian part of the Panonian Basin System. The typical geological column of field „A", including, Kloštar Ivanić formation, is shown in **Figure 2.1.**

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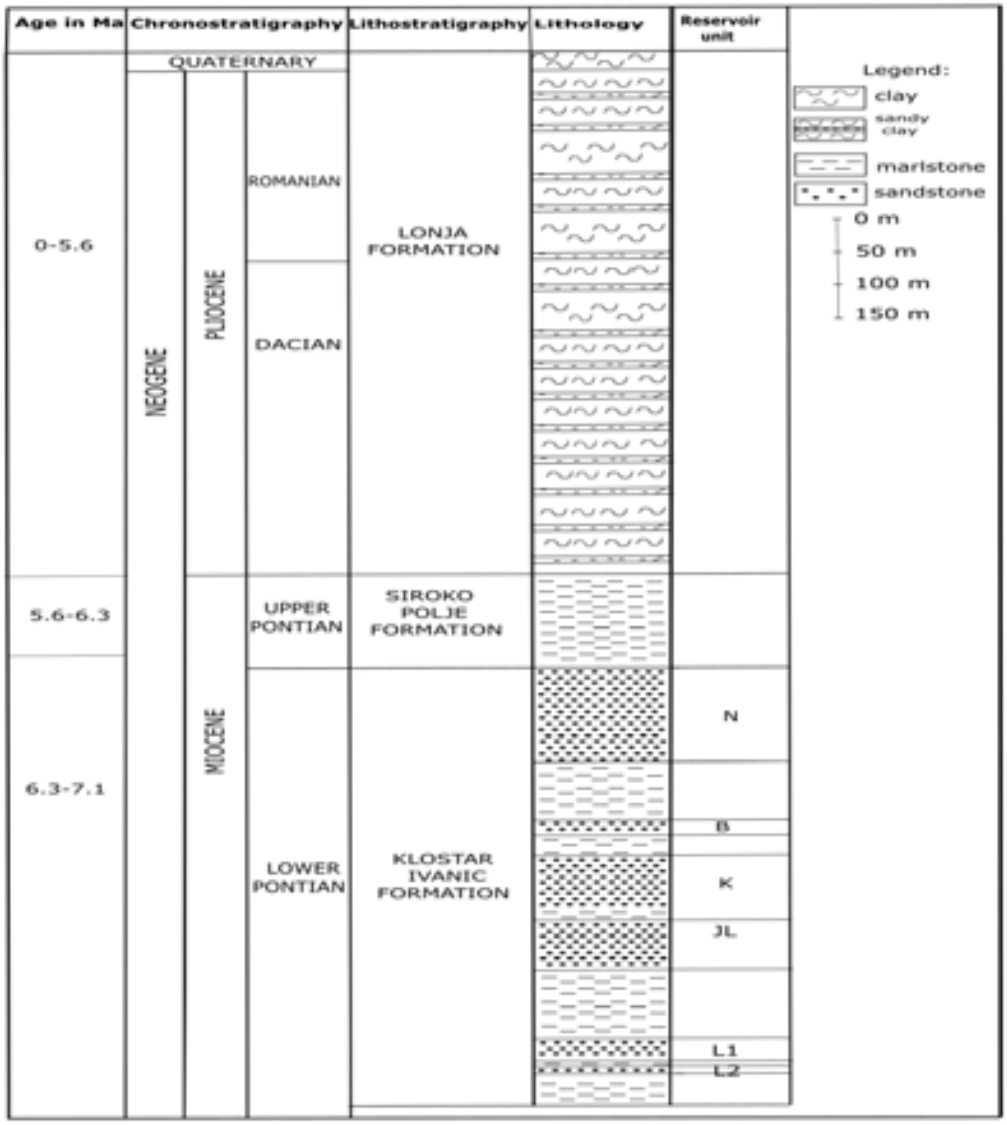

Figure 2.1: Geological column of field "A"

The lithological property of the Lower Pontian reservoirs of formation Kloštar Ivanić is a good sort of medium-clastic particles. In the lower part of the reservoir there are mostly hard sandstones, which, according to the roof part of the formation, and especially in the Široko Polje (Upper Pontian) formation, become weakly bonded and even milled, unbound sands. The target of this study is the "L" reservoir, which is shown on thickness map **(Figure 2.2**).

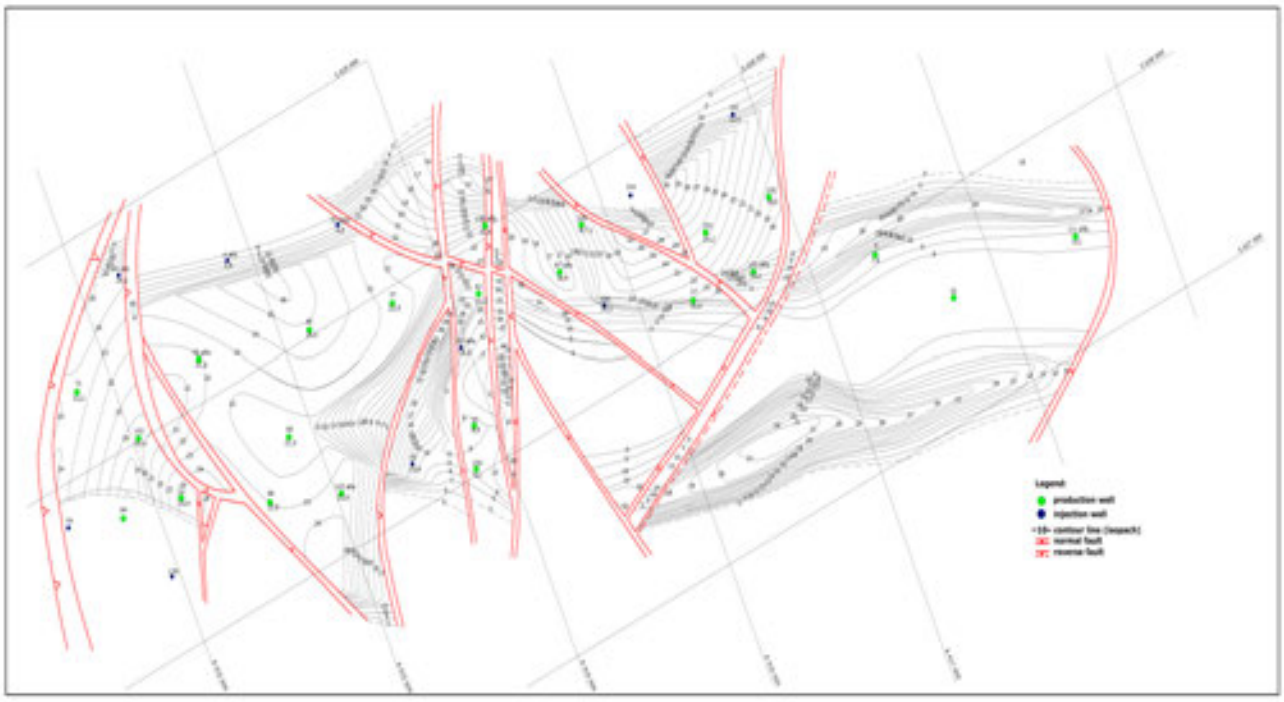

Figure 2.2: Thickness map for reservoir "L" (**from ***)

For the "L" reservoir, the average mean porosity for gas is 18.5%, for oil 20.0%, while the average permeability is 20.6 • 10^{-3} μm^2 (**from ***). From the "L" reservoir hydrocarbons are produced form 22 wells, and due to the large share of reserves in the "A" field, formation water injection is used since 1993 with 10 injection wells in order to increase oil recovery. Injection wells of field "A" will be analysed in the following chapters.

3. Interpolation methods for a small data set

The simplest interpolation methods for processing a small set of data are: nearest neighbourhood and inverse distance weighting (e.g., **Malvić, 2008; Mesić Kiš & Malvić 2014; Mesić Kiš 2017**). These methods contain simple mathematical models and are therefore suitable for processing a small set of data, such as the number of injection wells in field „A".

3.1. Nearest neighbourhood method

The nearest neighbourhood method is the simplest interpolation method that fills the value of a network, taking into account the value of the nearest adjacent data, and the result of the method is zonal distribution of values (e.g., **Husanović & Malvić 2014; Kitikidou et al., 2014**).

Space distance is calculated according to the expression for Euclid's distance (**Equation 3.1**):

$$d\ (x,T) = \sqrt{(x_1 - T_1)^2 + \cdots + (x_n - T_n)^2} \qquad \text{Eq. 3.1.}$$

Where are:
d - distance,
n - number,
x and T - points in space.

It is usable when there is a small number of data, i.e. when there are relatively large areas where there is no data, and they need to be schematic mapped (e.g., **Husanović & Malvić, 2014**).

3.2. Inverse Distance Weighting

The inverse distance method is simple interpolation methods, where the value of the variable is estimated by the value closest to the measured value. The number of points involved in the assessment is determined by the radius of the circle around the data. The particular data is inversely dependent on the distance of the input data and the location at which the value will be estimated. **Equation 3.2.** to estimate the inverse distance method (e.g., **Balić et al., 2008; Medved et al., 2010; Ly et al., 2011**) is:

$$z_{IU} = \frac{\frac{z_1}{d_1^p} + \frac{z_2}{d_2^p} + \cdots \frac{z_n}{d_n^p}}{\frac{1}{d_1^p} + \frac{1}{d_2^p} + \cdots \frac{1}{d_n^p}} \qquad \text{Eq. 3.2}$$

Where are:

z_{IU} - estimated value,
$d_1 \ldots d_n$ - distances of locations 1…n to the estimated location z_{IU},
p - distance exponent,
$z_1 \ldots z_n$ - real values at locations 1…n.

The result of the interpolation depends on the exponent of distance that is usually chosen with values between 1 and 3, and the most commonly used amount of 2, which has been empirically proven to be the most appropriate value for acceptable depth geo-mapping. The method is applicable if the input variables are not highly grouped and the data number is less than 15, because then mathematical more demanding methods are unable to develop a quality view (e.g., **Husanović & Malvić, 2014**).

4. Application of interpolation methods on field „A“

The methods were applied to mapping injection quantities are: the nearest neighbourhood and inverse distance, and maps are made in the program SURFER 15. Data on injected quantities were collected for the period from 1985 to 2015, and for this period were made maps of injected water quantities. Maps of injected amount of water in the Lower Pontian sandstone reservoir "L" in the period of twenty years is shown on **figure 4.1.**

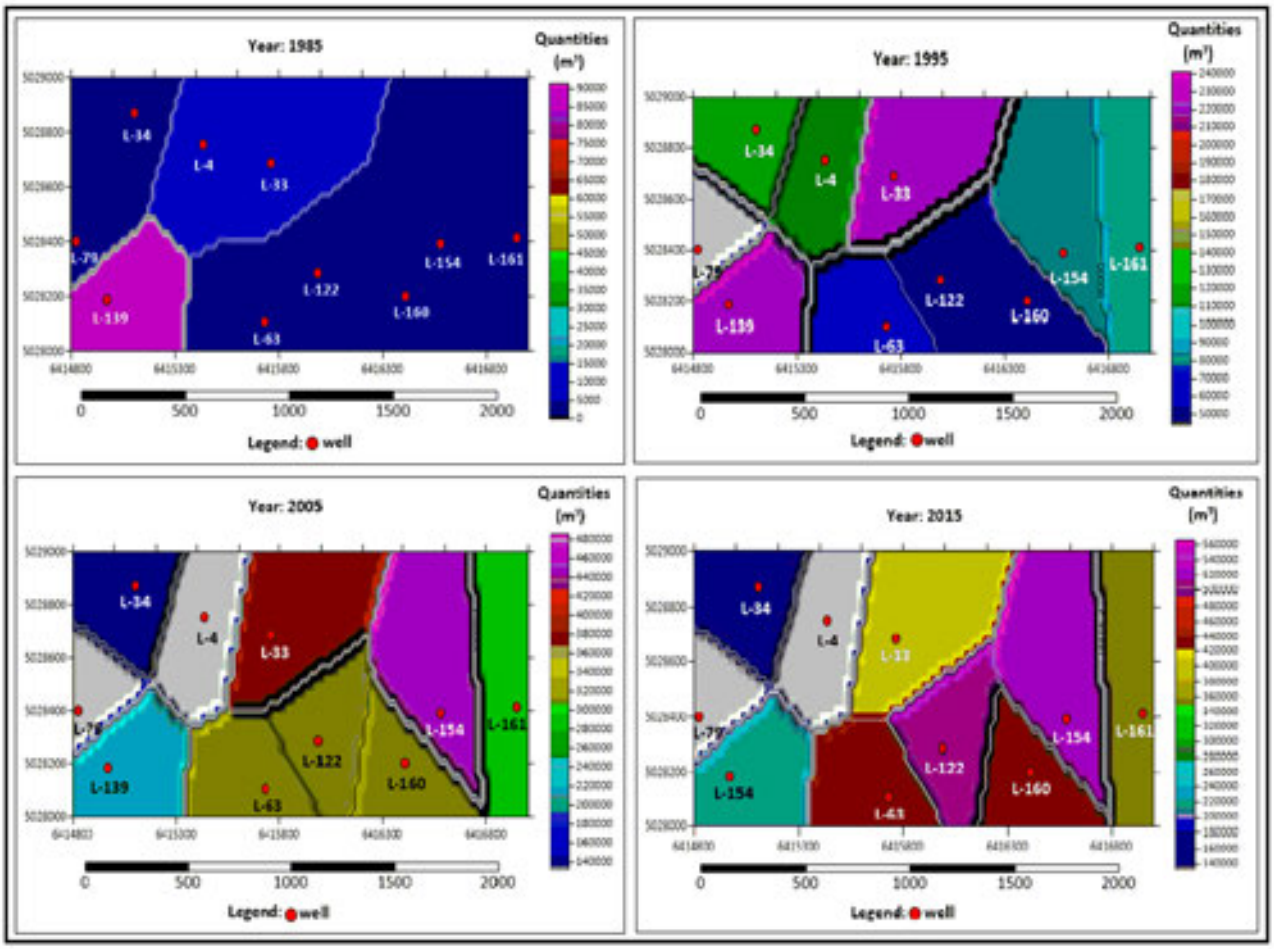

Figure 4.1: The map of injection water quantities obtained by the nearest neighbouring method

The map obtained by the nearest neighbouring method has defined the polygons (zones) from the input data of the reservoir, which is the characteristic of this method. During the injection of formation water, it can be noticed that the amount of injected water in some wells increased significantly, but the polygon appearance did not change from the original polygons, but the colors changed according to the amount injected. It can also be applied to the generated maps, there is no overlapping of individual zones (polygons), which makes this method applicable to this kind of mapping. The advantages of this method of mapping are getting rough image spread of water fronts in the mapped area, and polygons reflect the maximum range of individual water injection well. Such range can be prevented by impermeable fault, or change of lithological properties of the reservoir or block which is seen by the nonlinear polygon boundaries. The disadvantages of this method is the lack of a transition zone between the individual polygons. **Figure 4.2.** are shown maps injected amount of formation water in the Lower Pontian sandstone reservoir "L" in the period of twenty years, obtained by the method of inverse distance.

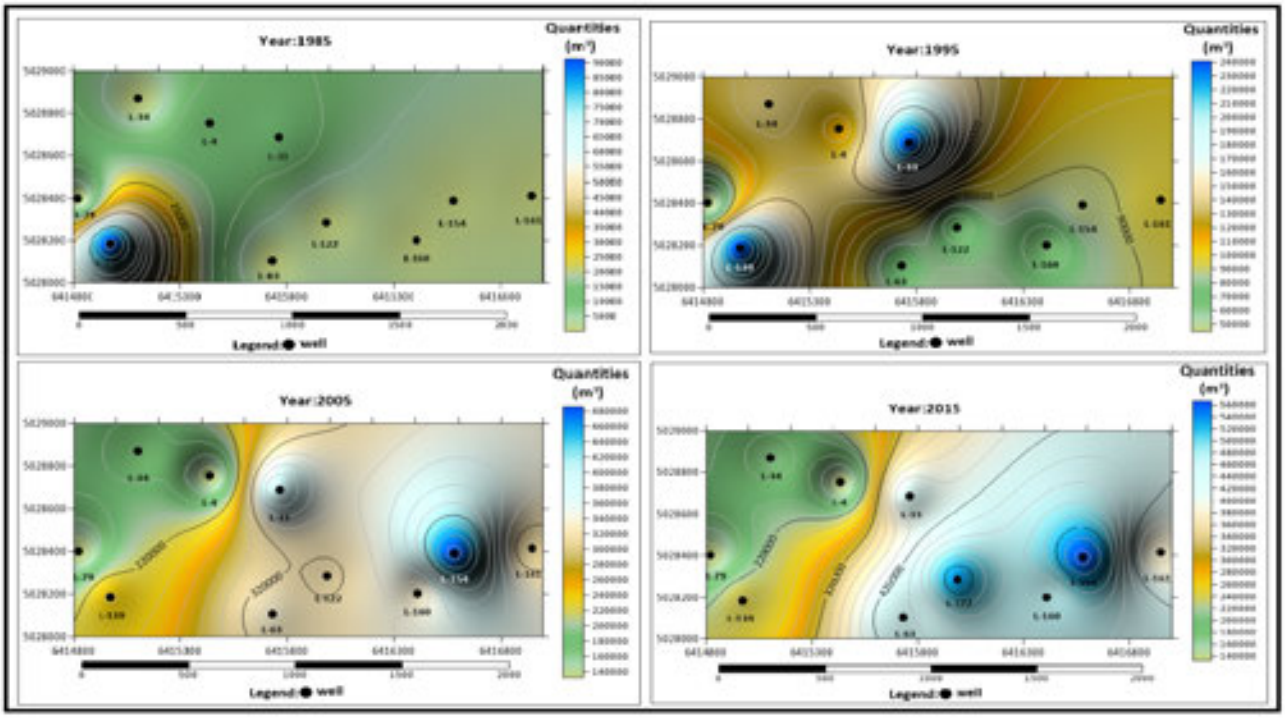

Figure 4.2: The map of injection water quantities obtained by the inverse distance weighting method

The maps obtained by the inverse distance method showed a clear spread of the waterfront across the mapped space, changing the colors depending on the amount injected. During a longer time injection of water, it can be noticed that the injected quantities of the eastern part of the mapped area are smaller, while in the west part larger, so it can be concluded that the lithological properties grow from the east to the west of the map area, or the persistence of a number of faults that are impermeable or poorly permeable ("sharper" transition zone). The advantage of this method is mapping of the quantitative transient zone between the injection wells. Transitional zones can be interpreted as a change of lithological properties within the map area, or in the case of a small or almost no transition zone to the possibility existence of impermeable faults. The disadvantage of this method is in of a large transition zone is the loss of the visual spatial reach of the waterfront for a single injection well.

5. Discussion and conclusion

In the case of a small number of data application methods nearest neighbours and inverse distance in example of the oil and gas field “A” are applicable and complement each other. The advantage of the nearest neighbouring method is to obtain a rough polygonal (zone) area, and can be taken as the extent of water expansion within a mapped area for a single injection well. The disadvantages of the nearest neighboring method are the lack of a transition zone between individual wells, and when there are several inside the same reservoir.

Then the advantages of the inverse distance method were observed, where maps were obtained with transient quantity zones between the individual injection wells. It can be seen clearly spreading water front through the mapped area and the ability to detect changes in these quantities, depend on the lithological composition of deposits and position the fault zones. In the case of multiple faults in the reservoir, more hydrodynamic units will be formed, which will significantly affect the ultimate appearance of the map obtained. For mapping injected amount of brine water, permeability or impermeability faults within the reservoir is the most important factor because it determines the spread of possible water fronts within the reservoir. This can be seen through a larger transition zone between different values of the injected amount on the map. The disadvantages of inverse distance methods is the loss of a "clear line" of the intersection range in the individual wells at larger transition zones between the wells, although it is arbitrarily set at polygonal methods.

When analysing the waterflooding of reservoirs, with the analysis of structural geological maps, effective thickness maps, hydrodynamic measurement data and well logging measurements, the application of geomathematical tools in the analysis of the reservoir is definitely of help to better understanding the reservoir, and thus achieving a greater final oil and gas recovery.

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Abstract in Croatian

Dubinsko kartiranje ležišta ugljikovodika u slučaju malog broja podataka na primjeru donjopontskih ležišta zapadnog dijela Savske depresije

Pridobivanje ugljikovodika iz donjopontskih ležišta Savske depresije je "zreloj" fazi, što podrazumijeva primjenu sekundarnih metoda (utiskivanje slojne vode). Zbog malog broja utisnih bušotina, u radu su primijenjene metode kartiranja: najbližeg susjedstva i inverzne udaljenosti. Oboje metode su primjene na naftno-plinskom polju A koje se nalazi u sekundarnoj fazi pridobivanja ugljikovodika. Parametar za kartiranje je količina utisnute slojne vode i dobivanje prostorne raspodjele u ležištu „L".

Ključne riječi: metoda najbližeg susjedstva, metoda inverzne udaljenosti, Savska Depresija, Hrvatska

Author contribution

Josip Ivšinović done all paper.