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Manual interpolation of different subsurface structures and application of numerical integration methods in volume calculations

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Abstract

The two analysed hydrocarbon reservoirs in this paper were targets for creating the structural maps, which includestructural maps of the reservoir layers, isochore and isopach maps (from the hydrocarbon - water contact to both the reservoir's top and bottom). Each of the maps includes the base elements such as the title, corresponding scale, equidistance, legend, and an arrow pointing north. In addition to calculating the final reservoir volume, geological sections were made along the maps. Detailed analyses have shown which of the parameters affect the differences shown on the maps and how, while simultaneously pointing towards their similarities. The surface area was defined using linear interpolation with partial extrapolation, which in turn was used to calculate the total volume of the reservoir structure. These methods are based on numerical integration, two of which were used in this paper, namely the Simpson's and Trapezoidal rules. The analysed structures are described as irregular brachianticlines, which had to be identified both in the maps and in calculations to get the desired results.

Keywords: interpolation; volume; reservoir; brachianticline; Simpson's rule, Trapezoidal rule.

1. Introduction

A reservoir is a geomorphological structure saturated with oil, gas or geothermal water, which can be characterized by numerous conditions of genesis, the most significant of which are depth, temperature, pressure and surrounding layers whose primary purpose is to create traps preventing fluid migration. Furthermore, in the case of strctural traps the shapes of reservoirs can considerably vary, from the simplest domes to more irregular anticlines and ultimately brachianticlines. The goal of the paper is to create, analyse and compare two similar but not identical brachiantiklines using the structural maps of reservoirs's top and bottom, isochore and isopach maps, along with a geological sections. Volume calculations are made based on the aforementioned isopach maps. The maps were manually interpolated, for example like interpolation made on similar structures in Šapina (**2016**). One of the key characteristics of a reservoir structure is its volume, which requires extensive and detailed calculations. Since geological structures are generally not simple geometric shapes whose parameters can be interpreted with basic, primitive functions, to calculate their volume approximation methods based on numerical integration are used. Such methods have a vast role in numerous areas of mathematics, statistics, economics and engineering, with the two most prominent, the Simpson's rule and the Trapezoidal rule (e.g., **Malvić et al.**, **2014**). To improve the accuracy of reservoir volume calculation, both of the methods are used simultaneously, and their difference must not exceed 20 %. Volumes of the productive part of the layers are used in different cases, e.g. when calculating the storage capacity of CO_2 in sandstone in the western part of the Sava Depression (**Podbojec and Cvetković, 2015)** or other applications.

2. Methods

In the process of making and analysing the structural maps, numerous methods from the field of technical and natural sciences can be applied, with interpolation, planimetry and volume calculation being the most significant. Each of the methods is crucial for each step in the making of the maps and study in general. Initially, a certain number of specially distributed point data representing wells were given, the values of which were then interpolated to create structural maps mentioned above. Planimetry is a method which is directly linked to interpolation and is a technique used for measuring the surface area of a cross-section by tracing the bordering line of a section with a planimeter (e.g., **Malvić, 2015**). The last and perhaps the most important step, involves two approximation methods based on numerical integration, the Simpson's rule and the Trapezoidal rule, in an subsurface reservoir volume calculation. The shape of a geological structure such as a reservoir is usually approximated geometrically as a truncated cone, and the two taforementioned methods are used to calculate a similar a structure, with the goal of minimising errors of the final result.

2.1. Interpolation

Interpolation is, in the physical sense, defined as an approximation of numerical values of a function in a set points based on known surrounding values. Evaluation or interpolation is possible in one to three dimensions and applies to numerous scientific fields such as the natural sciences (**e.g., Grezio and Pinardi, 2006**), biotechnical sciences (e.g., **Galić, 2021**) and even in the humanistic sciences (e.g., **Čimin, 2013**). In underground mapping, interpolation is primarily used to draw lines connecting equal values on a map by allocating specific values to point data in an inter-well space (e.g., **Malvić, 2008).** For interpolation to be successful, it must be assumed that the values of surrounding, known points are sufficient to to accurately represent the value of a new, unknown point (**Davidović, 2016)**.

What is further, depending on the number of known data and their purpose, the same can be applied in geostatistics, where the most common applications are Inverse distance and Kriging. Linear interpolation is a multitude of methods, that provides the most accurate values of unknown points for the largest number of tested profiles of natural fields (e.g., **Kovač, 1982**). The Kriging is commonly, the most reliable method of interpolation when there is a known number of data on a narrow field (more than 20) and their relatively even spatial arrangement (**Malvić, 2008**). This interpolation method was developed by mining engineer D.G. Krige with the help of statistician H.S. Sichel for the needs of the mining industry in the early 1950s to improve the assessment of the ore reserves (e.g., **Davidović, 2016**). However, ths particular method requires compensation for the effects of data clustering, known as declusterization (e.g., **Mesić Kiš & Malvić, 2014**).

Considering all that was formerly mentioned and in terms of simplicity, the method of classic interpolation was used to analyse the maps in this paper. The spatial distribution of the wells was pre-determined, and in both cases almost equal, with 42 wells in structure 1 and 45 wells in structure 2. By increasing the number of input point data, errors in drawing the isolines are less likely to happen. To go along with interpolation, the method of extrapolation should not be overlooked. Similarly, it is a method based on approximation of point data values outside of the inter-well area.

2.2. Planimetry

The following method is planimetry, the method of determining the surface area of a bordered cross-section using a planimeter. It is typically used in basic planning when a selected cross-section is divided into equal elements whose surface areas are determined separately, and the final value is the sum of those elements (e.g., **Cindori Kovačević, 2016**). In this case, the surface area of our structural figure is defined by lines of equal thickness called isopachs, which are shown on isopach maps from contact to the reservoir's top and bottom.

A planimeter is an instrument that directly measures relative values (e.g., **Malvić, 2015**) by tracing the isolines bordering a specific figure, the absolute difference of which, multiplied by the conversion factor represents the surface area of the said figure. In this paper, planimetry is done using a polar planimeter (**Figure 1**) whose polar arm rotates around a weighted-down unmoving pole. The relative values are then read from the wheel brim and collected before and after the process.

The readings make up a four-digit number, each in the range 0-9 in a set order: the first digit is read from the biggest wheel and is measured between two digits pointed by an arrow, the smaller of which is chosen; the second digit is read on the perpendicular wheel, where the recorded value is a number pointed to by a zero on a perpendicular wheel; the third digit is read from the same wheel as the second and is a value od a fine line observed on a subscale from the perpendicular wheel, and finally the fourth digit which is read from the so-called nonius, a perpendicular wheel where the chosen value is shown on a corresponding line in a perpendicular subscale. As already stated, the absolute difference between the two relative values was calculated, which is finally multiplied by a conversion factor, defined by the scale of a map. The final numerical value is the surface area of the said figure from which the reservoir volume was calculated using numerical integration.

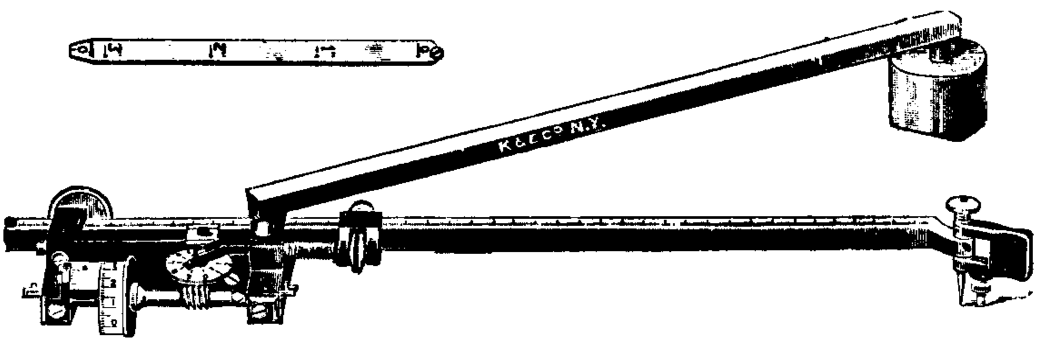


Figure 1: Polar planimeter (available at: https://www.leinweb.com/snackbar/planimtr/wheatley/s10-4.html).

2.3 Volume calculations

Calculation of the volume of an underground structure is one of the primary tasks in the reservoir geology and petroleum engineering. The shapes of all geological structures are irregular which greatly impacts their analytical and geometrical analysis. Generally, specific integration methods are used when calculating the surface area and volume of a geological structure,. Analytically speaking, integration is a method of determining a value using bordering parameters of a basic function. As it was previously stated, geological structures are not simple geometric shapes whose parameters can be defined using a basic function. This means that in order to calculate their volume based on numerical integration, methods must be applied that use a set, definite number of numerical values when integrating.

Historically, the term numerical integration was first used in 1915 in a study by David Gibbs (**Uddin & Kowsher, 2019**) which only notes its value in the mathematical field. Moreover, numerical integration is a simple term whose numerous methods are applicable in countless fields, such as mathematics, statistics, economics and engineering, but its value is the most notable for the field of geosciences. The two of the most notable numerical integration methods used in geosciences are the Simpson's rule and the Trapezoidal rule. Both of these methods originated from the fundamental and long-term Newton-Cotes method (**Uddin & Kowsher, 2019**). Newly developed methods such as the Simpson's and the Trapezoidal rule were developed to correct the errors of the previously used methods.

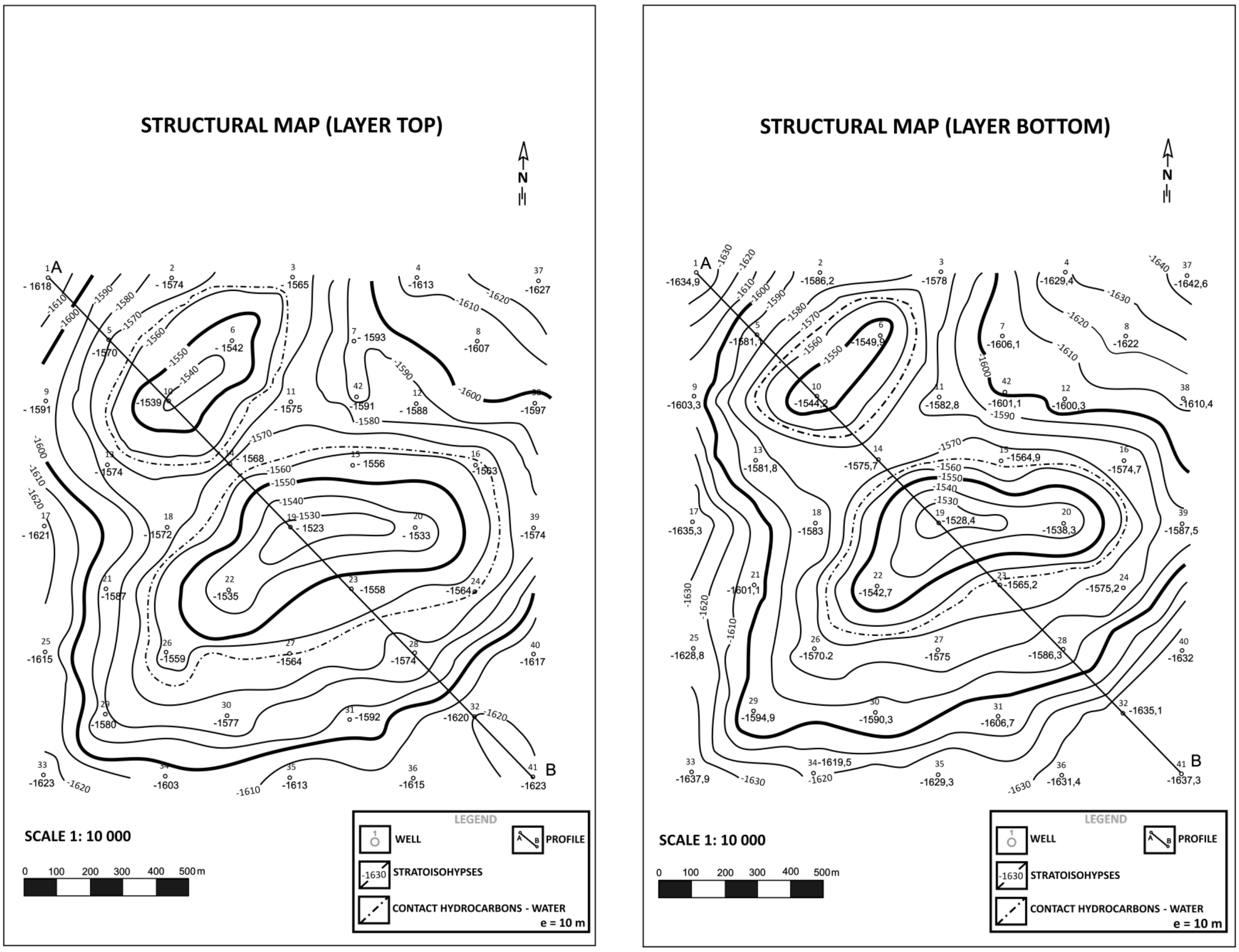
The Trapezoidal rule is an approximation of an integral using polynomials of the first order, or in geometric terms, it is an approximation of a surface area framed by the function's graph, a trapezoid with defined points. To eliminate large errors when applying the above rule, certain intervals are divided into smaller segments that are separately approximated. In this paper, the Trapezoidal rule is used in the case of an odd number of segments (or even case for the toppest segement), or an even number of isopachs for the calculation of the last, top segment of the structure. Everything withstanding, it is primarily used as a verification method in the final volume calculation.

Simpson's method, on the other hand, depending on the number of chosen segments, uses the polynomial of the second order (Simpson 1/3 rule, even number of segments). In this paper, the method is used with both an even and an odd number of segments and isopachs seeing as its accuracy is superior compared to the Trapezoidal method. These two methods are applicable in reservoir volume calculations when their irregular shape can be geometrically interpreted as a prismoidal, a figure whose points lie in one or two parallel planes, and when their values are equal across (**Malvić, 2015**). When considering the conventional structural traps, that approximating geometric figure is a truncated cone.

An acceptable difference in the calculation of reservoir volume, is considered to be a maximum of 20 %. This is the absolute difference between volumes calculated using both approximation methods.

3. Interpolation, planimetry and calculation of structure 1

Based on the given data, the following maps were created: a structural map of the reservoir's top and bottom, an isochore map, isopach maps from contact to the top and bottom, as well as a geological section, and finally the reservoir volume was calculated.



a **b**

Figure 2: (a) Structural map (layer top) - equidistance 10 m; (b) Structural map (layer bottom) - equidistance 10 m.

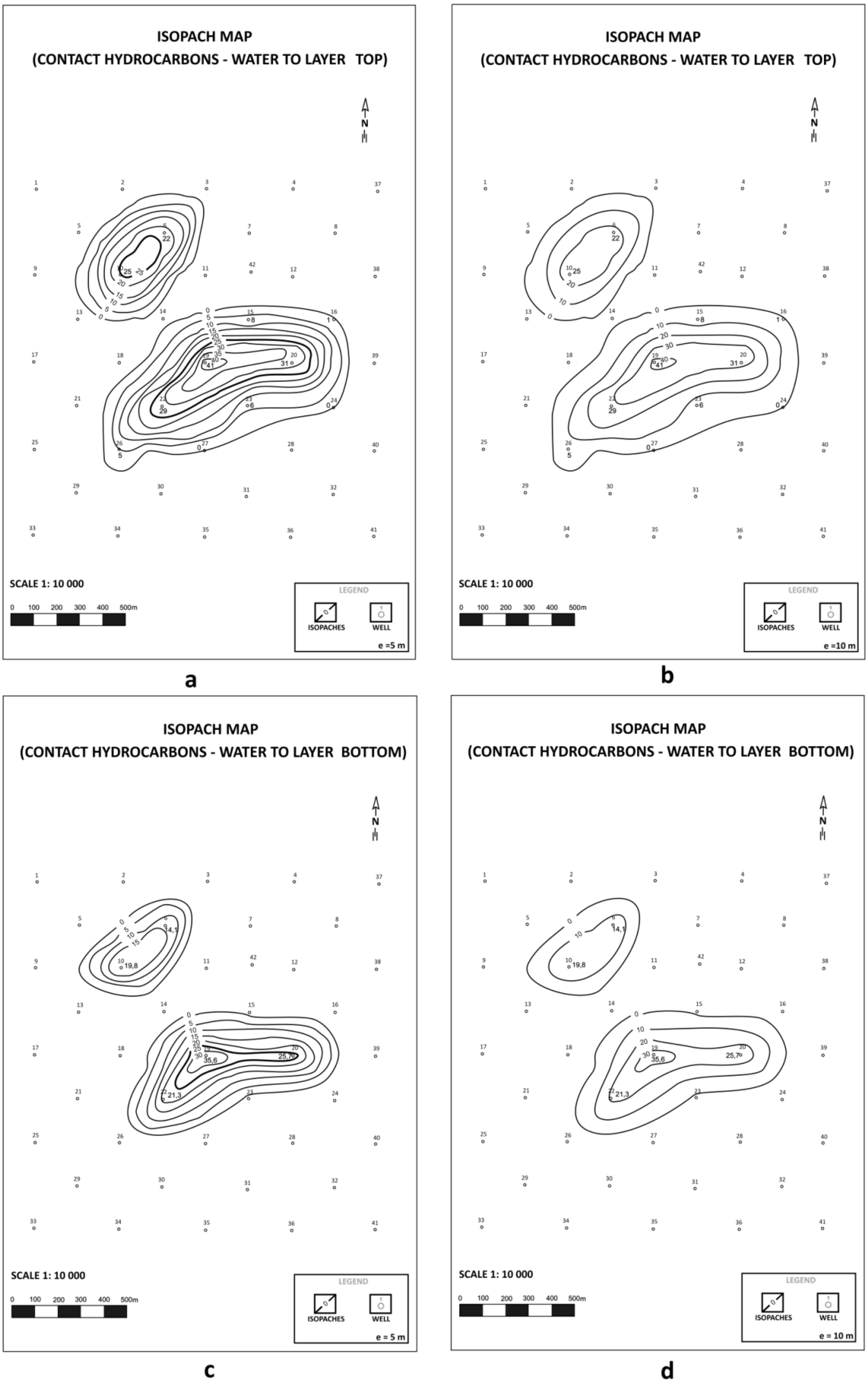


Figure 3: (a) Isopach map (HC - layer top) - equidistance 10 m; (b) Isopach map (HC - layer top) - equidistance 5 m; (c) - Isopach map (HC - layer bottom) - equidistance 5 m; (d) Isopach map (HC - layer bottom) - equidistance 10 m.

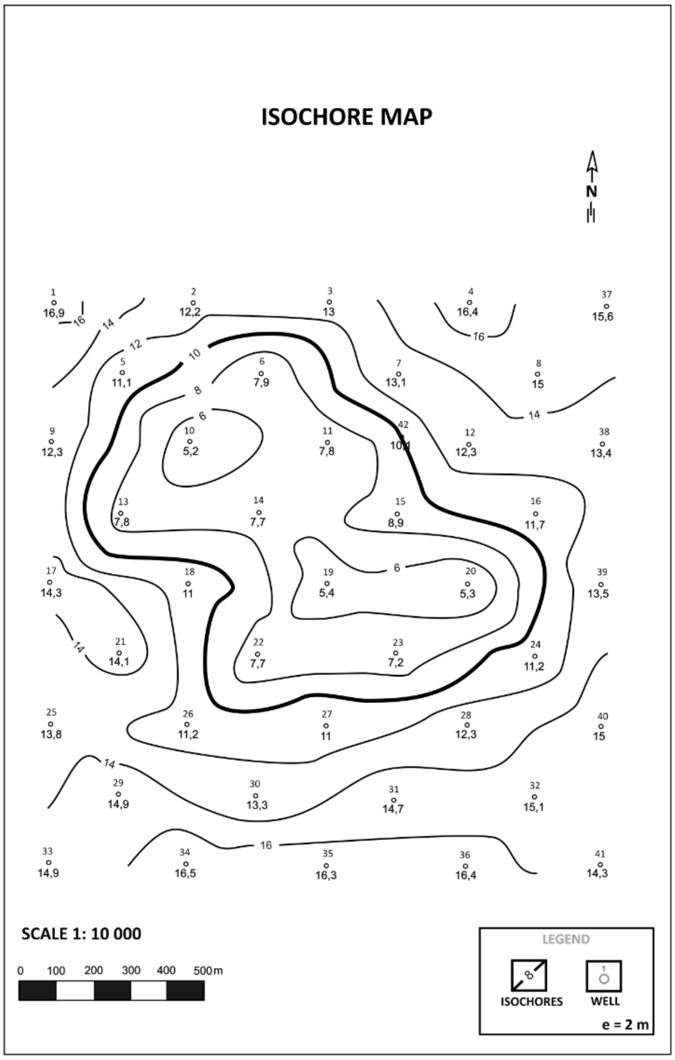


Figure 4: Isochore map - equidistance 2 m

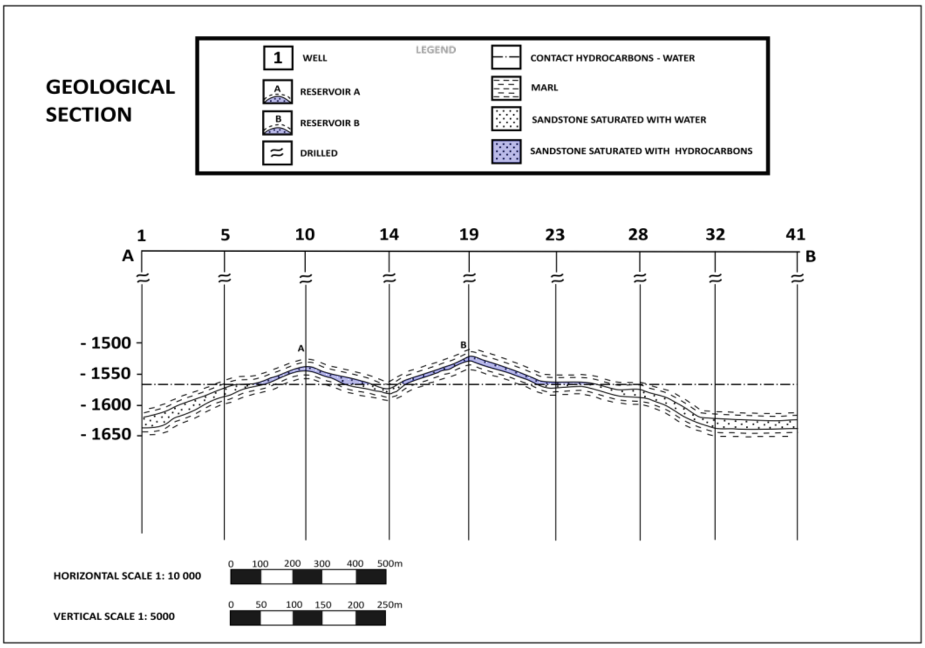


Figure 5: Geological section

Structural maps are defined as maps that show structural relations on a specific chosen layer. The structural maps of both the top and bottom layers were formed based on the absolute depths and the lines shown on the map connecting points of equal, real depths of the top and bottom layers are called stratoisohypses. The scale used for making the above-mentioned maps is larger meaning that the structure itself is significantly reduced in size, resulting in lesser calculated reservoir volume. Generally speaking, when selecting a scale of similar size, greater equidistance interval of 10 meters is applied to avoid the clustering of stratoisohypses. The mapping is done based on said table parameters and equidistance results in a descriptive, i.e., interpretative map. Given the positive results, the next step was to analyse the finished structure. To achieve greater data visibility every fiftieth isoline was thickened..

At first glance, the structure shown in **Figure 2a** does not have a defined shape seeing as the morphological diversity is quite severe. However, after further analysis, it was concluded with certainty that the structure is an irregular anticline, also known as a brachianticline. The highest isolines create tops of an anticline. The hydrocarbon-to-water contact line cuts the top las it is interpolated on the map itself. Seeing as the contact itself is not connected via the saddle form, we can conclude that the structure consists of two separate reservoirs. Again, because of the greater geomorphological diversity presented, it can be approximated that the volume calculations will result in a larger error. Despite that, it was concluded that the errors will fall within the maximum appropriate error limit and that the assignment can be continoued. Based on the interpolated, hydrocarbons-to-water contact line, as shown in **Figure 2a**, the isopach maps were created with contact to both top and bottom layers. By creating the above maps, the first official step to volume calculations has been taken. The isopach map showcasing contact to the top layer has been created by setting the reservoir layer thickness zero in places where specific points cut the top layer. This cutting line is now defined as the "new" isopach zero point from with all others are interpolated, using equidistance of 10 metes. The preceding map is shown in **Figure 3b**.

However, the created map presents an issue with the final volume calculation; it does not provide enough segments or isopachs to approximate the volume using the Simpson's and the Trapezoidal rule (**Eq. 1 and 2**) :

$$V_{trap} = \frac{h}{2} \left(a_0 + 2a_1 + 2a_2 + \ldots + a_n \right) \quad (1)$$

Where are:
V_{trap} - Trapezoidal volume
a_n - area bounded with the isopach
h - equidistance.

$$V_{simp} = \frac{h}{3} \left(a_0 + 4a_1 + 2a_2 + 4a_3 + \ldots + 4a_{n-1} + a_n \right) \quad (2)$$

Where are:
V_{simp} - Simpson's volume
a_n - area bounded with the isopach
h - equidistance.

For that reason, the equidistance was "thickened" and changed to 5 meters, from which we have secured enough segments for the shown calculation. The comparison between the original isopach map with an equidistance of 10 meters, and the map with an equidistance of 5 meters is shown in **Figures 3a** and **3b**.

By doubling the equidistance, enough segments have been created to continue with the volume calculation process accorting to Simpson's and Trapezoidal rules. The reservoir was cut every 5 meters with isopach planes and the cross-section surface areas were measured with a planimeter. For ease of understanding, the two separate reservoir structures will from now onward be reffered to as „reservoir A" (upper, left corner) and „reservoir B" (right). The planimetry results are shown in **Table 1**, while the surface areas are applied in **Eq. 1 and 2.**

Table 1: Planimeter results for section crossing (Isopach map contact hydrocarbons - water to layer top - Figure 3a). Multiplicative constant is 800.

Isopach no. („reservoir A“)	1st starting point of planimeter	2nd finishing point of planimeter	|1st -2nd|	Absolute area [m^2]
0	5259	5446	187	149 600
5	5518	5694	176	140 800
10	5714	5863	149	119 200
15	5889	5991	102	81 600
20	5006	5038	32	25 600
25	5051	5068	17	13 600
Isopach no. („reservoir B“)	1st starting point of planimeter	2nd finishing point of planimeter	|1st -2nd|	Absolute area [m^2]
0	6991	7651	660	528 000
5	7632	8151	519	415 200
10	8139	8557	418	334 400
15	8548	8868	320	256 000
20	0242	0448	206	164 800
25	0434	0572	138	110 400
30	0567	0663	96	76 800
35	0651	0699	48	38 400
40	0688	0691	3	2400

Reservoir "A“ includes an even number of isopach and an odd number of segments. Moreover, Simpson's rule (**Eq.1**) is only applicable in cases with an odd number of isopach and an even number of segments. A similar issue has been discussed in the paper where a new approach to the was presented (**Malvić et al., 2014**). In that case, the combination of both the Simpson's rule and the Trapezoidal rule is to be used as follows: the Simpson's volume equation ise used to calculate the second to last isopach (**Eq. 2**), while the Trapezoidal rule is applied to calculate the last isopach (**Eq. 3**).

$$V_{trap} = \frac{h}{2}\,(a_{n-1} + a_n) \quad (3)$$

Where are:
V_{trap} - Trapezoidal volume
a_n - area bounded with the isopach
h - equidistance.

The volume of the cap is added at the very end itself, seeing as the total volume is increased by the addition, however minor it is. This particular volume, above the final isopach, has very little impact on the total volume, in fact only a few percentages, nevertheless, it is not negligible. The volume itself is defined by a height that is lesser than the equidistance. If there is point data in the area defined by the highest isopach, the undefined height can be approximated from the difference between the last known isopach height and the number associated with the specific point data. In another case, if no point data exists in that area, the height can be arbitrarily determined, and it usually varies between 1 and 2 meters. Furthermore, that specific height is calculated using the pyramid and sphere approximation given in **Eq. 5** and **Eq. 6**. Finally, the total volume is presented as the arithmetic mean of the two values (**Eq. 7**).

$$V_p = \frac{h_n\, a_n}{3} \tag{5}$$

Where iare:
V_p - pyramidal approximation
a_n - area bounded with the last isopach
h_n - distance from the last isopach to the top of the structure.

$$V_{sf} = \frac{h_n^3 \pi}{6} + \frac{a_n h_n}{2} \tag{6}$$

Where are:
V_{sf} - spherical approximation
a_n - area bounded with the last isopach
h_n - distance from the last isopach to the top of the structure.

$$V_{top} = \frac{1}{2}(V_p + V_{sf}) \tag{7}$$

Where are:
V_{sf} - spherical approximation
V_p - pyramidal approximation
V_{top} - top volume.

The total volume, for „reservoir A“, is a sum of all three mentioned volumes, the results of which are shown in **Table 2** below. Contrastingly, „reservoir B“ is made up of an odd number of isopachs, as well as an even number of segments. This make sit possible to use only Simpson's equation (**Eq. 2**) in combination with the formula for the cap volume (**Eq. 7**) for the total volume calculation. Repeatedly, the overall volume is the sum of both, as shown in **Table 2.**

Table 2: Volume results (Figure 3a - Isopach map contact hydrocarbons - water to layer top)

Reservoir	e (m)	V_p (m^3)	V_{sf} (m^3)	V_T (m^3)	Number of sections	Used areas	Total volume (m^3)	Volume calculated with Trapezoidal formula (m^3)
„A“	5	4533.33	6800.53	5666.93	5	a_0, a_5, a_{10} a_{15}, a_{20}, a_{25}	Simpson's (first n-1 sections) + Trapezoidal (n-th section) + top (above n-th section) 2275666.93	2244000
„B“	5	800	1200.52	1000.26	8	a_0, a_5, a_{10} a_{15}, a_{20}, a_{25} a_{30}, a_{35}, a_{40}	Simpson's + top formulas 8271666.927	8306000

Similarly, the bottom layer structural map was made using the absolute depths of the top layer and subtracting it from the drilled layer thickness. The formed map, as shown in **Figure 2b**, also showcases the hydrocarbons-to-water contact line meaning that the same mapping procedure can be applied. Moreover, on an isopach map to the bottom layer, the contact line is now the new starting, isopach zero interpolated using equidistance of 10 meters. Still, the original equidistance does not produce a map with enough structural elements for the volume approximation. Thus, the equidistance is altered and thickened to 5 meters, which successfully ensures the use of Simpson's and Trapezoidal rule in volume calculatons. The comparison between the original isopach map with an equidistance of 10 meters, and the map with an equidistance of 5 meters is shown in **Figures 3c** and **3d**.

The planimetry results for the isopach map to the bottom layer are shown in **Table 3**. The equations of „reservoir A“ and „reservoir B“, calculations are the same as shown in the case of the isopach map to the top layer, since „reservoir A“ has an even number of isopachs, and „reservoir B“ has an odd number of isopachs (**Table 4**).

Table 3: Planimeter results for section crossing (Isopach map contact hydrocarbons - water to layer bottom - Figure 3c). Multiplicative constant is 800.

Isopach no. („reservoir A“)	1st starting point of planimeter	2nd finishing point of planimeter	$\lvert 1^{st} - 2^{nd} \rvert$	Absolute area [m^2]
0	6287	6435	148	118 400
5	6392	6491	99	79 200
10	6481	6532	51	40 800
15	6517	6561	44	35 200
Isopach no. („reservoir B“)	**1st starting point of planimeter**	**2nd finishing point of planimeter**	$\lvert 1^{st} - 2^{nd} \rvert$	**Absolute area [m^2]**
0	3766	4166	400	320 000
5	4153	4467	314	251 200
10	4461	4678	217	173 600
15	4665	4810	145	116 000
20	4801	4897	96	76 800
25	4883	4925	42	33 600
30	4911	4922	11	8800

Table 4: Volume results (Figure 3c - Isopach map contact hydrocarbons - water to layer bottom)

Reservoir	e (m)	V_p (m^3)	V_{sf} (m^3)	V_T (m^3)	Number of sections	Used areas	Total volume (m^3)	Volume calculated with Trapezoidal formula (m^3)
„A“	5	56320	84537.91	70428.955	3	a_0, a_5 a_{10}, a_{15}	Simpson's (first n-1 sections) + Trapezoidal (n-th section) + top (above n-th section) 1053762.285	984000
„B“	5	16426.67	24731.95	20579.31	6	a_0, a_5, a_{10} a_{15}, a_{20}, a_{25} a_{30}	Simpson's + top formulas 4075245.997	4078000

To meet the designated maximum fault requirements, the calculations need to have their absolute difference below 20%. The difference contained in the percentage includes the total volume calculated using Simpson's rule versus the overall volume calculated using the Trapezoidal rule. The percentage results are shown in **Table 5**.

Table 5: Simpson's and Trapezoidal total volumes difference

Map	Isopach map contact hydrocarbons - water to layer top	Isopach map contact hydrocarbons - water to layer bottom
Difference (%)	$\frac{\lvert V_T - V_S \rvert}{V_T} \cdot 100$	$\frac{\lvert V_T - V_S \rvert}{V_T} \cdot 100$
„Reservoir A"	1.41	7.09
„Reservoir B"	0.41	0.07

The error is more significant in „reservoir A" compared to reservoir B, but is still below the the permissible error limit of 20%. In „reservoir B", the error is barely noticeable and quite insignificant meaning that the approximation is virtually ideal. The difference is relatively small and within the boundary which signifies the acceptance of the calculated volume. Based on drilled layer thickness intervals, an isochore maps likewise constructed. Unlike the formerly analysed isopach maps, the isochore maps showcase lines of equal, drilled layer thickness (**Figure 4**).

The terms isopach and isochore are often incorrectly used in the petroleum industry as synonyms for thickness measurements, although they are fundamentally different. The isochore map refers to the actual thickness of the drilled layer, whereas the isopach maps illustrate thickness measured perpendicularly to the layer's top and bottom or to the fluid contact.

It is important to note that the thickness values presented on an isochore map are the result of a subtraction between absolute depths of the top and bottom layers, while the actual thickness is presented in **Figure 3a** and **Figure 3c**. Isopach and isochore maps are comparable if the layer is perfectly horizontal. Isochore maps show what can be seen when analysing a cross-section of a structure, namely a geological section, which is created using a definite number of wells to better determine the structure. The chosen profile connects wells 1 to 41 all the while cutting across the structure from northwest to southeast, which is shown in **Figure 5**. However, an issue that was encountered when constructing the profile was the inter-well space. In practice, the problem is solved by correlating the from carottage readings or measurements with the seismology being the one that solves the inter-well space. Seismology can, likewise, be used to view and examine a particular layer while it is not able to detect a reservoir, which is why to correlation between the different geophysical methods is of great significance. In this instance, when making the geological profile, the solution to the uncertainty of the inter-well space is resolved using stratoisohypses that pass through the area in question. The hydrocarbons-to-water contact line intersects both the top and bottom layers at two different points, indicating the existence of two separate reservoir structures. Seeing as the contact line is non-continuous the layer shown can be defined as a brachianticline, although the shape is generally not easily detectible when looking only at the geological section alone.

One can easily be misled when analysing the profile and conduct that the reservoir consists of two perfect domes, which is why it is particularly important to use multiple geological profiles to correctly determine the final shape. The chosen profiles must cut across the structure in different directions. For that reason, in this paper, structural maps of the top and bottom layers are used to to create the said profile we used (**Figure 2a and Figure 2b**). The deepest of stratoiohypses represent the determining factor in defining the final shape of an underground structure. Looking at a profile, such as the one shown in **Figure 5**, it is easily ascertainable that both of the brachianticlines show a level of symmetry from their tops, and that both flanks are continuous in their deeping. The slope of the structure is uniform and somewhat continuous. Additionally, when speaking of tops, the structure consists of two, which directly points to great geomorphological diversity. The thickness of the layer shown on the geological section is apparent, but not actual and can vary throughout the structure. The main purpose of a section is to obtain a better visual understanding of an subsurface structure and to confirm the assumptions made from structural maps.

4. Interpolation, planimetry and calculation of structure 2

As already explained in the introduction to this work, as well as for structure 1, it was also necessary to create structural and thickness maps (isohypses, isopachs, and isochores maps) based on the different numerical data, to construct a characteristic geological profile, to calculate the surfaces of isopachs with the help of a planimeter and calculate the volume of the productive part of the layer.

The input number of wells was 45, and the greatest depth was -920 meters on well-9. Backed up by given numerical data, the frist map was created, a structural map (layer top) which is visible in **Figure 6a**. When looking at the map, it is noticeable that there are seven stratoisohypses divided into two parts at the lowest absolute depth of -800 meters. The map shows how the isolines together form an elliptical shape that represents elongated brachyanticline, a structure that runs regularly from north to south and is almost centrally symmetrical. In addition, it is visible that the hydrocarbons-water contact at -870 meters marked with a "dash-dot-line" intersects the roof layer top, as the contact itself is interpolated on the map. A scale of 1: 5000 with an equidistance of 20 meters was chosen for the structure, based on evaluation of of the input data. The geological section A-B, which was later used to create the section itself, can be seen on the structure map alongside the boreholes and the stratoiso hypses with the corresponding depths.

The values of the absolute depths of the top slab of the productive layer were read directly from the input data, while the values of the depth of the bottom slab were obtained by the absolute addition of the depth of the roof slab to the perforated permeable interval. Tha data was used to create the subsurface depth map of the layer, which is visible in **Figure 6b**. The input number of wells was 45, with the greatest depth being -924.8 meters at the Well-9. The values of the stratisohypsies, of which there are seven in total, fall regularly from the edge towards the center, i.e. from -900 meters to -800 meters deep, surrounding a body as in the case of the structural map (layer top). Together, the isolines form an ellipse, the shape of which is characteristic of the structural trap called brachnianticline, which is elongated and symmetrical, just like in the case of the structural map (layer top). In addition, there are also so-called extrapolated lines, i.e. assumed lines that are shown as interrupted on the map and were created due to a smaller amount of data in this part of the terrain. The hydrocarbons-water contact is indicated at an absolute depth of -870 meters, which is highlighted on the map with a "dash-dot-line", incicaring that the contact intersects the subsurface of the layer. The map was made at a scale of 1:5000 with an associated equidistance of 20 meters. Just as in the case of the structural map (layer top), the section A-B is visible, which was used to obtain the vertical reservoir visualisation.

When creating the layer thickness map in **Figure 8**, the values of the drilled permeability interval in meters were used. The isoline representing the thinnest permeable interval is marked with "2" on the map, while the isoline representing the thickest interval is marked with "12". In addition, due to the reduced amount of data and the reduced number of wells, part of the sixth line on the map has been extrapolated, which indicates the assumption of further expansion. A scale of 1:5000 was used in the creation, but the equidistance was reduced to obtain a sufficient number of isolines. Accordingly, an equidistance of two meters was used.

The principle of creating an isopach map (contact hydrocarbons-water to layer top), which is visible in **Figure 7a**, is similar to the creation of a structural map (layer top), but in this case, the wells that were located at a greater depth than the hydrocarbons-water contact were omitted. Wells that are located at a shallower depth than the absolute depth at which the hydrocarbons-water contact is located are assigned a recalculated value. The new values correspond to the absolute difference between the contact distance and the structural map (layer top). This map shows eight isolines that are equidistant at a distance of ten meters. The highest isopach on the map is indicated as 70, and is simultaneously divided into two structures. The upper, more elongated and larger isoline and the lower, smaller and more regular isoline. In places and in wells where the reservoir intersects the roof, the thickness of the reservoir part is zero. It is precisely for the reason that this isopach is marked with zero on the isopach map (contact hydrocarbons-water to layer top), and represents the hydrocarbons-water contact itself, which is at -870 meters. By separating the bottom from the contact to the roof surface of the layer, the brachianticline was again obtained, which confirms the assumption about the geological structure. A scale of 1:5000 with the already mentioned equidistance of ten meters was used to create the map. The equidistance is reduced in contrast to the equidistance used in the creation of structural maps (roof and bottom layer) as there is a reduction in the number of isopachs.

Analogous to creating an isopach map (contact hydrocarbons-water to layer top), an isopach map (contact hydrocarbons-water to layer bottom) was created (**Figure 7b**). In this case, the wells that were located at a shallower depth than the hydrocarbons-water contact were given new values representing the absolute difference between the contact distance and the depth of the bottom surface of the layer. Seven isopachs are visible on the map, with the highest isopach at 60 meters and the lowest at zero meters. The 'zeroth' isopach simultaneously represents the oil-water contact, which in this case, just as in creation of an isopach map (contact hydrocarbons-water to layer top), is the reference depth that has been given a new value, zero. By separating the bottom itself from the contact to the bottom layer, the previously stated hypothesis on a structural trap brachyanticline is confirmed. The assumption about the mentioned geological structure is confirmed by the isolines that shape the ellipse. A scale of 1:5000 was used for the creation, but in this case with an equidistance of 10 meters due toa reduced number of isopachs.

The structural map (layer top) (**Figure 6a**) and the structural map (layer bottom) (**Figure 6b**) were used to create the geological profile. The above-mentioned line A-B was placed on them, passing through the points of the Well- 2, -6, -12, -18, -24, -30, -37, and Well-42 with the aim of transferring as many points as possible to make the curve of the geological profile more precise. To check the accuracy of the transmission of the distance and the geological profile obtained, the number of the corresponding points of the roof surface of the layer was lowered by the value of the drilled interval. Its value should correspond to the points determined for the subsurface curve of the layer. The profile (**Figure 9**) shows that the hydrocarbons-1qwater contact, marked as a "dash-dot-line", is located at -870 meters. At the same time, it intersects both the roof surface and the bottom surface of the layer, so the bed itself is therefore located between them. Furthermore, observing the given section, almost continuous thickness of the layer can be concluded. The permeable layer is marked with the sandstone hatch, with only formation water saturation below the oil-water contact, while above the contact there is oil saturation, marked in green. The hatch for the marl represents an impermeable layer that has the role of preventing fluid migration from the deposit, therefore in this case the marl is located above the roof surface and at the same time below the bottom surface of the layer. The scale is visible in the lower left corner, which is the same in both the horizontal and vertical parts, and in this case, it is 1:5 000.

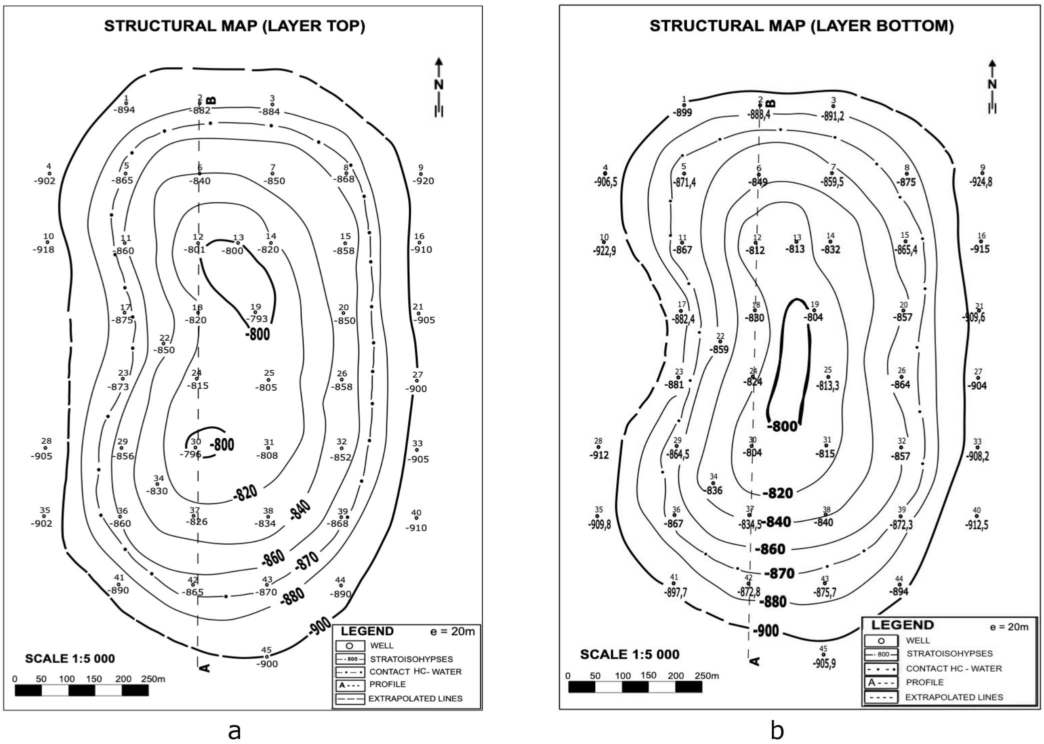


Figure 6: (a) Structural map (layer top) ; (b) Structural map (layer bottom)

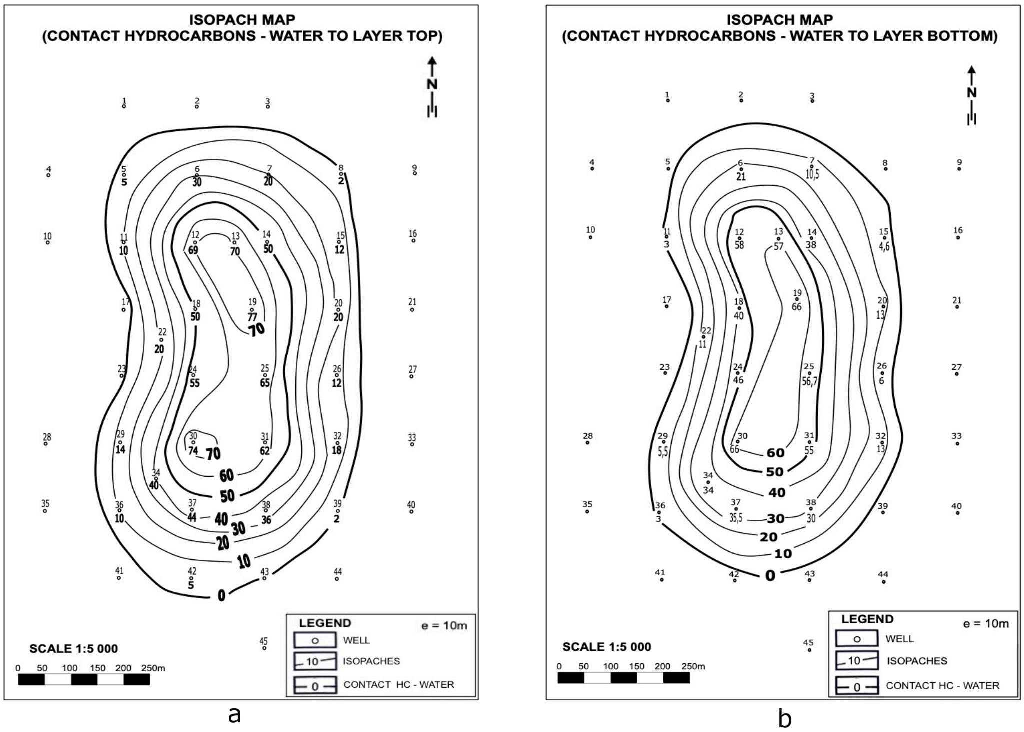
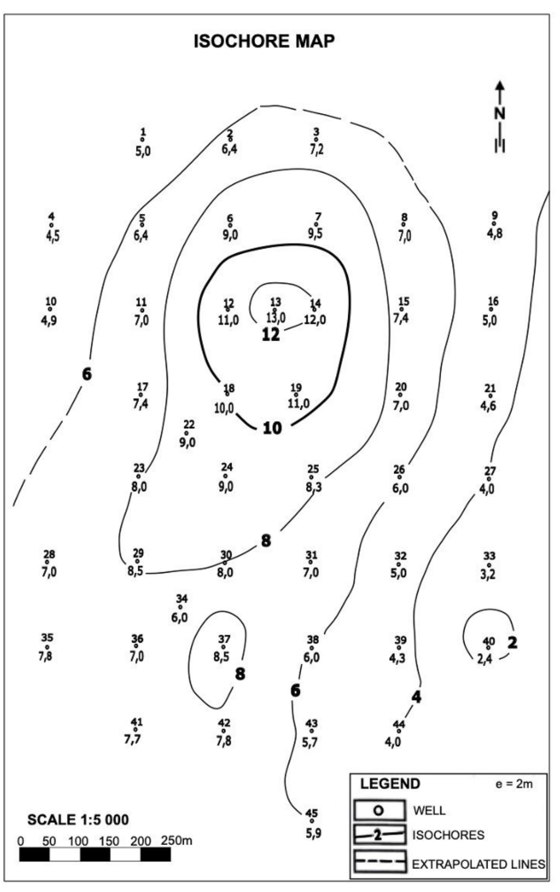


Figure 7: (a) Isopach map (HC - layer top); (b) - Isopach map (HC - layer bottom)



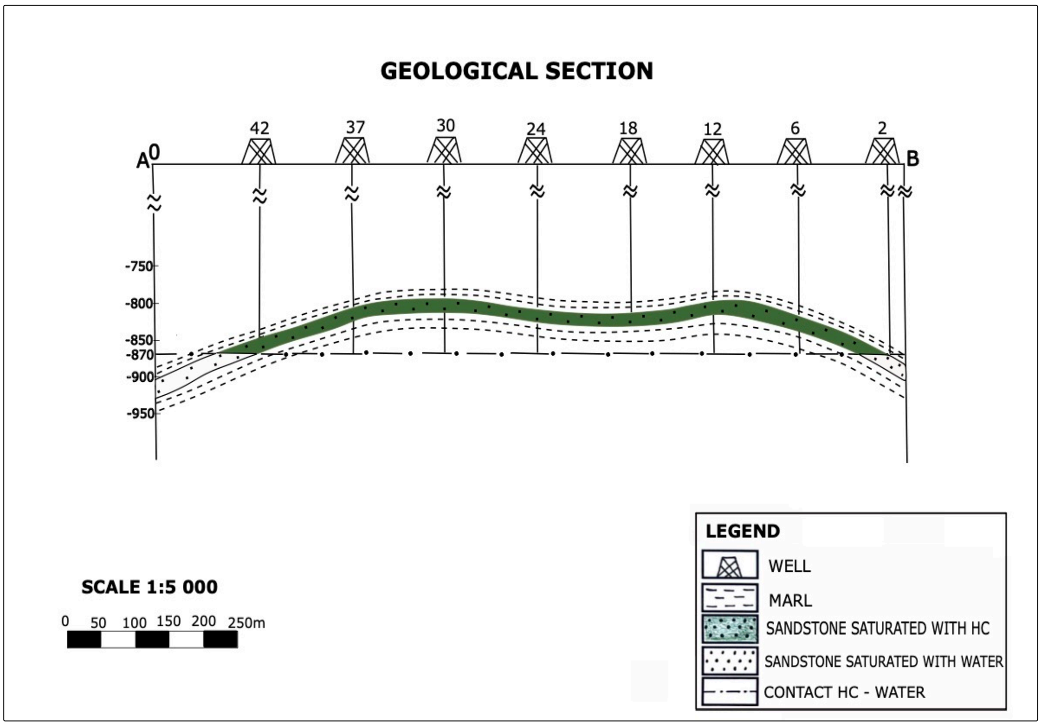


Figure 8: Isochore map
Figure 9: Geological section

To enable a better understanding of the obtained data and its processing to estimate the available hydrocarbon volume, the calculation of the reservoir volume is a key process. For assessment and calculation of this volume, it is necessary to know the area obtained by planimetry of the isopach map (contact hydrocarbons-water to layer top) and on the isopach map (contact hydrocarbons-water to layer bottom). The data obtained by planimetry for the isopach map (contact hydrocarbons-water to layer top) are given in **Table 6**, where when calculating the area of the "70" isopach, it was necessary to measure the surfaces separately and then add them up and observe the specified isopach as a whole in the further calculation. Accordingly, the data obtained for the isopach map (contact hydrocarbons-water to layer bottom) can be seen in **Table 7**. In the tables, the absolute difference between the first and second measurements represents the relative surface, converted into an actual surface by multiplying by a factor of 200, respecting the scale 1: 5000, which was given as a constant in the planimeter instructions. The correct choice of volume estimation method also depends on the number of interpolated isosurfaces on the maps. In the example of volume calculation for structure 2, the isopach map (contact hydrocarbons-water to layer top) has an even number of isopachs, and an odd number of isopachs for the subsurface, which is why the procedure itself will differ.

Table 6: Planimeter results for section crossing (Isopach map contact hydrocarbons – water to layer top). Multiplicative constant is 200.

Isopach no.	1st starting point of planimeter	2nd finishing point of planimeter	$\|1^{st} - 2^{nd}\|$	Absolute area [m^2]
0	2873	5029	2156	431 200
10	5081	6752	1671	334 200
20	6763	8091	1328	265 600
30	8095	9148	1053	210 600
40	9131	9971	840	168 000
50	1798	2433	635	127 000
60	2418	2771	353	70 600
70_1	2596	2701	105	21 000
70_2	2766	2782	16	3 200
70 ($70_1 + 70_2$)	/	/	121	24 200

Table 7: Planimeter results for section crossing (Isopach map contact hydrocarbons - water to layer bottom). Multiplicative constant is 200.

Isopach no.	1st starting point of planimeter	2nd finishing point of planimeter	$\|1^{st} - 2^{nd}\|$	Absolute area [m^2]
0	5858	7601	1743	348 600
10	7582	8931	1349	269 800
20	8933	9978	1045	209 000
30	1265	2139	874	174 800
40	2162	2718	556	111 200
50	2741	3081	340	68 000
60	3096	3251	155	31 000

Accordingly, in the isopach map, contact hydrocarbons-water to layer top (**Figure 7a**) even number of isopachs appear, which is why it is necessary to use a combination of the two already mentioned formulas, the Simpson's and the Trapezoidal formulas, in the calculation. The Simpson's formula (**Eq. 2**) was used to calculate the structure 2 for the first six sections under the condition that the equidistance is 10 meters (h=10 m), and to calculate the volume of the last section, the Trapezoidal formula (**Eq. 3**) was used with the same equidistance of 10 meters (h=10 m).

The volume of the cap was obtained by **Eq. 5** and **Eq. 6** from which the final volume (**Eq. 7**) of the cap was calculated as the mean value of the results obtained using these two formulas. Within the formula, it is necessary to determine the height from the last isopach to the top of the structure, which on the isopach map (contact hydrocarbons-water to layer top) is 7 meters (h_7=7 m), as there is a well with actual thickness of 77 meters within the last isopach. The final volume (**Eq. 8**) was obtained by summing the volumes obtained from Simpson's formula, the Trapezoidal formula, and the cap volume formula.

$$V_{total} = V_{simp} + V_{trap} + V_{top} = 14\ 065\ 339.8\ m^3 \quad (8)$$

To be able to check the accuracy of the calculation and find a possible error, the total volume was calculated only with the help of the Trapezoidal formula (**Eq. 9**), again using an equidistance of 10 meters (h=10 m).

$$V_{trap} = \frac{h}{2}\ (a_0 + 2a_1 + 2a_2 + 2a_3 + 2a_4 + 2a_5 + 2a_6 + a_7) = 14\ 037\ 000 m^3 \quad (9)$$

As already stated, the calculation error must be less than 20 %, and it refers to the absolute difference between the obtained results (**Eq. 10**). Since the accuracy of the calculation depends on the equidistance, the choice of scale, the number of isopachs and the area's thinning, in the case of the isopach map (contact hydrocarbons-water to layer top), the absolute difference in the results is very small, i.e. it is only 0.3 %. The map was made with a smaller scale, i.e., 1:5000, with an equidistance of 10 meters used, which ensured the number of isopachs on the map. Accordingly, a sufficient number of segments was provided for a full call of Simpson's and Trapezoidal formulas. As shown on the map (**Figure 7a**) an elongated brachnianticline negatively affects the accuracy while numerous other, already mentioned parameters, preserve the smaller error percentage.

$$\left|\frac{V_{trap}-(V_{simp}+V_{trap})}{V_{trap}}\right| = 0{,}003 = 0{,}3\% \quad (10)$$

After calculating the volume of the isopach map (contact hydrocarbons-water to layer top), the isopach map is calculated (contact hydrocarbons-water to layer bottom). An odd number of isopachs is visible on the map (**Figure 7b**), which is why the calculation can be carried out using only Simpson's formula (**Eq. 2**) for all six sections, i.e. all seven isopachs with an equidistance of 10 meters (h=10 m).

The value of the volume of the cap was obtained in the same way as for the calculation of the roof area of the layer, using the formulas **Eqs. 5, 6**, and **7**. The main difference is the height between the last isopach and the top of the structure, which in this case is 6 meters (h_6=6 m) as there is a well at 66 meters of actual thickness inside the last isopach. The final volume was obtained by summing the volumes obtained from Simpson's formula and the cap calculation formula (**Eq. 11**).

$$V_{uk} = V_{simp} + V_{top} = 10\ 312\ 223.22\ m^3 \quad (11)$$

Again, as in the case of the volume of the roof surface, the volume was finally calculated using only the Trapezoidal formula (**Eq. 12**) with an equidistance of 10 meters (h=10 m).

$$V_{trap} = \frac{h}{2}\ (a_0 + 2a_1 + 2a_2 + 2a_3 + 2a_4 + 2a_5 + a_6) = 10\ 226\ 000\ m^3 \quad (12)$$

The obtained volume calculated by only the Trapezoidal formula served to check the accuracy of the results and to determine their mutual deviations, which must not exceed the already mentioned 20 %. It is also within the permissible deviations for the calculation of the subsurface area, namely 0.08 %, which is shown in Eq. 13.A major influence on the accuracy of the calculation is again the reduced scale of 1:5000 with the used equidistance of 10 meters, which enabled a sufficient number of isopachs. In addition, the small separation of the area with only one head contributed to the accuracy of the results.

$$\left|\frac{v_{trap}-v_{simp}}{v_{trap}}\right| = 0{,}0008 = 0{,}08\% \qquad (13)$$

5. Comparison of mapping and volume calculations

As was already determined, the goal of this paper was to identify and record the similarities and differences between Structure 1 and Structure 2 after analysing them in detai. The comparison is based, in its entirety, on created structural maps.

Firstly, starting with structural maps of the top layers (**Figures 2a and 6a**), it has been noticed that they have been interpolated with a similar number of input data. In the case of structure 1 the number of input point data, or rather wells is 42, and in case of structure 2, 45 wells. The main difference is in the absolute depths, both defining the well depths and the hydrocarbons-to-water contact line. Namely, in structure 1 the contact line is at an absolute depth of -1564 m, and in structure 2 at -870 m. In both structures, the contact line intersects the top layer. By observing both structures, the similarities regarding the shape were spotted and it was concluded that both of them can be described as brachianticlines, formed by isolines to an ellipse-like shape. The next perceived difference lies in the uniformity of the structures formed by stratoiohypses, with two distinct peaks in the case of structure 1, and a single peak in structure 2. Specifically, the first („reservoir A“), smaller of the two peaks is more spheric, and in the case of a second, bigger peak („reservoir B“) is elliptic in shape. Contrastingly, the single peak making up the structure 2, can be described as an elongated ellipse. The third biggest difference is the scale: structure 1 has a scale of 1:10 000, and structure 2 has a scale of 1: 5 000, resulting in the difference in equidistance, which is 10 meters for structure 1, and 20 meters for structure 2. The reduction or increase of the equidistance in both structures is a direct result of the scale choice, dictating the number of isolines.

Analogous differences and similarities are observed In the matter of the structural map of the bottom layer (**Figures 2b and 6b**). The main difference is again in the absolute depths of the specific wells and contact line. Both contact lines for structures 1 and 2 intersects the bottom layer. The presence of two peaks in structure 1 indicates a greater level of geomorphological diversity than in the case of structure 2, which consists of a single top. Furthermore, the structure shape is an irregular anticline, or rather brachianticline which can negatively affect the volume calculations. The difference is again observed in the scale and equidistance. When speaking of structure 1, due to the greater number of stratoisohypses, a larger scale is selected, namely 1:10 000, with a 10 m equidistance. For structure 2, whose depths and isoline numbers are smaller, the selected scale is 1: 5000, with an equidistance of 5 meters.

In the comparison of the layer thickness maps (**Figures 4 and 8**), a correlation with the number of isochores is observed, where their numbers in both maps are almost equal. One of the differences is in maximum thickness, which is 16 meters in structure 1, and 12 meters in structure 2. Secondly, they differ in the minimal thickness of the drilled intervals, whicj is 2 m in the case of the second structure, and 6 meters in the case of the first structure. The equidistance used in both maps is the same, namely 2 m, in order to display as many isolines as possible. Even with the same equidistance, the scales differ and correspond to the scales used for the respective maps in previous analyses.

Regarding the isopach maps from contact to the top layer (**Figures 3a and 7a**), the first noted similarity is in the referential zero, or an isopach determining the hydrocarbon-to-water contact. The greatest thickness in structure 1 between the top layer and the contact is 25 m in „reservoir A“, and 40 m in „reservoir B“. In the case of structure 2, the greatest difference is 70 m. It can be likewise notice that the second structure is non-continuous, and the 70-th isopach is divided into two separate peaks, while the first structure has single top. In the first structures, multiple isolines represent the same thickness and are scattered across the map. The scale is also different when comparing the two maps, 1:5000 for structure 2, and 1:10 000 for structure 1. The equidistances are also different, 5 m in structure 1, and 10 meters in structure 2.

A omparison between the isopach maps from contact to the bottom layer follows (**Figures 3c and 7b**). In both structures, the hydrocarbon-to-water contact is taken as the reference depth, i.e. the new starting point, with the value of 0. Furthermore, the values are positive because they represent layer thickness, not layer depths. in structure 2, the thickness from the contact line to the bottom layer is 60 meters, and in structure 1 it is much less at just 15 meters for „reservoir A“, and 30 meters in „reservoir B“. The scale in structure 1 is again 1:10 000, with an equidistance of 5 meters. Similarly, the scale for the second structure is 1:5 000, with an equidistance of 10 meters.

In the last comparison, before the volume analysis, two characteristic geological sections, i.e. profiles were observed (**Figures 5 and 9**). It is to be noted that in the two cases, the hydrocarbons-to-water contact lines intersects both the top and bottom layers of the oil-saturated sandstone. The saturated sandstone layer is surrounded from the top and bottom by impermeable layers of marl. The main purpose of the marl is to prevent fluid migration, specifically the hydrocarbons. The second structure shows a continuous reservoir, while the second structure has two separate reservoirs within the sandstone layer, reservoirs „A“ and „B“. Due to an unusual geomorphological diversity shown in the structural maps of the top and bottom layers, the thickness of the permeable layer in structure 1 is variable. Structure 2 showcases even thickness across the entire layer. Vertical scales are the same in both cases and are 1: 5000. The horizontal differentiates, in structure 1 it is 1: 10 000, and in structure 2 it is once again 1: 5 000.

After analysing all the structural maps in detail and identifying and observing possible correlations, the final volume results are presented. Finally, it was determined which parameters are most likely to have an impact and change and in what way. After carefully examining and analysing the **Tables 2** and **4** and **Eq. 8, 9, 11** and **12**. it is clear that the total volume figure is greater for structure 2, with the main deciding perimeter being the smaller scale, 1:5 000. Contrastingly, the total volume figure in structure 1 is significantly smaller, partly due to the bigger scale of 1:10 000. Separating the two reservoirs making up the total of structure 1, it can be concluded that „reservoir B“ has a greater contribution in volume than „reservoir A“. The reason lies in the overall number of segments used in the calculations, with „reservoir B“ having twice as many segments as „reservoir A“.

There is a certain analogy that can be drawn between the two approximation methods, **Table 8** shows the absolute difference in Simpson's and Trapezoidal volumes. As was already established, the absolute difference must not exceed the limit of 20 % recommended in the literature The figures shown in the table below meet the criteria.

Table 8: Simpson's and Trapezoidal total volumes difference

Map	Isopach map contact hydrocarbons - water to layer top	Isopach map contact hydrocarbons - water to layer bottom
Difference (%)	$\frac{\lvert V_T - V_S \rvert}{V_T} \cdot 100$	$\frac{\lvert V_T - V_S \rvert}{V_T} \cdot 100$
Structure 1: „Reservoir A“	1.41	7.09
Structure 1: „Reservoir B“	0.41	0.07
Structure 2	0.30	0.08

From the table above it can been seen that the second structure renders smaller faults compared to the first. The parameters that have greatly contributed to such a result are primarily the scale of 1:5 000 in combination with its selected equidistance of 10 meters. Further, these two parameters, namely the smaller apparent scale and equidistance interval help to achieve a sufficient amount of segments to approximate the volume of the structures using Simpson's rule and Trapezoidal rule. When observing the geomorphological diversity, it was concluded that it only affected one structure, creating two separate reservoirs from structure 1 and consequently creating a bigger overall error in volume. Even though both structures can be described as brachianticlines, and the faults in volume results vary, they ultimately come under 10 %. it can also be noted that, even though the most "regular" shape in structure can be observed in „reservoir A“ of structure 1, it shows the biggest fault in volume compared to both structure 2 and „reservoir B“ of structure 1. That is due to the chosen scale of 1:10 000 which resulted in a smaller amount of segments and isopachs, and finally in greater error. To conclude, the final results depends on multiple different parameters, none of which can be ignored in volume calculations.

6. Conclusions

The main goal of this study was to examine and compare two papers analysing constructed structural maps, in addition to volume calculations, using fundamental knowledge of physical and mathematical laws combined with the knowledge of petroleum geology and engineering acquired during our present education. Analysing the input data, and comparing it to the structural maps it is easily ascertainable that the overall reservoir volume depends on numerous parameters. In one respect, when studying the structures against their respective maps, it is clear that the first structure consists of two separate reservoirs, while structure 2 can be considered as a whole. The shape of both deciding structures can be described as irregular anticline, or brachianticline. The shape of the structure alone can be a very decisive factor for volume calculations, where a greater number of reservors or peaks result in a huger overall error. Furthermore, the predetermined input data is specific to each of the maps making up the two fundamental studies and is founded on different scales and equidistance. The productive, reservoir part of structure 1 was supposed to be interpolated according to an equidistance of 10 meters. However, that equidistance in combination with the scale of 1:10 000, results in only two segments, three isopachs in „reservoir A“, and four segments, five isopachs in „reservoir B“, as is shown in **Figure 3b**. In the case of a map shown in **Figure 3d**, that same equidistance results in only one segment, two isopach in „reservoir A“, and three segments, four isopachs in „reservoir B“. However, as it was previously mentioned, the number of resulting isopachs and segments is not considered adequate for the use of Simpson's and Trapezoidal equations in volume calculations. Taking that into consideration, the equidistance was thickened to 5 meters which resulted in five segments, six isopachs for „reservoir A“, and eight segments, nine isopachs with „reservoir B“ of structure 1, shown in **Figure 3a**. With the same new equidistance of 5 meters, shown in **Figure 3c**, there are now three segments, four isopachs in „reservoir A“, and six segments, seven isopachs in „reservoir B“. With structure 2, however, the initial set equidistance of 10 meters, as shown in **Figure 7a**, resulted in six segments, and seven isopachs. Finally, seven segments and eight isopachs are given in **Figure 7b**. Similarly, the results displayed in **Table 8**, for both structures, show that the final volume fault is significantly smaller, seeing as there is a greater number of isopachs compared to structure 1. The fault percentage is greater in structure 1, which is due to the greater geomorphological diversity, namely the two separate reservoirs which ultimately contribute to the irregularity of the structure. Equidistance is also one of the parameters for controlling the number of segments and isopachs, and indirectly the volume fault. In relation to the layer thickness, a larger equidistance in thinner layers does not equate to an adequate number of segments used in volume calculations and on the other hand, that same equidistance, but with thicker layers, can result in the expected number of segments. Accuracy and errors of the volume result heavily depend on the equidistance, with a smaller equidistance lesading to a greater number of results, segments thus diminishing the need for approximation. According to the convention of admissible equidistance, the optimum equidistance at which accuracy is greatly improved, is only 1 or 2 meters. Simpson's method requires at least four segments, otherwise, the results would not be permissible. In the case of „reservoir A“ of the structure 1, the error percentage is quite high at more than 7 %, and even using a more suitable equidistance does not result in an acceptable number of segments. It is important to note that the overall error does not exceed the permissible one of 20 %, and the approximation of reservoir volume is accurate. Using the example of „reservoir A“ in structure 1, it can be deduced that the number of isopachs particularly affects accuracy. A a certain percentage of error is still present, but it is greatly reduced when increasing the number of applied subintervals. Lastly, the scale is also important factor in calculations. The larger the scale, the larger the overall reservoir volume, as is seen in this paper.

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Abstract in Croatian

Klasična interpolacija i izračun volumena dviju usporedivih ležišnih struktura - metodološke i interpretacijske sličnosti i razlike

Analizirana su dva ležišta ugljikovodika na temelju strukturnih i karata debljina koje su obuhvatile - karte dubina krovinske i podinske plohe sloja, debljine sloja te debljina od kontakta ležišta do krovinske i podinske plohe sloja. Svaka karta potkrijepljena je osnovnim elementima kao što su njezin naziv, odgovarajuće mjerilo i ekvidistancija, oznaka sjevera te pripadajuća legenda. Uz navedeno, izrađeni su i geološki profili ležišta te je proveden proračun volumena produktivnog dijela sloja. Detaljnom usporedbom detektirano je koji parametri i na koji način utječu na postojanje razlika, a istovremeno na mogućnost korelacije između istih. Klasičnom ručnom interpolacijom i djelomičnom ekstrapolacijom dobivene su površine za planimetriranje kao ulazi za izračun volumena struktura. Te metode se temelje na numeričkoj integraciji, a u radu su korištene one najpoznatije, Simpsonova i Trapezna jednadžba. Dvije uspoređene strukture su brahiantiklinale, svaka sa svojim specifičnostima, koje su trebale biti prepoznate na kartama i volumetrijskom izračunu kako bi oba pristupa dala konkretna rješenja.

Ključne riječi: interpolacija; volumen; ležište; brahniantiklinala; Simpsonova jednadžba, Trapezno pravilo.

Authors contribution

Maria Rudec (undergraduate student) supervised abstract, introduction and comparison of mapping and volume calculations. **Marko Uzelac** (undergraduate student) provided the interpolated maps, tables, equations, planimeter results and calculations under the title interpolation, planimetry and calculation of the structure 1 and style. **Ivana Brajnović** (undergraduate student) provided the interpolated maps, tables, equations, planimeter results and calculations under the title interpolation, planimetry and calculation of the structure 2. **Lorena Birko** (undergraduate student) supervised methods, conclusions, style and translation of this work.