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Burial depth estimation for possible hydrocarbon source rocks within the area of the Comănești Basin. Application on the S300 well, Șipoteni structure (Romania)

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Abstract

The objective of the present study was the estimation of burial depths for possible hydrocarbon source rocks of Oligocene age from the Vrancea Nappe. The study was carried out on the Șipoteni structure, located within the geographical area of the Comănești Sedimentary Basin, and resulted in a 1D model of the sedimentary column opened by the S300 well. The latter has opened formations belonging to the Sarmatian of the Comănești Basin, as well as to the Lower Miocene, Oligocene and Eocene (the Tarcău and Vrancea nappes). The structure occupies a central position within the Comănești Basin, being the only one within this area with reservoirs in all three structural units. By employing the method proposed by Athy (1930), based on the data from the well files, the laws for porosity variation with depth that apply to the main lithological types within the formations were obtained. The modelling of burial evolution for the formations with source rocks was carried out using the "back-stripping" method, by means of which the initial deposition depths for the possible source rocks were restored. Moreover, the burial curves of these rocks with geologic time were plotted, based on both current and decompacted thicknesses.

Keywords: burial history, back-stripping, hydrocarbon source rocks, Șipoteni structure.

Introduction

Within the Eastern Carpathian Unit, the Comănești Basin represents an important region when it comes to hydrocarbon accumulation. The main source rocks from this area were considered the Oligocene bitumoliths, disposed within the bituminous marls, lower dysodiles and upper dysodiles of the Vrancea and Tarcău nappes (Ștefănescu et al., 2005; Grasu et al., 2007; Belayouni et al., 2009; Amadori et al., 2012).

The differentiated evolution in terms of burial of the likely source rocks within the basin may have influenced the degree of maturation of the organic matter in the

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composition of these rocks, since it is a well-known fact that burial depth plays an important role in this respect.

As a matter of fact, there are several studies (Stănescu and Morariu, 1986; Dicea et al., 1991; Vodă and Vodă, 1992; Caminschi et al., 1998; Pandele and Stănescu, 2001; Grasu et al., 2007) whose authors consider that, in certain areas, the burial depths of these source rocks have influenced the degree of maturation and, therefore, hydrocarbon generation.

For the Comănești Basin area, more precisely the Moinești region, Carminschi et al. (1998) have carried out a simulation for the estimation of burial depths in the case of the Oligocene source rocks from the Tarcău and Vrancea nappes, conducted using the Basin Mod 1D software.

The estimation of burial depths for certain marker units is closely linked to one's knowledge of the geological evolution of the studied area, as well as to the consideration of all factors that may have influenced the evolution of the basin and the most accurate approximation of the erosion hiatuses.

Study area

The area on which the present paper is centred corresponds, geographically speaking, to the Comănești Basin (Eastern Carpathians). The basin is defined by a series of oil structures and oil structural assemblies with hydrocarbon accumulations in one, two or all three of the structural units (Comănești Basin, Tarcău Nappe and Vrancea Nappe) opened by the wells.

The Comănești Basin is a Neogene post-tectonic basin, discordantly overlapping the flysch formations of the Tarcău and Vrancea nappes.

Initially, the geological formations that constitute these two nappes (Tarcău and Vrancea) were deposited within a single sedimentary basin. During the intra-Burdigalian (Old Styrian) tectonic movements, the geological formations were folded and eroded and, during the Badenian stage, the New Styrian movements caused the thrusting of the Tarcău Nappe over the Vrancea Nappe, which was, in turn, thrust on top of the Subcarpathian Nappe.

Given that, during the Burdigalian, the geological formations from the Tarcău and Vrancea nappes were folded and eroded before the yielding of the thrust; Săndulescu (1984) refers to them as "epiglyptic nappes".

One of the structural units with importance in terms of hydrocarbon reservoirs is the Comănești-Podei-Șipoteni unit, situated in the central region of the Comănești Basin, near the Trotuș Valley (Fig. 1). This structure expands from Comănești toward the SSE, along the Comănești-Podei-Dărmănești line, over a length of approximately 6–7 km, being limited to the west and the north by the Leorda structure, and to the east by the Văsiești structure. The central-eastern sector of the structural complex is known as the Șipoteni structure, while the main structure is called Comănești-Podei (Pandele and Stănescu, 2001).

The specific feature of this structure lies in the fact that it is the only structure within which hydrocarbon reservoirs have been identified in all three units (Vrancea Nappe, Tarcău Nappe and Comănești Basin).

Tectonically speaking, the structure is divided into blocks separated by longitudinal and transversal faults, the former being considered sealed, while the latter are inter-communicable.

From a stratigraphic point of view, within the structure, the wells have intercepted formations of Sarmatian age (within the Comănești Basin), but also of Lower Miocene, Oligocene and Eocene age (within the Tarcău and Vrancea nappes). It is worth mentioning that the units of the Tarcău Nappe have undergone differential erosion during the stage which preceded the deposition of the formations from the Comănești Basin, which is the reason why the contact surface between these two units is a nonconforming one (Fig. 2a).

One of the deepest and most representative wells of this structure is the S300 exploration well, which has reached a final depth of 3257 m. The intercepted units are shown in the lithological column of the well (Fig. 2b).

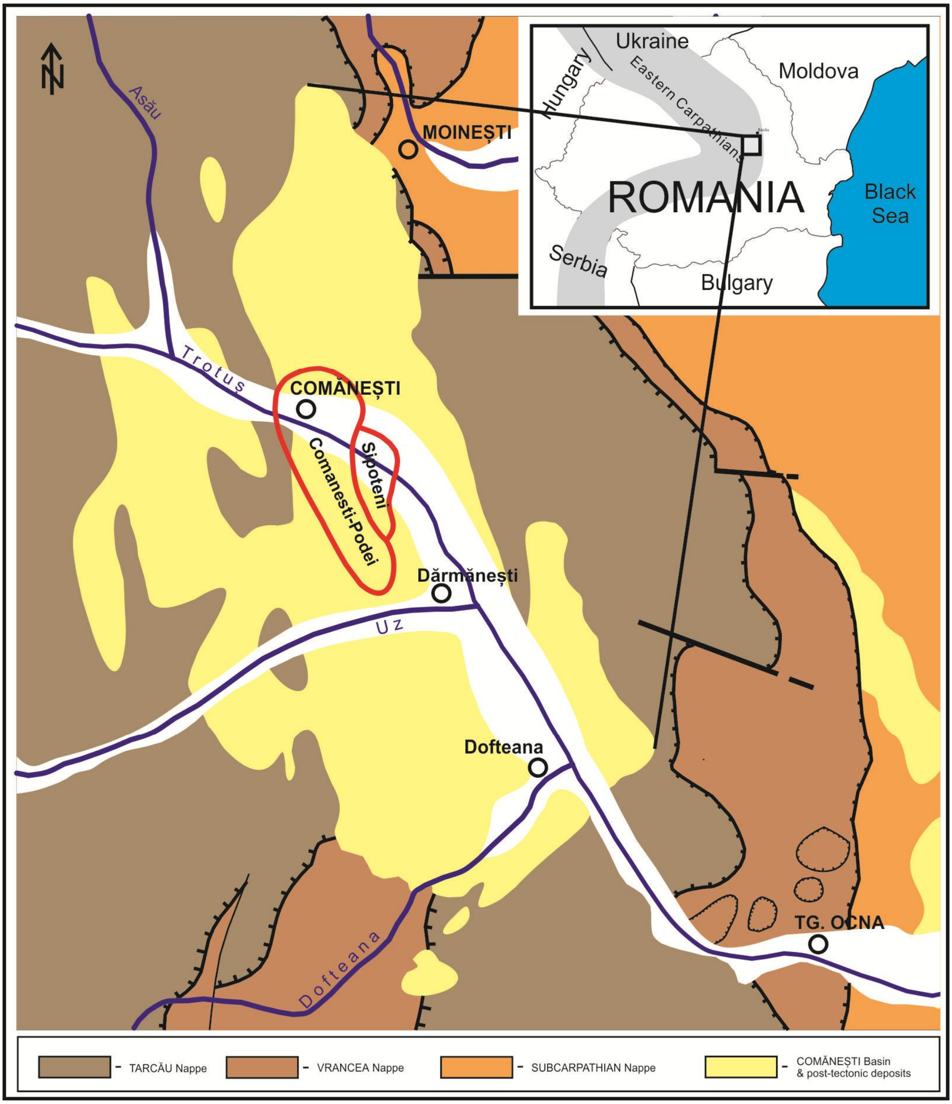

Fig. 1 The framing of the Comănești Basin in the context of the Eastern Carpathians and the localization of the Comănești-Podei-Șipoteni oil structure (not to scale).

Methodology

The modelling of burial history allows the restoration of the thicknesses of the geological formations at the time of their deposition within the sedimentary basin.

Burial history may be considered a component of the subsidence analysis of sedimentary basins, analysis which follows the evolution of the basin's basement or that of a marker unit based on sediment input, changes in sea level over geological time, relative to the current eustatic level, as well as on the palaeo-depth of sediment deposition.

The estimation of burial depths for formations with possible hydrocarbon source rocks in a certain area requires information regarding the evolution of these formations over time, the geological ages and the current thicknesses of the units of interest and the sedimentary column above, as well as knowledge of possible hiatus periods, of the rock types that compose the formations and the laws of the variation of their porosity with depth.

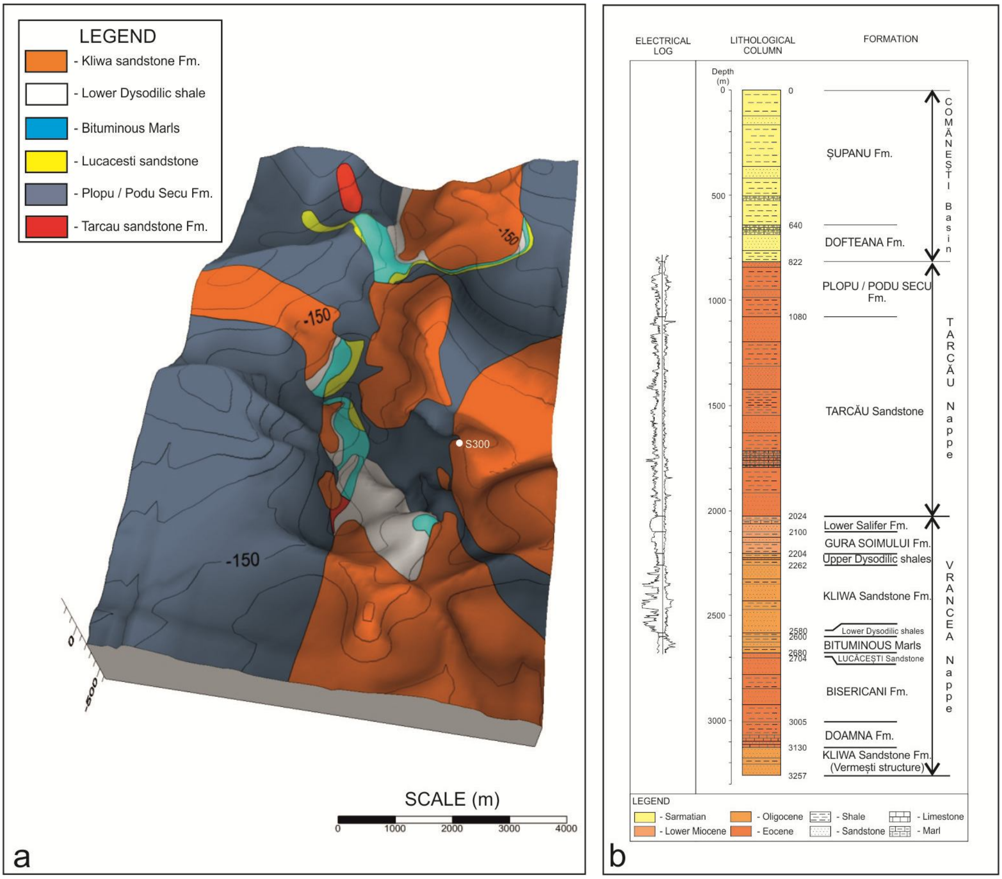

Fig. 2: a) The representation of the Tarcău Nappe formations at the contact with the Comăneşti Basin within the Comăneşti-Podei-Şipoteni structure and the localization of the S300 well (based on Petrom data); b) The synthetic lithological column of the S300 well.

Sediment decompaction implies removing the progressive effect, over geological time, of rock volume modifications with depth (Ţambrea, 2007). In other words, after the deposition of sediments within the sedimentary basin, their compaction begins, due to the cumulative effect of several factors, such as porosity loss, lithological type, occurrence of excessive pressure or diagenesis. Thus, as a result of these factors, a lithological unit may currently have a reduced thickness, compared to the one it had at the time of deposition. However, the main factor that causes changes in the thickness of a geological formation is represented by the reduction in rock porosity with increasing depth.

In this respect, a number of laws of porosity variation with depth have been formulated in the literature (e.g. Athy, 1930; Falvey and Middleton, 1981; Baldwin and Butler, 1985; Șaramet et al., 2010). In the present paper, we have employed the most used variation model, proposed by Athy (1930), according to which porosity decreases exponentially with burial depth, in agreement with the following equation:

$$\phi = \phi_0 \cdot e^{-c \cdot z} \quad (1)$$

where: Φ is the rock porosity at the depth z;
Φ_0 – the initial surface porosity;
c – the basin constant of the analysed rock.

Given the lack of information for the studied area (either from the literature or from the well files), the possible effects of overpressure or diagenesis were not considered. However, we believe that, although we have neglected these effects in our analysis, the resulting errors do not significantly influence the final results.

The back-stripping method (Watts and Ryan, 1976) is the process of reconstructing the thicknesses of geological formations at various stages of their evolution within the sedimentary basin.

This process involves the progressive removal of the sediment load and the retrieval of the depths of a marker lithological unit at the time of its deposition. Knowing the spatial and temporal framing of the formations within the basin, their staged "stripping" may be achieved (Watts and Ryan, 1976; Steckler and Watts, 1978; Watts and Steckles, 1981). In the case of 1D modelling, for the lithological column opened by a well, the analysis involves the assumption of the Airy isostasy (Allen and Allen, 2005). In order to complete the modelling, one requires lithological, chronological and spatial information on the formations within the sedimentary column analysed.

Once the surface porosity at the time of deposition, on the one hand, and the compaction constant of the rocks, on the other, are known, their porosity at any burial depth can be determined.

This method involves the separation of the sedimentary column into units bound in space and time. Usually, within the basin, there are also periods of non-deposition or intervals when erosion causes the removal of deposits. The units missing from the sedimentary column, which are, however, framed in geological time, are called "hiatuses," and it is recommended to take them into consideration during analysis in order to obtain burial depth values as accurate as possible.

Decompaction is carried out through the vertical translation of the sedimentary columns onto the porosity-depth exponential curve. The decompaction general equation results from the mathematical transposition of these vertical translations (Angevine et al., 1993):

$$h_0 = -\frac{\phi_0}{c} \cdot e^{(-c \cdot z_0)} \cdot \left[e^{(-c \cdot h_0)} - 1\right] + h_A + \frac{\phi_0}{c} \cdot e^{(-c \cdot z_A)} \cdot \left[e^{(-c \cdot h_A)} - 1\right] \quad (2)$$

where: h_0 represents the initial thickness of a sedimentary column;
h_A – the current thickness of the column;
z_0 – the depth of the upper limit of the sedimentary column at the time of deposition;
z_A – the current depth of the upper limit of the sedimentary column.

Since the method requires the use of the trial and error procedure, in the present paper we have employed the Turbo Basic dialect-based software, developed within the Geology Department of the "Alexandru Ioan Cuza" University of Iași.

Results and discussion

Using Athy's model (1930) for the variation of porosity, and the porosity values determined at various depths based on the determination logs for real resistivity and on the lithological columns available for five wells dug within the area of the Șipoteni structure (280, 286, 300, 350, 380), the values of the surface porosity – "Φ_0" – and the basin constant – "c" – have been obtained for the main lithological types – shales and sandstones (Fig. 3). Given that the lack of data did not allow their determination, in the case of the marls, the values used were those proposed by Ionescu (2000). All of the values for these parameters have been grouped, together with matrix density (Ionescu, 2000), within Table 1.

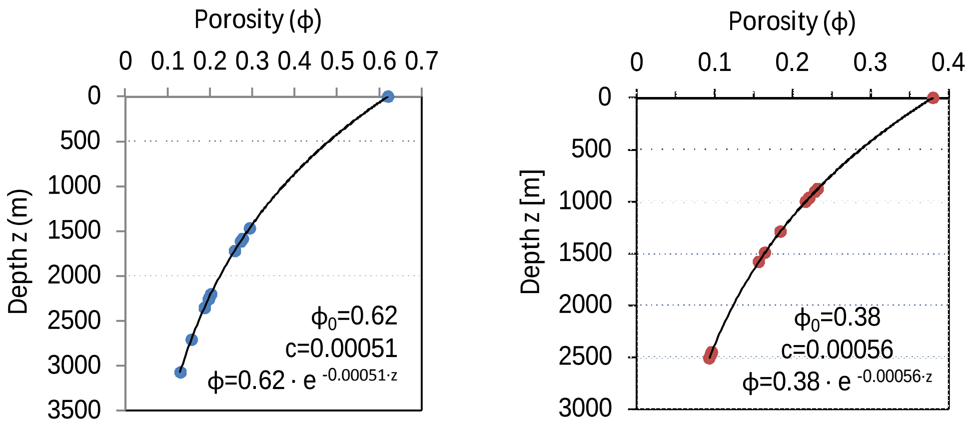

Fig. 3 A compaction model for shales (a) and sandstones (b) attained for Șipoteni structure.

Table 1 Compaction parameters used in the present paper for the main lithological types

Lithology	Matrix density, ρ_m (kg/m^3)	Surface porosity ϕ_0	Porosity-depth coefficient, c (km^{-1})	Source
Shale	2720	0.62	0.51	Present paper
Sandstone	2650	0.38	0.56	
Marl	2715	0.52	0.62	Ionescu (2000)

Once the compaction parameters were known, the computation of formation porosity and the use of the back-stripping method for the lithological column of the S300 well in order to assess the burial depths of Oligocene source rocks became possible.

For this purpose, the lithological column of the S300 well was divided, based on the geological and geophysical data, into lithological units, defined in time and space. The volume fractions for the lithological components of each unit (Fig. 4a) were established based on the quantitative analysis performed on cores and cuttings. The absolute ages of the formations, as well as those of the hiatuses, were estimated using the stratigraphic chart of the Paratethys devised by Popov et al. (2003). The age of the thrusting of the Tarcău Nappe over the Vrancea Nappe has been called into discussion by several researchers, considering that this event took place during the New Styrian tectogenesis (intra-Badenian). The age used for the subsidence analysis was estimated at 15–16 My. Indeed, this framing may insert minor errors, estimated at up to 1 My. However, these errors do not have a considerable influence upon the aspect of the sediment burial curve.

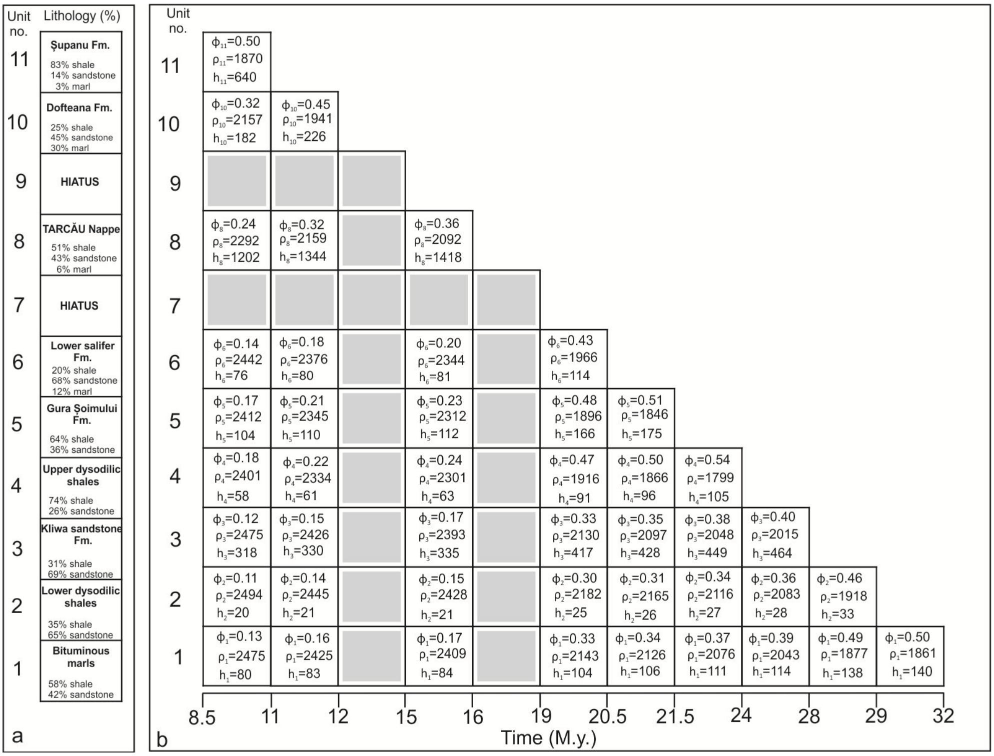

Fig. 4 Back-stripping analysis on the S300 well: a) The units included in the burial analysis and their lithological constituent; b) The back-stripping chart with output data.

The hiatuses were estimated based on bibliographic data, but also on the analyses of certain geological profiles and sections made for the area of the Comănești-Podei-Șipoteni structural unit or for the entire Comănești Basin (Micu et al., 1990). Three hiatus periods were, thus, identified – one for the upper limit of each structural unit.

Compared to the typical profile of the deposits of the Vrancea Nappe, in the S300 well, the Lower Miocene formations – the Condor Strata (~20–40 m – Dumitrescu et al., 1970) and the Hârja Formation (~150 m – Dumitrescu, 1952) – are missing from the upper part of the column. Also, by analysing the cross-cut profiles made within the Comănești-Podei-Șipoteni structural unit, greater thicknesses were identified for the Lower Salifer Formation (~1000 m), suggesting that the latter has also undergone significant erosion. Overall, the minimum thickness of the deposits in the area that were eroded before the thrusting was estimated at approximately 1100 m.

The youngest post-thrusting deposits belong to the Upper Sarmatian of the Comănești Basin (Săndulescu, 1984). Thus, the non-conforming limit between the flysch deposits of the Tarcău unit and the post-tectonic deposits of the Comănești Basin may coincide with a hiatus period, due to the uplift of the deposits of the Tarcău Nappe and to the removal by erosion of an important part of these deposits. In the case of many wells within the area of the structure, since the deposits belonging to the Tarcău unit are exclusively of Eocene age, we considered that the rest of the sedimentary column was removed during this period. By in-lining the sedimentary succession with the one from other regions in which these formations can be found (Lucăcești sandstone, bituminous marls, lower dysodilic shales, and Kliwa sandstone), and by analysing the geological section from the Comănești Sheet of the 1:50.000 geological map (Micu et al., 1990), the minimum thickness of the removed deposits was estimated at about 1300 m. The erosion may have been greater, but, lacking the practical possibilities of reaching such values, the risk of inserting errors and of, consequently, overrating the burial curves was high.

The existence of a brown coal strata in the Sarmatian column of this part of the Comănești Basin, at depths of 400–500 m (Grasu et al., 2004), also implies a pronounced erosion of the deposits of this unit. A simple computation involving the temperature at which brown coal forms (40–50°C – Einsele et al., 1991), a geothermal gradient of 2.3–2.45°C/100m (Negoiță, 1970), and a surface temperature of 9°C may imply a coal-forming depth of approximately 1250–1750 m. The difference between these depths and the actual depth at which the coal deposits are found within the Comănești Basin is of about 750–1250 m, being considered as erosion in this analysis (in the computations, an average value of 1000 m was used). The presence of Meotian deposits in certain areas of the basin suggests that the erosion started after the Meotian and continued until around 5 Ma.

The bituminous marls from the Vrancea Nappe were chosen as marker unit, being the source rock-bearing formation situated at the greatest depth within the lithological column of the S300 well.

The data entered into the computation program were the following: the number of lithological units, the current depths at the bottom and at the top, the surface porosity, the compaction coefficient, and the matrix density for each formation/unit (Tab. 2). The decompacted depths and thicknesses, as well as the porosities and densities for each burial stage, were obtained after running the computing program. The results obtained have been summarized within the back-stripping chart in Figure 4b.

Table 2 The input data for the back-stripping analysis of the formations opened by the S300 well

Unit	Formation	Depth (m)		Thickness (m)	Age (My)		Φ_0	c (1/km)	ρ_s (kg/m^3)
		Top	bottom		top	bottom			
11	Șupanu Fm.	0	640	640	8.5	11	0.58	0.52	2710
10	Dofteana Fm.	640	822	182	11	12	0.48	0.57	2687
9	Hiatus unit	822	822	0	12	15	-	-	-
8	Tarcău Nappe (thrusting)	822	2024	1202	15	16	0.51	0.54	2690
7	Hiatus unit	2024	2024	0	16	19	-	-	-
6	Lower Salifer Fm.	2024	2100	76	19	20.5	0.44	0.56	2672
5	Gura Șoimului Fm.	2100	2204	104	20.5	21.5	0.53	0.53	2695
4	Upper dysodilic shales	2204	2262	58	21.5	24	0.56	0.52	2702
3	Kliwa sandstone Fm.	2262	2580	318	24	28	0.45	0.54	2672
2	Lower dysodilic shales	2580	2600	20	28	29	0.46	0.54	2675
1	Bituminous marls	2600	2680	80	29	32	0.52	0.53	2691

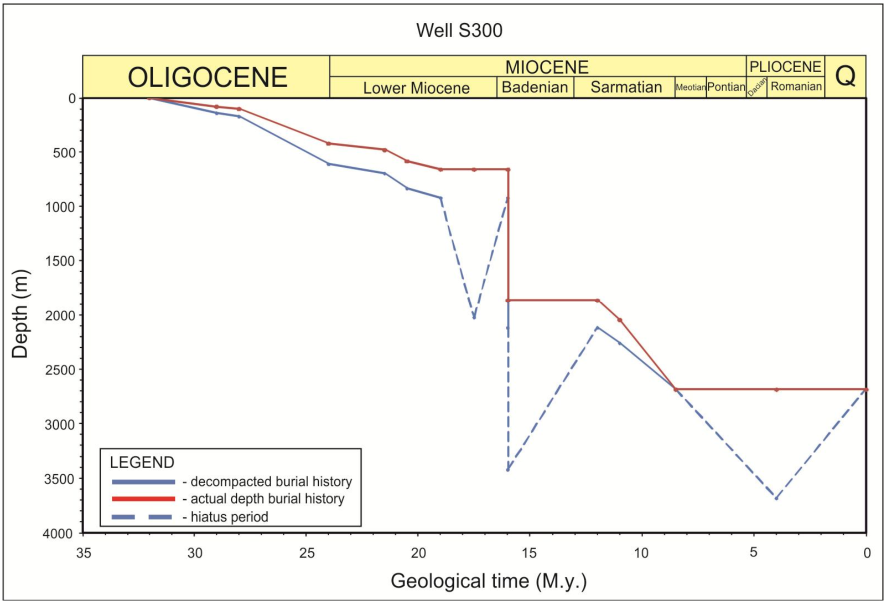

Fig. 5 The burial curve for the bituminous marls formation, drawn based on the current and decompacted thicknesses determined by means of the back-stripping analysis (S300 well).

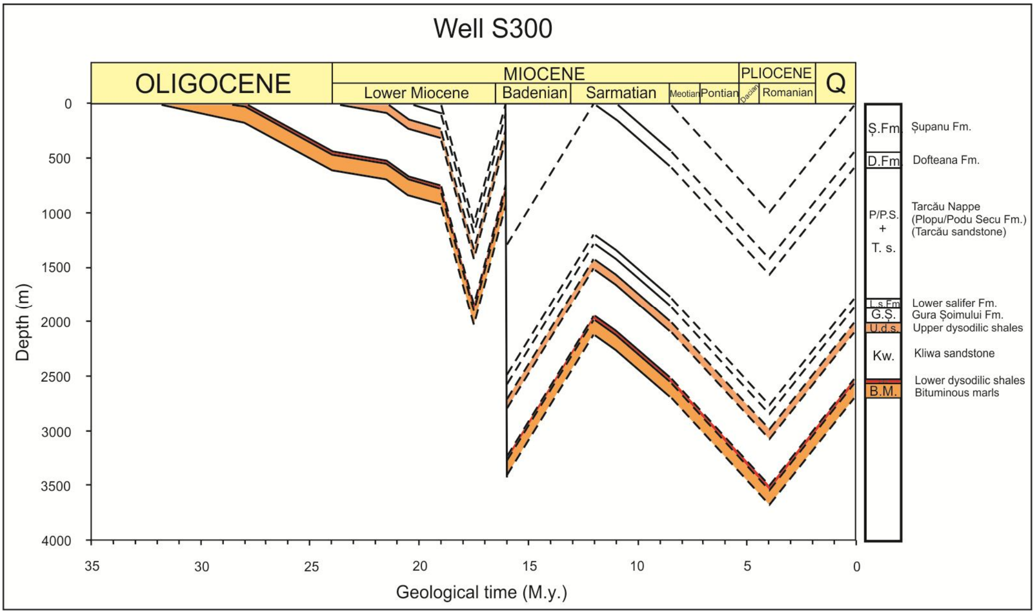

Fig. 6 The burial history of the Oligo–Miocene formations – S300 well. The coloured units indicate the formations from the Vrancea Nappe thought to be likely hydrocarbon source rocks (bituminous marls, lower dysodilic shales and upper dysodilic shales).

The decompacted thickness values obtained for each burial stage of the marker formation were graphically plotted as opposed to the geological time, thus obtaining the 1D model of the burial curve for the S300 well. Fig. 5 shows the differences between the decompacted curve and the actual curve of burial depths for the marker unit analysed in the case of the S300 well. The burial curves for the superjacent units have also been drawn (Fig. 6). The dashed lines represent the stages during which the deposits were buried and, subsequently, subjected to erosion.

By analysing the graphical representation of the burial curves, we can deduce that all three likely source rock-bearing formations reached burial depths of over 3000 m, although, currently, they are placed at lower depths.

The variations in burial depth that occurred, over geological time, due to tectonic events and the erosion that affected both the nappes of the Outer Flysch, as well as the sedimentary Comănești Basin, may have influenced the generation of hydrocarbons from the Oligocene source rocks discussed.

Conclusions

The present study was carried out in order to determine the burial depths of the likely hydrocarbon source rock-bearing formations within the Șipoteni structure that have been opened by the S300 well.

The analysis of burial history represents a means of displaying the evolution of the formations of interest within a sedimentary basin.

In order to perform this analysis, we have used a series of stratigraphic and geologic data, as well as the ages, lithologies, current depths of the formations etc.

It was also necessary to know the hiatus periods, if they existed. Within the burial model for the S300 well, three erosion hiatuses were identified, whose thicknesses were indirectly estimated, based on the information from the literature and on the analysis of geological sections.

Using the porosity values, the laws for porosity variation with depth of the main lithological types (shale and sandstone) were obtained. When compared with the values provided in the literature, surface porosity displays slightly lower values, which could be attributed to the lateral compressions exerted by the thrusting.

The results obtained through the back-stripping analysis indicate that the Oligocene source rocks were buried at depths greater than 3000 m. The time span during which these formations remained at these depths was relatively short, due to the tectonic and erosional events that affected the structural units. The thrusting played an important role in the burial of these formations.

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