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The influence of the thrust over the evolution of the thermal regime of the Vrancea Nappe source rocks (Eastern Carpathians). A 1D simulation of the Șipoteni oil structure (Romania)

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Abstract

The aim of the present paper is to highlight the variations in thermal regime caused by the thrusting of the Tarcău Nappe over the Vrancea Nappe during the New Styrian tectono-genesis. The one-dimensional analysis was carried out for the sedimentary column opened by the S300 well within the Șipoteni oil structure (Comănești Basin area). This involved the overlapping of the temperature isolines over the burial curves of the source rock-bearing formations. The computation of temperatures for the time period after the thrust was performed using the equation for heat transfer in an unsteady regime (Angevine and Turcotte, 1983), which requires knowing certain local physical and thermal parameters. Regarding the thermal parameters, given the lack of laboratory or *in situ* measurements, thermal diffusivity was indirectly estimated, through mathematical simulation, while the thermal gradient of the structure was established using temperature measurements carried out at various depths during the well-digging process. As far as the other parameters (regarding thickness and other aspects of the nappes) are concerned, they were determined based on the back-stripping analysis and the history of sediment burial, being closely related to the local conditions of the nappes. The results obtained have shown that, for the oil structure studied, the influence of the thrust over the thermal regime was not great enough to be considered a major factor in the generation of hydrocarbons from the source rocks. It was most likely the thickness of the thrust nappe which had an essential role. In other areas, where it was considerably larger, the former may have even played a decisive part.

Keywords: thrust, back-stripping, hydrocarbon source rocks, Șipoteni, thermal regime.

Introduction

The thermal regime of a sedimentary basin plays an important role in the maturation degree of the organic matter within the formations with potential hydrocarbon-generating source rocks. In order to generate hydro-carbons, among other conditions related to time and burial, a source rock-bearing formation must achieve an optimal thermal field.

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This thermal field may suffer modifications (anomalies) when the basin is affected by events of a tectonic nature, such as the emplacement of nappes.

Regarding the Tarcău and Vrancea Nappes, within the Outer Flysch of the Eastern Carpathians, most authors (Stănescu and Morariu, 1986; Dicea et al., 1991; Vodă and Vodă, 1992; Caminschi et al., 1998; Pandele and Stănescu, 2001; Grasu et al., 2007) regard the thrusting as the decisive factor when it comes to the reaching of the temperature conditions required for hydrocarbon generation within the Oligocene source rocks of the underlying nappe (Vrancea). The authors above consider that the thrusting is also responsible for the emplacement of similar source rocks within the Tarcău Nappe, under thermal conditions that are not optimal for the generation of hydrocarbons.

Furthermore, Stănescu and Morariu (1986) attribute these temperature anomalies to the thermal flow induced by the friction processes associated with the thrusting plane, considering that the source rocks of the Vrancea Nappe may have generated hydrocarbons immediately after the thrusting.

Study area

In the present paper, we have chosen to perform an analysis on the impact of the thrust upon the thermal regime of the Șipoteni oil structure.

This structure belongs to a structural unit (Comănești-Podei-Șipoteni) located within the geographical area of the Comănești Sedimentary Basin (Fig. 1a).

The formations that were opened by wells in this area belong to the Comănești Basin, as well as to the Tarcău and Vrancea nappes, which display epiglyptic features (Săndulescu, 1984).

Initially, the geological formations that embody the two nappes were deposited within a single sedimentary basin. During the Old Styrian movements, however, these 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.

The Șipoteni structure is composed of a number of tectonic blocks separated by a series of longitudinal and transversal faults (Fig. 1b).

Stratigraphically speaking, the formations opened by wells within this structure are of Sarmatian age (the deposits of the Comănești Basin), but also of Lower Miocene, Oligocene and Eocene age (the deposits of the Tarcău and Vrancea nappes) (Fig. 1c).

One of the most representative wells dug within the area of this structure, on which we have carried out the current analysis, is the S300 exploration well, whose lithological column can be found in Fig. 1d.

Methodology

In the regions affected by the emplacement of thrusts, the thermal regime displays certain characteristics derived from the evolution of temperatures during and after the thrust.

More precisely, with the thrust of two nappes, a disturbance occurs in the thermal regime through the connecting of the detachment plane (décollement) of the thrust nappe (with a higher temperature) with the upper part of the underthrust nappe, characterized by lower temperatures. Thus, as time passes, a cooling of the rocks above the décollement takes place, along with the heating of the underthrust deposits, until thermal equilibrium is restored.

If within the underthrust nappe there are immature source rocks and the burial underneath this nappe is large enough, then this may lead to the occurrence of the thermal conditions needed for the generation of hydrocarbons. However, the time factor should not be excluded, given that, even if the required temperature conditions are met, the time span may still be too short.

As a result, the reconstruction of paleotemperatures, at different post-thrust time intervals, is important when it comes to the highlighting of the evolution of the thermal field of the sediments within the hydrocarbon-bearing formations of interest.

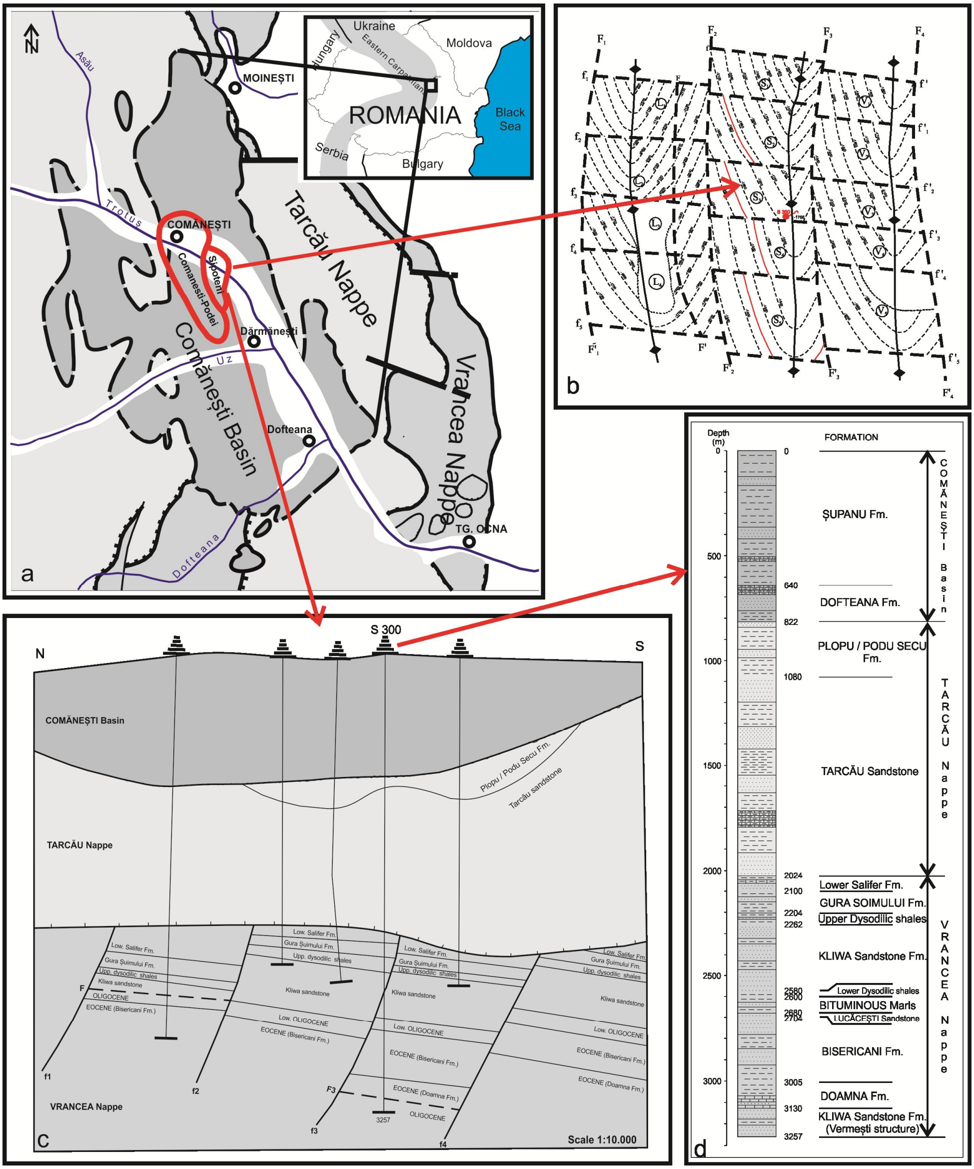


Fig. 1 a) Localization of Comănești-Podei-Șipoteni structural unit within the Comănești Basin; b) Structural sketch of the base of the Gura Șoimului formation in the Șipoteni structure (based on Petrom data, 1999); c) Longitudinal geological section through the Șipoteni structure, with the representation of the S300 well (based on Petrom data, 1998); d) Synthetic column of the S300 well (after Chelariu and Negru, 2014).

Angevine and Turcotte (1983) have proposed a model for the determination of the pole-temperature field in regions affected by thrusts (Fig. 2) based on a series of physical and thermal parameters.

The model relies on the equation of heat transference in an unsteady regime, according to which temperature distribution within thrust nappes may be estimated as follows:

$$T(z,t) = T_0 + \Gamma_T \cdot z + \frac{1}{2} \cdot \Gamma_T \cdot h \cdot \left[\mathrm{erf}\left(\frac{h-z}{2\sqrt{a \cdot t}}\right) - \mathrm{erf}\left(\frac{h+z}{2\sqrt{a \cdot t}}\right)\right] \quad (1)$$

where:

$T(z,t)$ represents the temperature in space and time;
T_0 – the temperature at the surface of the décollement;
Γ_T – the temperature gradient;
z – the thickness from the décollement to the considered point;
h – the thickness of the nappe;
a – the thermal diffusivity coefficient;
erf – the error distribution function.

The model proposed by the authors above can be applied to a 1D analysis, and it involves the instantaneous emplacement of the thrust nappe. In the modeling process, a series of factors are neglected, such as the variation in thermal diffusivity, the convective heat flow through the groundwater, and the heat conduction, which is seen as occuring only vertically. This last hypothesis is based on the fact that the horizontal evolution of a nappe is larger than its thickness, and, thus, the nappe may be regarded as an infinite semi-space.

As shown in equation (1), for the modeling of the temperature field, it is necessary to know the geothermal gradient and the thermal diffusivity.

The geothermal gradient and the surface temperature were determined based on the temperatures registered at various depths within four wells from the Comănești-Podei-Șipoteni structure, including the S300 well, on which the current paper is centered.

Once the value of the geothermal gradient is known, by applying equation (2), the estimation of the formation temperatures at various depths becomes possible:

$$T_z = T_s + \Gamma_T \cdot z \quad (2)$$

where:

T_z represents the temperature at depth “z”;
T_s – the initial temperature at the surface of the soil;
$\Gamma_T = \Delta T/\Delta z$ – the temperature gradient, in other words the temperature variation ΔT with the depth interval Δz.

Thermal diffusivity is the parameter that governs the heat spreading process within the rocks, described by the ratio between thermal conductivity (λ) and thermal capacity ($\rho \cdot c_p$), according to equation (3):

$$a = \frac{\lambda}{c_p \cdot \rho} \quad (3)$$

Thermal conductivity is the capability of a rock to conduct or diffuse heat, depending, among others, on lithology, porosity and temperature (Clauser, 2011). Most sedimentary rocks are composed of a matrix and interstitial space generally saturated with water.

The estimation of conductivity for the lithological formations was carried out in the direction of the known temperature variation (vertically) by applying the harmonic mean model, considering that the strata opened by the borehole are horizontal or semi-horizontal (Beardsmore and Cull, 2001):

$$\lambda_{med} = 1/\sum_{i=1}^{n}\frac{\mu_i}{\lambda_i} \tag{4}$$

where:

λ_{med} is the mean conductivity of the formation;
λ_i – the conductivity of the lithological component “i”;
μ_i – the volume ratio of the lithological component “i”.

For each lithological type within the formations, knowing the porosity of the rocks, the computing equation was applied:

$$\lambda_i = \lambda_s^{1-\phi} \cdot \lambda_f^{\phi} \tag{5}$$

where

λ_i is the conductivity of the lithological type “i”;
λ_s – the conductivity of the matrix;
λ_f – the conductivity of the fluid within the pores.

Temperature corrections for the thermal conductivity values, both for the rock matrix and for the fluid within the pores, were applied based on the geothermal gradient.

For the corrections applied to the matrix, the empirically established equation of Somerton (1992) was used:

$$\lambda(T) = \lambda_{20} - 10^{-3} \cdot (T - 293) \cdot (\lambda_{20} - 1{,}38) \cdot [\lambda_{20} \cdot (1{,}8 \cdot 10^{-3} \cdot T)^{-0{,}25\lambda_{20}} + 1{,}28] \cdot \lambda_{20}^{-0{,}64} \tag{6}$$

where:

$\lambda(T)$ is the thermal conductivity corrected at temperature T;
λ_{20} – the thermal conductivity determined at room temperature (~20°C),
while for the corrections related to the fluids within the pores, the equation proposed by Toulouakian et al. (1970) was employed:

$$\lambda_f = -7{,}42 \cdot 10^{-6} \cdot T^2 + 5{,}99 \cdot 10^{-3} \cdot T - 0{,}5 \tag{7}$$

where:

T is the temperature for which the fluid conductivity correction is required.

Thermal capacity represents the density multiplied by the specific heat, which has an important contribution to the retention of heat by rocks.

Density is strongly related to rock porosity and can be expressed by the following equation:

$$\rho_i = \rho_s \cdot (1 - \phi) + \rho_f \cdot \phi_i \tag{8}$$

where:

ρ_i is the density of the rock “i”;
ρ_s – the density of the matrix;
ρ_f – the density of the fluid within the pores.

As in the case of thermal conductivity, making *in situ* corrections for the temperature was required. For this, the empirical equation obtained by Holman in 1976 (in Waples and Waples, 2004) was used:

$$\rho_f = \rho_{f_{20}} / [1 + (T - 20) \cdot \beta_f] \qquad (9)$$

where

β_f is the coefficient of the water thermal expansion, and can be computed as follows:

$$\beta_f = 2.115 \cdot 10^{-4} + 1.32 \cdot 10^{-6} \cdot T + 1.09 \cdot 10^{-8} \cdot T^2 \qquad (10)$$

Based on the density values of the lithological types within each formation, the densities of the formations as weighted arithmetic means were subsequently computed using the equation:

$$\rho_{med} = \sum_{i=1}^{n} \rho_i \cdot \mu_i \qquad (11)$$

Specific heat was computed using the following equation (Somerton, 1992):

$$c_{p_i} = \frac{\rho_s \cdot c_{p_s} \cdot (1 - \phi) + \rho_f \cdot c_{p_f} \cdot \phi}{\rho_i} \qquad (12)$$

The correction of specific heat for the water within the rock pores at *in situ* temperature was carried out using the empirical law proposed by the same author:

$$c_{p_f} = (4245 - 1{,}841 \cdot T) / \rho_f \qquad (13)$$

The determination of specific heat for the formations was carried out as the arithmetic mean of the heat of the component rocks, weighted with their volume ratio (Clauser, 2011):

$$c_{p_{med}} = \sum_{i=1}^{n} c_{p_i} \cdot \mu_i \qquad (14)$$

Results and discussion

The plotting of the temperature values acquired for the S300 well and three other wells within the area of the structural unit (C1107, S320 and S295, respectively – Tab. 1) based on their corresponding depth yielded the line in Fig. 3, whose equation is the following:

$$T_z = 9.13 + 0.0281 \cdot z \qquad (15)$$

This equation results in a geothermal gradient of 2.81^{o}C/100 m and a surface temperature of 9.13°C, values that allowed the computation of the formation temperatures required to make the corrections of the thermal parameters.

The thermal parameters were estimated based on the back-stripping graph devised for the decompacted lithological column of the S300 well (Chelariu and Negru, 2014), having as marker unit the bituminous marls formation (Fig. 4).

The parameter values for the matrix and the fluid within the pores (saline water in this case) used in the computations are provided in Table 2. The mean density of the formation water (at room temperature) was mathematically estimated through the correlation of the density values for the contents with NaCl obtained from the analysis of reservoir waters collected from different wells at the time of their drilling (Fig. 5).

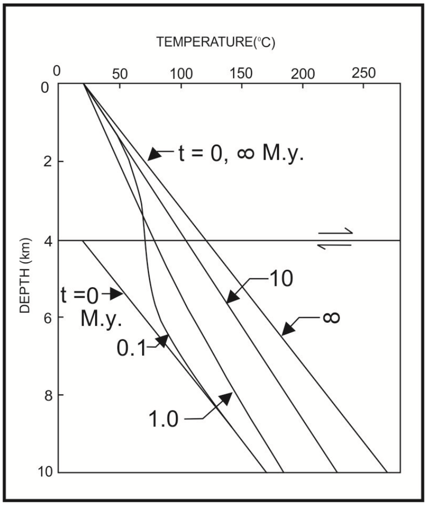


Fig. 2 Model of the temperature profile of the thrust plate several times after emplacement, for a plate thickness of 4 km and a thermal diffusivity of $5\cdot10^{-3}$ cm^2/s (after Angevine and Turcotte, 1983).

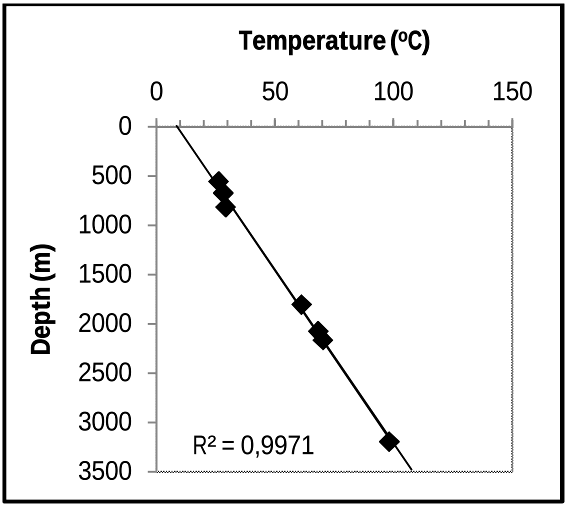


Fig. 3 Determination of the geothermal gradient for the Comănești-Podei-Șipoteni structural unit, based on the temperature values registered within the wells.

Tab. 1 The temperature-depth pairs registered within the wells

Well	Temperature within the well (°C)	Depth of the record (m)	Surface temperature (°C)	Geothermal gradient Γ_T (°C/100m)
C1107	26	549	9.13	2.81
C1107	28	667		
C1107	29	809		
S320	61	1800		
S320	68	2070		
S295	70	2160		
S300	98	3192		

The back-stripping graph in Figure 6 shows the values computed for the thermal parameters of the lithological units during each burial stage, after the corrections associated with the *in situ* conditions had been made. By compiling these values and weighting them with the thickness of the lithological units, a mean thermal diffusivity value of $5.67\cdot10^{-3}$ cm^2/s resulted for the entire burial period of the marker unit (the bituminous marls formation).

Tab. 2 The values of the thermal parameters for the matrix and the interstitial water used in the present study (after Yalçin et al., 1997, Boutmani et al., 2007; Beardsmore and Cull, 2001; Demetrescu et al., 2007; Kappelmayer and Haenel, 1974; Ionescu, 2000)

	Thermal conductivity (W/m/K)	Heat capacity (kJ/kg/K)	Density (g/cm^3)
Shale	1.98	0.933	2.720
Sandstone	4.4	0.824	2.650
Marl	3.2	0.916	2.715
Water	0.6	-	1.088

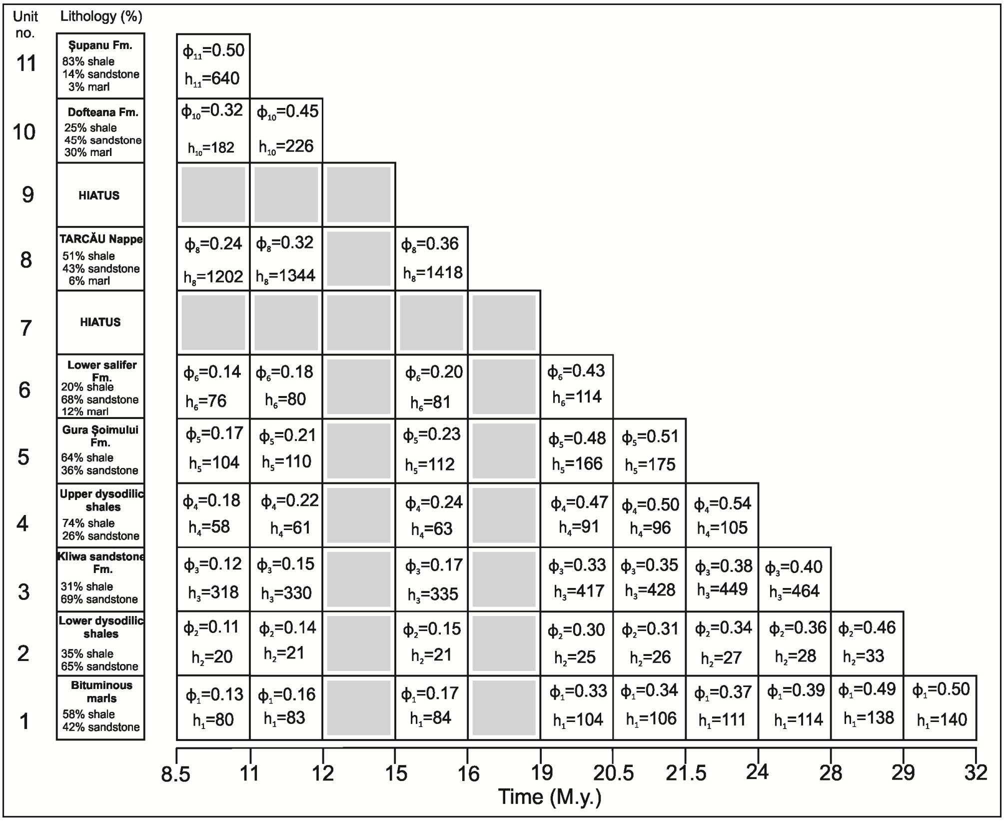


Fig. 4 Back-stripping diagram for the decompacted formations opened by the S300 well (after Chelariu and Negru, 2014).

Although this method of parameter estimation cannot be entirely trusted due to the lack of direct *in situ* or laboratory measurements, the thermal diffusivity value obtained using this mathematical simulation is not only comparable with that used by Angevine and Turcotte (1983) in their paper ($5\cdot10^{-3}$ cm^2/s), but also with the mean value for the first 50 km of the terrestrial lithosphere ($6\cdot10^{-3}$ cm^2/s, after Airinei, 1987). This has led us to believe that the estimate of the diffusivity could be used in the analysis of the impact of the thrust upon the evolution of the thermal field without the risk of introducing significant errors.

NaCl [g/l]	$\rho_{w\,20}$ [Kg/m^3]
0.0	1022.0
87.6	1069.5
94.9	1073.5
119.5	1086.8
136.1	1095.7
136.8	1096.1
161.7	1109.6
86.3	1068.8
126.4	1090.5
138.0	1096.8
143.5	1099.8
144.6	1100.4
149.9	1103.2
151.7	1104.2
156.8	1107.0
Average = 122.3	**$\rho_{w\,20}$ = 1088.3**

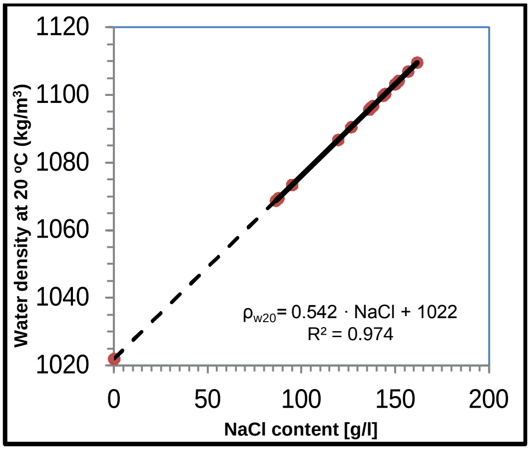
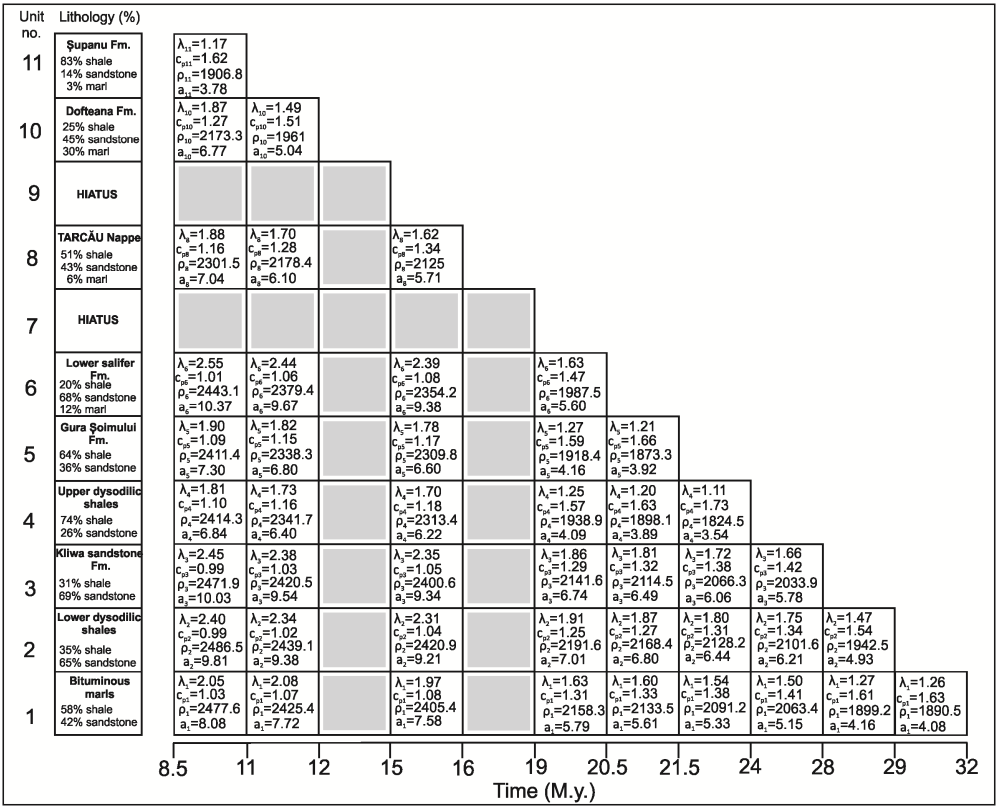


Fig. 5 The estimation of the mean density of the interstitial water at room temperature (20°C) based on the analysis of the water samples collected from the wells drilled within the area of the Șipoteni structure.



Unit no.	Lithology (%)											
11	**Șupanu Fm.** 83% shale 14% sandstone 3% marl	$\lambda_{11}=1.17$ $c_{p11}=1.62$ $\rho_{11}=1906.8$ $a_{11}=3.78$										
10	**Dofteana Fm.** 25% shale 45% sandstone 30% marl	$\lambda_{10}=1.87$ $c_{p10}=1.27$ $\rho_{10}=2173.3$ $a_{10}=6.77$	$\lambda_{10}=1.49$ $c_{p10}=1.51$ $\rho_{10}=1961$ $a_{10}=5.04$									
9	**HIATUS**											
8	**TARCĂU Nappe** 51% shale 43% sandstone 6% marl	$\lambda_{8}=1.88$ $c_{p8}=1.16$ $\rho_{8}=2301.5$ $a_{8}=7.04$	$\lambda_{8}=1.70$ $c_{p8}=1.28$ $\rho_{8}=2178.4$ $a_{8}=6.10$		$\lambda_{8}=1.62$ $c_{p8}=1.34$ $\rho_{8}=2125$ $a_{8}=5.71$							
7	**HIATUS**											
6	**Lower salifer Fm.** 20% shale 68% sandstone 12% marl	$\lambda_{6}=2.55$ $c_{p6}=1.01$ $\rho_{6}=2443.1$ $a_{6}=10.37$	$\lambda_{6}=2.44$ $c_{p6}=1.06$ $\rho_{6}=2379.4$ $a_{6}=9.67$		$\lambda_{6}=2.39$ $c_{p6}=1.08$ $\rho_{6}=2354.2$ $a_{6}=9.38$		$\lambda_{6}=1.63$ $c_{p6}=1.47$ $\rho_{6}=1987.5$ $a_{6}=5.60$					
5	**Gura Șoimului Fm.** 64% shale 36% sandstone	$\lambda_{5}=1.90$ $c_{p5}=1.09$ $\rho_{5}=2411.4$ $a_{5}=7.30$	$\lambda_{5}=1.82$ $c_{p5}=1.15$ $\rho_{5}=2338.3$ $a_{5}=6.80$		$\lambda_{5}=1.78$ $c_{p5}=1.17$ $\rho_{5}=2309.8$ $a_{5}=6.60$		$\lambda_{5}=1.27$ $c_{p5}=1.59$ $\rho_{5}=1918.4$ $a_{5}=4.16$	$\lambda_{5}=1.21$ $c_{p5}=1.66$ $\rho_{5}=1873.3$ $a_{5}=3.92$				
4	**Upper dysodilic shales** 74% shale 26% sandstone	$\lambda_{4}=1.81$ $c_{p4}=1.10$ $\rho_{4}=2414.3$ $a_{4}=6.84$	$\lambda_{4}=1.73$ $c_{p4}=1.16$ $\rho_{4}=2341.7$ $a_{4}=6.40$		$\lambda_{4}=1.70$ $c_{p4}=1.18$ $\rho_{4}=2313.4$ $a_{4}=6.22$		$\lambda_{4}=1.25$ $c_{p4}=1.57$ $\rho_{4}=1938.9$ $a_{4}=4.09$	$\lambda_{4}=1.20$ $c_{p4}=1.63$ $\rho_{4}=1898.1$ $a_{4}=3.89$	$\lambda_{4}=1.11$ $c_{p4}=1.73$ $\rho_{4}=1824.5$ $a_{4}=3.54$			
3	**Kliwa sandstone Fm.** 31% shale 69% sandstone	$\lambda_{3}=2.45$ $c_{p3}=0.99$ $\rho_{3}=2471.9$ $a_{3}=10.03$	$\lambda_{3}=2.38$ $c_{p3}=1.03$ $\rho_{3}=2420.5$ $a_{3}=9.54$		$\lambda_{3}=2.35$ $c_{p3}=1.05$ $\rho_{3}=2400.6$ $a_{3}=9.34$		$\lambda_{3}=1.86$ $c_{p3}=1.29$ $\rho_{3}=2141.6$ $a_{3}=6.74$	$\lambda_{3}=1.81$ $c_{p3}=1.32$ $\rho_{3}=2114.5$ $a_{3}=6.49$	$\lambda_{3}=1.72$ $c_{p3}=1.38$ $\rho_{3}=2066.3$ $a_{3}=6.06$	$\lambda_{3}=1.66$ $c_{p3}=1.42$ $\rho_{3}=2033.9$ $a_{3}=5.78$		
2	**Lower dysodilic shales** 35% shale 65% sandstone	$\lambda_{2}=2.40$ $c_{p2}=0.99$ $\rho_{2}=2486.5$ $a_{2}=9.81$	$\lambda_{2}=2.34$ $c_{p2}=1.02$ $\rho_{2}=2439.1$ $a_{2}=9.38$		$\lambda_{2}=2.31$ $c_{p2}=1.04$ $\rho_{2}=2420.9$ $a_{2}=9.21$		$\lambda_{2}=1.91$ $c_{p2}=1.25$ $\rho_{2}=2191.6$ $a_{2}=7.01$	$\lambda_{2}=1.87$ $c_{p2}=1.27$ $\rho_{2}=2168.4$ $a_{2}=6.80$	$\lambda_{2}=1.80$ $c_{p2}=1.31$ $\rho_{2}=2128.2$ $a_{2}=6.44$	$\lambda_{2}=1.75$ $c_{p2}=1.34$ $\rho_{2}=2101.6$ $a_{2}=6.21$	$\lambda_{2}=1.47$ $c_{p2}=1.54$ $\rho_{2}=1942.5$ $a_{2}=4.93$	
1	**Bituminous marls** 58% shale 42% sandstone	$\lambda_{1}=2.05$ $c_{p1}=1.03$ $\rho_{1}=2477.6$ $a_{1}=8.08$	$\lambda_{1}=2.08$ $c_{p1}=1.07$ $\rho_{1}=2425.4$ $a_{1}=7.72$		$\lambda_{1}=1.97$ $c_{p1}=1.08$ $\rho_{1}=2405.4$ $a_{1}=7.58$		$\lambda_{1}=1.63$ $c_{p1}=1.31$ $\rho_{1}=2158.3$ $a_{1}=5.79$	$\lambda_{1}=1.60$ $c_{p1}=1.33$ $\rho_{1}=2133.5$ $a_{1}=5.61$	$\lambda_{1}=1.54$ $c_{p1}=1.38$ $\rho_{1}=2091.2$ $a_{1}=5.33$	$\lambda_{1}=1.50$ $c_{p1}=1.41$ $\rho_{1}=2063.4$ $a_{1}=5.15$	$\lambda_{1}=1.27$ $c_{p1}=1.61$ $\rho_{1}=1899.2$ $a_{1}=4.16$	$\lambda_{1}=1.26$ $c_{p1}=1.63$ $\rho_{1}=1890.5$ $a_{1}=4.08$

Fig. 6 Back-stripping diagram with the thermal parameters calculated for the formations of the S300 well.

Thus, knowing the geothermal gradient and the mean thermal diffusivity, the simulation of the influence of the thrust over the thermal regime of the two nappes was carried out using the model proposed by Angevine and Turcotte (1983).

The analysis suggested a rapid initiation of the thrust of the Tarcău and Vrancea nappes about 16 Ma and, for the post-thrust evolution stage, in modelling the temperature field, the thermal effects of the overlapping were included.

For the pre-thrust stage, the temperature isolines (for 10°C intervals) computed based on the geothermal gradient were overlapped onto the burial curve of the bituminous marls formation from the Vrancea Nappe (Chelariu and Negru, 2014). This was necessary in order to highlight the great degree of the impact of the thrust upon the thermal field.

At the time of the thrust, the overlapping of two different thermal fields most likely took place. Specifically, the rocks from the base of the Tarcău Nappe, with a higher temperature, were placed on top of the sediments from the upper part of the Vrancea Nappe, triggering the heating of the latter.

In order to employ the thermal equation of the heat (equation (1)) so as to carry out the proposed modelling, it was necessary to establish the parameters involved in the computation of the temperatures (the initial thickness of the nappe, the initial depth of the marker unit underneath the décollement, the thermal diffusivity coefficient, the thermal gradient, the temperature at the surface of the décollement and the time of the thrust).

The surface temperature at the time of the thrust was approximated using the map in Figure 7 (from Hanschel and Kauerauf, 2009), considering the appropriate geological time and the latitude of the interest area. Thus, for the moment regarded as the initiation of the thrust, a surface temperature of 14°C was estimated. Knowing this temperature and the geothermal gradient, and estimating the initial thickness of the Tarcău Nappe (for the studied area), based on the analysis of the burial history, as being around 2.5 km, a temperature of the décollement of $T_0 = 84.25^{o}C$ results. The decompacted depth of the bituminous marls marker formation related to the décollement (z) was established as 914 m at the moment of the thrust (according to the back-stripping graph).

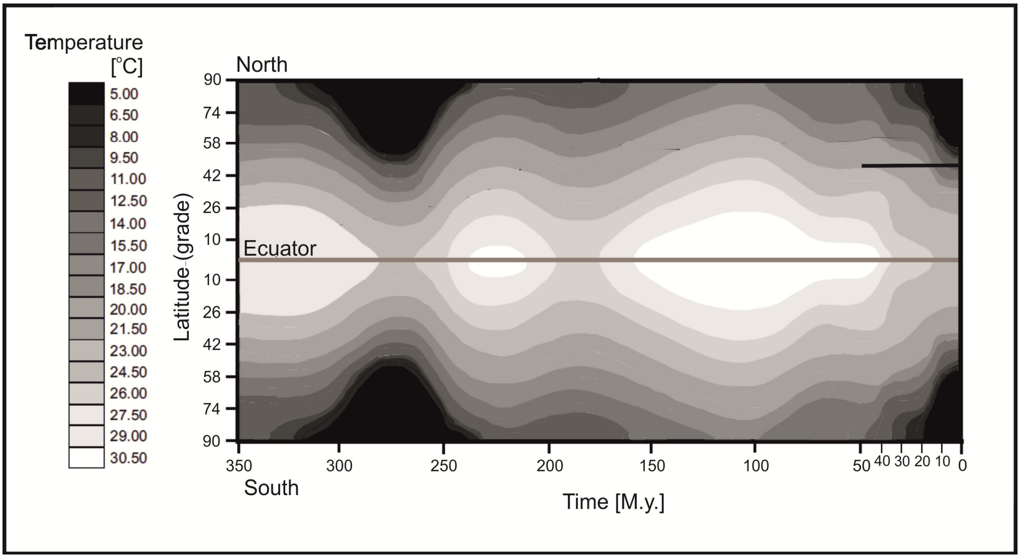


Fig. 7 Surface paleo-temperature map (from Hanschel and Kauerauf, 2009); the black line indicates the approximate latitude for the studied area).

Given that the most important changes in the thermal regime took place over a quite short time interval after the thrust, the plotting of the temperatures for this time period on top of the burial curve may generate interpretation difficulties (Edman and Surdam, 1984). Consequently, we calculated the temperature values at various stages during the first million years after the thrust. The computed temperatures were grouped in Table 3, while the trend curve for the time interval is provided in Figure 8.

Tab. 3 Temperature values T for the marker formation at different stages after the thrust (S300 well)

z (m)	914						
t (M.a.)	0.01	0.1	0.2	0.4	0.6	0.8	1
T (^{o}C)	109.65	98.31	97.59	99.1	100.42	101.38	102.11

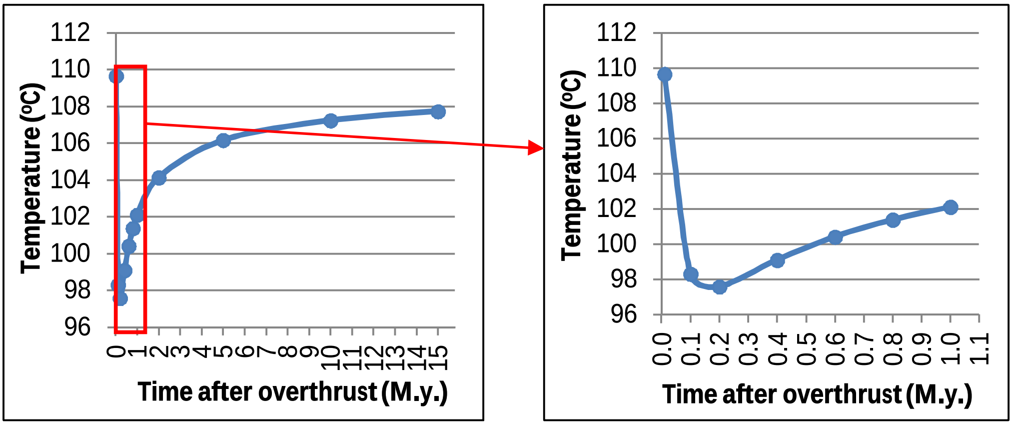


Fig. 8 Evolution of marker unit temperature for the 15 My after the thrust, with details for the 1st million years.

At first sight, we notice that the highest temperature corresponds to 0.01 My after the thrust, then a sudden decrease occurs, followed by an increase with a quite constant gradient. When interpreting the curve reflecting the evolution of temperatures for the considered point during the 15 My after the thrust, we notice, however, that the disturbance of the thermal regime took place mostly throughout the first million years.

Although, according to the proposed model, the bituminous marls formation was placed within a temperature range favorable for the maturation of source rocks (97.59–102.11°C), we cannot determine whether this maturation took place after the thrust, given that the period during which the temperature anomalies triggered by the thrust manifested themselves was quite short.

After the thrust occurred, the burial curve of the marker formation followed different trajectories over time, its evolution being influenced by the erosion of the Tarcău Nappe, the deposition of the Comănești Basin, and, again, by erosion. Consequently, the marker unit analyzed did not have an evolution at a constant depth, thus requiring the overlapping of the modified isotherms onto the burial curve (Fig. 9). These were traced by joining the points of equal temperatures at various time intervals after the thrust (0.01; 0.1; 0.2; 0.5; 1; 2; 5; 10 and 15 My). However, we observed, again, that the variations of the temperature isolines due to the thrust did not have play a significant role.

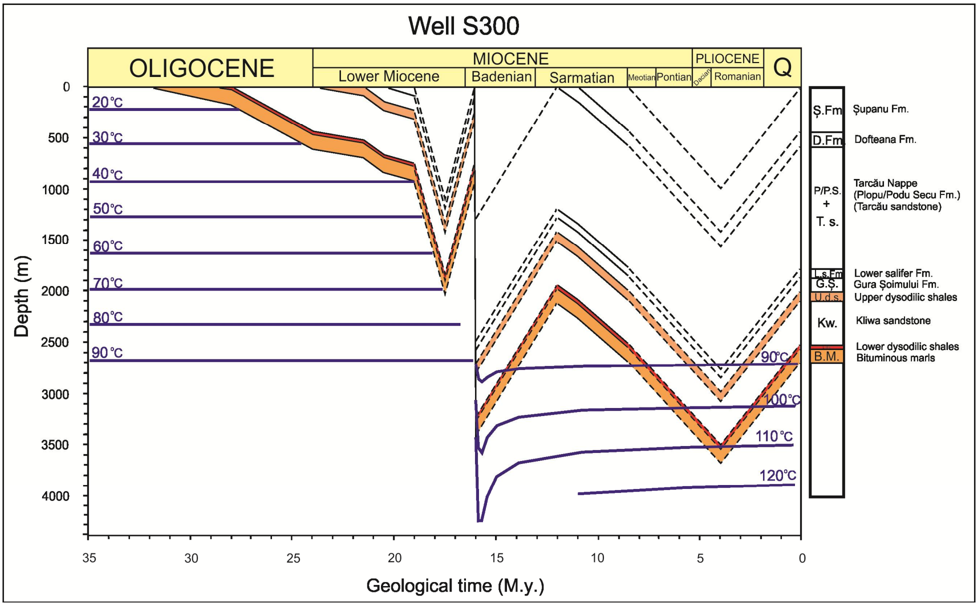


Fig. 9 Temperature isolines overlapping the burial curves of the formations opened by the S300 well, with emphasis on the anomalies caused by the thrust of the Tarcău Nappe (modified after Chelariu and Negru, 2014).

Conclusions

Thrusting is considered by many researchers as an important factor in the triggering of disturbances in the thermal regime of sedimentary basins. Based on the intensity of the disturbances, the thrust may influence the evolution of the maturation degree of the source rocks within the underthrust nappe.

The present paper is based on a 1D simulation of the evolution of the thermal field, meant to aid in the establishing of the degree of the influence of the thrust over this field.

The one-dimensional analysis carried out on the Oligocene source rocks of the Vrancea Nappe accessed by the S300 well (Șipoteni structure) revealed that, although the thrust did trigger a rise in temperatures, this increase does not appear to have been great enough so as to become decisive in the hydrocarbon generation process, at least for the studied area or well.

The thickness of the thrust nappe plays an important role in this process, as well. However, the thickness of the Tarcău Nappe within the area of the Șipoteni structure was, again, most likely not large enough to become a decisive factor. Nevertheless, the thickness of this Outer Flysch nappe increases from the east to the west and it is possible that, in other areas, it may have influenced the process of hydrocarbon generation.

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