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AUI GEOLOGIE

Subsidence analysis of the Getic Depression on Totea-Vladimir structure

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Abstract

The aim of the present study is the subsidence and the evolution analysis of the sedimentary basin related to the Getic Depression over the geological time and within the Totea-Vladimir structure area. In order to achieve the basin subsidence modeling, both information resulting from digging four wells on structure and a series of seismic profiles were used.
The results indicate that in the studied area, during the evolution of the sedimentary basin, there were two main periods of increased subsidence, such as Burdigalian and Sarmatian-Meotian. The first period corresponds to an extensional stage while the second one corresponds to a basin developed on strike-slip faults.

Keywords: Totea-Vladimir structure, subsidence, backstripping, Getic Depression.

1. Introduction

From a geographical point of view, Totea-Vladimir structure belongs to the west-central region of the Getic Piemont, located in the south-eastern part of Gorj County (Romania), within Hurezani and Licurici localities (Fig. 1).

In geological terms, the structure corresponds to the west-central part of the Getic Depression (Fig. 2), and its drilled wells revealed significant gas-bearing deposits belonging to the Romanian-Burdigalian period.

The constant interest for discovering new hydrocarbon accumulations has led over the years to the study of the Getic Depression geological formations by different researchers from both the specialised industry and the academic world.

In the present paper, a modeling of the geological formations subsidence was developed in the Totea-Vladimir structure area through data analysis and interpretation resulting from the drilling of four wells and their correlation with the available seismo-stratigraphic profiles.

2. Geology of the Getic Depression

The Getic Depression represents a fore-deep basin that has developed in response to the Moesian Platform flexure at the contact with the Meridional Carpathians orogeny. In

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terms of geology, the Getic Depression deposits are separated in the north by the tertiary transgression limit (where post-tectonic sediments cover the structure of the inner part of the Southern Carpathians) while in the south, the surface projection of the disconnecting Miocene age plan (Pericarpathian Fault) is in contact with the Moesian platform (Maţenco et al., 1997a). The eastern limit is given by the northward prolongation of the Intramoesian Fault, which separates the Getic Depression deposits from the Eastern Carpathians nappes, whereas the Danube River represents the western boundary (Fig. 2).

3. Stratigraphy

According to Mutihac and Mutihac (2010), the Getic Depression has functioned as a sedimentary basin since the Palaeogene and until the Quaternary, with the deposition of Frăţeşti Formation. Within these deposits with a thickness of approximately 6000 m (Răbăgia and Maţenco, 1999) form part two discontinuities, one of the Lower Miocene age (old Styrian movements) and another belonging to the Lower Sarmatian (Moldavian movements). These discontinuities have delimited three cycles of sedimentation during the evolution of the depression (Mutihac and Ionesi, 1974; Maţenco et al., 1997b; Răbăgia and Maţenco, 1999): the Palaeogene cycle, ending in the Lower Burdigalian, Burdigalian-Lower Sarmatian cycle and Sarmatian-Pliocene cycle.

The Carpathian foreland begins its geological evolution with sediments during the Late Cretaceous to Palaeogene times (Maţenco et al., 1997b), consisting of a clastic sequence represented by an external sedimentary facies that cannot be named either flysch or molasse since the sedimentation of these sequences is synchronous with the flysch sedimentation in the Eastern Carpathians, but they have the molasse appearance in the Meridional Carpathians (Jipa, 1980). The Palaeogene deposits are transgressively disposed over the Late Cretaceous and they have a variable thickness, around 2.000 m, indicating an active subsidence which contributed to the opening of the Getic basin.

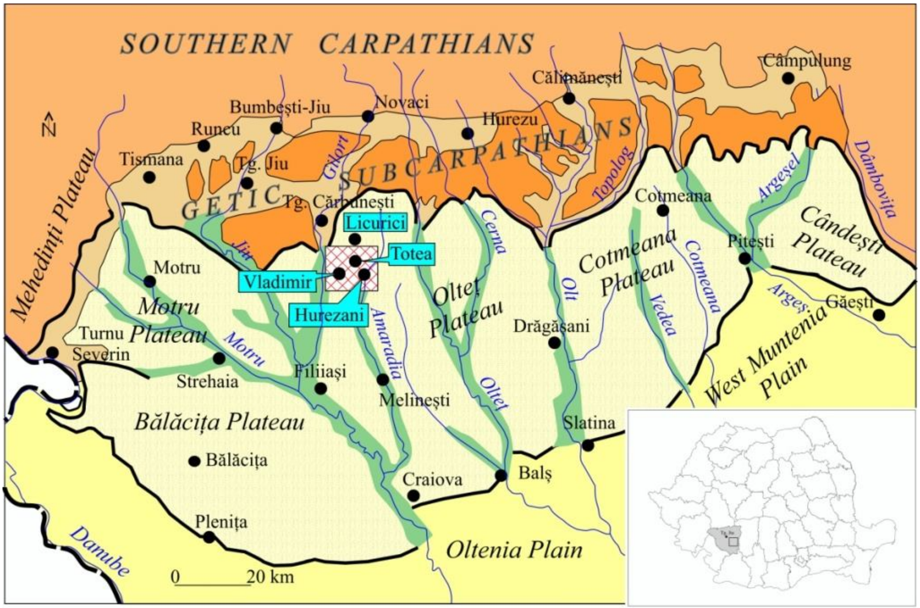

Fig. 1 Location of the study area (according to Badea et al., 2010, with amendments).

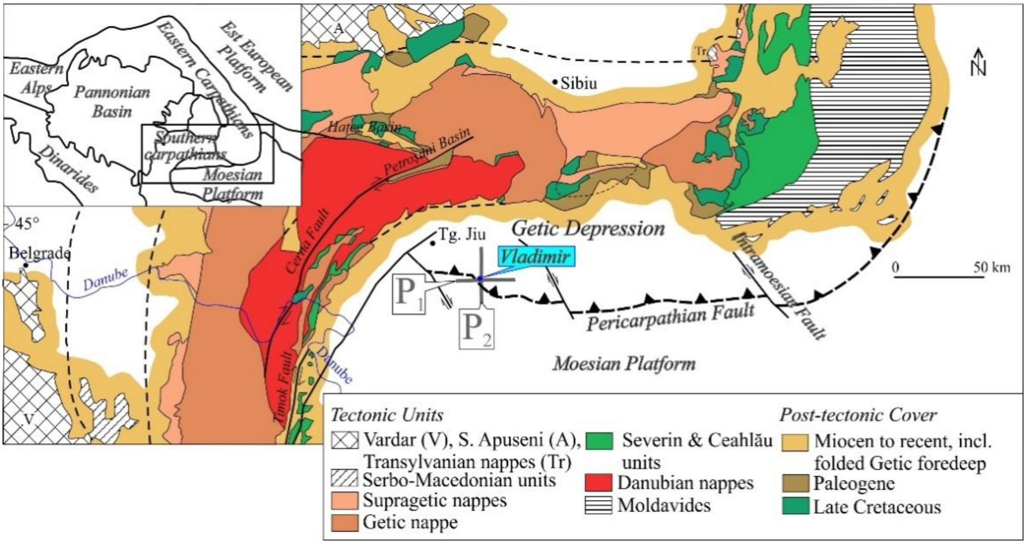

Fig. 2 Structural map of the Getic Depression in relation to the Meridional Carpathians and the Moesian Platform. P1-P2 lines indicate the seismic profiles (according to Săndulescu, 1984; Maţenco et al., 1997b, with amendments).

According to Ştefănescu et al. (2006), the Palaeogene deposits begin with a thick pile of marine polymictic conglomerates interspersed with sandstones layers that have the Dacides as the source area. These conglomerates grade into sandstones alternating with grey marls on the lateral flanks (Fig. 3).

Eocene formations have a thickness of about 2000 m and are formed in the northern part of the depression from a clastic sequence of polymictic conglomerates alternating with sandstones, clays and marls (Olaru and Roban, 2007).

The Oligocene cycle developed in the northern part of the depression in a roughly clastic sequence with a thickness of 200 m, alternating with a fine one, which in the Argeș Valley has a thickness of 200–600 m (Olaru and Roban, 2007) and consists of clays, menilites and sandstones. In the southern part, there are different sequences with a thickness of 500–1500 m represented by alternations of sandstones/sands, marls, shales, with limestones and conglomerates interlayers.

The deposits accumulated within the Aquitanian-Lower Burdigalian have a thickness of 150–500 m and consist of a detritic sequence of conglomerates, sandstones, shales, marls and a evaporitic sequence (Olaru and Roban, 2007) consisting of gypsum/anhydrite and salt represented by the Lower Salty Formation. This is the sedimentation continuity over Oligocene and it was intercepted by the wells drilled between Olt and Jiu rivers, at Colibași, Prigoria, Govora, Băileni and Bustuchini (Mutihac and Mutihac, 2010). Due to the sedimentation effect on a regressive background, the depositional environment was considered to be proximal-coastal and lagoon-restrictive.

Miocene sedimentary cycle is mainly composed of clastic deposits (Răbăgia and Maţenco, 1999), the massive base sediments being gradually replaced by finer sediments. The Lower Miocene is characterized by accumulations of conglomerates up to 2000 m thick followed by about 500 m of finer marine deposits.

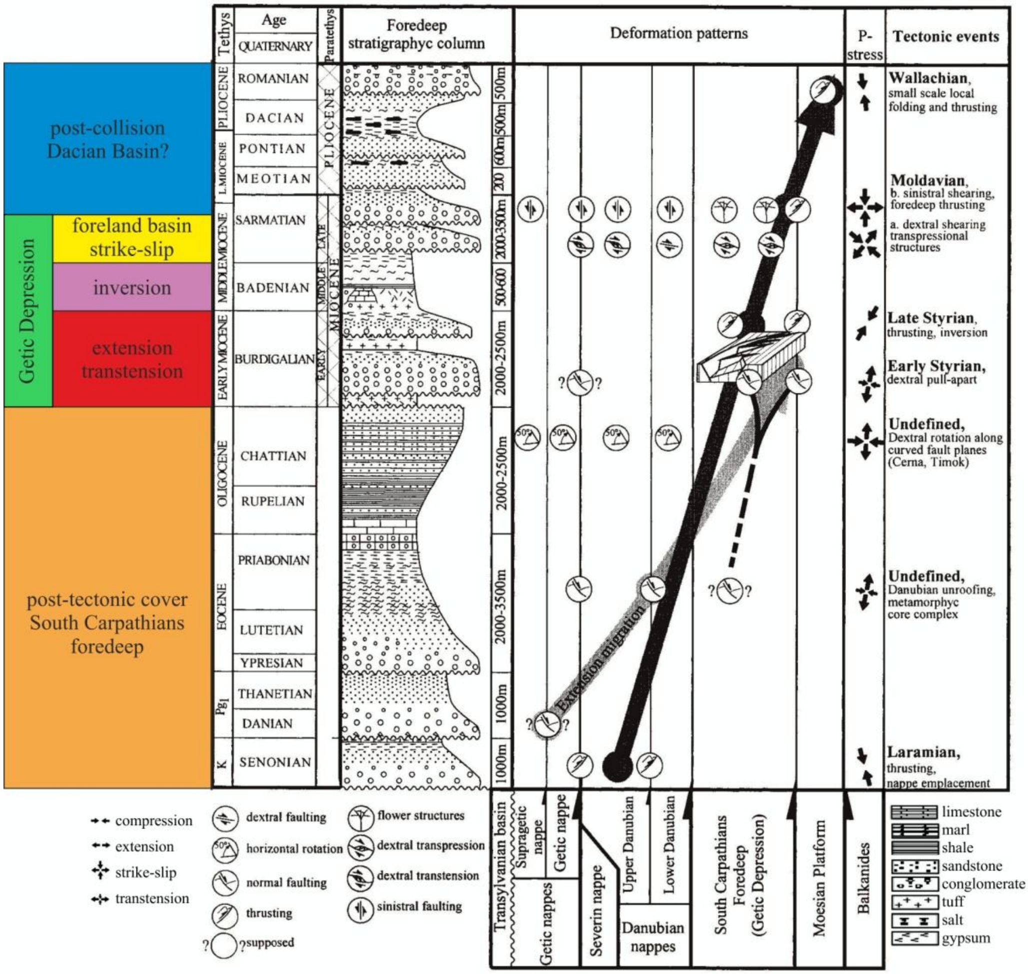

Fig. 3 Lito-stratigraphic column and the correlation of Tertiary tectonic events (according to Răbăgia and Maţenco, 1999, with additions).

Mățău Formation (Middle-Upper Burdigalian) is in continuous sedimentation over Sărata Formation, and the crossover can be observed through a transition from sandstones and gray marls of Sărata Formation to the reddish conglomerates of Mățău Formation (Olaru and Roban, 2007).

The Upper Burdigalian sediments succeed a regional disparity that can be observed on both seismic profiles (Răbăgia and Maţenco, 1999) and within the outcrops. These deposits reach a thickness of 1000–2000 m, in the northern part, consisting of a succession of rough based sequences (conglomerates, sandstones) and upper finer sequences (sands, sandstones and marls). In the southern part, the deposits of this range consist of lithic sandstones, marls, clays and conglomerates. According to Olaru and Roban (2007), these deposits characterize a proximal-coastal environment, perhaps continental-alluvial conditions (in the north), and a distal environment (in the south).

The last cycle of sedimentation includes clastic deposits with a thickness of approximately 2000 m (Răbăgia and Maţenco, 1999), covering the distorted foredeep. The deposits' series of the Getic Depression ends with the Lower Sarmatian deposits, and the sediments deposited later on are part of the Dacian Basin (Jipa, 2006), which has a much greater expansion since the Getic Depression area is under its central-western section.

4. Tectonic model

The Getic Depression represents a sedimentary basin whose tertiary development was interpreted by Săndulescu (1984) as being of a simple foredeep model developed in front of the Meridional Carpathians, but recent works (Maţenco et al., 1997b; Maţenco and Schmid, 1999; Răbăgia and Maţenco, 1999; Tărăpoancă, 2004; Tărăpoancă et al., 2007) indicate a more complex tectonic evolution. According to the authors of these works, the Getic Depression is a complex sedimentary basin (Getic Basin), in whose evolution one could distinguish several tectonic stages (Fig. 3).

A first step characterizes the Palaeogene period (Laramic movements) - Lower Miocene, and it is a foredeep stage (post-tectonic cover) as it was also interpreted by Săndulescu (1984).

In the second stage of the evolution (Lower Miocene), Răbăgia and Maţenco (1999) revealed a transtensional basin characterized by extension/transtension movements from NW-SE to N-S and the syntectonic sedimentation of deposits belonging to the Lower Burdigalian.

The new Styrian movements of the Middle Miocene (Upper Burdigalian - Badenian) led to the development of a reverse fault system and contractions in the NE-SW direction, the above-mentioned authors pointing out, at this stage, the syntectonic sedimentation of the Upper Burdigalian and the salt-containing deposits of the Badenian.

The fourth stage, resulting from the Moldavian movements (Upper Miocene), is characterized by a dextral displacement along NW-SE and by mounting the Getic Depression deposits over those of the Moesian Platform. At the same time, in this stage occurs the syntectonic sedimentation of deposits belonging to the Lower Sarmatian, followed by the emplacement of the Subcarpathian Nappe (Middle Sarmatian).

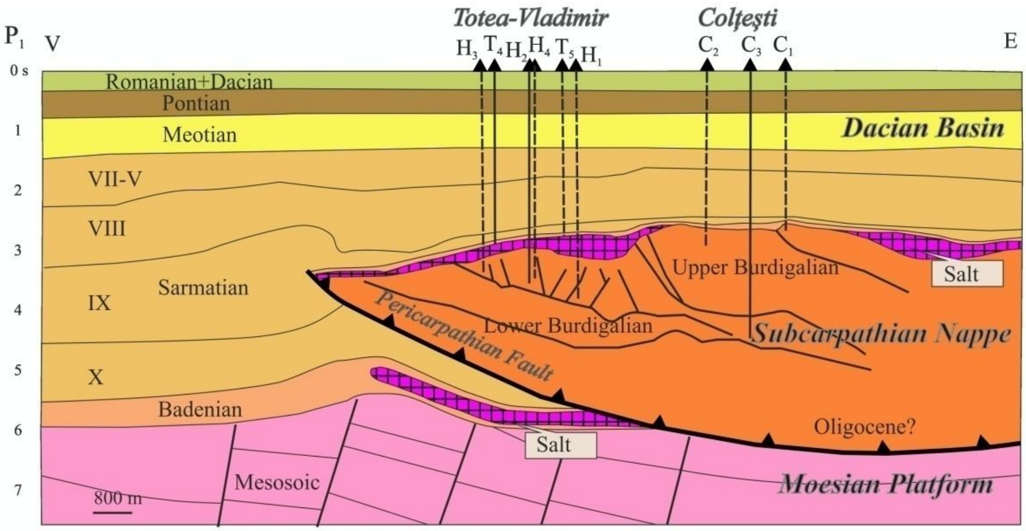

Fig. 4 Location of Totea-Vladimir structure (location shown in Fig. 2; OMV-Petrom archive).

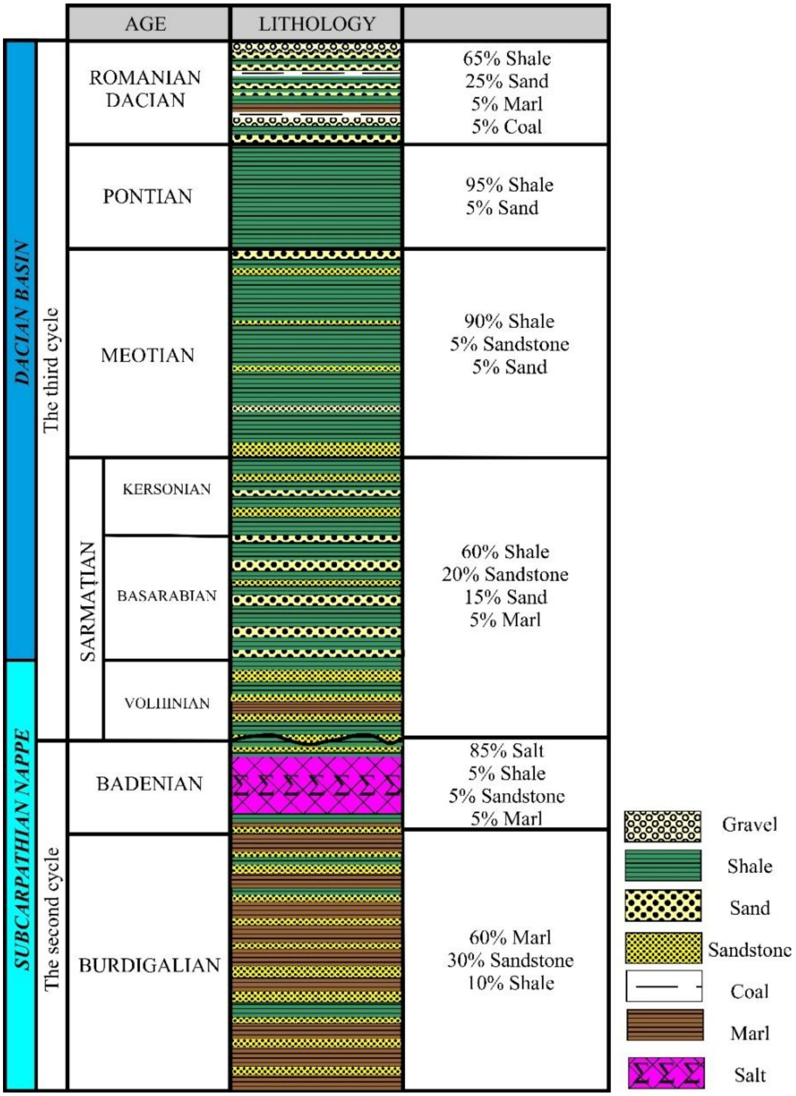

Fig. 5 Lithological column of deposits provided by the Burdigalian-Romanian period, within Totea-Vladimir structure.

The last stage (Upper Sarmatian - Romanian) is characterized by Jipa (2006) as a post-collision stage (post-tectonic cover - Dacian Basin).

5. Totea-Vladimir Structure

Totea-Vladimir is a gas structure located in the front of Subcarpathian Nappe (Fig. 4).

In stratigraphic terms, the wells drilled on the Totea-Vladimir structure opened sedimentary deposits belonging to the Burdigalian - Romanian period, which were separated into two major units (Fig. 5): The Subcarpathian Nappe (Middle Burdigalian-Sarmatian) and the Dacian Basin (Upper Sarmatian-Romanian).

Although the Oligocene has not been intercepted in drillings, it is assumed that in the catchment area, they find themselves in the bottom part of the Burdigalian sediments.

The Lower Burdigalian deposits were correlated with Sărata Formation (Aquitanian-Lower Burdigalian) which outcrops on the Argeș Valley and has a thickness that vary between 75 and 100 m (Olaru and Roban, 2007) and consists of sands, sandstones, clays and marls interspersed with evaporites (gypsum and anhydrite).

The Upper Burdigalian follows the continuity of sedimentation, being correlated with the Mățău Formation (Middle-Upper Burdigalian) that outcrops on the Argeș Valley. In these outcrops, Olaru and Roban (2007) indicate the transition from the sandstones and gray marls of Sărata Formation to the reddish conglomerates of Mățău Formation, consisting of gravels, sandstones and pelites. The authors also highlight the good reservoir rocks qualities of these deposits.

On Totea-Vladimir structure, the Badenian's thickness varies between 50 and 160 m and it consists predominantly of salt deposits.

The Sarmatian has at its base a sandstone-sandy facies, alternating with gray marls, followed by marly facies and sands.

The Meotian age consists of clays with intercalations of sands, while the deposits belonging to the Romanian-Dacian period are known as predominantly sandy accumulations, poorly consolidated with coal alternations.

In tectonic terms, since the Lower Miocene period, it has been developed a transcurrent basin characterized by the presence of a major thetic fault (in the northern part) associated with a series of antithetic faults as can be observed in Figure 6.

The Lower Miocene basin evolution was influenced by the NNE rotation of the Carpathians and the Moesian Platform subduction under the orogen, movements that led to the development of the extensional fault systems.

During the Middle Miocene, the compression movements have led to the reactivation of certain reverse faults, while the Sarmatian period was characterized by transpressional movements.

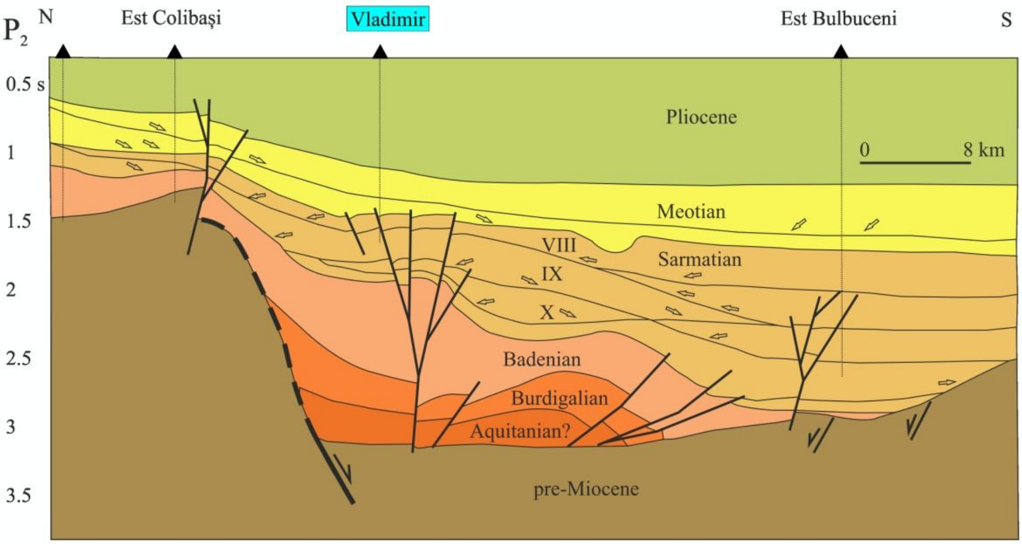

Fig. 6 Seismic Profile (P_2) in the central-western part of the Getic Depression (location shown in Figure 2, according to Răbăgia and Maţenco, 1999).

6. Subsidence analysis on Totea-Vladimir structure area

In order to estimate the burial depths of the geological formations, the backstripping method (Watts and Ryan, 1976) has been applied. This process allowed the thickness reconstruction of the formations opened by wells on the structure's area, at various stages during the geological evolution by the progressive removal of sediment loading.

The burial depth of sediments (S) was calculated by summing up the decompacted sediment thickness which was determined according to the geological time using the formula:

$$h_{i-1} = h_i \cdot e^{\frac{t_{i-1}-t_i}{t_n-t_0} \cdot \ln\frac{1-\phi_0}{1-\phi_n}} \tag{1}$$

where: h_{i-1} is the decompacted depth interval (m);

h_i – depth interval of interest to be decompacted (m);

t_i and t_{i-1} – geological timescales corresponding to h_i and h_{i-1} intervals (My);

t_n – maximum geological age (My);

t_0 – minimum geological age (My);

ϕ_0 – initial surface porosity;

ϕ_n – adequate porosity for final decompaction.

Summing up the decompacted thicknesses, the burial depths of sediments have been calculated using the following equation:

$$S = \sum h_i \tag{2}$$

Since no information was available on the paleobathymetry of the study area, this parameter was neglected.

The thickness of the unit for the hiatus period was estimated according to the model proposed by Badley (1987).

In order to highlight the sedimentary effect on the basin's subsidence of the struc-ture area and to calculate the compaction of sediments based on acoustic logging diagraphies, it was estimated the variation of rock porosity with depth using the equation (Athy, 1930):

$$\phi_i = \phi_0 \cdot e^{-c \cdot z_i} \tag{3}$$

where: ϕ_i is the rock porosity at z_i depth;

ϕ_0 – surface porosity;

c – compaction coefficient (m^{-1});

z_i – depth (m).

The porosity assessment based on the acoustic logging data was provided according to the methodology proposed by Raiga-Clemenceau et al. (1988), which takes into consideration the transit time and the matrix of the rock, as in the formula:

$$\frac{\Delta t_m}{\Delta t} = (1-\phi)^x \tag{4}$$

where: ϕ is the porosity;

Δt_m – matrix interval transit time;

Δt – acoustic diagraphy time of the well's geophysical logging, at the considered depth;

x – exponent of 2.19 (according to Issler, 1992).

Using the equation (4), the porosity may be expressed as follows:

$$\phi = 1 - \left(\frac{\Delta t_m}{\Delta t}\right)^{\frac{1}{x}} \tag{5}$$

The transit time in the matrix of the rock varies depending on the volume of clay:

$$\Delta t_m = (1 - V_{sh}) \cdot \Delta t_{ss} + V_{sh} \cdot \Delta t_{sh} \tag{6}$$

where: Δt_{ss} and Δt_{sh} are the transit time in sandstone (*52* µs/ft) and clay (*70* µs/ft);

V_{sh} – the amount of clay in the rock matrix.

The amount of clay was determined from the natural gamma radioactivity logging (GR), using the equation:

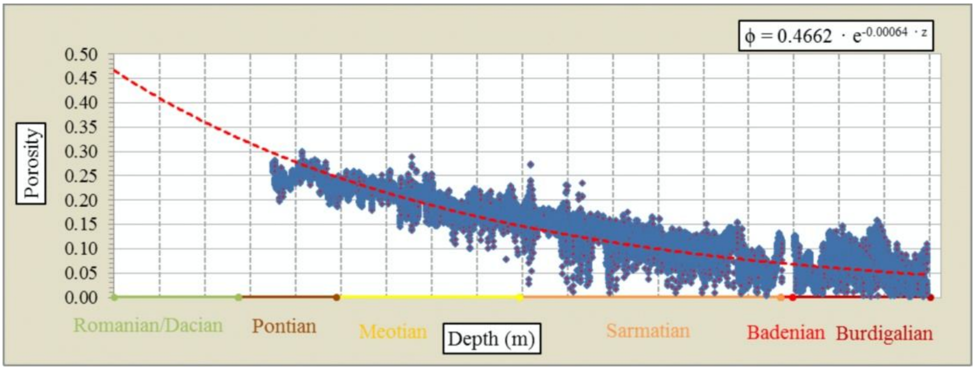

Fig. 7 Depth-Porosity variation of the rocks intercepted by wells on Totea-Vladimir structure.

$$V_{sh} = \frac{GR_{\log} - GR_{\min}}{GR_{\max} - GR_{\min}} \qquad (7)$$

where: GR_{log} is the value recorded through gamma ray log (API, i.e., American Petroleum Institute units);

GR_{min} and GR_{max} – gamma ray values of sandstone and clay.

The gamma ray logging values for sandstone range from 25 to 35 API units and for clay range from 80 to 120 API units (Nelson and Bird, 2005).

By designing the porosity values calculated for the depth of Totea-Vladimir structure (Fig. 7), it was obtained an average surface porosity value of ϕ_0 = 0,46 and a compaction coefficient of c = 0.00064 m^{-1}.

After estimating the porosities for different evolution stages of the formations studied, the average densities were calculated for the same intervals using the equation (8). The values provided by the specialty literature (Allen and Allen, 2005) have been used for the mineral frame densities and the rock pores fluid.

$$\rho = \rho_s \cdot (1 - \phi_i) + \rho_w \cdot \phi_i \qquad (8)$$

where: ρ_s is the density of mineral rock frame (kg/m^3);

ρ_w – density of rock pores fluid (kg/m^3).

The tectonic subsidence was calculated according to the following equation (Bond and Kominz, 1984):

$$Y = c' \cdot \left[S \cdot \left(\frac{\rho_m - \bar{\rho}}{\rho_m - \rho_w} \right) - \Delta SL_i \cdot \left(\frac{\rho_w}{\rho_m - \rho_w} \right) \right] + \left(Wd_i - \Delta SL_i \right) \qquad (9)$$

where: c' is the compensation degree;

ρ_m – mantle density(3300 kg/m^3);

$\bar{\rho}$ – average density of the column sedimentation;

Wd_i – water depth (m);

ΔSL_i – sea-level oscillation.

The compensation degree c' has been determined as a result of the deflection of the elastic lithosphere under periodic load, based on the existing flexural models (e.g., for continuous plate, broken plate etc.). The calculation formula used (Turcotte and Schubert, 2002) is the following:

$$c'(\lambda) = \frac{(\rho_m - \rho_s)}{\rho_m - \rho_s + \frac{D}{g} \cdot \left(\frac{2 \cdot \pi}{\lambda} \right)^4} \qquad (10)$$

where D is the flexural rigidity of the plate (N·m);

g – average gravity (≈ 9.81 m/s^2);

λ – wavelength (m);

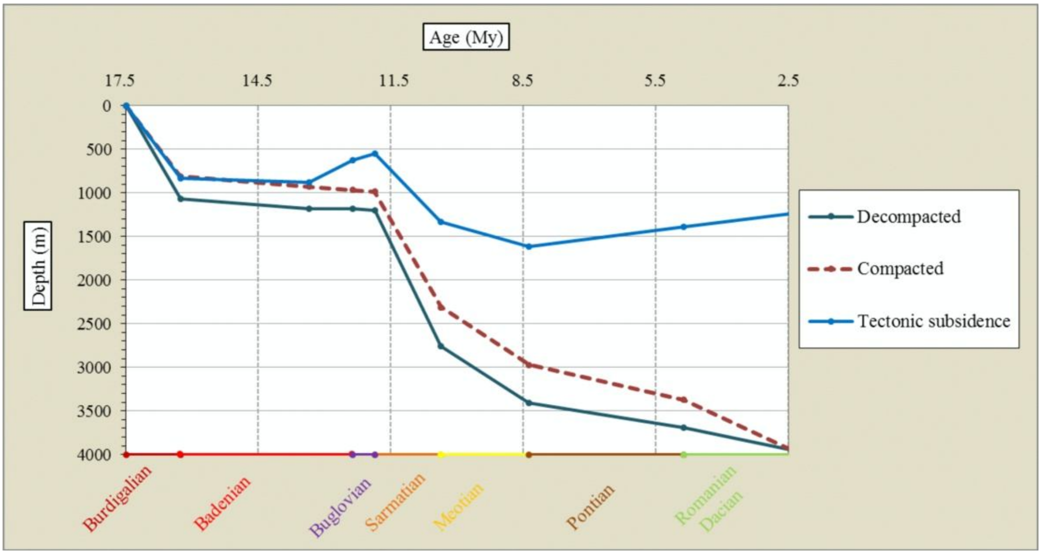

Fig. 8 Representation of the burial and tectonic subsidence curves for the formations opened on Totea-Vladimir structure.

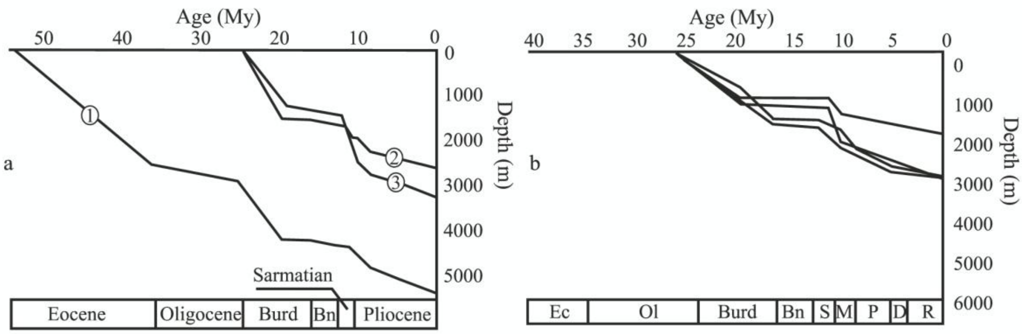

Fig. 9 Subsidence evolution in the Getic Depression area: a–according to Răbăgia and Maţenco (1999) (1–Ţicleni, 2–Alunu and 3–Bustuchini); b–subsidence curves corresponding to the extension of the lower Burdigalian (according to Maţenco et al., 2003).

The flexural rigidity was calculated using the equation:

$$D = \frac{E \cdot T_e^3}{12 \cdot \left(1 - \nu^2\right)} \qquad (11)$$

where E is Young's Modulus (N/m^2);
T_e – elastic thickness of lithosphere (m);
ν – Poisson's ratio.

The sea-level fluctuations (ΔSL_i) for the time spans corresponding to the geologic formations applied to wells on Totea-Vladimir structure were interpreted according to the Eustatism curve developed by Haq et al. (1987).

The burial and tectonic subsidence curves were represented in Figure 8. Comparing these curves with those obtained by certain authors (Răbăgia and Maţenco, 1999; Maţenco et al.,

2003) on other structures within the basin (Fig. 9), we can observe the same evolutionary steps concerning the subsidence of sedimentary units. Thus, there are two main periods of in-creased subsidence, in Burdigalian and Sarmatian-Meotian. The first period would correspond to an extensional stage while the second to a basin developed on strike-slip faults.

7. Conclusions

The Getic Depression has evolved within a foredeep sedimentary basin, initiated as a result of the Moesian Platform subduction under the Carpathian Orogen. Accordingly, the basin's foundation is mixed: Carpathian type and platform type. Over the foundation lays the sedimentary cover of the Carpathians' foredeep, which is separated by the Paleogene line in the internal foredeep misshapen with Carpathian base and the external foredeep with platform base.

The Totea-Vladimir structure, according to the well's data and the seismogeologic profiles, can be found at the front of the Subcarpathian Nappe, consisting of Burdigalian deposits covered by Badenian salt and Volhinian sandstones (with intercalations of marls and clays), over which the Basarabian and Romanian formations of the Dacian Basin were being placed. The rates of the sedimentary formations were calculated on the basis of the lithostratigraphic column type.

In order to describe the evolution of the studied structure, the subsidence stages that affected it in terms of the flexural subsidence of the foredeep basin were calculated and graphically represented. It should be noted that for the estimation of the subsidence a new mathematical model was used, which is based on the decompaction of sediments according to the geological time. As a result of the subsidence rate estimation, it has been possible to determine the type of sedimentary basin in which the Totea-Vladimir structure was eventually built. The result is a complex basin (sensu Perrodon, 1983), developed in several stages, after which Totea-Vladimir structure shows a structural architecture, such as a positive flower type (flower structure).

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