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Stratigraphic evidence of a Late Maeotian (Late Miocene) punctuated transgression in the Tanais Palaeobay (northern part of the Eastern Paratethys, South-West Russia)

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Abstract

The Tanais Palaeobay was located in the northern periphery of the eastern Paratethys Sea during the Late Miocene. New data from the Safianovo section (Rostov Dome, South-West of Russia) confirm that skeletal limestones (coquinites) of the Merzhanovskaja Formation belong to the *Congeria* (*Andrusoviconcha*) *amygdaloides navicula* Zone of the upper Upper Maeotian (the Maeotian is a regional chronostratigraphic unit of the Upper Miocene). Correlation of reference sections of these Upper Maeotian deposits within the Rostov Dome results in pattern of the palaeobay transgression, which was punctuated. The relative importance of local and global controls on this trangsression is not yet clear.

Keywords: Late Miocene, Late Maeotian, Eastern Paratethys, transgression, bivalves

Introduction

The Eastern Paratethys was a large Neogene sea in south-western Eurasia, which initially had permanent, then ephemeral connections with the other Paratethys seas, the Mediterranean Sea, and probably the Indian Ocean (Ilyina et al., 1976; Rögl & Steininger, 1983; Rögl, 1998, 1999; Golonka, 2004; Popov et al., 2006; Krijgsman et al., 2010). The wide shallow-water Tanais Palaeobay was located on the northern margin of the Eastern Paratethys (Fig. 1). Marchenko et al. (2008) showed that the Upper Miocene deposits of this palaeobay provide a clue to the understanding of the Eastern Paratethys dynamics, particularly because the flat and near-shore environments of this are the most suitable for documentation of the shoreline shifts.

Since the pioneer work by Bogatchev in the early 1900s (see Rodzjanko, 1970), the Upper Miocene deposits exposed in the Rostov Dome have been studied for about a century (Ivanitskaja & Pogrebnov, 1962; Rodzjanko, 1970, 1986; Ruban, 2002a,b,c,d,e, 2005; Ruban & Yang, 2004; Nevesskaya et al., 2005). Neverthelees, the stratigraphy of these deposits remains insufficiently well known and even somewhat controversial.

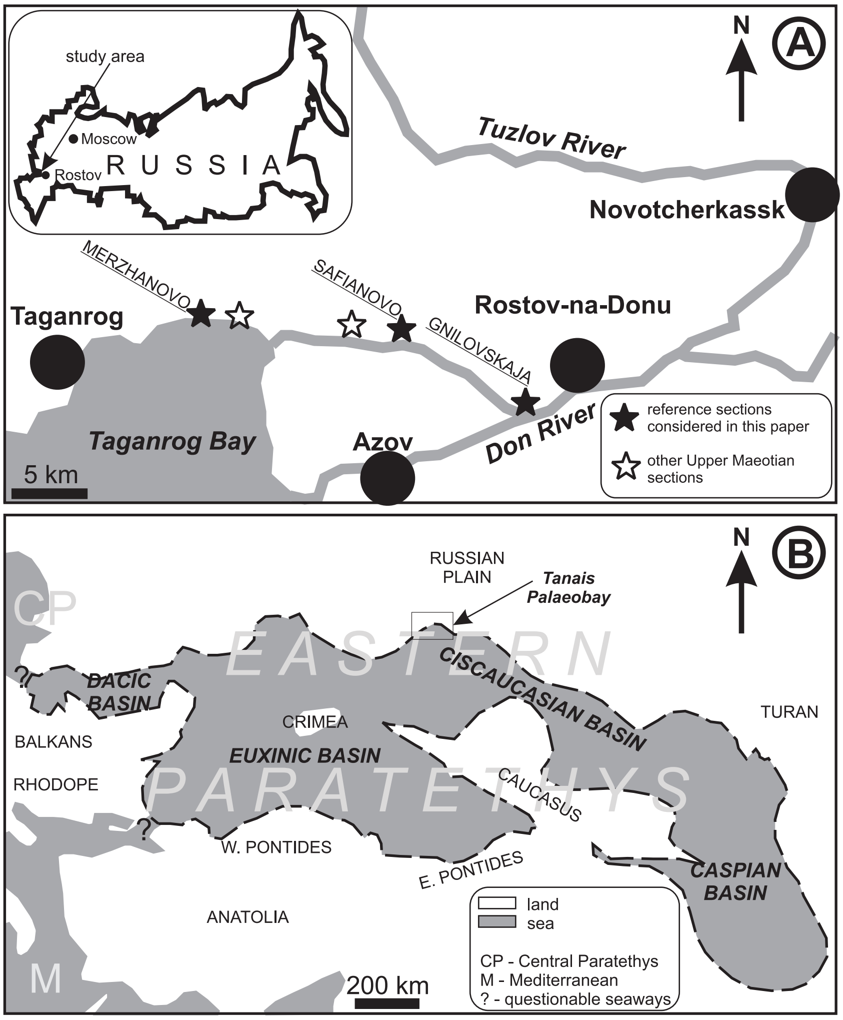

Fig. 1. Location of the study area.
A – Geographical location (adopted with modifications from Ruban, 2005); **B –** Palaeogeographical location (modified from Popov et al., 2006). The Eastern Paratethys is outlined by a dashed line.

New field studies in the central part of the Rostov Dome have yielded additional data on the relationship between the Upper Maeotian (a regional chronostratigraphic unit of the Upper Miocene, most probably roughly correlatable with the Tortonian-Messinian transition) sedimentary packages and the distribution of the stratigraphically important bivalve taxa that were described earlier by Ilyina et al. (1976), Nevesskaya et al. (2005) and Ruban (2005). The purpose of the present contribution is to present new stratigraphic evidence of a Late Maeotian transgression of the Tanais Palaeobay. The still poor knowledge on the Eastern Paratethys evolution, particularly among specialists outside Russia, can benefit from this local study.

Geological setting

The study area lies in South-West Russia (Fig. 1). It belongs tectonically to the Rostov Dome, which is a small tectonic unit in the southern part of the Russian Platform (Pogrebnov et al., 1970; Ruban, 2005). During the Late Miocene, the Rostov Dome was partly surrounded by the Eastern Paratethys Sea. This sea invaded the area from the south to form the wide, shallow-water Tanais Palaeobay (Fig. 1), where siliciclastic and carbonate sediments accumulated, often interrupted by episodes of sedimentary reworking.

The marine Upper Maeotian deposits in the study area are the Donskaja Formation and the Merzhanovskaja Formation (Ruban, 2002d, 2005). The Donskaja Fm. comprises clays, sandstones, marlstones, and limestones with a total thickness of ~10 m. It is overlain conformably by the Merzhanovskaja Fm., which is dominated by skeletal limestones (coquinites) consisting of recrystallized shells and fragments of the bivalve *Congeria*. The total thickness of this formation is up to 3 m. Sequence-stratigraphic studies recognise the Donskaja Fm. as a transgressive systems tract, and the Merzhanovskaja Fm. as a highstand systems tract of the same sequence (Ruban & Yang, 2004). The Late Maeotian depositional environments in the Tanais Palaeobay were brackish (Ruban, 2002b,e). The sea bottom was densely populated by bivalves, the shells of which form a densecoquinite throughout the area. The incised valley of the Severskij Donets Palaeoriver was located eastwards, where alluvial facies exist (Ruban, 2002c).

In order to develop a local biostratigraphic framework, Ruban (2005) recognized two biozones in the deposits under study. The *Congeria (Mytilopsis) panticapaea panticapaea* Interval Zone (early Late Maeotian in age) corresponds to the stratigraphic interval of the Donskaja Fm., whereas the *Congeria (Andrusoviconcha) amygdaloides navicula* Total Range Zone (late Late Maeotian in age) corresponds generally to the stratigraphic interval of the Merzhanovskaja Fm. Both zones are easily recognisable in sections because of a high abundance of index taxa (Fig. 2A). On the basis of bivalve analysis, the Donskaja Fm. of the Rostov Dome is early Late

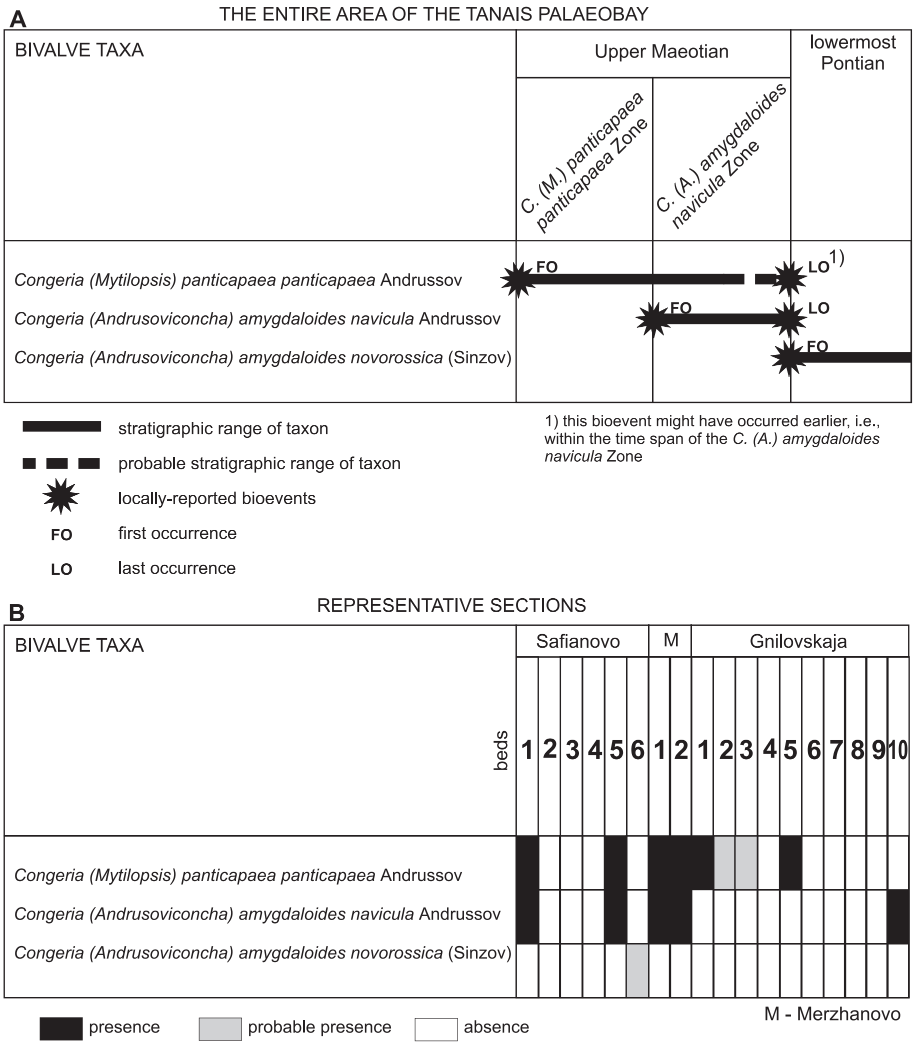

Fig. 2. Range chart of the characteristic bivalve taxa from the Upper Maeotian marine deposits of the Rostov Dome (data taken partially from Rodzjanko, 1970, Ilyina et al., 1976, and Ruban, 2002d, 2005).

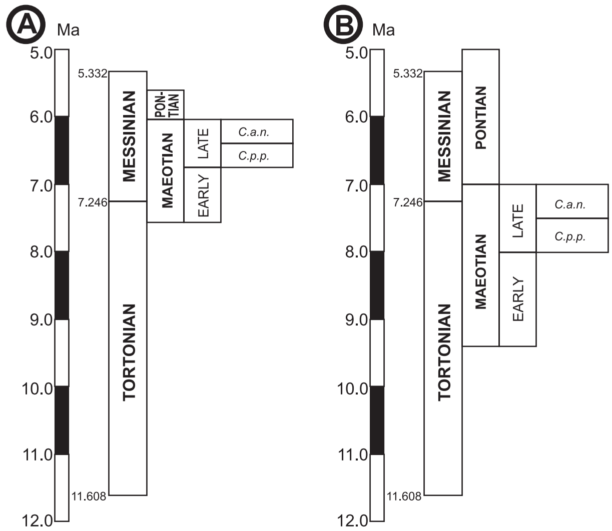

Fig. 3. Correlation of the Tortonian and Messinian global stages with the Maeotian and Pontian regional Eastern Paratethys stages.
A – On the basis of absolute ages established by Popov et al. (2006) and Krijgsman et al. (2010); **B –** On the basis of absolute ages provided by Chumakov et al. (1992), and following Ruban (2009). Chronostratigraphy after Gradstein et al. (2004) and Ogg et al. (2008). The Upper Maeotian bivalve-based biozones have been established in the Rostov Dome, but are potentially valid within the entire Eastern Paratethys. They are given as defined by Ruban (2005).
Abbreviations: C.p.p. = *C. (M.) panticapaea panticapaea* Interval Zone; C.a.n. = *C. (A.) amygdaloides navicula* Total Range Zone.

Maeotian in age, whereas the Merzhanovskaja Fm can be dated as late Late Maeotian (Ruban, 2002d, 2005).

The main problem of the Upper Miocene stratigraphy in the entire Eastern Paratethys, including the Tanais Palaeobay, is the uncertain correlation between the regional and the global stages (Golowina et al., 1989; Chumakov et al., 1992; Chumakov, 2000; Pevzner et al., 2003; Popov et al., 2006; Ruban, 2009; Krijgsman et al., 2010) (Fig. 3). New achievements in both the global (Hilgen et al., 2000a,b; Gradstein et al., 2004; Ogg et al., 2008) and the Mediterranean (Cita, 2009; Hüsing et al., 2009) Neogene stratigraphy, in combination with a successful correlation of the Paratethyan regional stages with global ones (Vasiliev et al., 2004, 2005; Snel et al., 2006; Lirer et al., 2009; Krijgsman et al., 2010) make it necessary to reconsider the Eastern Paratethys regional stratigraphy (Nevesskaya et al., 2005; Popov et al., 2006). The final objective of future studies should, obviously, be a total replacement of the regional units by the globally recognized ones (cf. Ruban, 2005, 2009).

Material and methods

The present study is based on material collected during fieldwork in 2009 and 2010. The Safianovo section (Figs. 1, 2B, 4, 5) was investigated in a detail. This section is important because of its location in between the earlier-studied areas, of which one is situated along the northern shore of the Taganrog Bay and the other in the western part of the city of Rostov-na-Donu. Additionally, the Merzhanovo section (Figs. 1, 2B, 6, 7) described previously by Ruban (2002d, 2005) was visited again. At both sections where the fieldwork for the present contribution was carried out, special attention was paid to the stratigraphic ranges of those bivalve taxa which serve as index taxa for the Upper Miocene biozonation (Ruban, 2005). The taxonomy of *Congeria* bivalves used by Nevesskaya et al. (1986) is followed here.

The lithology of the sections is described conventionally. Two aspects should, however, be detailed. First, carbonates consisting of (sometimes, strongly) re-crystallized fragmented bivalve shells are indicated here as 'skeletal limestones'. These are, in fact, detrital limestones, but the term 'skeletal' seems more appropriate here because the adjective 'detrital' does not imply an organogenic origin, whereas the adjective 'skeletal' does (Boggs, 2006). The term 'coquinite' (a consolidated coquina: see Boggs, 2006) is synonymous to 'skeletal limestone'. Second, the conglomerate-like rocks in the Upper Miocene carbonate successions of the Rostov Dome do not mark fundamental changes in lithology. They are linked with under- and/or overlying skeletal limestones, and the same carbonate consisting of recrystallized bivalve shells that serves as cement in the skeletal limestones, also serves as the cement of these conglomerates. Moreover, both complete and fragmented bivalve shells accumulated in the same way, i.e., as typical clastic deposits. Only skeletal limestones and skeletal

Fig. 4. Contact of beds 5 and 6 in the western flank of the Safianovo section (photo by O.A. Payus, A.A. Berdechnikova). Nomenclature of beds is shown in Fig. 8.

limestones with larger clasts are therefore considered as lithotypes here, so that no confusion can arise by distinguishing limestones from conglomerates. The classification of large clasts in the present study follows Blair & McPherson (1999), who use the term 'gravel' for particles of 2–4096 mm. They subdivide gravel into granules (2–4 mm), pebbles (4–64 mm), cobbles (64–256 mm), and boulders (256–4096 mm).

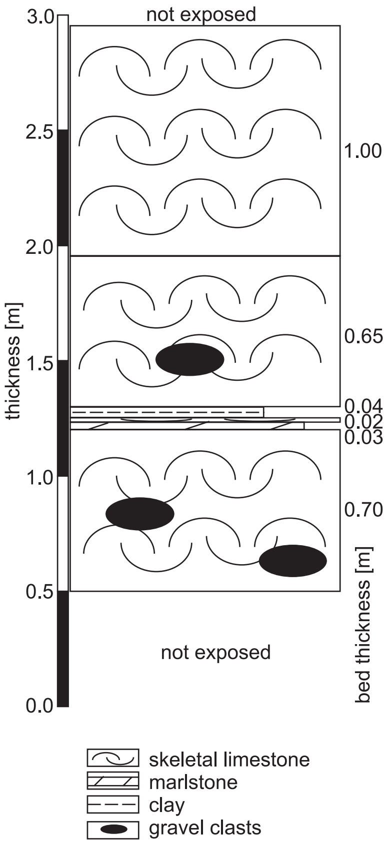

Fig. 5. Lithological log of the Safianovo section (Upper Maeotian interval).

A definite conclusion about the local Upper Maeotian stratigraphy and about the transgression in the Tanais Palaeobayrequires an accurate correlation of the three available reference sections, namely the Safianovo, Merzhanovo, and Gnilovskaja sections (Fig. 1). The correlation in the present contribution is based on both biostratigraphical and lithological marker horizons. The palaeobay transgression was established by the changes in the main area of accumulation of marine deposits, following the definition of a transgression as a landward shoreline shift (Catuneanu, 2006). The more sections represent a particular time slice, the wider was the area of marine accumulation at that time. It is worthy to note that the correlated sections of the Upper Maeotian deposits of the Rostov Dome represent a lateral transect through the dome (Fig. 1), which facilitates our analysis significantly. Quite similar palaeoenvironments within the palaeobay with frequent reworking of the deposits and one single dominant bivalve genus make such a recognition of a transgression impossible.

Results

Safianovo section

The Safianovo section is located in the village of Safianovo, i.e., ~10 km westwards of the city of Rostov-na-Donu (Fig. 1). The Upper

Fig. 6. Basal conglomerate (indicated by the arrow and the student's hand) in the Merzhanovo section (photo by A.A. Berdechnikova; A.I. Prigodich for scale).

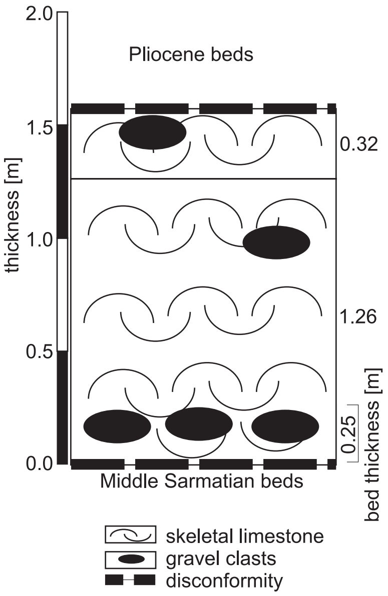

Fig. 7. Lithological log of the Merzhanovo section (Upper Maeotian interval). Range and thickness of the basal carbonates with coarse clasts is indicated separately.

Maeotian strata are exposed in the right steep slope of the Don River valley (Fig. 4). They are dominated by skeletal limestones, locally with granules, pebbles, and cobbles (Fig. 5). The skeletal limestones consist of recrystallized bivalve shells with a carbonate cement. Complete shells occur locally. The size of the shell fragments varies from 0.1 to 5 mm. There is no clear trend in the grain size. Gravel-sized clasts occur as haphazardly distributed intraclasts and as horizons in skeletal limestones; they vary in size but commonlydo not exceed 5 cm). They are generally rounded and flat, and are oriented parallel to the bedding (parallel bedding prevails). These deposits are typical for the Merzhanovskaja Fm. (Ruban, 2002d, 2005).

Two members are recognized: member 1 – with a thickness of 1.44 m – comprising beds 1–5 (two 2–4 cm thick intercalations of grey clays and light-grey to white marlstones constitute the beds 2 and 4), and member 2 – with a thickness of 1.00 m – forming in its entirety bed 6); the members have a sharp mutual contact (Fig. 4).

The total visible thickness of this section is ~ 2.5 m. It is necessary to note that the skeletal limestones of member 2 resemble (by their high porosity and thinner layering) the limestones that dominate the Aleksandrovskaja Fm., which is Pontian in age (Ruban, 2002d, 2005). This makes the position of bed 6 as a part of the Merzhanovskaja Fm. questionable. Below the main section, some grey clays (bed 0) are visible. They can be ascribed to the Donskaja Fm., which contains similar deposits in neighbouring sections (Ruban, 2002d, 2005). These clays cannot be attributed to an older formation, because the lower Upper Maeotian strata are nowhere eroded in the central part of the Rostov Dome (Ruban, 2005). A natural spring and slumped muddy material obscure the interval between these clays and the overlying skeletal limestones.

Bivalve remains (moulds and shell debris) are abundant in the beds of skeletal limestones (Fig. 2B). Beds 1 and 5 contain *Congeria (Andrusoviconcha) amygdaloides navicula* Andrussov, whereas *C. (Mytilopsis) panticapaea panticapaea* Andrussov occurs below bed 6. The *C. (A.) amygdaloides navicula* Zone starts with the first occurrence (FO) of the index taxon, which coexisted with the earlier taxon *C. (M.) panticapaea panticapaea* Andrussov (Ruban, 2005). Thus, our observations suggest that the entire interval of beds 1–5 belongs to the *C. (A.) amygdaloides navicula* Zone, and, therefore, it is late Late Maeotian in age. Bed 6 contains strongly diagenetically recrystallized skeletal limestones, so that identification of bivalves is a complicated task. One specimen of *Congeria* sp. was registered here. It may be attributed to either *C. (A.) amygdaloides navicula* Anrussov or *C. (A.) amygdaloides novorossica* (Sinzov). The latter taxon is characteristic of the lowermost Pontian of the Tanais Palaeobay (Ilyina et al., 1976) (Fig. 2A). Thus, an exact age of bed 6 is yet to be proved. No palaeontological data were obtained from the clays of the bed 0, but its attribution to the Donskaja Fm. implies an early Late Maeotian age, established earlier for this formation by Ruban (2002d).

Lithological, taphonomic, and palaeoecological features allow to interpret the depositional environment of the Upper Maeotian deposits in the Safianovo section. The skeletal limestones must have accumulated in shallow water near the shoreline. The gravel clasts in the limestones suggest a nearby shoreline. Probably, the clasts were formed due to destruction of the older (Middle Sarmatian) limestones. Original shell debris was easily reworked, as indicated by the by fragmentation of the bivalve shells (with various degrees of fragmentation – from unaffected, still complete shells to debris of about 1/10 of the original shell size, or even less). The resulting accumulated material is similar to that described by Nichols (2009) from clastic, wave-dominated beaches. The parallel bedding of the Upper Maeotian skeletal limestones resembles the bedding typical for carbonate beaches (Nichols, 2009). One should note that similar shell-dominated depositional environments are reported from vast areas in the modern, very shallow Azov Sea (Khrustalev & Mamykina, 1977). This modern analog also implies that biogenic productivity remains the main control on the deposition of shell concentrations (Khrustalev & Mamykina, 1977) despite active hydrodynamics and processes typical for clastic sedimentation. The bivalve *Congeria (Andrusoviconcha) amygdaloides navicula* Andrussov indicates a limited water depth, a lowered salinity, and probably warm seawater (Ilyina et al., 1976; Nevesskaya et al., 1986). This proves a nearshore environment in the Late Maeotian Tanais Palaeobay. The low diversity of the fossil assemblages, which are dominated by one single bivalve genus, is also typical for carbonate beaches (Nichols, 2009). Deposits now represented as clay and marlstone intercalations possibly accumulated during episodes of low energy and low biogenic productivity. One should note that rapid spatial shifts in the pattern of shell deposition occur in the modern Azov Sea (Khrustalev & Mamykina, 1977). It can therefore not be excluded that local lagoons or semi-enclosed bays favoured temporary deposition of clay particles.

Correlation of sections

The Upper Maeotian deposits of the Safianovo section can easily be correlated with those of the Merzhanovo and Gnilovskaja sections (Fig. 8). On the basis of available palaeontological data (Ruban, 2002d, 2005) (Fig. 2B), the *C. (A.) amygdaloides navicula* Zone comprises the entire beds 1–2 in the Merzhanovo section, which is the type section for the Merzhanovskaja Fm. (Ruban, 2002d). The Lower Maeotian and the *C. (M.) panticapaea panticapaea* Zone are absent in the Merzhanovo section due to a hiatus. One may hypothesize that the boundary between two beds in the Merzhanovo section corresponds to the boundary between the members 1 and 2 in the Safianovo section. If so, this boundary can serve as a within-zone correlation horizon, and, therefore, bed 6 of the Safianovo section belongs to the upper Upper Maeotian.

A new study of the Merzhanovo section (the exposures were changed by the slumping of some rock masses during the past few years), which is dominated by skeletal limestones with a total thickness of 1.58 m, revealed abundance of gravel clasts in a 0.25 m-thick bed at the base of the Merzhanovskaja Fm. (Fig. 6), which may be interpreted as a basal conglomerate with a carbonate cement, deposited after local ero-

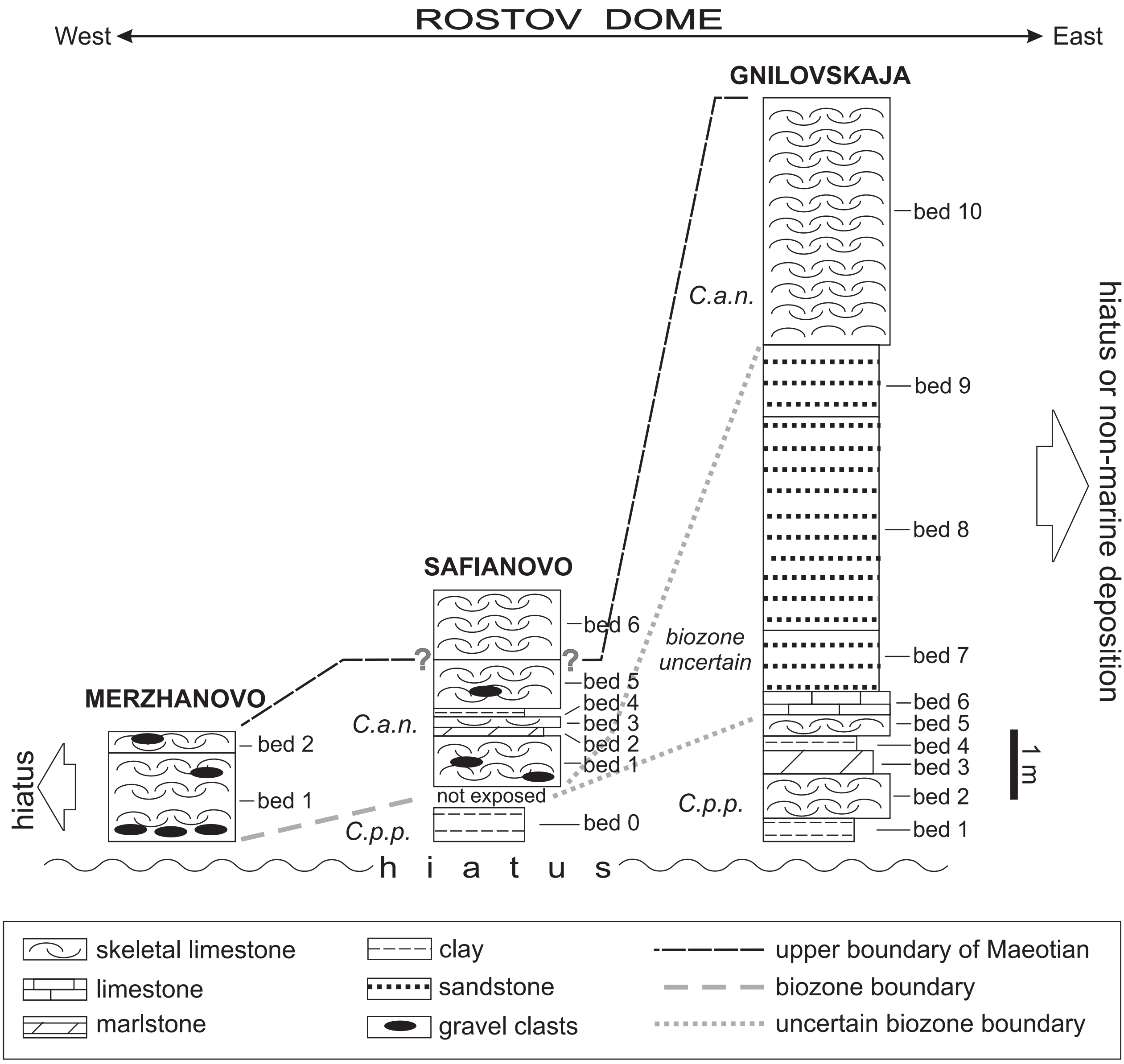

Fig. 8. Correlation of the reference sections of the Upper Miocene (Maeotian) marine deposits of the Rostov Dome (see Fig. 1 for location). True relationships with overlying deposits and the reality of hiatus between the Maeotian and Pontian deposites remain questionable. The Merzhanovo section is characterized after Ruban (2005), whereas the Gnilovskaja section is characterized after Rodzjanko (1970). See Figure 3 for biozone abbreviations.

sion at the shoreline. Thus, the complete Donskaja Fm. is absent in the Merzhanovo section, as already indicated by Ruban (2005).

Some interesting observations were made regarding the conglomerate layer in the Merzhanovo section. First, this layer is subdivided into two units. The lower unit contains less clasts, and these are relatively small (granules and pebbles). The upper unit contains a higher amount of clasts, and the proportion of pebbles and cobbles is larger. Second, gravel-sized clasts in this section are both rounded and angular, and not all are equally flat as those from the Safianovo section. Third, some large (1–2 cm in diameter) cavities filled with carbonate ooids were found in this basal layer.

In the Gnilovskaja section, which has – fortunately – adequately been described (Rodzjanko, 1970) before it was destroyed as a result of urban construction activities, the Beds 1–9 belong to the Donskaja Fm., whereas bed 10 belongs to the Merzhanovskaja Fm. Both Upper Maeotian biozones can be recognized in this section (Fig. 8). *C. (M.) panticapaea pantica-*

paea Andrussov and other early Late Maeotian faunas occurs below bed 6; *C. (A.) amygdaloides navicula* Andrussov dominates bed 10 (Rodzjanko, 1970) (Fig. 2B). Consequently, the *C. (M.) panticapaea panticapaea* Zone comprises beds 1–5, whereas the *C. (A.) amygdaloides navicula* Zone includes only bed 10. Due to a lack of representative palaeontological data from the limestones of bed 6 and the sandstones of beds 7–9, the boundary between the Upper Maeotian biozones in the Gnilovskaja section could be established only with significant uncertainty (Fig. 8). Anyway, it is clear that both the Safianovo and the Gnilovskaja sections exhibit a more or less comparable stratigraphic record of the Upper Maeotian; two biozones are registered in each of them. A lateral comparison of the thicknesses of various skeletal limestones in these sections provides indirect evidence that bed 6 of the Safianovo section is late Late Maeotian in age.

Record of the transgression

The correlation of the three representative sections of the Upper Maeotian strata in the Rostov Dome (Fig. 8) suggests a transgression in the Tanais Palaeobay. The absence of Lower Maeotian marine deposits in the study area implies that the Paratethys Sea invaded the area nor earlier than in the early Late Maeotian, when the deposits of the Donskaja Fm. accumulated. This ingression occurred within a restricted area in the central part of the dome, where now the Safianovo and Gnilovskaja sections are located. No marine deposits are known from the neighbouring areas (Fig. 8). In the mid-Late Maeotian, a phase of sand deposition occurred. It is very probable that the accumulation of these sediments was related to an increase in clastic input, which was recorded in deltaic deposits of the Severskij Donets Palaeoriver, which embouched into the bay from the east (Ruban, 2002c). Massive deposition of bivalve shells in the late Late Maeotian occurred over a relatively extensive area. Skeletal limestones of this age occur in all three reference sections (Fig. 8). This indicates a new pulse of the transgression which, probably, reached its maximum near the end of the Maeotian. The uppermost Maeotian deposits (upper member of the Merzhanovskaja Fm.) are found in both the Merzhanovo and Safianovo sections. Their presence in the Gnilovskaja section can be hypothesized, although it cannot be proven on the basis of the descriptions by Rodzjanko (1970). New data from the Merzhanovo section, i.e. a high amount of gravel-sized clasts, indicate that the last pulse of the transgression was strong. The late Late Maeotian sea first surrounded the area that had been occupied by seas during the Sarmatian, as indicated by skeletal limestones with less abundant and less large clasts at the bottom of the conglomeratic layer. A further increase in abundance and size of the gravel clasts suggests an intense erosion along the shoreline. Probably, this palaeoenvironment resembled that of the modern northern shore of the Taganrog Bay, where shell debris accumulates together with large clasts (granules, pebbles, cobbles and boulders). These clasts are supplied from the Upper Miocene limestones that are exposed at the steep bank. Destruction of these rocks by slumping prevails over erosion by active hydrodynamics. This explains the low degree of rounding. The presence of angular gravel clasts in the basal conglomeratic layer in the Merzhanovo section is evidence of similar processes.

Thus, our results indicate a punctuated Late Maeotian transgression in the Tanais Palaeobay (Fig. 9). This confirms the sequence-stratigraphic interpretation by Ruban & Yang (2004). However, the last pulse of the transgression occurred already after deposition of the Merzhanovskaja Fm. had started, which was entirely

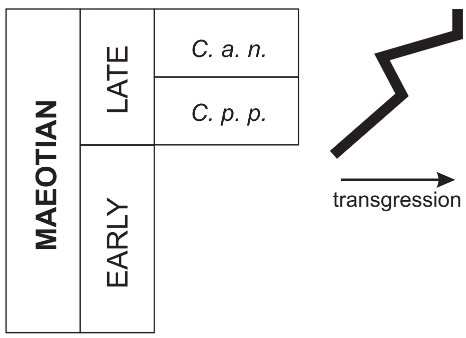

Fig. 9. Shoreline shifts in the Tanais Palaeobay during the Late Maeotian. See Figure 3 for abbreviations of the bivalve-based biozones.

attributed to a highstand systems tract by Ruban & Yang (2004). It appears that the boundary between the transgressive systems tract and the highstand systems tract should be placed more upwards in the sequence.

Discussion

The migration of the palaeobay shoreline was controlled by three factors: local tectonic activity, dynamics of the local sediment budget, and global eustasy. The local tectonic activity was unlikely strong enough to produce the short-term shoreline shifts documented by the present study: the Rostov Dome was a stable structural element (Pogrebnov et al., 1970), which experienced only very slow vertical movements. In contrast, the local sediment budget of the shallow-water palaeobay could influence the palaeobay geometry. The increase in clastic input by the Severskij Donets Palaeoriver is an example of this control.

Global eustasy left a significant imprint (Marchenko et al., 2008), although connections of the Eastern Paratethys and the world ocean remained somewhat restricted (Ilyina et al., 1976; Rögl, 1998, 1999; Popov et al., 2006; Krijgsman et al., 2010). The importance of this control might be assessed by comparison of the locally documented transgression with the global sea-level curves. For this purpose, alternative correlations of the global and regional stages (Fig. 3) should be considered in an unbiased way. Hardenbol et al. (1998), whose curve is used as a reference one by Ogg et al. (2008), indicate a long-term regressive trend within the time interval corresponding to the Late Maeotian, at least if the later the stage correlation by Popov et al. (2006) and Krijgsman et al. (2010) is correct. The same curve indicates a long-term regression through the time interval corresponding to the Late Maeotian, at least if the later stage correlation by Ruban (2009) is correct. Haq & Al-Qahtani (2005), who updated the earlier constraints by Haq et al. (1987), indicate an eustatic fall following by a less outspoken eustatic rise within the time interval corresponding to the Late Maeotian (timing again on the basis of the stage correlation by Popov et al., 2006, and Krijgsman et al., 2010). The Haq & Al-Quatani (2005) sea-level curve shows a significant eustatic rise through the time interval corresponding to the Late Maeotian (timing on the basis of the stage correlation by Ruban, 2009). It should be noted, however, that the curve by Haq & Al-Qahtani (2005) is very moderate in resolution. The high-resolution global sea-level curve by Miller et al. (2005) indicates a eustatic rise followed by an eustatic fall within the time interval corresponding to the Late Maeotian (timing on the basis of the stage correlation by Popov et al., 2006, and Krijgsman et al., 2010). This Miller et al. (2005) curve confirms the general trend of a eustatic sea-level rise through the time interval corresponding to the Late Maeotian (timing on the basis of the stage correlation by Ruban, 2009).

It is evident that differences between global sea-level curves and uncertainties in the correlations between global and regional stages do not permit to state that global eustasy was a controlling factor regarding the Late Maeotian transgression in the Tanais Palaeobay. The ongoing debates on possible connections of the Eastern Paratethys and the worldwide ocean (via the Mediterranean Sea, the Indian Ocean, or both) (e.g., Popov et al., 2006; Melinte-Dobrinescu et al., 2009; Krijgsman et al., 2010) do, obviously, not help to understand the causes of the basin-wide eustatic influence.

Conclusions

This new study of the Upper Maeotian deposits of the Rostov Dome leads to three main conclusions:

(1) The *C. (A.) amygdaloides navicula* Zone exists in the Safianovo section, which is situated in the middle between the areas studied earlier;

(2) A punctuated transgression took place in the Tanais Palaeobay during the entire Late Maeotian time interval;

(3) The presence of multiple eustatic constraints and pitfalls in establishing the chronostratigraphy in the Eastern Paratethys prohibits identifying the relative importance of eustatic control on the transgression.

Future studies should be aimed at a comparison of the local Late Maeotian punctuated transgression with shoreline shifts in the other areas of the Eastern Paratethys.

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References

Blair, T.C. & McPherson, J.G., 1999. Grain-size and textural classification of coarse sedimentary particles. *Journal Sedimentary Research* 69, 6–19.

Boggs, S., Jr., 2006. *Principles of Sedimentology and Stratigraphy*. Pearson Prentice Hall, Upper Saddle River, 662 pp.

Catuneanu, O., 2006. *Principles of Sequence Stratigraphy*. Elsevier, Amsetrdam, 375 pp.

Chumakov, I.S., 2000. K probleme nizhnego ponta (Novorossijskij pod'jarus) Evksino-Kaspija [Towards the problem of the Pontian (Novorossian Substage) of the Euxino-Caspian]. *Vestnik MGU, Serija 4, Geologija* 3, 17–23. (in Russian)

Chumakov, I.S., Byzova, S.I. & Ganzej, S.S., 1992. *Geokhronologija i korreljatsija pozdnego kajnozoja Paratetisa* [Geochronology and correlation of the Late Cenozoic of the Paratethys]. Nauka, Moskva, 95 pp. (in Russian)

Cita, M.B., 2009. Mediterranean Neogene stratigraphy: development and evolution through the centuries. *Sedimentology* 56, 43–62.

Golonka, J., 2004. Plate tectonic evolution of the southern margin of Eurasia in the Mesozoic and Cenozoic. *Tectonophysics* 381, 235–273.

Golovina L.A., Muzylev, N.G. & Trubikhin V.M., 1989. Nannoplankton i paleomagnitnaja stratigrafija neogenovykh otlozhenij Turkmenii i Azerbaidzhana [Nannoplankton and palaeomagnetic stratigraphy of the Neogene deposits of Turkmenia and Azerbaijan]. *Voprosy mikropaleontologii* 30, 79–89. (in Russian)

Gradstein, F.M., Ogg, J.G., Smith, A.G., Agterberg, F.P., Bleeker, W., Cooper, R.A., Davydov, V., Gibbard, P., Hinnov, L.A., House, M.R., Lourens, L., Luterbacher, H.P., McArthur, J., Melchin, M.J., Robb, L.J., Shergold, J., Villeneuve, M., Wardlaw, B.R., Ali, J., Brinkhuis, H., Hilgen, F.J., Hooker, J., Howarth, R.J., Knoll, A.H., Laskar, J., Monechi, S., Plumb, K.A., Powell, J., Raffi, I., Rohl, U., Sadler, P., Sanfilippo, A., Schmitz, B., Shackleton, N.J., Shields, G.A., Strauss, H., Van Dam, J., Van Kolfschoten, T., Veizer, J. & Wilson, D., 2004. *A Geologic Time Scale 2004*. Cambridge University Press, Cambridge, 589 pp.

Haq, B.U. & Al-Qahtani, A.M., 2005. Phanerozoic cycles of sea-level change on the Arabian Platform. *GeoArabia* 10, 127–160.

Haq, B.U., Hardenbol, J. & Vail, P.R., 1987. Chronology of fluctuating sea levels since the Triassic. *Science* 235, 1156–1167.

Hardenbol, J., Thierry, J., Farley, M.B., Jacquin, Th., de Graciansky, P.-C. & Vail, P.R., 1998. Mesozoic and Cenozoic sequence chronostratigraphic framework of European basins. [In:] de Graciansky, P.C., Hardenbol, J., Jacquin, Th. & Vail, P.R. (Eds): *Mesozoic-Cenozoic Sequence Stratigraphy of European Basins*. SEPM Special Publication 60, 3–13, 763–781.

Hilgen, F.J., Iaccarino, S., Krijgsman, W., Villa, G., Langereis, C.G. & Zachariasse, W.J., 2000a. The Global Boundary Stratotype Section and Point (GSSP) of the Messinian Stage (uppermost Miocene). *Episodes* 23, 172–178.

Hilgen, F.J., Bissoli, L., Iaccarino, S., Krijgsman, W., Meijer, R., Negri, A. & Villa, G., 2000b. Integrated stratigraphy and astrochronology of the Messinian GSSP at Oued Akrech (Atlantic Morocco). *Earth and Planetary Science Letters* 182, 237–251.

Hüsing, S.K., Kuiper, K.F., Link, W., Hilgen, F.J. & Krijgsman, W., 2009. The upper Tortonian-lower Messinian at Monte dei Corvi (Northern Apennines, Italy): completing a Mediterranean reference section for the Tortonian Stage. *Earth and Planetary Science Letters* 282, 140–157.

Ilyina, L.B., Nevesskaya, L.A. & Paramonova, N.L., 1976. *Zakonomernosti razvitija molljuskov v opresnjonnykh bassejnakh neogena Evrazii (pozdnij miotsen-rannij pliotsen)* [Trends of molluscs development in the Neogene brackish basins of Eurasia (Late Miocene-Early Pliocene)]. Nauka, Moskva, 288 pp. (in Russian)

Ivanitskaja, V.B. & Pogrebnov, N.I., 1962. *Geologitcheskoe stroenie Nizhnego Dona i Nizhnej Volgi* [Geology of the Lower Don and the Lower Volga]. RGU Edition, Rostov-na-Donu, 64 pp. (in Russian)

Khrustalev, Yu.P. & Mamykina, V.A., 1977. Dinamika donnykh osadkov Azovskogo marja [Dynamics of bottom sediments of the Azov Sea]. [In:] Kaplin, P.A. & Scherbakov, F.A. (Eds): *Paleogeografija i otlozhenija plejstotsena juzhnykh morej SSSR*. Nauka, Moskva, pp. 187–192. (in Russian)

Krijgsman, W., Stoica, M., Vasiliev, I. & Popov, V.V., 2010. Rise and fall of the Paratethys Sea during the Messinian Salinity Crisis. *Earth and Planetary Science Letters* 290, 183–191.

Lirer, F., Harzhauser, M., Pelosi, N., Piller, W.E., Schmid, H.P. & Sprovieri, M., 2009. Astronomically forced teleconnection between Paratethyan and Mediterranean sediments during the Middle and Late Miocene. *Palaeogeography, Palaeoclimatology, Palaeoecology* 275, 1–13.

Marchenko, A.S., Kopenok, O.B. & Ruban, D.A., 2008. Evstatitcheskij faktor v evoljutsii pozdnemiotsenovogo Tanaissoko paleozaliva Vostotchnogo Paratetisa [Eustatic factor in the evolution of the Late Miocene Tanais Palaeobay of the Eastern Paratethys]. [In:] Novikov, N.A., Kuznetsova, Yu.M., Tokarev, D.A., Getmanov, N.V. & Fomin, M.A. (Eds): *Trofimukovskie tchtenija–2008*, Vol. 2. INGGG, Novosibirsk, 68–70. (in Russian)

Melinte-Dobrinescu, M.C., Suc, J.-P., Clauzon, G., Popescu, S.-M., Armijo, R., Meyer, B., Biltekin, D., Çağatay, M.N., Ucarkus, G., Jouannic, G., Fauquette, S. & Çakir, Z., 2009. The Messinian Salinity Crisis in the Dardanelles region: chronostratigraphic constraints. *Palaeogeography, Palaeoclimatology, Palaeoecology* 278, 24–39.

Miller, K.G., Kominz, M.A., Browning, J.V., Wright, J.D., Mountain, G.S., Katz, M.E., Sugarman, P.J., Cramer, B.S., Christie-Blick, N. & Pekar, S.F., 2005. The Phanerozoic record of global sea-level change. *Science* 310, 1293–1298.

Nevesskaya, L.A., Gontcharova, I.A., Ilyina, L.B., Paramonova, N.P., Popov, S.V., Babak, E.V., Bagdasarjan, K.G. & Voronina, A.A., 1986. *Istorija neogenovykh molljuskov Paratetisa* [The history of the Neogene molluscs of the Paratethys]. Nauka, Moskva, 208 pp. (in Russian)

Nevesskaya, L.A., Kovalenko, E.I., Beluzhenko, E.V., Popov, S.V., Gontcharova, I.A, Danukalova, G.A., Zhidovinov, N.Ja., Zajtsev, A.V., Zastrozhnov, A.S., Pintchuk, T.N., Ilyina, L.B., Paramonova, N.P., Pis'mennaja, N.S. & Khondkarian, S.O., 2005. Regional'naja stratigrafitcheskaja skhema neogena juga Evropejskoj tchasti Rossii [Regional Neogene stratigraphic scale of the South of European Russia]. *Otetchestvennaja geologija* 4, 47–59. (in Russian)

Nichols, G., 2009. *Sedimentology and Stratigraphy*. Wiley-Blackwell, Chichester, 419 pp.

Ogg, J.G., Ogg, G. & Gradstein, F.M., 2008. *The Concise Geologic Time Scale*. Cambridge University Press, Cambridge, 177 pp.

Pevzner M.A., Semenenko V.N. & Vangengeim E.A., 2003. Position of the Pontian of the Eastern Parathethys in the magnetochronological scale. *Stratigraphy and Geological Correlation* 11, 482–491.

Pogrebnov, N.I., Potapov, I.I. & Smirnov, B.V. 1970. Tektonika [Tectonics]. [In:] Belov, F.A., Egorov, A.I. & Pogrebnov, N.I. (Eds): *Geologija SSSR*, Vol. 46. Nedra, Moskva, 515–577. (in Russian)

Popov, S.V., Shcherba, I.G., Ilyina, L.B., Nevesskaya, L.A., Paramonova, N.P., Khondkarian, S.O. & Magyar, I., 2006. Late Miocene to Pliocene palaeogeography of the Paratethys and its relation to the Mediterranean. *Palaeogeography, Palaeoclimatology, Palaeoecology* 238, 91–106.

Rodzjanko, G.N., 1970. Neogenovaja sistema [The Neogene System]. [In:] Belov, F.A., Egorov, A.I. & Pogrebnov, N.I. (Eds): *Geologija SSSR*, Vol. 46. Nedra, Moskva, 410–447. (in Russian)

Rodzjanko, G.N., 1986. Juzhnaja tchast' tsentral'nykh rajonov Vostotchno-Evropejskoj platformy [The southern part of the central regions of the East European platform]. [In:] Muratov, M.V. & Nevesskaya, L.A. (Eds): *Stratigrafija SSSR. Neogenovaja sistema*. Polutom 1. Nedra, Moskva, 268–287. (in Russian)

Rögl, F., 1998. Palaeogeographic considerations for Mediterranean and Paratethys seaways (Oligocene to Miocene). *Annalen des Naturhistorischen Museums in Wien* 99A, 279–310.

Rögl, F., 1999. Mediterranean and Paratethys. Facts and hypotheses of an Oligocene to Miocene paleogeography: Short Overview. *Geologica Carpathica* 50, 339–349.

Rögl, F. & Steinenger, F.F., 1983. Vom Zerfall der Tethys zu Mediterranean und Paratethys. *Annalen des Naturhistorischen Museums in Wien* 85A, 135–163.

Ruban, D.A., 2002a. K stratigrafii verkhnemiotsenovykh otlozhenij Rostovskogo svoda [Towards the stratigraphy of the Upper Miocene deposits of the Rostov Dome]. *Izveskija VUZov. Severo-Kavkazskij region. Estestvennye nauki* 1, 104. (in Russian)

Ruban, D.A., 2002b. Tanaisskij paleozaliv i Vostotchnyj Paratetis v meotitcheskoe vremja [The Tanais Palaeobay and the Eastern Paratethys in the Maeotian time]. *Nautchnaja mysl' Kavkaza. Prilozhenie* 7, 104–105. (in Russian)

Ruban, D.A., 2002c. Paleogeografija Rostovskogo svoda v meotise [Palaeogeography of the Rostov Dome during the Maeotian]. *Nautchnaja mysl' Kavkaza. Prilozhenie* 7, 106. (in Russian)

Ruban, D.A., 2002d. Litostratigrafija verkhnemiotsenovykh otlozhenij Rostovskogo svoda [Lithostratigraphy of the Upper Miocene deposits of the Rostov Dome]. *Nautchnaja mysl' Kavkaza. Prilozhenie* 14, 133–136.

Ruban, D.A. 2002e. Litologija i uslovija obrazovanija meotitcheskikh otlozhenij Rostovskogo svoda [Lithology and depositional environments of the Maeotian strata of the Rostov Dome]. [In:] Bogush, I.A. (Ed): *Problemy geologii, poleznykh iskopaemykh i ekologii Juga Rossii i Kavkaza*. Vol. II. YuRGTU, Novotcherkassk, 33–35.

Ruban, D.A., 2005. The Upper Miocene of the Rostov Dome (Eastern Paratethys): Implication of chronostratigraphy and bivalvia-based biostratigraphy. *Geološki anali Balkanskoga poluostrva* 66, 9–15.

Ruban, D.A., 2009. Regional stages: their types and chronostratigraphic utility. *Cadernos do Laboratorio Xeolóxico de Laxe* 34, 59–73.

Ruban, D.A. & Yang, W., 2004. Upper Miocene sequence stratigraphy of Rostov Dome, Russian Platform, Eastern Paratethys. *American Association of Petroleum Geologists 2004 Annual Convention. Abstracts Volume*. Dallas, 121.

Snel, E., Mărunţeanu, M., Macaleţ, R., Meulenkamp, J.E. & Van Vugt, N., 2006. Late Miocene to Early Pliocene chronostratigraphic framework for the Dacic Basin, Romania. *Palaeogeography, Palaeoclimatology, Palaeoecology* 238, 107–124.

Vasiliev I., Krijgsman,W., Stoica, M. & Langereis, C.G., 2005. Mio-Pliocene magnetostratigraphy in the southern Carpathian foredeep and Mediterranean-Paratethys correlations. *Terra Nova* 17, 376–384.

Vasiliev I., Krijgsman,W., Langereis, C.G., Panaiotu, C.E., Matenco, L. & Bertotti, G., 2004. Towards an astrochronological framework for the eastern Paratethys Mio-Pliocene sedimentary sequences of the Focsani basin (Romania). *Earth and Planetary Science Letters* 227, 231–247.

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