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The Slanicul de Buzau section, a unit stratotype for the Romanian stage of the Dacian Basin (Plio-Pleistocene, Eastern Paratethys)

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ABSTRACT

Climatic changes cause large paleoenvironmental responses in semi-isolated basins. We analyze here the sedimentary successions of the Dacian Basin (Romania) to evaluate Late Pliocene and Early Pleistocene paleoenvironmental changes through macro- and micropaleontology. These changes are dated by creating a magnetostratigraphic time frame for two long and continuous sections with a combined total thickness of 2850 m. The studied succession spans the time interval between 4.7 Ma and 1.6 Ma and records both the mid Pliocene Warm Period (3.3–2.9 Ma) and the onset of large-scale glaciations on the Northern Hemisphere (~2.7 Ma). Due to progressive basin infill, the paleoenvironment changes from brackish to fluvio-lacustrine with a major extinction event of lymnocardiine bivalves around 4.15 Ma. Rich and dominantly freshwater mollusk and ostracod faunas develop from this moment onwards. Between 3.2 Ma and 2.95 Ma, the reappearance of lymnocardiines identifies a short moment of higher salinities, the previously identified Plescoi event. In time, this correlates closely to the warmest interval of the Pliocene, and is therefore most likely related to connectivity to the Black Sea during maximum sea-level. After the climatic optimum, deposition continues in a fluvio-deltaic setting with only scarce finds of fauna. Increasing amounts of coarse grained fluvial sediments show a close relationship with the progressive cooling during the Pleistocene.

1. Introduction

The thick and continuous sedimentary successions of the Dacian Basin in Romania provide an excellent opportunity to study palaeoenvironmental changes in central Europe during the Plio-Pleistocene. Rich (macro) faunal assemblages reflect the evolution of the basin from brackish to fresh water and have traditionally been used as a basis for regional time scales (Papaianopol et al., 2003). This salinity change divides the studied time interval in two parts, the Dacian (brackish) and Romanian (freshwater) regional stages.

During the Plio-Pleistocene, global climate passes through a major transition from the mid-Pliocene warm period (MPWP) into the Pleistocene and the onset of Northern Hemisphere Glaciations. The MPWP (3.3–2.9 Ma) is the most recent analogue in the geological past for future climatic conditions with atmospheric CO_2 levels similar to present-day values and global mean temperature 2–3 °C higher (Lunt et al., 2009; Pagani et al., 2009). As a result, it has received significant attention from a climate modeling perspective in recent years (e.g. Haywood et al., 2013). Global sea-level was at maximum higher than present-day by 22 ± 10 m, with fluctuations of up to 70 m (e.g. Miller et al., 2012). After the MPWP temperatures start to decrease, and this ultimately leads to the formation of large-scale glaciations on the northern hemisphere (Rohling et al., 2014).

In semi-isolated marine basins, such climatic changes may cause a large paleoenvironmental response due to changes in the hydrological budget and/or gateway connectivity. The Black Sea–Dacian Basin region is a good example of a large semi-marine basin with a restricted connection to the Mediterranean Sea and global ocean. The sea level history of the Black Sea region is as a result highly complex and dynamic (Svitoch et al., 2000; Popov et al., 2010). Furthermore, the Black Sea receives runoff from many large rivers like the Danube, Dniestr, Dniepr and Don. Together, these rivers drain a large part of Europe. Therefore hydrological fluxes into the basin are highly dependent on climatic changes over a large area and good age control is vital to understand forcing mechanisms.

To better understand both basin infill and associated paleoenvironmental changes we present an integrated biomagnetostratigraphic study (mollusks and ostracods) on the stratotype sections for the Dacian–Romanian boundary and the Romanian regional stage. We improve on existing data by increasing the temporal resolution, which allows to better place changes in a climatic context. We follow a similar approach as recently used for the Mio-Pliocene deposits (Pontian regional stage) (Stoica et al., 2013). The studied outcrops along the Slanicul de Buzau river comprise a complete stratigraphic succession of the Dacian, Romanian and Pleistocene and the described section can serve as unit stratotype for the Romanian regional stage of the Dacian Basin.

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2. Geological setting of the Dacian Basin

The Dacian Basin represents one of the larger basins in the Paratethys region. Paratethys formed during the Oligocene as a semi-isolated marine to brackish basin stretching from Turkmenistan to Central Europe (Rögl, 1998; Popov et al., 2006). Due to a complex interplay between ongoing tectonics, basin infill and climatic changes, deposition gets increasingly concentrated into different sub-basins during the Pliocene. The local paleoenvironment determined the (endemic) faunal compositions which got used as basis for regional time scales (Nevesskaya et al., 2003). As a result, faunal composition is different between basins, which has led to the erection of multiple stratigraphic schemes (Fig. 1) (Jones and Simmons, 1996).

The Dacian Basin forms the foreland basin to the Carpathian mountains. The Slanicul de Buzau section is located in the Carpathian Bend Zone (Eastern Carpathian foredeep) where the NNW-SSE trending East-Carpathians continue as the E-W trending South-Carpathians (Fig. 1A). Highest subsidence rates along the Carpathian foreland basin are found just north of our study area in the Focşani Depression (Tărăpoancă et al., 2003). Around 5 km of Late Miocene, Pliocene and Pleistocene sediments are found in the Slanicul de Buzau valley. The Miocene to recent tectonic history can be subdivided in two phases, a Late Miocene–Pliocene subsidence phase and a Quaternary inversion phase causing intraplate folding (Matenco et al., 2007).

The Carpathian Bend Zone lies at the eastern end of the Carpathian mountains. Due to the proximity of the Black Sea, palaeoenvironmental conditions remained brackish longer than in any other part of the Dacian Basin. A west to east prograding sequence filling in the basin develops at ~4.6 Ma and replaces the brackish Black Sea influence of the Dacian regional stage (Jipa et al., 2007). At the boundary with the Romanian regional stage a paleoenvironmental change occurs and deposition continues predominantly in a freshwater setting. Due to the ongoing subsidence in the Focşani depression, deposition continues throughout most of the Plio-Pleistocene in lacustrine and fluvial environments (Necea et al., 2005). Ponto-Caspian lymnocardiines are found at a short moment during the middle/upper Romanian in the Dacian Basin, the so-called Plescoi event (Pană et al., 1968). This is interpreted as a short moment of brackish-marine influence coming from the Black Sea. It represents the peak sea-level in the Black Sea during the Pliocene and an accurate chronology is therefore important to understand causal mechanism.

3. Regional stage nomenclature and dating

Throughout Paratethys a wide variety of terminology is used for regional stages describing the Plio-Pleistocene. Regional nomenclature for the Dacian Basin includes the Pontian, Dacian and Romanian stages, overlain by sediments commonly referred to as Pleistocene. The freshwater Romanian stage correlates with the upper "*Paludina*" beds of the Pannonian Basin where this stage name is also sometimes used (e.g. Lučić et al., 2001). Elsewhere, Plio-Pleistocene deposits are grouped in the Kujalnikian and Gurian (Black Sea) and the Akchayglian and Apsheronian regional stages (Caspian Sea) (Nevesskaya et al., 2003). The time-equivalent of the Dacian stage is in the Black Sea region the Kimmerian stage, although the boundary with the underlying Pontian stage is placed at different ages (Krijgsman et al., 2010). Fauna similar to the Dacian Basin are found in Ukraine, but chronological constraints are limited due to the coarse-grained nature of the sediment (Matoshko et al., 2004, 2009).

3.1. Definitions of the Romanian stage

Like many of the regional stages in Paratethys, the first definitions of the Dacian and Romanian stages are based on mollusk fauna. The distinction of two stages in the late Neogene deposits of the Dacian Basin was first proposed in 1883 by Cobălcescu (Fig. 1C). He separated a 'system with *Psilodon*' and a 'system with *Unio*' in the region of Parscov and Beceni (in the Carpathian Bend zone, our study area). Stefanescu (1896, 1897) correlated the time interval following the Pontian regional stage with the Levantinian, a stage defined by Von Hochstetter (1870) for the Late Neogene freshwater deposits found in Turkey and subdivided it into three biozones defined by the occurrences of *Rugunio lenticularis* (Stefanescu), *Pristinunio pristinus* (Bielz) (= *P. procumbens* (Fuchs)) and *Ebersininaia stefanescui* (Tournouer). Teisseyre (1908) split the time following the Pontian into two since only the second part consisted of freshwater deposits and thereby defined the Dacian stage for the initial brackish water deposits. Krejci-Graf (1932) proposed the name Romanian as a replacement of the term Levantinian, since this was not a unique term solely describing deposits in the Dacian Basin. For a long time however, the term Levantinian continued to be used in literature, and some geological maps of Romania still show this instead of the Romanian. In 1965, Macarovici et al. suggested to re-introduce the term Romanian, as it became clear that the original Levantinian deposits were Late Miocene freshwater deposits, unrelated to the Dacian Basin deposits. The Romanian (and Dacian) as stages of the Paratethys were ratified by the working group on the Paratethys at a conference in Vienna in 1970. All aspects dealing with the faunal and sedimentological changes during the Romanian stage are compiled into a single, comprehensive book (Papaianopol et al., 2003). We follow the definitions of the boundary stratotype and stratotype section as described in this volume.

An alternative level for the Dacian–Romanian boundary is proposed by Andreescu et al. (2013). Because of the diachroneity related to the infill of the basin, it is proposed to incorporate the lower Romanian sub-stage (Siensian) in the Dacian and place the boundary near the base of the C2An.3n (Gauss) chron (Andreescu et al., 2013). This coincides with the traditional Lower Romanian (Siensian) to Middle Romanian (Pelendavian) boundary, which is supposed to be isochronous throughout the Dacian Basin.

The Romanian upper boundary correlates with the Gelasian upper boundary (Papaianopol et al., 2003) previously matching with the Pliocene/Pleistocene boundary. Recently, the base of the Pleistocene epoch has been lowered from 1.8 Ma to 2.6 Ma by including the Gelasian in the Pleistocene (Gradstein et al., 2012). In consequence, Andreescu et al. (2011, 2013) proposed to shorten the duration of Romanian by including its topmost, now Pleistocene part into a new regional stage termed Argedavian, representing all Pleistocene deposits of the Dacian Basin (Fig. 1). In contrast, since the position of the Pliocene/Pleistocene boundary is just a matter of convention, we approve the definition of Papaianopol et al. (2003). The Pliocene–Pleistocene transition is actually not reflected by any depositional or faunal change in the Dacian basin providing the separation of a new regional stage redundant.

3.2. Previous absolute age-dating Romanian

Starting in the late 70's, attention shifted to magnetostratigraphic dating of key sections. Publications from this time correlate to old versions of the Global Polarity Timescale (GPTS), and need to be adjusted to the astronomically tuned timescale of Hilgen et al. (2012). Early work on the Pliocene sections shows a correlation of the Plescoi event to the Kaena (C2An.1r) subchron at ~3.1 Ma (Trubikhin, 1989). The Dacian–Romanian boundary is correlated to the Cochiti (C3n.1n) subchron. This position is confirmed by studies of Radan and Radan (1998) and Van Vugt et al. (2001) working on the Lupoaia section in south-west Romania. This section is later re-interpreted by Popescu (2001), who correlates the Dacian–Romanian boundary one normal subchron lower (Nunivak, C3n.2n) based on palynology. However, recent magnetostratigraphic studies confirm the original correlation of the Dacian–Romanian boundary close to the Cochiti (C3n.1n) subchron for sections in both the south and east Carpathians (Vasiliev et al., 2004, 2005). In those studies, stage boundaries are

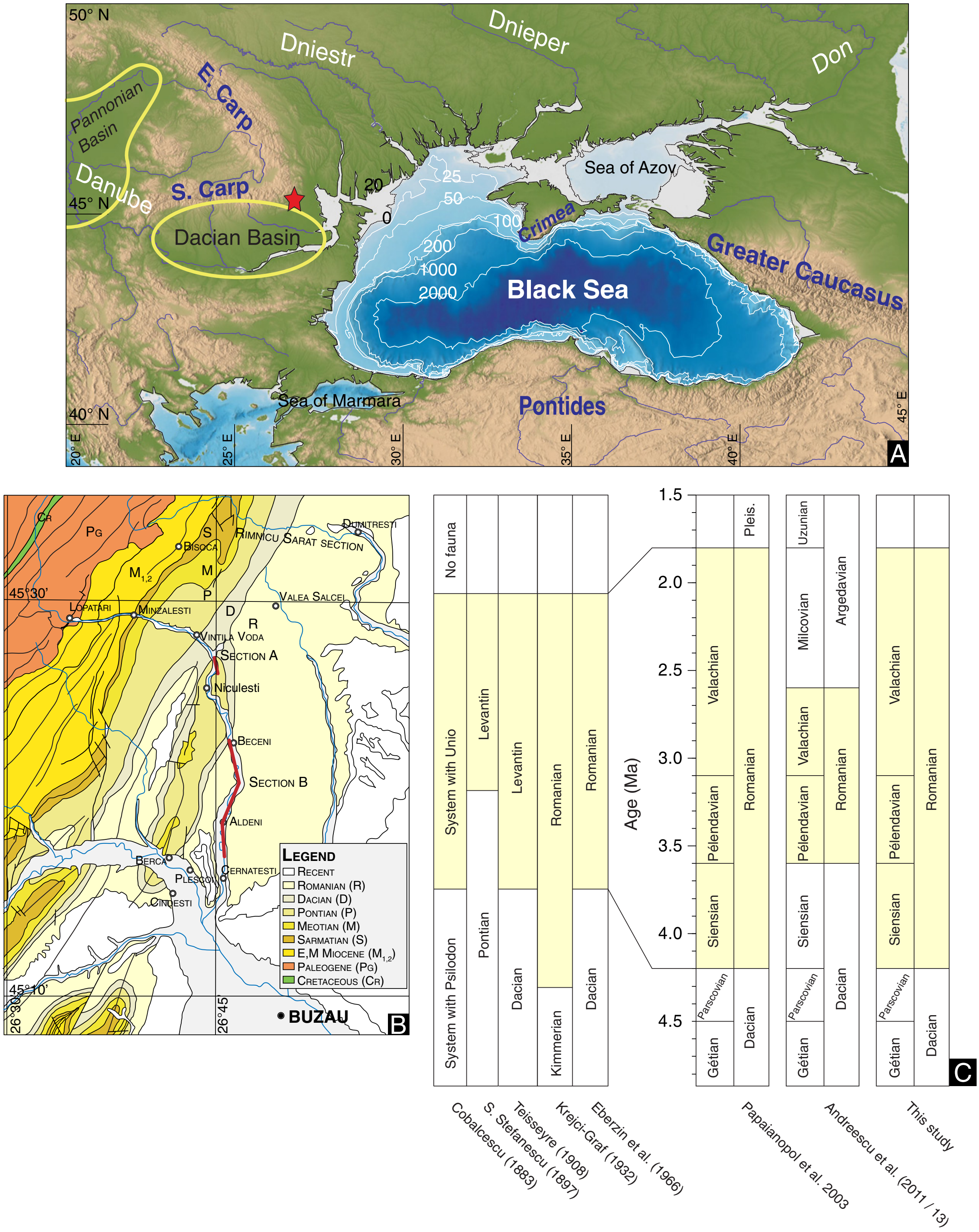


Fig. 1. A) Location map of the Black Sea and Dacian Basin, the red star marks the study area. B) Geological map of the study area (adapted from Dumitrescu et al. (1970) and Motas et al. (1966)). Studied sections are indicated in red. Letters on the map correspond to the letters in the legend for different time periods. C) Nomenclature proposed through time for the Plio-Pleistocene deposits of the Dacian Basin.

positioned based on the geological map of the study area and sections lack direct biostratigraphic control. To improve on this, we will incorporate the faunal changes into a magnetostratigraphic time frame.

4. The Slanicul de Buzau section

Two sections are sampled along the Slanicul de Buzau river to get a (near-complete) record of the Plio-Pleistocene deposits. The base of section A (45.440773° N, 26.744204° E) starts in sediments with typical Pontian fauna. Throughout the Dacian stage, coarsening upwards cycles of 10–30 m scale occur. Each of these cycles ends in a sandy interval topped by a hardground layer generally very rich in mollusk remains (Fig. 2a,b). At 250 m, a sudden change in orientation and dip is observed from 335/20 NE to 228/50 NW, relating to a (small?) fault or unconformity. Lithologically, no major changes occur until ~780 m. Here, the final coarsening upwards package is found and overlying sediments are mostly silty-clays with cross-bedded sands (Fig. 2c). Thin (max 50 cm) levels of coal start to appear and at times sediment is rich in small melanopsid gastropods (Fig. 2d). At 830 m, a weathered tuff lens is found. Paleomagnetic samples continue on a couple of smaller outcrops on the opposite side of the river until reaching the core of the syncline next to the local hospital (45.458599 N, 26.744476 E).

Section B begins ~6 km downstream from the base of the first section on the southern side of an anticline (45.386648 N, 26.760680 E).

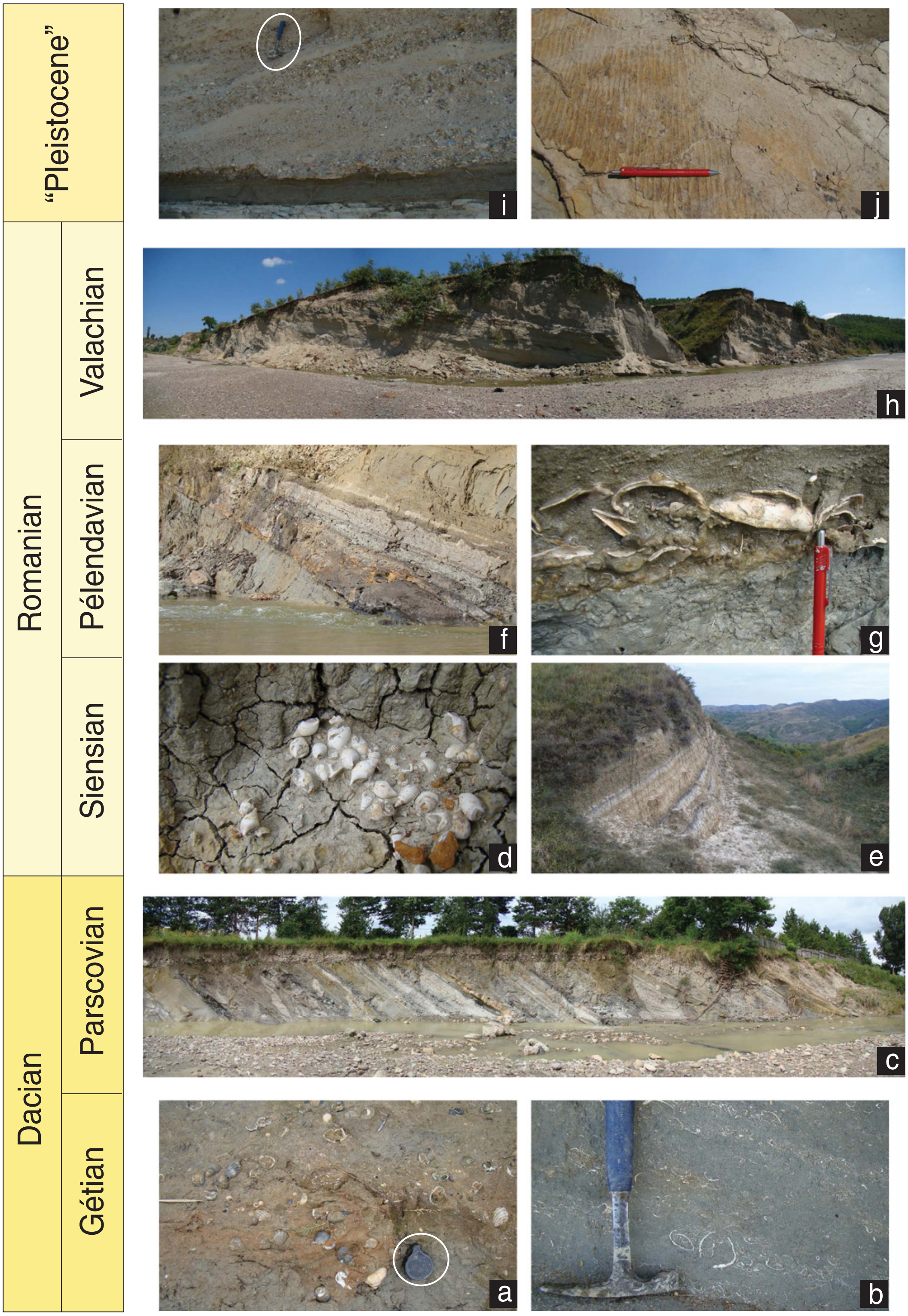


Fig. 2. Chronostratigraphic subdivisions and field photographs (discussed in the main text).

Additional micropalaeontological samples are taken below the base of the section in outcrops along the river to illustrate the Dacian fauna. Due to non-exposure the exact location of the Dacian–Romanian boundary cannot be established. Section B continues for more than 11 km downstream along the river in a series of long exposures along and in the river. GPS is used to estimate stratigraphic distances between outcrops. The top of the section is at 45.287240 N, 26.755020 E, although a further, scattered, continuation downstream is possible.

The lowermost part of section B consists of sands and clays with minor coal layers, similar to the top of section A. In this part of the section, multiple outcrops in hills on either side of the river expose short (5–10 m) intervals that are not exposed in the river. In these outcrops, paleosol levels are found (e.g. 45.380817 N, 26.774280 E, Fig. 2e) and in one outcrop minor amounts of secondary gypsum occur (Clauzon et al., 2007). Coal deposits increase in thickness (up to 50 cm) and cross-bedded fluvial sands of m-scale are found. These can be overlying a shell-lag, or contain pyritized roots and fossilized wood (Fig. 2f, g). Massive sands of up to 10 m thick are found in multiple places (e.g. 780–790 m).

In sandy lithologies at 840 m, a level with abundant lymnocardiine bivalves is found (45.362983 N, 26.772675 E). This is followed by a predominantly muddy interval of ~150 m. From this interval onwards, no mollusk fauna is observed. Paleosols and cross-bedded fluvial sands return after this and from ~1100 m the sandy deposits become the dominant lithology (Fig. 2h), with silty clays present in lesser amount. The grain size of the coarse beds increases to pebbly conglomeratic in sand bodies up to 10 m thick (Fig. 2i). Small wave ripples are observed in discrete horizons in the higher parts of the section, indicating deposition in standing bodies of water (Fig. 2j). Bedding changes from 200/55 SE at the base to 205/20 at 400 m and then gradually to 225/15 SE at the top of the section. Deposition is continuous beyond our section. Logging is not continued due to the increasingly shallow bedding tilt, which

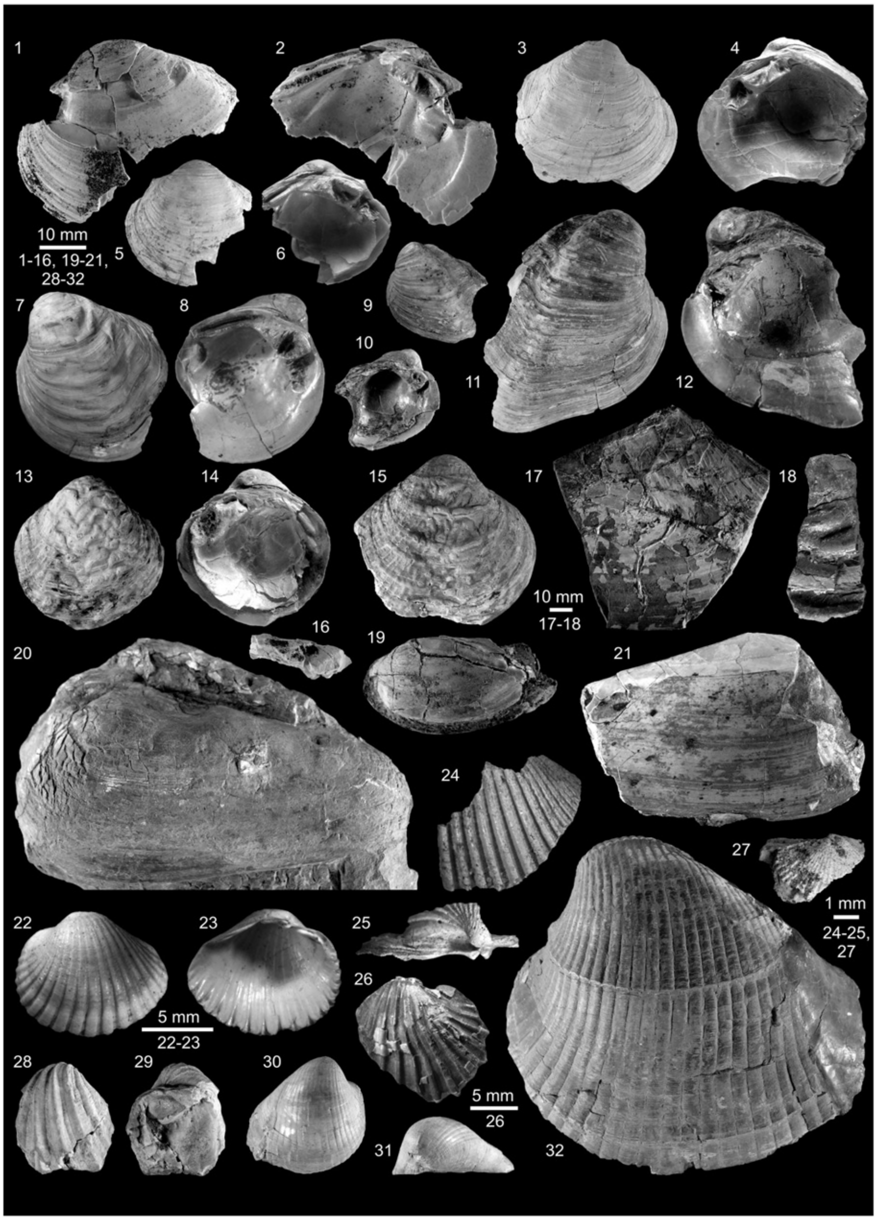


Fig. 3. Unionid (1–21) and limnocardiine (22–32) bivalves from the studied section (LV — left valve, RV — right valve, [no.]—sample number). 1–2. *Potomida prominulus* — LV, 10. 3–6. *P. slanicensis* — RV and LV, 15a. 7–8. *P. bielzi* — LV, 5. 9–12. *P. breastensis* — LV and RV, 11. 13–15. *Rugunio condai* — RVs, 11. 16. *Sulcopotomida cymatoides* — RV posterodorsal area fragment, 10. 17. *Pseudohyriopsis problematica* — articulated shell fragment, 8. 18. *Potamoscapha krejcii* — articulated shell ventral area fragment, SRD 17d. 19. *Unio* sp. — LV, 5. 20–21. *Jazkoa sturzae* — (20) LV, SRD 17d, (21) RV, SBR 9a. 22–23. *Euxinicardium gilletae* — LV, 1. 24–25. *E.* cf. *orolesi* — fragments, SBD 19. 26. *Euxinicardium*? sp. — RV fragment, SBR 15. 27. *Pseudocatillus*? sp. — LV fragment, SBD 19. 28–29. *Psilodon neumayri* — RV fragment, SBD 19. 30–31. *Prosodacnomya sturi* — RV, SBR 3. 32. *Zamphiridacna zamphiri* — LV, SBD 17.

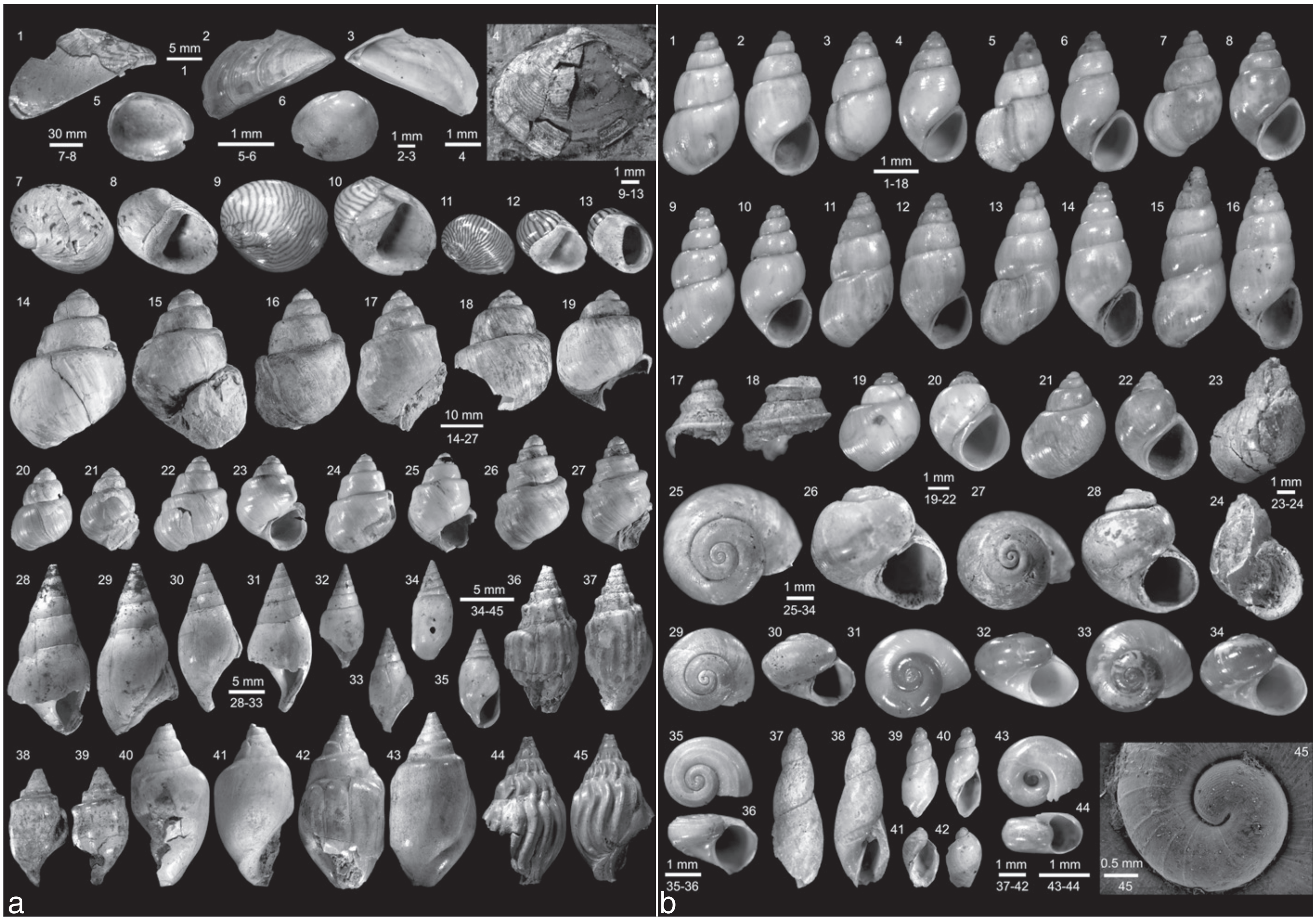


Fig. 4. a) Dreissenid (1–3) and sphaeriid (4–6) bivalves, and neritid (7–13), viviparid (14–27), and melanopsid (28–45) gastropods from the studied section (abbreviations as in Fig. 3). 1–3. *Dreissena polymorpha* — (1) RV, 3, (2–3) RV, 6. 4. *Pisidium clessini* — RV, 12. 5–6. P. *iasiense* — RV, 3 (2). 7–8. *Theodoxus licherdopoli licherdopoli* — 11 (3). 8–13. *T. licherdopoli scriptus* — (9–10) 15a, (11–13) 16 (1). 14–15. *Viviparus rumanus* — SBR4 (1). 16–19. *V. argesiensis* — (16–17) morph 1 — SBD17, (18–19) morph 2 — 6. 20–21. *V. mammatus* — 2. 22–25. *V. bifarcinatus* — 12. 26–27. *V. stricturatus* — 11 (1a). 28–35. *Melanopsis rumana* — 15a. 36–37. *M. hybostomaamaradica* — 5. 38–39. *M. slavonica* — 9. 40–41. *M. pterochila* — 11 (4a). 42–43. *M. onusta* — 11 (4a). 44–45. *M. soubeirani* — 5. b) Hydrobiid (1–22), emmericid (23–24), valvatid (25–36, 45), lymnaeid (37–42), and planorbid (43–44) gastropods from the studied section. 1–8. *Hydrobia* cf. *magna* — (1–2) morph 1, (3–4) morph 2, (5–6) morph 3, (7–8) morph 4, all from 3 (2). 9–10. *Hydrobia* cf. *radmanesti* — 3 (2). 11–16. *Hydrobia* cf. *syrmica* — 11 (3). 17–18. *Pyrgula eugeniae* — SRD17d. 19–22. *Lithoglyphus acutus* — (19–20) 3 (1), (21–22) 8. 23–24. *Emmericia*? sp. — 15. 25–26, 29–34. *Valvata* (*Valvata*) *sulekiana* — (25–26) 13, (29–30) 13, (31–34) 12. 27–28, 35–36, 45. *Valvata* (*Cincinna*) *sibinensis* — (27–28) 16 (2), (35–36) 3 (1), (45) 16 (1). 37–40. *Omphiscola*? *acuaria* — 15a. 41–42. *Radix* aff. *korlevici* — 16 (1). 43–44. *Gyraulus* cf. *katurici* — 15a.

would have made stratigraphic correlations between outcrops highly uncertain.

5. Biostratigraphy

5.1. Methods

Both sections are logged and stratigraphic levels determined in the field where possible. Large distances between outcrops exist in the upper part of the Romanian due to the low bedding tilt. In this part stratigraphic differences between outcrops are determined using GPS.

In mollusk bearing horizons the hand-picked samples as well as the representative sediment bulk samples were collected. 29 stratigraphic levels were sampled, 17 in the interval 744–879 m of Section A and 12 in the interval 143–839 m of Section B. These represent together a largely continuous stratigraphic interval ranging from the uppermost Dacian (Parscovian) to the lowermost Upper Romanian (Valachian). In general, the preservation is poor and results from intra-formational fragmentation due to secondary salt infiltration of the deposits, providing the laboratory preparation and identification as challenging. Therefore the sediment bulk samples were first handpicked to save the still complete specimens and then washed in water over a sieve net. This procedure resulted in about 2500 specimens available for the present taxonomic study. Basic mollusk taxonomic literature consulted include Wenz (1942), Pană et al. (1981), Marinescu and Papaianopol (1995) and Papaianopol et al. (2003). Subsequently, the references comprising the original taxa designations have been checked (see Appendix).

Around 150 micropaleontological levels were sampled in section B. Ostracod preservation is poor in section A and therefore this section is not studied in detail. To assess the ostracod distribution across the Dacian–Romanian boundary, we sampled a short downwards extension of section B within Dacian deposit (downstream from 45.403505 N, 26.762835 E). Due to poor exposure we cannot give the exact stratigraphic gap to the main section. Every sample weighed 500–1000 g or more. For better disaggregation, samples were boiled ½–1 h with sodium carbonate solution. Before boiling, it was necessary to dry the sediment in order to remove interstitial water. The boiled samples were washed through a battery of sieves (63–500 μm). For illustration of ostracod species we use a ZEISS–Stemi SV11 microscope with a NIKON digital camera.

Most Eastern Paratethys ostracods were first described in Russian with hand drawn figures. We also used some works where fossil ostracods from Ponto-Caspian areas are illustrated using SEM pictures (Yassini, 1986; Boomer et al., 1996, 2010; Stoica et al., 2013; Van Baak et al., 2013) as well as monographic works on recent fresh water ostracod fauna from Europe (Meisch, 2000; Fuhrmann, 2012). However, correct identification of Paratethyan ostracods is not an easy task due to confusion that persists as a result of the large number of new species proposed over the last decades by some authors based on subjective criteria or on minor morphological differences often caused by local environmental conditions. Taxonomic documentation on the present identifications is provided in Fig. 3, Fig. 4, Fig. 7 and Fig. 8.

5.2. Mollusks

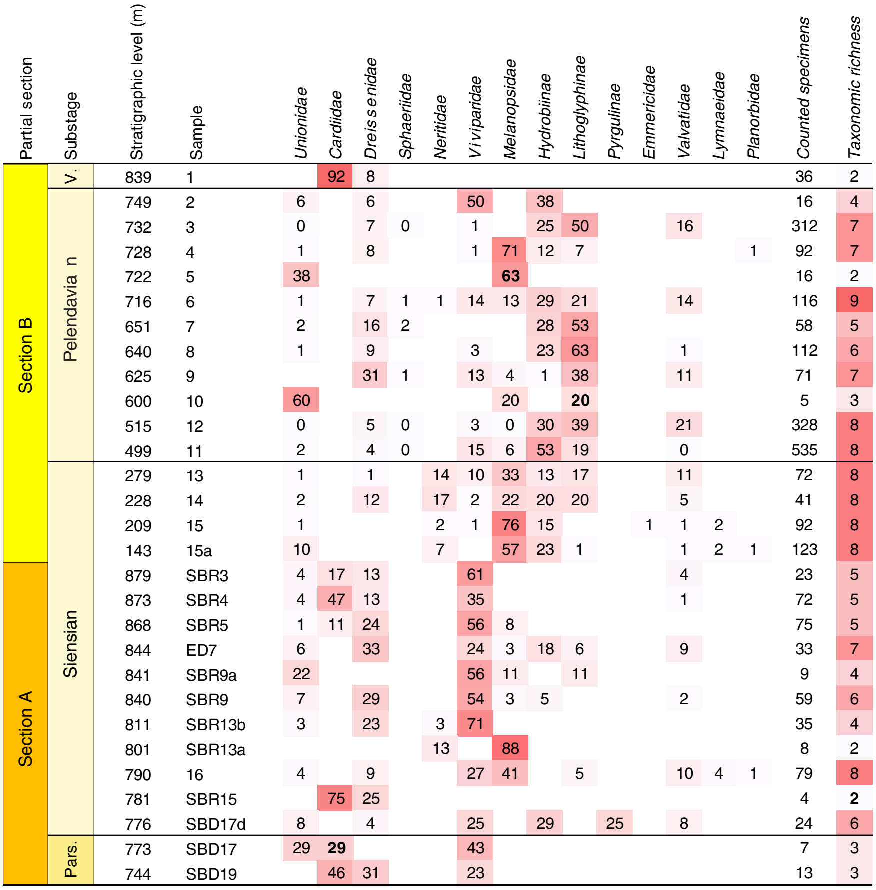
46 mollusk species belonging to 12 families and 15 subfamilies are identified from the two studied sections. The mollusk distribution pattern marks the Parscovian/Siensian boundary through a prominent extinction event in cardiid bivalves at 780 m. The disappearance of characteristic Dacian marker-fossils like the large sized *Zamphiridacna zamphiri* or the thick walled *Psilodon neumayri* contributes an easy recognition of the Romanian stage lower boundary (Fig. 5 and Fig. 6). In the lower Siensian, the final extinction of cardiids in the Dacian basin occurs. The group is represented in this interval mainly by a monotypic presence of *Prosodacnomya sturi*. Furthermore, the Siensian/Pelendavian boundary is marked by a change to more abundant and ornamented fauna. Finally the Pelendavian/Valachian boundary is indicated by the massive reappearance of the cardiids represented by the highly dominant *Euxinicardium gilletae*. This pattern fits well with the available literature data on regional mollusk stratigraphy (e.g. Papaianopol et al., 1995, 2003).

Changing environmental conditions are the main trigger for this ecostratigraphy. The cardiids belong to the subfamily Lymnocardiinae which is an euryhaline bivalve group bounded to restricted marine and brackish continental environments and are generally absent in fresh water (Nevesskaya et al., 2001, 2013). The absence of lymnocardiines in the Late Pliocene fresh water deposits of the Pannonian Basin implies that their re-occurrence in the Dacian basin is a consequence of a transgressive event through a reconnection with the Black Sea region.

One conspicuous feature of the family-level gastropod distribution is the presence of two evolutionary faunas. The Parscovian and Siensian deposits are characterized by the dominance of viviparid snails, the Pelendavian deposits are marked by a bloom of the hydrobiids and melanopsids. Examples of hydrobiid- and melanopsid-dominated environments are abundant in the Neogene of SE Europe and seem to be characteristic for long-living, freshwater lakes (Harzhauser and Mandic, 2008). Hence, the increased taxonomic richness during Pelendavian could reflect installation of stable, long-living, perennial lake conditions in the late Pliocene of the Dacian Basin providing numerous ecological niches for mollusk settlements.

5.3. Ostracods

Throughout the section, *Cyprideis* ex. gr. *torosa* (Jones) is a common species and forms populations of both adults and juveniles exceeding several thousands of individuals per sample (Fig. 9). These mass occurrences indicate that associations are in place and not subsequently concentrated by differential sedimentary transport. Abundant development of *Cyprideis* is not unusual when considering the ability of this taxon to easily adapt to large and repeated variations in salinity (Wagner, 1957, 1964; Van Harten, 1996; Meisch, 2000). This species is commonly found both in the brackish Dacian part of the section and in the fresh water Romanian deposits, but disappears at the base of the Valahian.



Partial section	Substage	Stratigraphic level (m)	Sample	*Unionidae*	*Cardiidae*	*Dreissenidae*	*Sphaeriidae*	*Neritidae*	*Viviparidae*	*Melanopsidae*	*Hydrobiinae*	*Lithoglyphinae*	*Pyrgulinae*	*Emmericidae*	*Valvatidae*	*Lymnaeidae*	*Planorbidae*	*Counted specimens*	*Taxonomic richness*
Section B	V.	839	1		92	8												36	2
	Pelendavian	749	2	6		6			50		38							16	4
		732	3	0		7	0		1		25	50			16			312	7
		728	4	1		8			1	71	12	7					1	92	7
		722	5	38						**63**								16	2
		716	6	1		7	1	1	14	13	29	21			14			116	9
		651	7	2		16	2				28	53						58	5
		640	8	1		9			3		23	63			1			112	6
		625	9			31	1		13	4	1	38			11			71	7
		600	10	60						20		**20**						5	3
		515	12	0		5	0		3	0	30	39			21			328	8
		499	11	2		4	0		15	6	53	19			0			535	8
	Siensian	279	13	1		1		14	10	33	13	17			11			72	8
		228	14	2		12		17	2	22	20	20			5			41	8
		209	15	1				2	1	76	15			1	1	2		92	8
		143	15a	10				7		57	23	1			1	2	1	123	8
Section A		879	SBR3	4	17	13			61						4			23	5
		873	SBR4	4	47	13			35						1			72	5
		868	SBR5	1	11	24			56	8								75	5
		844	ED7	6		33			24	3	18	6			9			33	7
		841	SBR9a	22					56	11		11						9	4
		840	SBR9	7		29			54	3	5				2			59	6
		811	SBR13b	3		23		3	71									35	4
		801	SBR13a					13		88								8	2
		790	16	4		9			27	41		5			10	4	1	79	8
		781	SBR15		75	25												4	**2**
		776	SBD17d	8		4			25		29		25		8			24	6
	Pars.	773	SBD17	29	**29**				43									7	3
		744	SBD19		46	31			23									13	3

Fig. 5. Stratigraphic distribution of mollusk (sub-)families represented in the studied section. Relative abundances in the samples are given in percentages. Taxonomic richness is indexed at subfamily level.

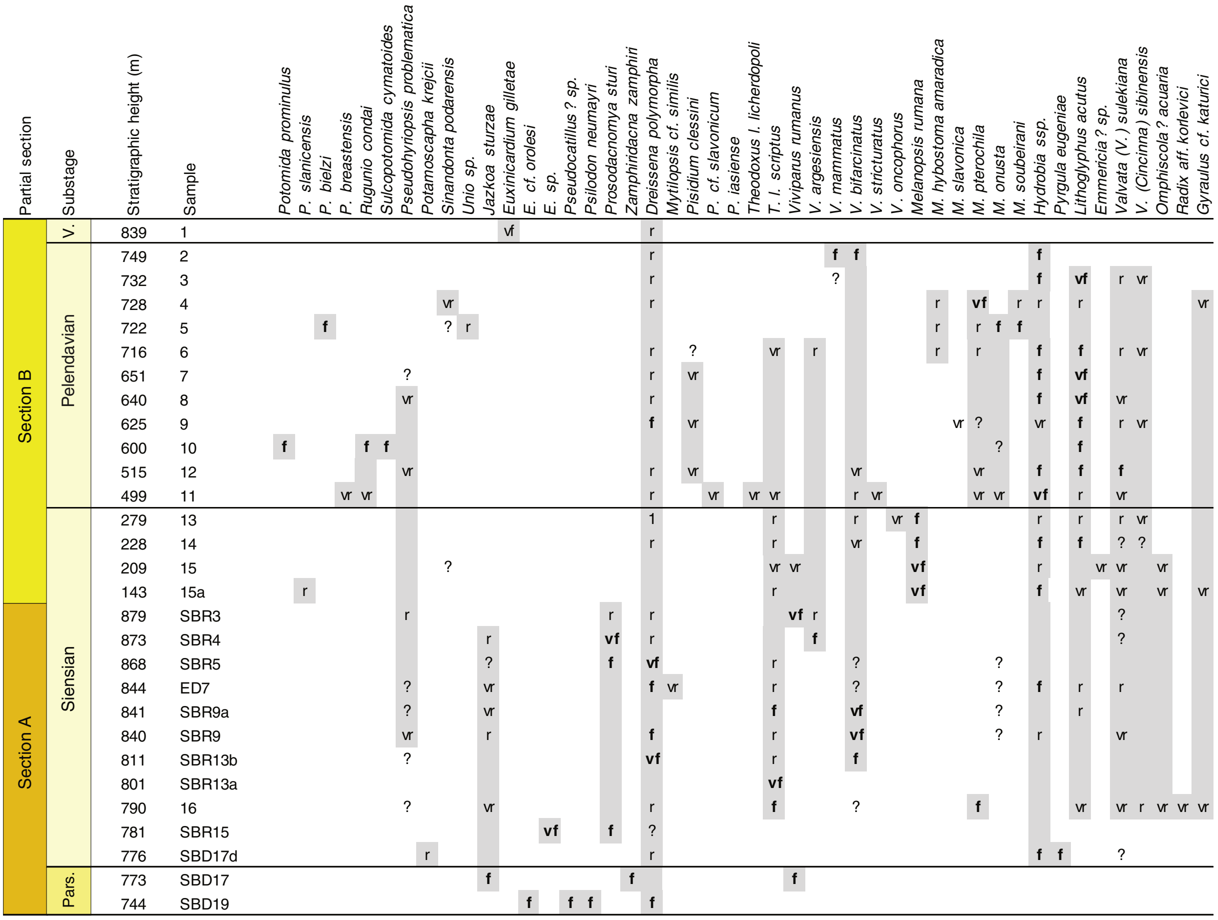


Fig. 6. Stratigraphic distribution of the species-level mollusk taxa identified in the studied section. Occurrence ranges in the section are indicated by the gray shaded column. Abbreviations: very rare <5%, rare <20%, frequent <50%, very frequent, ≤100%.

The downwards extension of section B (samples BR41-49) contains an ostracod association dominated by typical Upper Dacian (Parscovian) taxa. Due to the decrease in salinity at the boundary between Dacian and Romanian some of them do not pass the boundary. This is the case for *Caspiocypris ornatus* Hanganu, *Pontoniella acuminata* (Zalányi), *Camptocypria* Zalanyi spp., *Loxoconcha kochi* Méhes, *Cytherissa bogatschovi* (Livental), with the exception of *C. bogatschovi* var. *plana* (Klein). Other species cross the boundary and continue to evolve during the Romanian, for instance *Heterocypris* sp., a species that has a close affinity with *H. incongruens* (Ramdohr) and *Amnicythere* sp. Other species crossing the boundary are *Amnicythere bona* (Stepanajtis), *Loxoconcha babazananica* (Livental), *Ilyocypris gibba* (Ramdohr), *Limnocythere dorsotuberculata* Negadaev-Nikonov, *Darwinula stevensoni* (Brady & Robertson).

The lowermost samples from the Romanian succession (Lower Siensian) contain no ostracods. Above this barren zone, the Siensian ostracod fauna is represented, beside the abundant *Cyprideis* ex. gr. *torosa*, by fresh water taxa dominated by *Candona neglecta* Sars (especially juvenile stages, considered by different authors as *Candoniella* sp.) and less frequently by *Ilyocypris gibba*, *Limnocythere dorsotuberculata*, *Metacypris cordata* Brady & Robertson, *Cyclocypris laevis* (O. F. Müller), *Pseudocandona compressa* (Koch) (many juveniles or fragmented shells), *Zonocypris membranae* (Livental), *Scottia* ex. gr. *browniana* (Jones), *Eucypris* sp., *Cytherissa bogatschovi* (Livental) var. *plana* (Klein), *Amnicythere cymbula* (Livental). In the Middle Romanian interval (Pelendavian) the ostracod association is much richer in individuals of taxa already mentioned in Siensian.

A specific level (~770 m, sample BR 10a) provided a rich ostracod association dominated by *Cytherissa bogatschovi* var. *plana*, *Loxoconcha babazananica*, *Amnicythere* sp., *A. cymbula* and *Scottia* ex. gr. *browniana* together with many specimens of minute lymnocardiine bivalve *Pseudocatillus* sp. (Fig. 8b). The presence of the lymnocardiine bivalve suggests a short-termed flooding from the Black Sea, increasing the salinity from fresh to low brackish water conditions. Beyond that, the presence of *Cytherissa bogatschovi* var. *plana* may point to a first pulse of colder conditions. Genus *Cytherissa*, and in particular its type species *Cytherissa lacustris* (Sars), is considered an eurythermal form, with preference for cold water and is widely distributed in the sub-littoral and profound zones of cold lakes (Danielopol et al., 1990; Meisch, 2000).

Scottia browniana is described mainly from Pleistocene Palearctic areas (Kempf, 1971), but it is also found in the Pliocene. Hanganu (1976, 1985) described from the Upper Dacian sediments two species named *Scottia bonei* and *Scottia kempfi* that show many similarities with *Scottia browniana*. Very similar morphs (slightly elongated in shape) were described in the Pliocene deposits from Russia as *Scottia browniana kubanica* (Schneider, in Mandelstam et al., 1956). Krstic (2003, 2006) mentioned this species in middle and especially upper *Paludina* beds of the Pannonian Basin, when the climate started to become colder, in high energy environments of deltaic facies or shallow lakes affected by wave action.

Loxoconcha babazananica (in many papers considered as *Loxoconcha immodulata* Stepanajtys) is also well represented at this level, proving together with *Amnicythere cymbula*, *Amnicythere* sp., a slight increase

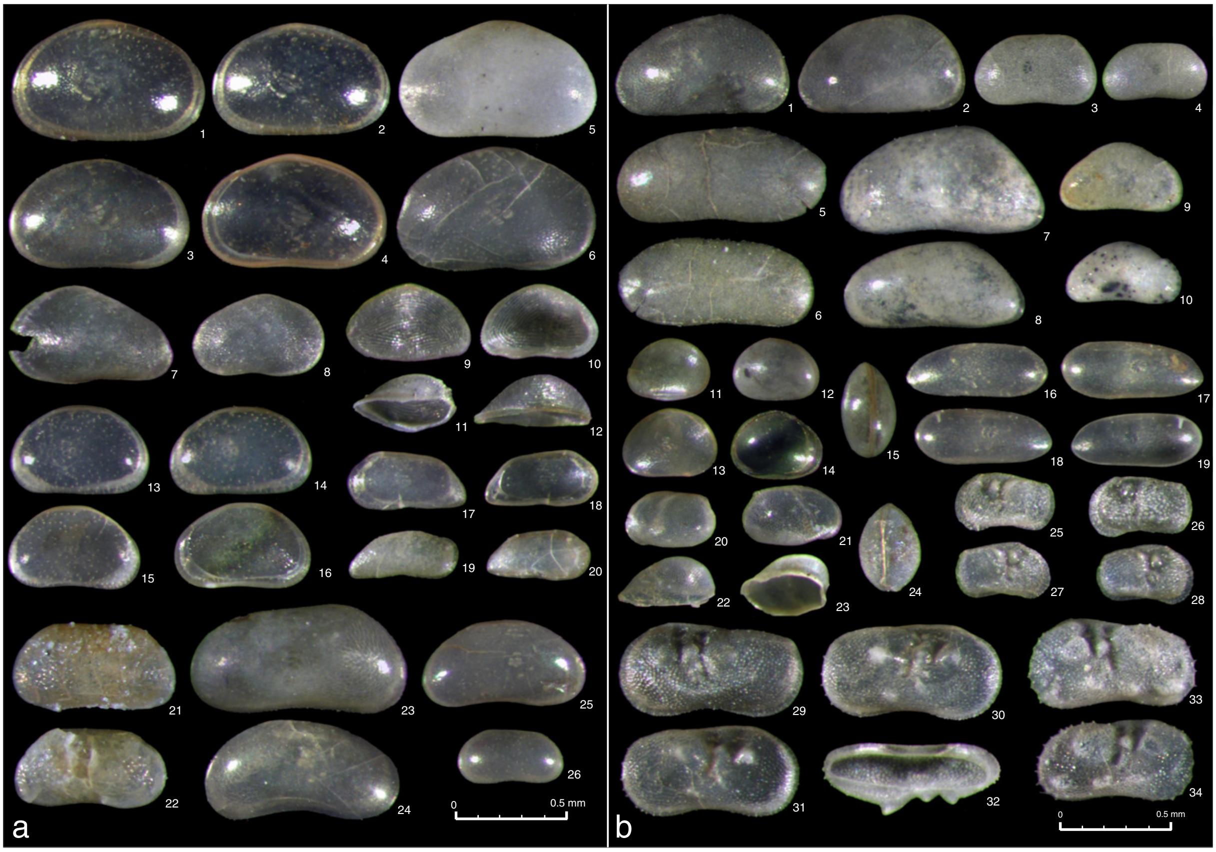


Fig. 7. Pliocene ostracods from Slanicul de Buzau Valley (Section B) (LV — left valve, RV — right valve, C — carapace, BR, ER — micropalaeontological samples). a) 1–4. *Heterocypris* sp., (all specimens from sample BR 44); 1, 2. LV, external view; 3. RV, external view; 4. RV, internal view; 5, 6. *Heterocypris* ex. gr. *salina* (Brady); 5. LV, external view, ER 33; 6. RV, external view, BR 13; 7, 8. ?*Eucypris* sp., juveniles, all specimens from sample BR 13; 7. LV, external view, A1 juvenile; 8. RV, A2 juvenile; 9–12. *Zonocypris membranae* (Livental); 9. LV, external view, BR 13; 10. LV, internal view, BR 13; 11. LV, ventral view, ER 33; 12. LV, dorsal view, BR13; 13–16. *Scottia* ex. gr. *browniana* (Jones); 13, 14. LV, external view, BR 15; 15. RV, external view, BR 14; 16. RV, internal view, BR 10; 17–20. *Pontoniella acuminata* (Zalányi), (all specimens from sample BR 48); 17. LV, external view; 18. LV, internal view; 19, 20. RV, external view; 21, 22. *Caspiocypris ornatus* Hanganu, BR47; 21. LV, external view; 22. RV, external view; 23–26. *Candona neglecta* Sars; 23. LV, external view, BR 44; 24. RV, external view, BR 10a; 25. RV, A1 juvenile, external view, BR 10a; 26. A3 juvenile, external view, frequent named *Candoniella* sp. b) 1–4. *Pseudocandona compressa* (Koch); 1, 2. LV, external view, ER 101 + 30 m; 3. LV, A1 juvenile, external view, BR 13; A2 juvenile, external viev, BR 13; 5, 6. *Fabaeformiscandona* sp., ER 22; 5. C, view from LV; 6. C, view from RV; 7, 8. *Candona* ex. gr. *candida* (O. F. Müller), RV, external views, ER 101 + 30 m; 9, 10. *Typhlocypris* sp., RV, external views, BR 9; 11–15. *Cyclocypris laevis* (O. F. Müller); 11. C, view from LV, BR 29a; 12. C, view from RV, BR 29a; 13. LV, external view, BR 29a; 14. LV, internal view, ER 21; 15. C, dorsal view, BR 29a; 16–19. *Darwinula stevensoni* (Brady & Robertson) (all specimens from sample BR 44); 16. LV, external view; 17, 18. RV, external views; 19. RV, internal view; 20–24. *Metacypris cordata* Brady & Robertson; 20. LV, external view, BR 13; 21. RV, external view, BR 13; 22. RV, dorsal view, BR 13; 23. RV, internal view, BR 13; 24. C, dorsal view, ER 21; 25–28. *Limnocythere dorsotuberculata* Negadaev–Nikonov; 25. LV external view, female, BR 13; 26. LV external view, male, ER 33; 27, 28. RV, external views, females, BR 13; 29–32. *Ilyocypris gibba* (Ramdohr), (all specimens from sample ER 33); 29. LV, external view; 30, 31. RV, external views; 32. RV, dorsal view; 33, 34. *Ilyocypris* sp.1; 33. LV, external view, ER 33; 34. RV, external view, ER 33;.

of salinity. This species of *Loxoconcha* was first described by Livental (1929) in Plio-Pleistocene (Akchagylian and Apsheronian) deposits of Azerbaijan (Babazanan section) and is widespread from Upper Miocene to recent throughout the Black Sea and Caspian region. It is likely this species migrated from there into the Dacian Basin. The level rich in *Euxinicardium gilletae* shells (839 m) contains less abundant brackish ostracods, possibly because it is developed in sandy littoral facies where *Cyprideis* is the dominant taxa.

After a couple of meters of brackish conditions, a fresh water ostracod assemblage with species of *Ilyocypris*, *Zonocypris* and *Limnocythere* becomes dominant. From ~900 m onwards (Upper Romanian — Valachian), ostracods and mollusks become very scarce, coinciding with a change to fluvial environments. Only a few levels contain rare fresh water ostracods like *Candona neglecta* (mainly juveniles), *Pseudocandona compressa*, *Ilyocypris gibba*, *Eucypris* sp.(fragments). At the top of the analyzed section a single level with abundant fresh water ostracods, like *Candona neglecta*, *Candona* ex. gr. *candida*, *Darwinula stevensoni*, *Cyclocypris laevis*, *Pseudocandona compressa*, *Eucypris* sp. is found. At this level planorbid gastropods are also common.

6. Magnetostratigraphy

6.1. Methods

In section A, 85 levels in 1030 m are sampled, in section B 143 levels in 1750 m. Two standard paleomagnetic samples per level are taken with an electrical drill and a generator as power supply. Paleomagnetic measurements are performed at Paleomagnetic Laboratory 'Fort Hoofddijk' at Utrecht University, The Netherlands. Initially, one specimen per sample level is thermally demagnetized. In case of unclear results, a specimen from the second sample at the same level is demagnetized. To determine the natural remanent magnetization (NRM), samples are thermally demagnetized and measured on a 2G Enterprises DC SQUID cryogenic magnetometer (noise level 3×10^{-12} Am^2).

Thermal behavior of the magnetic carriers is analyzed in air on a modified horizontal translation type Curie balance (noise level 5×10^{-9} Am^2). On material from the same sample further analysis is performed. Alternating field (AF) demagnetization is performed on an in-house built robotized sample handler controller attached to a

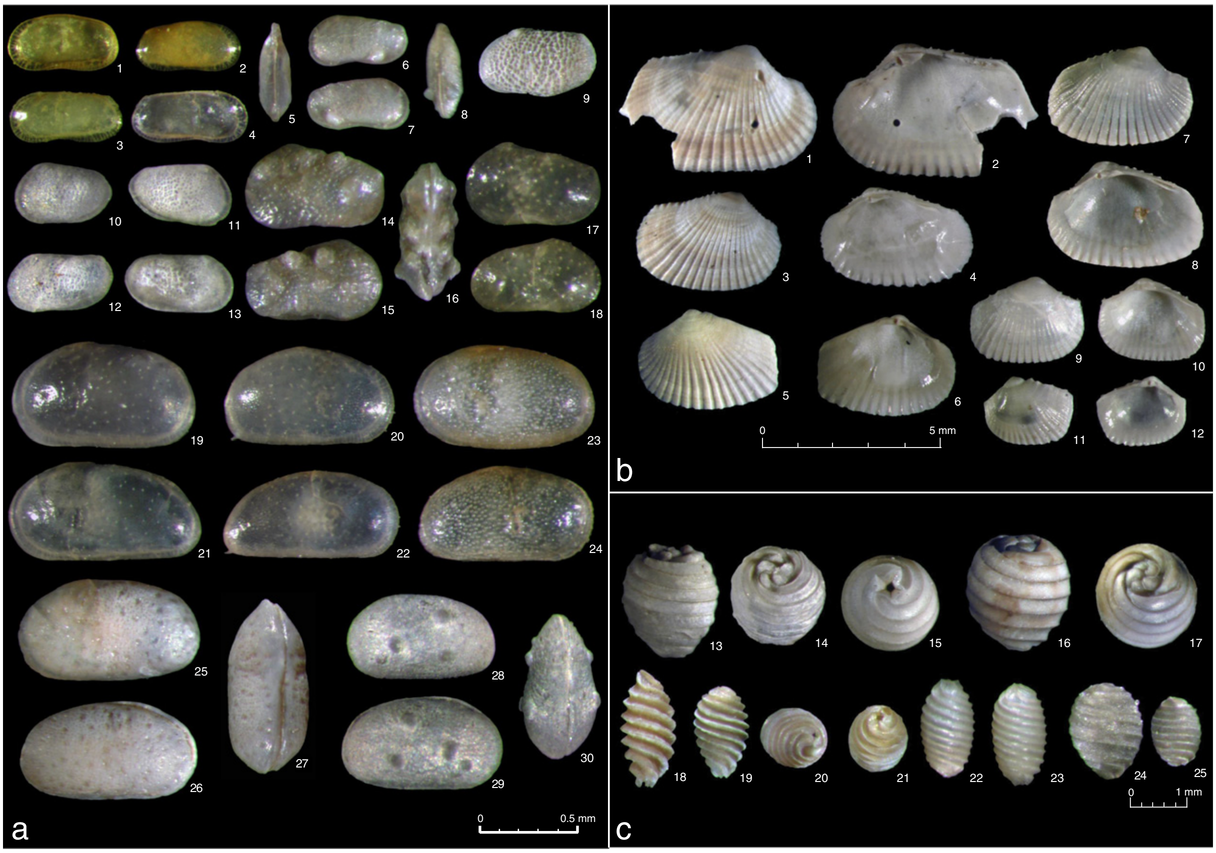


Fig. 8. Ostracods, micro-bivalves and characean oogonia from Slanicul de Buzau Valley (Section B) continued (abbreviations as in Fig. 7). a) 1–5. *Amnicythere cymbula* (Livental), (all specimens from sample BR 10); 1. LV, external view, female; 2. RV, external view, female; 3. LV, external view, male; 4. RV, external view, male; 5. C, dorsal view; 6–8. *Amnicythere* sp., very similar with *Amnicythere bona* (Stepanajtis in Agalarova et al., 1961) (all specimens from sample BR 14); 6. LV, external view; 7. RV, external view; 8. C, ventral view; 9. *Loxoconcha* ex. gr. *kochi* Méhes, LV, external view, BR 48; 10–13. *Loxoconcha babazananica* Livental, possible synonym of *Loxoconcha immodulata* Stepanajtys (all specimens from sample BR 9); 10. LV, external view, female; 11. RV, external view, female; 12. LV, external view, male; 13. RV, external view, male; 14–16. *Cytherissa bogatschovi* (Livental) (all specimens from BR 48); 14. C, view from LV; 15. C, view from RV; 16. C, ventral view; 17, 18. *Cytherissa bogatschovi* (Livental) var. *plana* (Klein) (all specimens from sample BR 10); 17. LV, external view; 18. RV, external view; 19–27. *Cyprideis* ex. gr. *torosa* (Jones); 19. LV, external view, female, BR 11; 20. RV, external view, female, BR 11; 21. LV, external view, male, BR 11; 22. RV, external view, male, BR 11; 23. LV, external view, female, BR 48; 24. RV, external view, female, BR 48; 25. C, view from LV, female, BR 48; 26. C, view from RV, female, BR 11; 27. C, dorsal view, female, BR 48; 28–30. *Cyprideis* ex. gr. *torosa* (Jones), nodded specimen, ER 17; 28. C, view from LV, female; 29. C, view from RV, female; 30. C, dorsal view, female. b) 1–12. *Pseudocatillus* sp. (all in different juvenile stages, samples BR10, 10a); 1, 3, 7, 9. RV, external view; 2, 4, 8, 10. RV, internal view; 5, 11. LV, external view; 6, 12. LV, internal view. c) *Charophyta* gyrogonites. 13–17. *Nitellopsis* ex. gr. *meriani* (Braun); 18–21. *Chara* sp. 22, 23. *Chara escheri* A. Braun ex F. Unger; 24, 25. *Chara* group *globularis* Thuiller.

horizontal 2G Enterprises DC SQUID cryogenic magnetometer. These measurements allow to check for the acquisition of a gyroremanent component, which is typical for greigite-bearing material (Roberts et al., 2011). The Isothermal Remanent Magnetization (IRM) is acquired on the same specimen from the AF-demagnetized (300 mT) state. IRM curves consist of 61 data points and are decomposed into coercivity components using the fitting program of Kruiver et al. (2001).

6.2. Demagnetization and rock magnetic properties

Magnetic properties for the Late Miocene and Pliocene in the Dacian Basin have previously extensively been studied (Vasiliev et al., 2004, 2007, 2008), which shows that they are excellent magnetic carriers. The studied samples can be subdivided into two groups. The first group forms the majority (~90%) of the samples. Representative samples are shown in Fig. 10. In thermomagnetic runs, this group shows reversible behavior up to 150 °C (Fig. 10). The general hyperbolic shape of the curves indicates a dominant paramagnetic component. For strong samples, a small increase in magnetization can be observed around 200 °C. An increased, irreversible demagnetization occurs in the interval 250–400 °C. Above 400 °C magnetization increases, indicating the new formation of magnetic components. This is likely to be (non-magnetic) pyrite oxidizing into (magnetic) magnetite. This behavior indicates that these samples are dominated by iron-sulfide magnetic carriers (Vasiliev et al., 2007).

IRM curves are fitted with four coercivity components. The first has a $B_{1/2}$ (field of half the Saturation IRM) of less than 20 mT and a negligible contribution to the total IRM. This component does not represent a physical component, but is necessary for skewed-to-the-left distributions (Kruiver et al., 2001). Two components of roughly equal $B_{1/2,}$ but differing dispersion parameters (DP) carry the bulk (90%) of the signal. The narrow component tends to have DP values around 0.15, while the wider one is between 0.3 and 0.4. A fourth, high-coercivity component is interpreted with $B_{1/2}$ values above 200 mT, but represents only a minor part of the total SIRM. We interpret the wider of the two main components as a larger grain size, likely to be authigenic greigite, where the narrow component (smaller grain size) may represent magnetosomal greigite (Vasiliev et al., 2008; Chang et al., 2014). Alternating field (AF) demagnetization shows the acquisition of a gyroremanent component at fields above 40 mT (Fig. 10). Also this is typical for samples with greigite as magnetic carrier.

The second group of samples shows a continuous decrease in magnetization up to a maximum temperature of 580 °C to 600 °C, indicating an iron oxide as magnetic carrier. IRM curves are fitted with a single

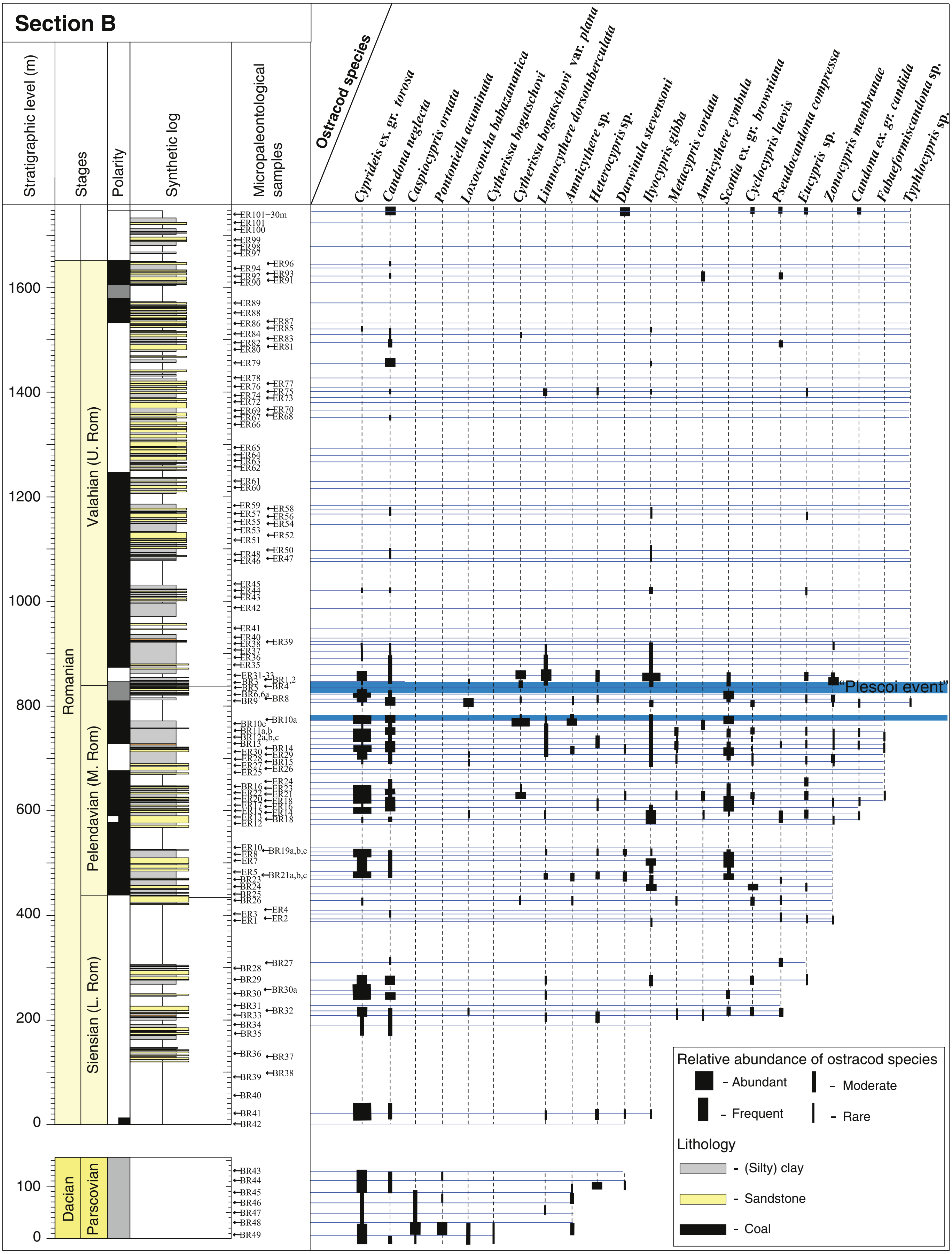


Fig. 9. Ostracod range chart for section B.

dominant component with a $B_{1/2}$ of 40–50 mT and a DP of 0.26. These are typical values for a magnetite component with a detrital origin. These samples, found throughout the middle and upper Romanian, do not acquire a gyroremanent component during AF demagnetization.

Given the thermomagnetic properties, all samples are stepwise, thermally demagnetized until alteration becomes evident, or otherwise up to a maximum of 600 °C. We interpret three different components, a first low temperature (LT) component up to ~250 °C, a second medium component up to 400 °C (MT), and a third high temperature component up to a maximum temperature of 600 °C (HT). The MT and HT components are interpreted as (near) primary of origin and represent the Characteristic Remanent Magnetization (ChRM).

6.3. Magnetic polarity pattern

Section A has five polarity zones, three, long reverse periods and two short normal intervals (Fig. 11). The lower reversal of the lower normal interval coincides with the change in bedding direction at 250 m. This suggests that there may be a (short) hiatus in the record. Section B consists of nine polarity zones (Fig. 12). Throughout the section, isolated samples show opposing polarities, but these are not interpreted as true polarity zones. Only when multiple samples in a row show a consistent polarity change, they are interpreted as a polarity zone. The lower part of the section (<440 m) is reverse, the middle part (440–1250 m) predominantly normal and the upper part (1250–1750 m) again predominantly reverse. In the long normal interval, two reverse zones are found, the first between 675 and 730 m, and the second between 845 and 875 m. The lower reversal of this second zone is however not very well constrained and is preceded by 45 m of samples showing mixed polarity. In the top reverse zone, one short normal is found between 1530 m and 1650 m.

The reverse directions observed in the top normal zone can be explained in two ways. The first is that normal zone consists of measurements from two outcrops 700 m apart. Due to the shallow bedding of ~12–15°, some uncertainty exists in the GPS correlation between the outcrops, and therefore may result in inaccurate stratigraphic positions. Alternatively, the reverse samples may show a delayed acquisition of the magnetic field.

Stereographic plots show an interesting difference between the two sections. In the older section, tectonically corrected samples show a 15–20° counter clockwise rotation (Fig. 11). In the younger section, (uncorrected) in-situ directions show a similar rotation (Fig. 12) Here, the tectonic correction causes directions to correct towards no rotation.

7. Discussion

7.1. Correlation to GPTS

We correlate the two normal zones in section A to chrons C3n.2n (Nunivak) and C3n.1n (Cochiti), following the results of Vasiliev et al. (2004) from the nearby section of Rimnicu Sarat. Hence, the Dacian–Romanian boundary is located directly above C3n.1n (Cochiti) in good agreement with Van Vugt et al. (2001). We exclude a correlation one normal chron lower to the C3n.2n (Nunivak) and C3n.3n (Sidufjall), as proposed by Popescu (2001) for Dacian and Romanian deposits in the western Dacian basin, because the C3n.3n (Sidufjall) is part of the Pontian regional stage (Krijgsman et al., 2010).

Our section B provides a relatively straightforward correlation between chrons C2Ar and C1r.3r. This means that a possible overlap between the two sections has to be within the long C2Ar reverse chron. Unfortunately, we are not able to improve this correlation by extending the records upwards nor downwards to get to the next reversal due to the local field conditions.

Our proposed correlation for the two sections gives us a (near-complete) record between 4.8 Ma and ~1.7 Ma. Sedimentation rates in the two sections differ markedly (Fig. 13). Section A shows sedimentation rates of ~130 cm/kyr, similar to the results from nearby Rimnicu Sarat (Vasiliev et al., 2004). In section B, the rate is lower at ~66 cm/kyr, while the Rimincu Sarat rate remains high. This may be explained by our younger section going increasingly further to the south, away from the depocenter at the time in the Focsani Depression to the north (Tărăpoancă et al., 2003).

7.2. Dacian–Romanian transition; brackish to fresh water change around 4.2 Ma

In our studied sections, the disappearance of large numbers of limnocardiine mollusks records a change from brackish to freshwater deposits and represents the boundary between the Dacian and Romanian stages. We date this boundary at 4.15 Ma, slightly younger than the C2Ar-C3n.1n (Cochiti) magnetic reversal at 4.187 Ma. Our results replace the 4.07 Ma proposed by Vasiliev et al. (2004) in the nearby valley of Rimnicu Sarat, which was based on interpolation on the geological map of the boundary.

The change from brackish to fresh water is transitional and brackish fauna finds are also made in the lower Romanian. An eastwards prograding unit develops during the Lower Dacian in the western Dacian Basin (Jipa et al., 2007). Here, coastal series of coarsening upward deposits are observed in sections and boreholes and are overlain by fluvial deposits and coals. This process represents the gradual reduction of existing accommodation space and complete infill of the Dacian Basin (Jipa and Olariu, 2009; Leever et al., 2010). Due to high subsidence rates in the Focşani depression/Carpathian Bend Zone, deposition is continuous and the brackish influence is longest of the entire Dacian Basin due to the proximity to the Black Sea.

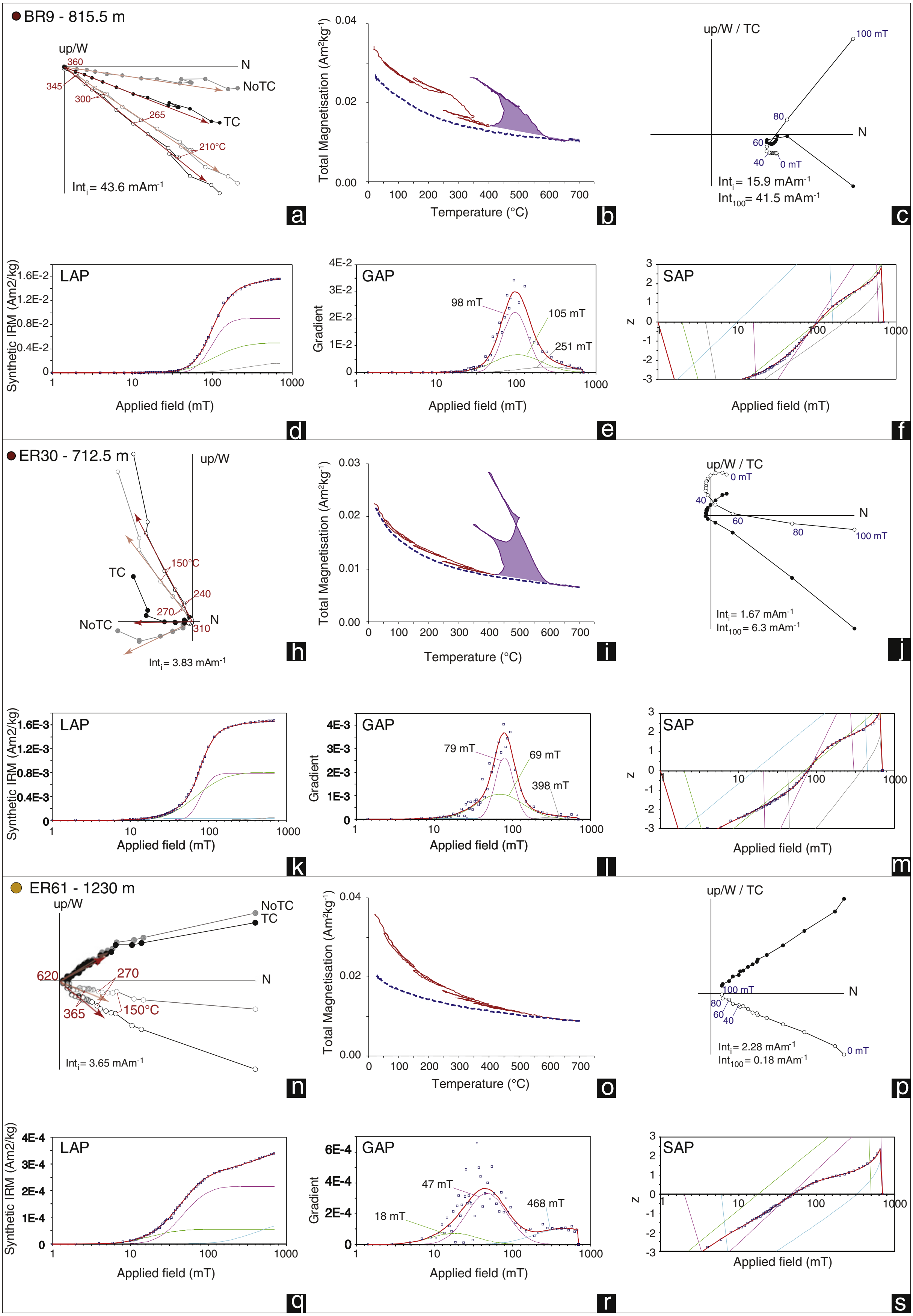
7.3. Plescoi event, reflooding of the Dacian Basin (3.1 Ma)

Our magnetostratigraphic time frame indicates the Plescoi flooding event occurred between 3.2 and ~2.95 Ma. This clearly links the Plescoi event to the mid Pliocene Warm Period (MPWP). During the MPWP, three 'super-interglacials' (KM3, K1 and G17) spanning multiple precession cycles occur (Raymo et al., 2011). The high frequency of magnetic reversals in this interval allows us to tentatively correlate the first (within chron C2An.2n) and second (within chron C2An.1r (Kaena)) episodes of higher salinity to KM3 and K1 (Fig. 14). The end of the highstand and renewed onset of fluvial deposition in the lowermost part of chron C2An.1n occurs around 2.95 Ma, close to the end of the MPWP.

The introduction of typical Black Sea lymnocardiine bivalve genera during the Plescoi event is most likely related to a highstand of the Black Sea, flooding (part of) the Dacian Basin. Maximum sea-level across this time is an open question, but most likely it was in the range of 22 ± 10 m (Miller et al., 2012). In the present-day situation, a rise to +20 m would flood the Dacian Basin to close to the study area (Fig. 1). Therefore, we assume that the Plescoi event correlates to the moments of maximum sea-level during the MPWP.

Alternatively, a switch to a positive water budget may have raised sea-level in the Black Sea. Around 4 Ma the Black Sea region experienced maximum aridity with a precipitation increase around 3 Ma, although this could also be the direct result of the highstand in the Black Sea (Van Dam, 2006; Böhme et al., 2010). Such a change has been proposed for the flooding of the Dacian Basin at 5.5 Ma during the Late Pontian Bosphorian substage (Krijgsman et al., 2010). However, for the Black Sea to rise due to a more positive hydrological budget, the Black Sea needs to be isolated from the Mediterranean Sea, since a connection would keep sea-level stable regardless of the hydrological budget.

Connectivity between Black Sea and Mediterranean Sea is not very well constrained for the Pliocene. The present-day connection to the Mediterranean Sea goes through the Bosporus – Sea of Marmara – Dardanelles gateway. During the latest Miocene, a marine connection was


BR9 - 815.5 m
up/W
N
NoTC
TC
360
345
300
265
210°C
Int$_i$ = 43.6 mAm^{-1}
a
Total Magnetisation (Am^{2}kg^{-1})
0.04
0.02
0.00
0 100 200 300 400 500 600 700
Temperature (°C)
b
up/W / TC
100 mT
80
60
40
0 mT
N
Int$_i$ = 15.9 mAm^{-1}
Int$_{100}$ = 41.5 mAm^{-1}
c
Synthetic IRM (Am2/kg)
LAP
1.6E-2
1.2E-2
0.8E-2
0.4E-2
0
1 10 100 1000
Applied field (mT)
d
GAP
Gradient
4E-2
3E-2
2E-2
1E-2
0
98 mT
105 mT
251 mT
Applied field (mT)
e
SAP
z
3 2 1 0 -1 -2 -3
10 100 1000
Applied field (mT)
f
ER30 - 712.5 m
up/W
TC
NoTC
N
150°C
240
270
310
Int$_i$ = 3.83 mAm^{-1}
h
Total Magnetisation (Am^{2}kg^{-1})
0.03
0.02
0.01
0.00
0 100 200 300 400 500 600 700
Temperature (°C)
i
up/W / TC
0 mT
40
60
80
100 mT
N
Int$_i$ = 1.67 mAm^{-1}
Int$_{100}$ = 6.3 mAm^{-1}
j
Synthetic IRM (Am2/kg)
LAP
1.6E-3
1.2E-3
0.8E-3
0.4E-3
0
1 10 100 1000
Applied field (mT)
k
GAP
Gradient
4E-3
3E-3
2E-3
1E-3
0
79 mT
69 mT
398 mT
Applied field (mT)
l
SAP
z
10 100 1000
Applied field (mT)
m
ER61 - 1230 m
up/W
NoTC
TC
N
620
270
365
150°C
Int$_i$ = 3.65 mAm^{-1}
n
Total Magnetisation (Am^{2}kg^{-1})
0.04
0.02
0.00
0 100 200 300 400 500 600 700
Temperature (°C)
o
up/W / TC
N
100 mT
80
60
40
0 mT
Int$_i$ = 2.28 mAm^{-1}
Int$_{100}$ = 0.18 mAm^{-1}
p
Synthetic IRM (Am2/kg)
LAP
4E-4
3E-4
2E-4
1E-4
0
1 10 100 1000
Applied field (mT)
q
GAP
Gradient
6E-4
4E-4
2E-4
0
47 mT
18 mT
468 mT
Applied field (mT)
r
SAP
z
1 10 100 1000
Applied field (mT)
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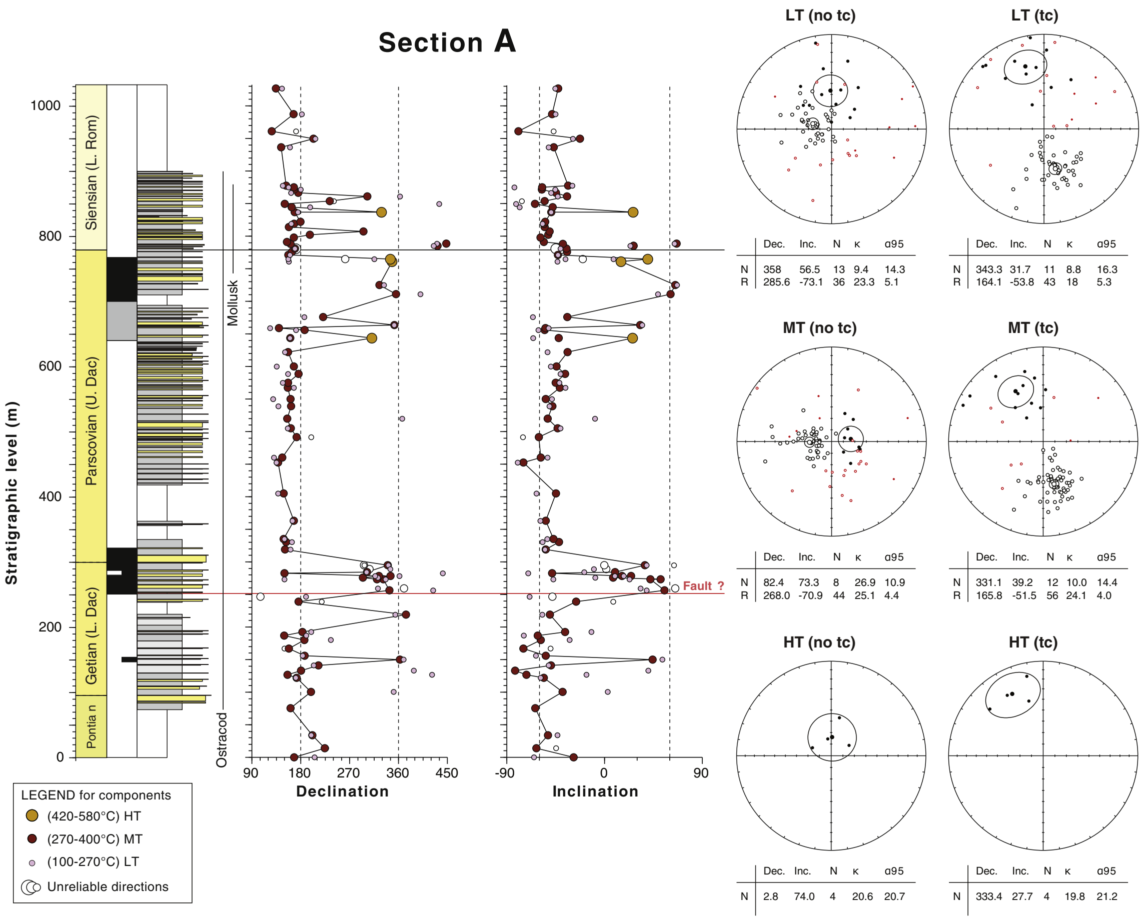

Fig. 11. Magnetostratigraphy of section A. Left to right: stratigraphic level, regional stages and lithology. Magnetic polarity column: black/white/gray represent normal/reverse/unclear polarity. Stereographic projections: LT: low temperature, MT: medium temperature, HT: high temperature. Solid (open) dots: downward (upward) projections, small red dots are directions that lie outside a 45° cut-off. Tables (N, normal, R reverse): Dec (Declination), Inc (Inclination), N (number of samples), κ (precision parameter of Fischer (1953)), α95 (95% cone of confidence).

present, causing the flooding and reconnection of Paratethyan basins during the Pontian regional stage (Krijgsman et al., 2010). This connection was however probably lost prior to the Late Pliocene (Cagatay et al., 2006). Most importantly, the Sea of Marmara basin is said to have opened and flooded in the Late Pliocene (Gökasan et al., 1997; Görür et al., 2000). The timing of the opening is however not very well constrained, and a Late Pliocene age is mostly inferred from the changes in the Black Sea sea-level (Cagatay et al., 2006).

Throughout Paratethys, the Late Pliocene is characterized by higher than previous sea-levels during the Akchagylian stage. Much confusion exists about this regional stage due to differing lithostratigraphic and biostratigraphic uses (Van Baak et al., 2013). A scarcity of long, continuous Pliocene records causes especially in the Black Sea many problems. The oldest recognized highstand deposits in the Black Sea region however tend to be in the time interval between 3.3 Ma and 3.0 Ma (Nevesskaya et al., 2003; Popov et al., 2006).

7.4. Upper Romanian; post-flooding fluvial environment, onset of Northern Hemisphere Glaciations (from 2.6 Ma)

Following the Plescoi event, deposition continues in a freshwater setting. In this upper part of the section, fauna is scarcely observed. A paleoenvironmental change occurs between 2.9 Ma and 2.6 Ma, where fluvial deposits start to dominate the record. The regional switch to coarser grained material has been interpreted in two possible ways (Necea et al., 2005). A Quaternary phase of inversion and uplift (Valachian tectonic phase) of the entire Carpathian–Pannonian system forms a tectonic explanation to increased sediment supply (Matenco et al., 2007). Alternatively, the larger climatic oscillations of the Pleistocene may have caused increased sediment transport (Necea et al., 2005). The change towards sandy, fluvial lithologies at ~1100 m is located in the middle part of chron C2An.1n at an age of ~2.7 Ma. This coincides roughly with the globally recognized cooling related to

Fig. 10. Demagnetization diagrams and rock magnetic properties of selected samples. a) h) n) Thermal demagnetization diagrams, both with (TC) and without (NoTC) bedding tilt correction, multiple temperature steps are indicated. Int_I; intensity prior to demagnetization. b) i) o) Thermomagnetic runs through multiple loops of heating and cooling. Solid red line heating, dashed blue line cooling after maximum temperature. c) j) p) Alternating field demagnetization diagrams, diagrams plotted after tilt correction (TC). Intensities given prior to demagnetization (Int_I) and after 100 mT (Int_{100}). d) k) q) Linear acquisition plot (LAP), e) l) r) Gradient acquisition plot (GAP) and f) m) s) standardized acquisition plot (SAP) of IRM experiments (Kruiver et al., 2001). Measurements displayed as blue squares. $B_{1/2}$ values of interpreted components indicated.

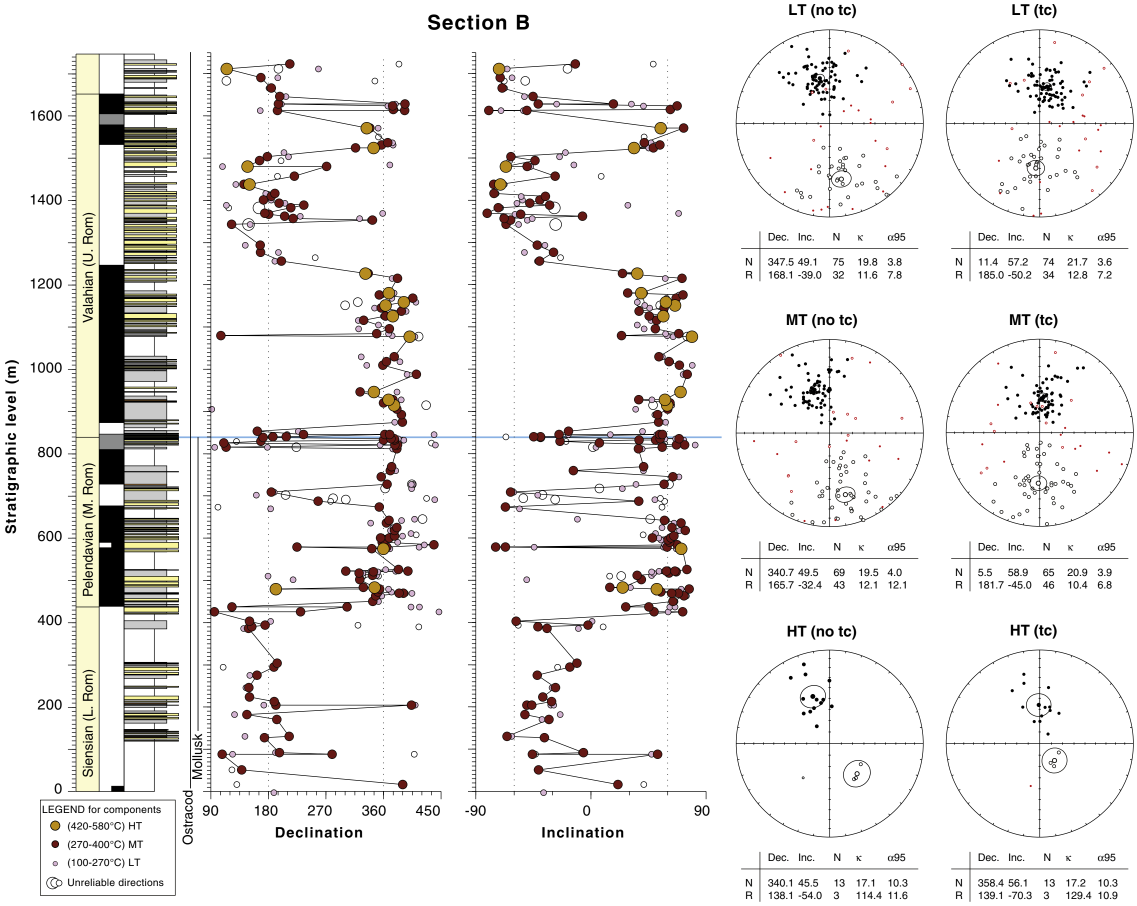

Fig. 12. Magnetostratigraphy of section B. Symbols and layout similar to Fig. 12.

intensification of glacial conditions on the northern hemisphere (Rohling et al., 2014). Especially glaciations during isotope stage 100–98–96 at ~2.5 Ma (lowermost Matuyama chron) are pronounced (Lisiecki and Raymo, 2005). In our section B, the lowermost Matuyama interval (~1300 m) is particularly rich in coarse fluvial sands. We therefore prefer a climatic cause for the observed increase in fluvial activity and coarser grained deposits.

The upper boundary of the Romanian is related to the Valachian tectonic phase, which causes inversion and uplift on the basin margins (Matenco et al., 2007). In many places this coincides with a hiatus (Papaianopol et al., 2003). In our section, we do not observe a hiatus at this time, similar to seismic interpretations close to the study area (Leever et al., 2006). We therefore place the top of the Romanian stage at the top Olduvai reversal at 1650 m.

We do not prefer to relocate the top of the Romanian as recently suggested (Andreescu et al., 2011). The use of the term Pleistocene in the regional nomenclature is unfortunate, but the recent lowering of the Pleistocene epoch in the global timescale does not need to result in a redefinition of the Romanian upper boundary. Important in defining this boundary is a regional tectonic event, not the internationally accepted base of the Pleistocene.

7.5. Unit-stratotype for the Romanian section

The long sections along Slanicul de Buzau river provide a (near) complete description of the Romanian stage, with both lower and upper boundary present. The described section can therefore be seen as the unit-stratotype for the Romanian stage and can be used as a reference section for the Plio-Pleistocene of the Dacian Basin. The Romanian is the final, predominantly fresh water lake phase of the Dacian Basin before changing into a continental/fluvial setting.

The lower boundary of the Romanian stage is marked by a prominent extinction event in cardiid bivalves. The disappearance of characteristic Dacian marker-fossils like the large sized *Zamphiridacna zamphiri* or the thick walled *Psilodon neumayri* contributes an easy recognition of the Romanian stage lower boundary (Fig. 6). The lower boundary of the Romanian is located at 45° 27.181′N, 26° 44.730′E. The upper boundary is defined at the top Olduvai (C2n) magnetic reversal at an age of 1.778 Ma. This reversal postdates a paleoenvironmental change to fluvial deposition in the section. The upper boundary of the Romanian is located at 45° 17.361′N, 26° 45.126′E. In other places this boundary is related to an unconformity, related to a tectonic inversion phase starting at ~2 Ma (Papaianopol et al., 2003).

In the Slanicul de Buzau valley also complete sections of the Maeotian, Pontian and Dacian regional stages can be found. Together, these sections cover ~6.5 Myrs of Late Miocene, Pliocene and Pleistocene deposition in semi-isolated marine, brackish and fresh water environments. The total thickness of this succession is over 5 km. This entire succession forms the ideal record to study the paleoenvironmental and paleoclimatological history of the Dacian Basin.

8. Conclusion

We describe the Late Pliocene sedimentary evolution of the Dacian Basin in Romania. The Slanicul de Buzau river section represents ~2.5 Myrs of basin evolution and climatic changes. The exposed sections serve as unit-stratotype for the Romanian regional stage, the final freshwater lake phase prior to continental/fluvial deposition. Rich mollusk and ostracod fauna define regional stages and are used to describe

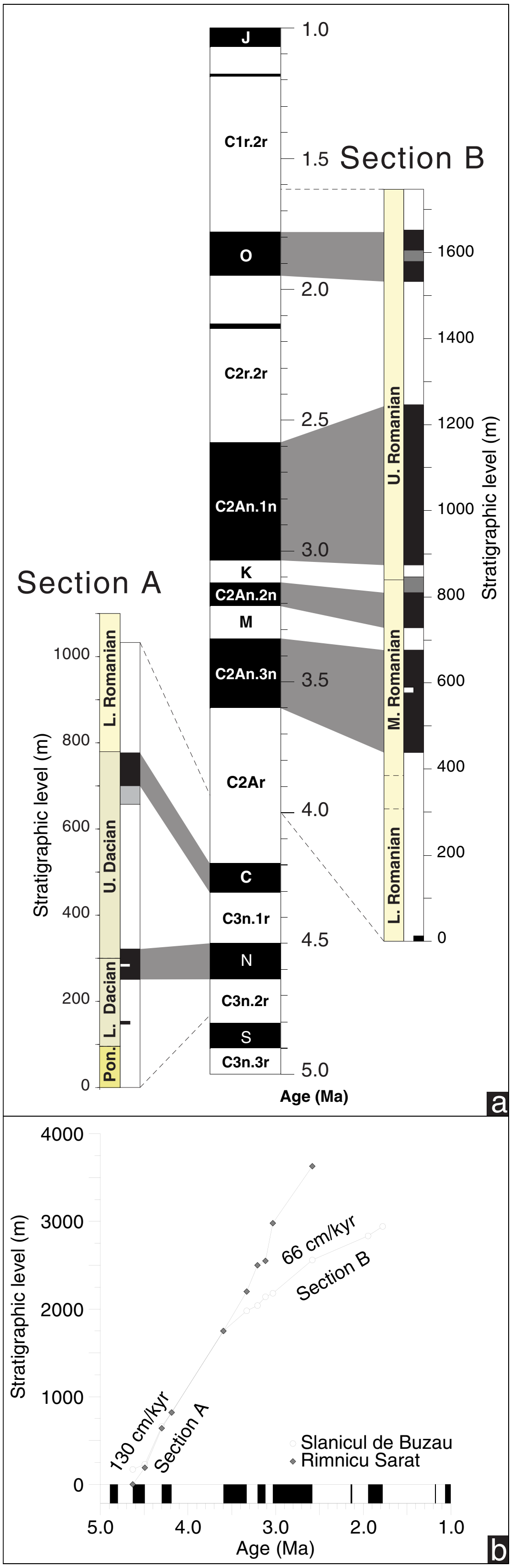

Fig. 13. a) Magnetostratigraphy correlation to GPTS. b) Age-depth model for the sections in Slanicul de Buzau valley and compared to similar records in nearly Rimnicu Sarat valley (Vasiliev et al., 2004). Section B is correlated to Rimnicu Sarat at the base of chron C2An.3n.

long-term paleoenvironmental change. Magnetostratigraphic dating allows to correlate these changes to global climate. The base of the Romanian stage marks the extinction of most caspibrackish species and is dated at 4.2 Ma. A short influx of caspibrackish species indicates a highstand of the Black Sea at 3.1 Ma, which likely correlates to the K1 'super-interglacial'. The original definition of the top of the Romanian stage is related to the Valachian tectonic phase of inversion (~2 Ma). This is not recognized in our section and therefore the upper Romanian boundary is placed at the top of the Olduvai subchron (1.8 Ma).

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Appendix A. Mollusk taxa identified in the studied section including their (sub-)family affiliation

BIVALVIA
UNIONIDAE
ANODONTINAE
Potomida prominulus (Stefanescu, 1889)
P. slanicensis (Teisseyre, 1907)
P. bielzi (Bielz, 1864)
P. breastensis (Ionescu-Argetoaia, 1918)
Rugunio condai (Porumbaru, 1881)
Sulcopotomida cymatoides (Brusina, 1874)
Pseudohyriopsis problematica (Cobalcescu, 1883)
Potamoscapha krejcii (Wenz in Krejci-Graf & Wenz 1931)
Sinanodonta podarensis Papaianopol, 1997
UNIONINAE
Unio sp.
Jazkoa sturzae (Cobalcescu, 1883)
CARDIIDAE
Euxinicardium gilletae (Andreescu, 1972)
E. cf. *orolesi* (Papaianopol, 1982)
Euxinicardium? sp.
Pseudocatillus? sp.
Psilodon neumayri (Fuchs, 1873)
Prosodacnomya sturi (Cobalcescu, 1883)
Zamphiridacna zamphiri (Cobalcescu, 1883)
DREISSENIDAE
Dreissena polymorpha (Pallas, 1771)
SPHAERIIDAE
Pisidium clessini Neumayr in Neumayr & Paul, 1875
Pisidium cf. *slavonicum* Neumayr in Neumayr & Paul, 1875
P. *iasiense* Cobalcescu, 1883

GASTROPODA
NERITIDAE
Theodoxus licherdopoli licherdopoli (Stefanescu, 1896)
T. licherdopoli scriptus (Stefanescu, 1896)
VIVIPARIDAE
Viviparus rumanus (Tournouër, 1879)
V. argesiensis (Stefanescu, 1896)
V. mammatus (Stefanescu, 1889)
V. bifarcinatus (Bielz, 1864)
V. stricturatus Neumayr, 1869
V. oncophorus (Brusina, 1874)
MELANOPSIDAE
Melanopsis rumana Tournouër, 1880
M. hybostoma amaradica Fontannes, 1887

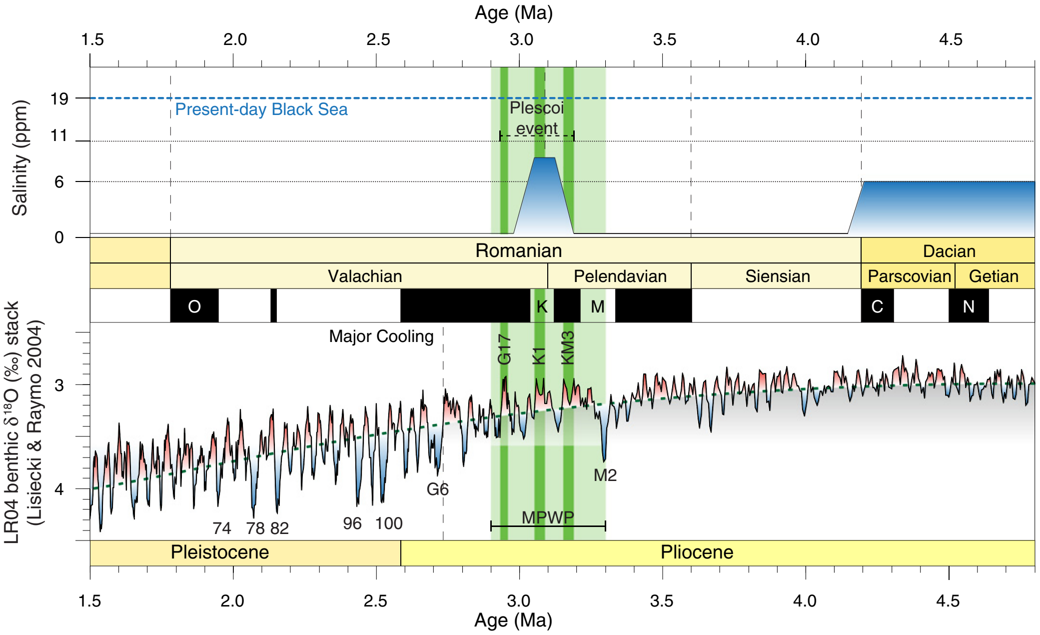

Fig. 14. Correlation between the Dacian Basin record and global climate. Top to bottom: age; salinity estimate based on fauna with present-day Black Sea for reference; Dacian Basin regional chronostratigraphic stages; GPTS (Hilgen et al., 2012) and LR04 oxygen isotope stack (Lisiecki and Raymo, 2005). Indicated are main events and climatic extremes.

M. slavonica Neumayr in Neumayr & Paul, 1875
M. pterochila Brusina, 1874
M. onusta Stefanescu, 1896
M. soubeirani Porumbaru, 1881
HYDROBIIDAE
HYDROBIINAE
Hydrobia cf. *magna* (Pană, 2003)
Hydrobia cf. *radmanesti* (Fuchs, 1870) *prososthenia radmanesti*
Hydrobia cf. *syrmica* Neumayr in Neumayr & Paul, 1875
PYRGULINAE
Pyrgula eugeniae (Neumayr in Herbich & Neumayr, 1875)
LITHOGLYPHINAE
Lithoglyphus acutus Cobalcescu, 1883
EMMERICIDAE
Emmericia? sp.
VALVATIDAE
Valvata (*Valvata*) *sulekiana* Brusina, 1874
Valvata (*Cincinna*) *sibinensis* Neumayr in Neumayr & Paul, 1875
LYMNAEIDAE
Omphiscola? *acuaria* (Neumayr, 1869)
Radix aff. *korlevici* (Brusina, 1884)
PLANORBIDAE
Gyraulus cf. *katurici* (Brusina, 1897)

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