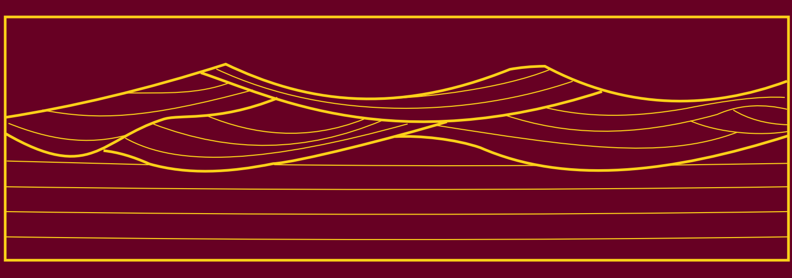
Dan C. Jipa, Cornel Olariu

DACIAN BASIN

DEPOSITIONAL ARCHITECTURE AND SEDIMENTARY HISTORY OF A PARATETHYS SEA



DACIAN BASIN

DEPOSITIONAL ARCHITECTURE AND SEDIMENTARY HISTORY OF A PARATETHYS SEA

Dedicated to the memory of
Prof. Gheorghe Murgeanu,
teacher, adviser and mentor,
whose guidance essentially contributed to the
birth and rise of sedimentology in Romania

DAN C. JIPA

CORNEL OLARIU

DACIAN BASIN
DEPOSITIONAL ARCHITECTURE AND SEDIMENTARY HISTORY OF A PARATETHYS SEA

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CONTENTS

FOREWORD AND ACKNOWLEDGEMENTS

The sedimentogenetic study of the Dacian Basin has been a scientific adventure for several decades. The first presentation of the general features of the Basin was made a couple of years ago, with a book in the Romanian language (Jipa, ed., 2007). The present publication on Dacian Basin expands and develops the main aspects presented in the Romanian book. Some chapters have been dropped, some chapters have been rewritten and new chapters added.

At the present time, the Dacian Basin investigation is far from being complete. The sedimentogenetic information we have in this book refers especially to the outcropping deposits (the littoral zone of the Basin). The deposits in the central and southern part of the Dacian Basin are not treated comprehensively enough, as our subsurface information is fragmented, scarce or non-existent.

The authors' team is made of two scientists from different generations, giving hope that the Dacian Basin sedimentological study will be continued and enhanced by future researchers.

The authors are grateful to Radu Olteanu (Geological Institute of Romania), Sorin C. Radan (Geological Institute of Romania), Liviu Maţenco (Vrije Universiteit, Amsterdam) and Cristina Poenaru (GeoEcoMar, Bucharest) for their expert contributions in the chapter regarding the Dacian Basin presentation.

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Our Dacian Basin understanding was influenced by stimulating and challenging discussions we had in front of the outcrops with Ron Steel (University of Texas at Austin), Henk Weerts (National Service for Archeology, Utrecht), Liviu Maţenco (Vrje Universiteit, Amsterdam), Radu Olteanu (Geological Institute of Romania), Marius

Stoica (University of Bucharest), Victoria Lubenescu. (Prospectiuni S.A., Bucharest) and Ion Andreescu (Geological Institute of Romania).

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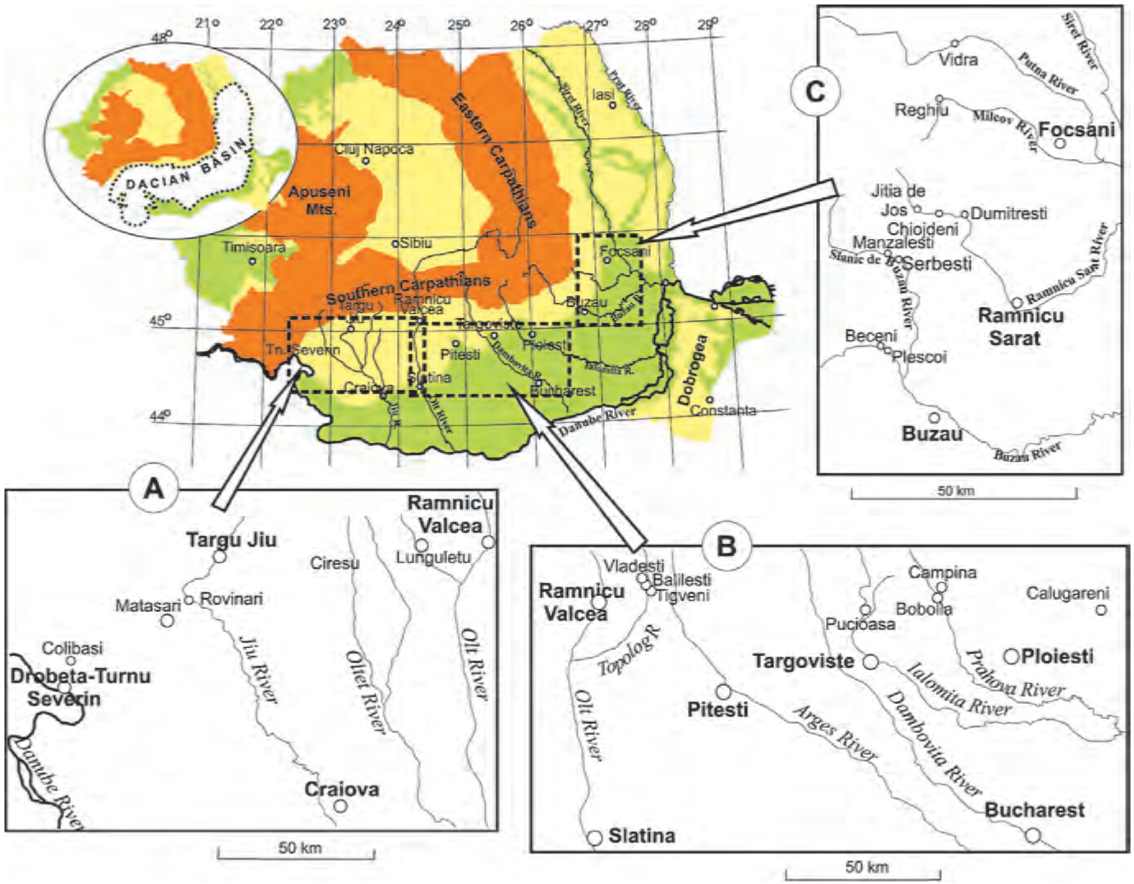


PLATE 1. Location of the Dacian Basin geographic names used in the present book. **A**. Western Dacian Basin. **B**. Central Dacian Basin. **C**. Northern Dacian basin. Physical map of Romania partly based on Anastasiu (2001)

Chapter 1

DACIAN BASIN. GENERAL BACKGROUND

1.1. PRESENT-DAY AND PALEOGEOGRAPHIC SETTING

Tectonic setting is one of the main factors which determine the sedimentary development of a basin. The distance to high relief continental areas is a major factor controlling the supply of clastic sediment to basins. The connection with a marine water body establishes the base level for the acumulation processes of the sedimentary basin.

The name *Dacian Basin* (*Bazin Dacic* in the Romanian language) comes from Andrusov (1917). As evidenced by Marinescu (1978), N. Andrusov applied this name only to the southern and western part of the area called today the *Dacian Basin*. The area northward of Buzău River was attached to the *Euxinian Basin*.

It was only several decades later that the name *Dacian Basin* was introduced into the Romanian geological terminology. Its position was consolidated through a long time of stratigraphic and paleontologic investigations conducted by I. C. Motaş, Emilia Saulea, N. Macarovici, F. Marinescu, Ioana Pană, I. Papaianopol, I. Andreescu, R. Olteanu and many other scientists.

Presently the name *Dacian Basin* refers to the area which extends from the foot of the Southern Carpathians and of the Eastern Carpathians bend zone (Fig.1.1), to the present course of the modern Lower Danube River. The arc-shaped mountains at the connection between the Carpathians and the Balkans formed the western boundary of the Basin. The Dobrogean high limited the eastern extension of the Dacian Basin and restricted communication with the Black Sea Basin.

Almost the entire Dacian Basin area is included within the present-day south-eastern territory of Romania. During later evolutionary stages the Dacian Basin extended south of the present location of the Danube River in the northern part of Bulgaria and the northeastern Serbia.

Dacian Basin sediments crop out in the area close to the Carpathians (Fig. 1.2). The central and outer (in rapport with the Carpathians) parts of the basin are covered with Quaternary deposits. This establishes the main lines of the basin investi-

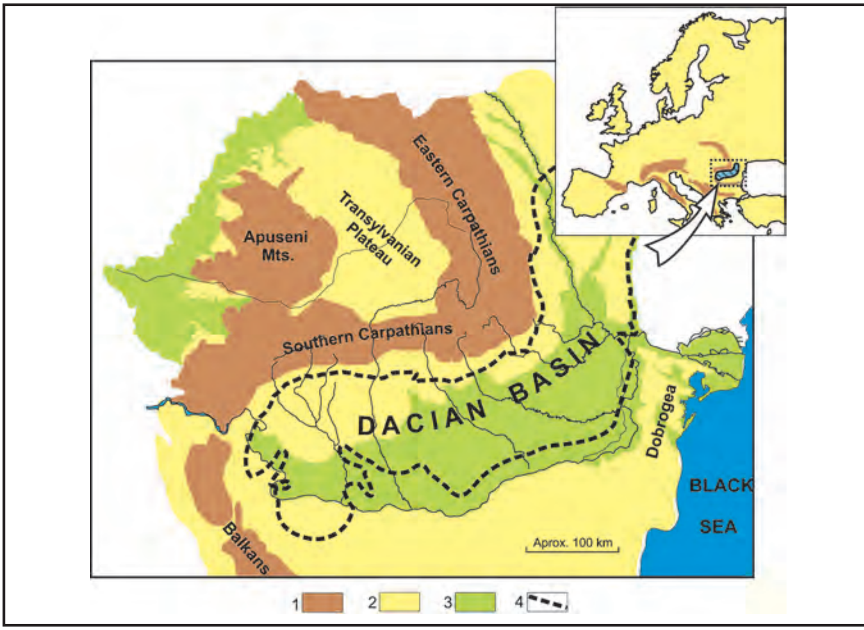


FIGURE 1.1. Dacian Basin location on the physical map of Romania. Upper-right corner: index sketch with location on the Europe map. **Legend**: 1. Highland relief. 2. Hilly relief. 3. Lowland relief. 4. Dacian Basin outline during Maeotian (after Saulea *et al.*, 1969 and Hamor *et al.*, 1988). Physical map of Romania partly based on Atanasiu (2001).

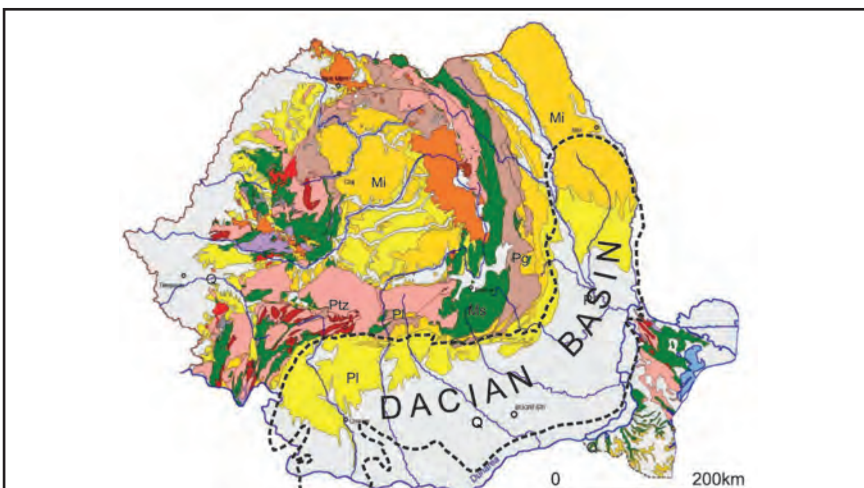


FIGURE 1.2. Dacian Basin geological location. Quaternary deposits cover most of the Dacian Basin area. Background map simplified from the geological map of Romania, scale 1:1000000, made by the Geological Institute of Romania. Dacian Basin outline during Maeotian (after Saulea *et al.*, 1969 and Hamor *et al.*, 1988). **Legend**: **Q** – Quaternary deposits. **Pl** – Pliocene deposits. **Mi** – Miocene deposits. **Ms** – Mesozoic deposits. **Ptz** – Crystalline rocks.

gation method: direct observations in the sub-Carpathians, *i.e.,* the proximal area, and use of subsurface data in the outer, southern and eastern areas.

The Dacian Basin was a component of the large epicontinental sea named Paratethys by Laskarev (1924). After its opening during the late Eocene time (34 Ma) (Rusu, 1977; Baldi, 1979), Paratethys went through several major environmental phases with specific conditions. The initial (Lower Oligocene) Paratethian phase of decreased water salinity and endemism was replaced during Middle Oligocene by prevailing open marine conditions, with dominant clastic sedimentation (Rögle, 1999). As a result of restricted internal communication, brackish water and endemic fauna dominated the final Paratethys stage. Formed during this last stage (late Sarmatian, *s. l.*), the Dacian Basin coexisted within the Paratethys with the Pannonian, Euxinian and Caspian basins (Fig. 1.3).

1.2. STRATIGRAPHY

The Dacian Basin evolved during a period of time when Paratethys was represented by distinct basins with restricted and variable communication between them. These basins shared some common characteristics, including reduced water salinity, and were dominated by clastic sedimentation. However, significant differences existed between the Paratethian basins: these include basin size and physiography, the occurrence, development and evolution of fauna and their respective environments, and others.

One essential distinction existing between the Paratethys basins came out of the succession of the interconnections moments (leading to uni- or bi-directional, selective faunal migrations) and moments of isolation and implicitly endemism. Biostratigraphic markers which resulted from the successive connection and isolation of these basins generated differing stratigraphic scales, making it difficult to compare one Paratethys basin with the other.

1.2.1. Biostratigraphic scale[1]

A Dacian Basin scale based on stratigraphic rules and paleontologic dating had to rely on specific features of the basin and on characteristics shared with the neighboring Paratethys basins. The initial stratigraphic scale based on paleoecological and paleontologic analysis of the Dacian Basin was devised by Teisseyre (1907).

As a result of its paleogeographic setting (Fig. 1.3), the Dacian Basin developed in rather close communication with the Euxinian Basin, while the relationships with the Pannonian Basin have been more restricted. That is why the biostratigraphic scale of the Dacian Basin includes several stages similar to the Euxinian Basin stages (Table 1.1): Sarmatian *sensu lato*, Maeotian and Pontian.

[1] Author: Radu Olteanu

Due to a major Pliocene paleoenvironmental change affecting the Dacian Basin (passage from brackish to fresh-water environment), the stages corresponding to this period of time (*i.e.* Dacian and Romanian) have been built up on biostratigraphic features typical of the Dacian Basin (Table 1.1).

TABLE 1.1. The biostratigraphic scale used in the Dacian Basin area

Stages (and authors)	**Substages** (and authors)
ROMANIAN (S. Ştefănescu, 1888) *Levantin* (N. Mihăilă, 1969)	***Valahian*** (I. Andreescu, 1981)
	Pelendavian (I. Andreescu, 1981)
	Siensian (I. Andreescu, 1981)
DACIAN (W. Teisseyre, 1907)	***Parscovian*** (I. Andreescu, 1972)
	Getian (N. Macarovici, Fl. Marinescu, I. Motaş, 1995)
PONTIAN (Barbot de Marny, 1869; N. Andrusov, 1897)	***Bosphorian*** (N. Andrusov, 1923)
	Portaferrian (P. M. Stevanovic, 1952)
	Odessian (N. Macarovici, Fl. Marinescu, I. Motaş, 1995)
MAEOTIAN (N. Andrusov, 1890)	***Moldavian*** (M. David, 1922)
	Oltenian (I. Atanasiu, 1940)
SARMATIAN (s.l.) (Barbot de Marny, 1869)	***Kersonian*** (I. Simionescu, 1903)
	Bessarabian (I. Simionescu, 1903)
	Volhynian (I. Simionescu, 1903)

FIGURE 1.3. Paratethys domain during the Maeotian time. Simplified and modified after Ilyina *et al*. (in Popov *et al*., 2004), Papaianopol *et al*. (1987) and Magyar *et al*. (1999).

The Sarmatian stage, which includes the time when the Dacian Basin formed, is one of the highly disputed biostratigraphic units. The Sarmatian as a stratigraphic concept comes from E. Suess (1866), and it was initially used in the Vienna Basin. Later on, scientists realized that the term Sarmatian was used for two stratigraphic intervals of quite different extent (Fig. 1.4). Consequently, in this book, the term Sarmatian has the *sensu lato* meaning whenever it is used in the Dacian Basin context.

The Maeotian stage was defined by Andrusov (1890) in the Kerch peninsula. The Maeotian sequence of the Dacian Basin is rather different from the stratigraphically similar succession in the Euxinian Basin. Only the "Dosinia beds" episode shows faunal similarities with the Euxinian Maeotian sequence.

The Pontian stage is also of Euxinian origin, vaguely outlined by Barbot de Marny (1869) and defined more precisely later by I.F. Sinzov.

There are significant biostratigraphic differences between Dacian and Euxinian meanings of the Pontian sedimentary succession, but the similarities outnumber the dissimilarities.

The Maeotian and Pontian substages in the Dacian Basin (Table 1.1) reflect the regional ecological and faunal particularities of the basin, during a time when the basin was into an advanced stage of infilling with sediments.

The Paratethys stratigraphic scales are built up using ecological stages. Although all the major water basins of the Paratethys were brackish, important differentiation existed between salinity ranges and ecological conditions. The distinction between an oligohaline biotope and a mesohaline biotope is of a similar impact as the difference between the brackish and normal-marine biotopes. Consequently, the tem-

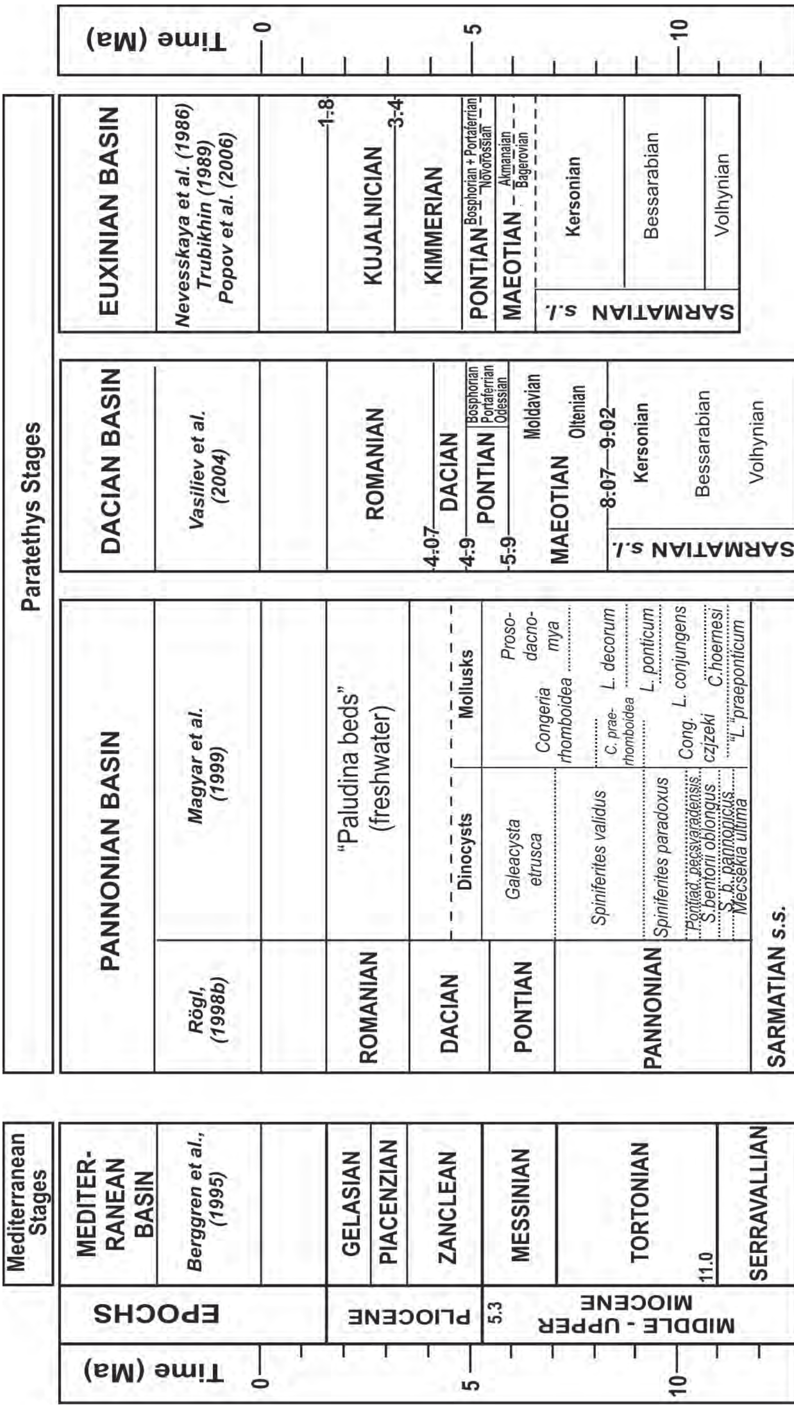


FIGURE 1.4. Stratigraphic scales of the Paratethys domain (Caspian Basin not included). The apparent disagreement in connection with the Pontian stage time duration between the Dacian and Euxinian basins is probably due to different magnetostatigraphic approaches.

poral limits of these "brackish stages" are different from one area to another. The ecological facies pertaining to a brackish stage may occur in different space units or time intervals. The best example is that of the "Pontian type" fauna or "Sarmatian type" fauna from the Mediterranean area, faunas which have nothing in common with the Paratethian Pontian or Sarmatian faunal assemblages. These aspects could also create difficulties for the construction of the magnetostratigraphic scales.

1.2.2. Toward a reliable chronostratigraphic and geochronologic framework of the Dacian Basin[1]

Many contributions of Romanian and/or foreign researchers refer to the ages of the *Dacian Basin* sedimentary deposits. Still, an unique (and unanimously accepted) chronostratigraphic and geochronologic framework has not yet been achieved (Fig.1.5). To reach a high-resolution dating of the *Miocene* and *Pliocene* (sub)stage boundaries, various new techniques have been integrated with the traditional biostratigraphy, principally magnetostratigraphy, astrochronology and cyclostratigraphy.

Reliable sampling techniques, sophisticated paleomagnetic laboratories, along with an increasing number of data analysis methods and more refined criteria were developed worldwide to retrieve the paleogeomagnetic fossile, *i.e*. the primary Natural Remanent Magnetisation (*NRM*) component (Characteristic Remanent Magnetisation/*ChRM*, isolated in laboratory). This magnetic signal, commonly weak in the sedimentary deposits in which it is printed/"frozen", may be affected by noise from a number of perturbation processes or may be obscured subsequently to rock formation, along their geological and geochemical history.

A breakthrough in age determination has been the astronomical dating (Hilgen, 1991, 1994, Hilgen *et. al*., 1995, Berggren *et al*., 1995, Krijgsman, 1996). An *Astronomically calibrated* (*Polarity*) *Time Scale* [**A(P)TS**] has been constructed (first, for the *Pliocene* – *Pleistocene* time interval; Lourens *et al*., 1996), and even incorporated in the existing (very usable) standard *Geomagnetic Polarity Time Scale* (**GPTS**) of Cande and Kent (1995; **CK95**). Since 2004, the ***Astronomical Tuned Neogene Time Scale*** (**ATNTS2004**; Lourens *et al*., 2004), characterised by an unprecedented resolution and accuracy, is in use.

In this shortly defined context, the geological time scales (**GTS**) in figure 1.5, particularly the ages assigned to the chronostratigraphic boundaries, should be carefully considered before adopting one of them. To compare and evaluate these **GTS**'s (models **A**, **B**, **C**, **D**) with the intention of assuming a (reliable) version for the *Dacian Basin* (possibly, a composite **GTS**), at least the following major aspects should be taken into consideration:

[1] Author: Sorin-Corneliu Rădan

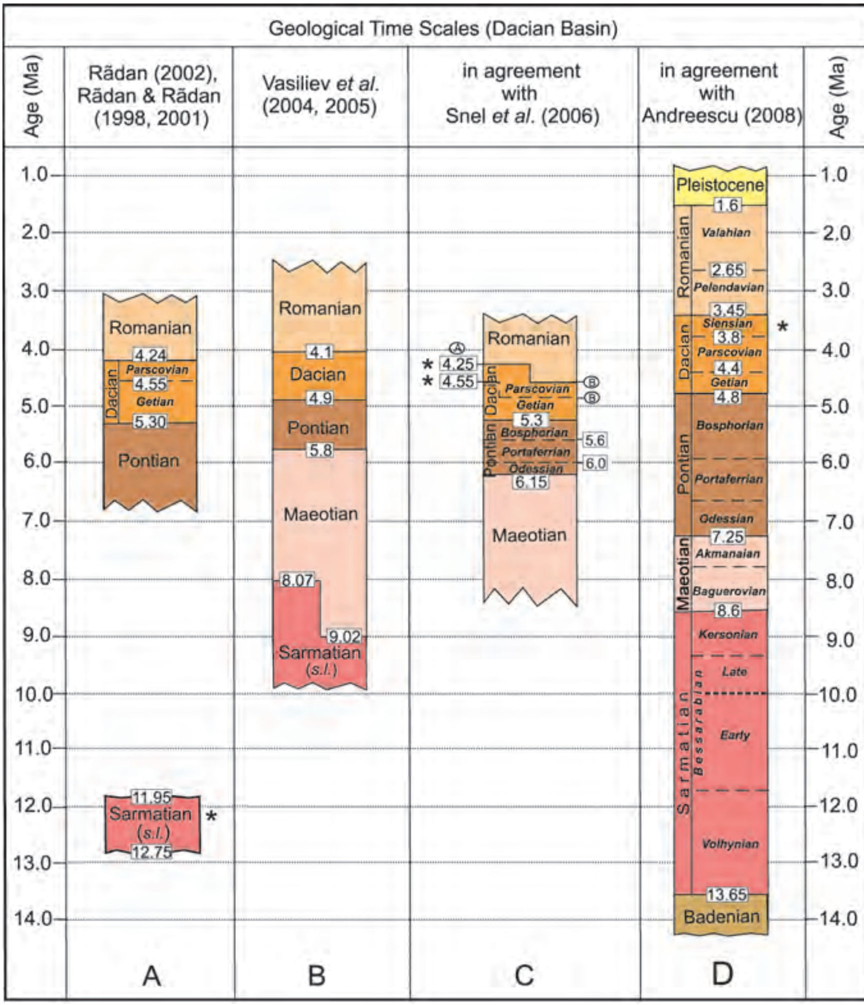


FIGURE 1.5. Geological Time Scales referring to the chronostratigraphic and geochronologic framework of the Dacian Basin, as inferred from magnetobiostratigraphic and astrochronologic studies published throughout the last decade.

NOTE 1: The colors used for the chronostratigraphic units/stages are suggested by the Geological Time Table of Haq (2007), published by Elsevier;
NOTE 2: In the model **A**, the fragment on the Sarmatian (stage) resulted from the magnetobiostratigraphic investigation of the "Scăricica" Section in the Comăneşti Basin (Rădan & Rădan, 2001; Rădan, 2002);
NOTE 3: In the model **C**, the (sub)stage boundaries marked by asterisk (*) are according to Rădan & Rădan (1998) and van Vugt *et al.* (2001) (option A , in Snel *et al.*, 2006);
NOTE 4: In the model **D**, the Siensian substage belongs to the (Upper) Dacian (cf. Andreescu, 2008), and not to the (Lower) Romanian (as in the models **A**, **B** and **C**), in keeping with the Neogene chronostratigraphic nomenclature in Romania (*e.g.*, Papaianopol *et al.*, 1995; Rădulescu *et al.*, 1995).

a) the sampling reliability of the *magnetic recording medium* (represented by the sedimentary sequences), particularly the stratigraphic distance between the paleomagnetic sites wherefrom the samples were collected, which should be in agreement with:

- the sedimentation rates in the investigated sections joined with the frequency of the paleogeomagnetic events present inside of the **GPTS**/**ATNTS** (with regard to *Miocene* – *Pliocene*, in this case);
- the sedimentary cyclicity joined with the astronomical forcing (where applicable).

Several examples of the disagreement between the *stratigraphic spacing* (related to the paleomagnetic sites wherefrom the oriented samples were taken) and the resulting *temporal spacing* are provided by some sections investigated in the eastern *Dacian Basin* (model **GTS-D** in Fig.1.5; see Andreescu, 2008). This incongruity may be particularly regarded in connection with the calibration of the achieved section magnetic polarity columns to the standard **GPTS**'s or **APTS**'s, relating to the succession of the normal - reversed polarity zones established for the corresponding chronostratigraphic time span - *Sarmatian* to *Romanian*.

b) the complexity of the laboratory deconvolution works of the paleomagnetic record printed in the rock with a view to the *ChRM* isolation (the paleogeomagnetic field direction/magnetic polarity "fingerprint").

Hence, there is no specific (lab) information to support the magnetic polarity columns assigned to the sections on which the model **D** in Fig.1.5 is based (Andreescu *et al*., 2008);

c) the complementary tools (*e.g.*, *biostratigraphy*, *astronomical forcing*, *cyclostratigraphy*) involved in achieving and interpreting the magnetic polarity columns associated with the sedimentary sequences of the studied sections.

For instance, van Vugt *et al*. (2001), who achieved in the „Fort Hoofddijk" paleomagnetic laboratory from Utrecht (The Netherlands) the same magnetic polarity zonation for a corresponding stratigraphic interval (belonging to the Lupoaia section/western Dacian Basin), previously investigated by Rădan & Rădan (1998) in the paleomagnetic laboratory from the Geological Institute of Romania, added toward a high-resolution magnetochronologic calibration – the astronomical forcing of the sedimentary cycles (cf. Lourens *et al*., 1996). According to the astronomical tuning of van Vugt *et al*. (2001) and to the magnetobiostratigraphic criteria used by Rădan & Rădan (1998), the *Dacian/Romanian* boundary shown in the model **A** (Fig.1.5) becomes 4.27±0.05 Ma, which, anyway, is very close to the age marked in the mentioned **A**-pattern (*i.e.*, 4.24±0.05 Ma, cf. **GPTS- CK95**).

Another comment refers to the model **B** (Fig.1.5). The authors (Vasiliev *et al*., 2004) carry out an analysis of the *astronomical forcing* of the *sedimentary cycles* from the studied area (eastern Carpathian foredeep), but, on the other hand, they recognize that "a detailed biostratigraphic record directly tied to their sections" is missing. Consequently, the authors of the pattern **B** "limit themselves to the biostratigraphic data and the stage boundaries from the published geological maps and the seismic profiles" (Vasiliev *et al*., 2004). Of course, in the circumstances, the uncertainties in the biostratigraphic positions of the stage boundaries (*Maeotian*/*Pontian*, *Pontian*/*Dacian*, *Dacian*/*Romanian*) could influence their "numerical date", although the most recent **ATNTS2004** (Lourens *et al*., 2004) is used for the correlation of the magnetic polarity columns achieved for the sections. Subsequent works (Vasiliev *et al*., 2005; Stoica *et al*., 2007) pay attention to this aspect and fossil (faunal) assemblages of the *Upper Pontian* and *Lower Dacian* are presented from a magnetostratigraphically studied region in the southern Carpathian foredeep. The mollusc assemblages show a gadual transition at the *Pontian*/*Dacian* boundary (Stoica *et al*., 2007), which was magnetostratigraphically dated at **~**4.9 Ma (as is shown in Fig.1.5). High-resolution biostratigraphic studies are still necessary to better constrain the location of this stage boundary in the sections (Stoica *et al*., 2007). Besides, detailed biostratigraphic records are required to directly constrain the ages of the other stage boundaries from Fig.1.5–pattern **B**. Attention shoud be directed to the *Sarmatian*/*Maeotian* boundary, because of the uncertainties even in the correlation of the acquired magnetostratigraphic record (related to this part) to the **ATNTS2004** (Vasiliev *et al*., 2004).

Therefore, the importance of the *biostratigraphy* involved within the magnetostratigraphic studies, which actually led to the well-known term "*magnetobiostratigraphy*", is self-evident, and this traditional method cannot be substituted by the tools which have become available and are used as "age constaints", *e.g*. the *astronomical forcing/cyclostratigraphy*.

d) the **GPTS** or the **APTS**/**ATNTS** to which the authors of the parallel **GTS**'s (Fig.1.5-**A**, **B**, **C**, **D**) made the magnetochronologic calibration.

Thus, different polarity timescales have been used: in the models **A**, **B**, **C** – **CK95** and/or **APTS**/**ATNTS2004**; in the model **D** – a **GPTS** older than **CK95** (as stated by Andreescu, 2008 in his work). Regarding the latter (**D**), it is doubtful which of the earlier **GPTS**'s (surely not **CK92**, but most likely not later than 1985) is applicable to the entire time span from the Badenian/Sarmatian boundary to the Romanian/Pleistocene boundary;

e) the discrepancies in relation to the stage nomenclature and/or the constitution of some chronostratigraphic units, *e.g*. the substages assigned to *Dacian* and *Romanian*; see in Fig.1.5-**D** that the *Dacian* consists of three substages, the upper one – *Siensian* – belonging to the *Romanian*/lower substage in all the other 3 geological time scales/**GTS**'s (Fig.1.5-**A**, **B**, **C**).

If **d)** is taken into consideration and all the four models from Fig.1.5 are recalibrated to the most recent timescale, *i.e.* **ATNTS2004** (Lourens *et al*., 2004), then the dating of the chronostratigraphic boundaries of the *Upper Miocene-Pliocene* stages in the parallel **GTS**'s - **A**, **B**, **C**, **D** is as follows:

- ***Pontian/Dacian boundary***:
  - model **A**: **~ 5.3 Ma**; model **B**: **~ 4.9 Ma**; model **C**: **~ 5.3 Ma**; model **D**: **~ 5.24 Ma**;
- ***Dacian/Romanian boundary***:
  - model **A**: **~ 4.24 Ma**; model **B**: **~ 4.1 Ma**; model **C**: **~ 4.25 Ma** (option A – according to Rădan & Rădan, 1998 and van Vugt *et al*., 2001, in Snel *et al*., 2006); model **D**: **~ 3.65 Ma**.

If **e)** is now considered, and an unique nomenclature and subdivisions of the *Pliocene* chronostratigraphic units within all the four models is adopted, *i.e*. the *Siensian* is the lower substage of the *Romanian*, in keeping with the Neogene chronostratigraphic nomenclature in Romania (Papaianopol *et al*., 1995; Rădulescu *et al*., 1995), then the age of the ***Dacian/Romanian boundary*** (according to the magnetobiostratigraphic data published by Andreescu, 2008) becomes **~ 4.1 Ma** (by calibrating to the **ATNTS2004**), *i.e.* identical or close to the ages that are assigned to this boundary in the models **A**, **B** and **C** – option A .

For the above-mentioned and other specific details related to each of the four geological time scales illustrated in Fig.1.5 (**A**, **B**, **C**, **D**), the reader is referred to Rădan (1998, 2000, 2002), Rădan & Rădan (1996, 1998, 2001), Rădan *et al*. (1996), van Vugt *et al*. (2001), Vasiliev *et al*. (2004, 2005), Stoica *et al*. (2007), Snel *et al*. (2006), Andreescu (2008).

To conclude, there is not yet an acceptable – unique – **Geological Time Scale** assignable to the ***Dacian Basin***, but the models **A**, **B**, **C**, **D** from Fig.1.5, as inferred from papers published throughout the last decade, could represent contributions toward a future reliable chronostratigraphic and geochronologic framework of this important part of the Parathetys.

1.3. OUTLINE OF THE DACIAN BASIN BIOSTRATIGRAPHY[1]

Like the other Paratethian basins, the evolution of the Dacian Basin during Late Neogene produced specific geological and ecological marker events. That is the reason why the Dacian Basin corresponds partially to the Paratethys Mio-Pliocene biostratigraphy, but on the other hand it shows specific fauna (Fig. 1.6). Although some stratigraphic stages, like Sarmatian, Maeotian or Pontian, have the same name in more than one Paratethys basins (including the Dacian Basin), they do not show the same, synchronous biostratigraphic assemblages.

[1] Author: Radu Olteanu

Sarmatian (s. l.) biostratigraphy. The presence of the fauna with *Venus konkensis* (a Ponto-Caspian species), together with specimens of *Ervilia* and *Modiola* and several marine residual elements from the Badenian (*Conus, Arca*), made apparent the brackish water characteristics of the Dacian Basin (Popa-Dimian Elena, 1962). This is accepted as a pre-Sarmatian horizon.

The Volhynian stage made its first appearance through a restricted community dominated by *Cytheridea, Bythocypris* (the only species coming from the marine Badenian facies) and *Sclerochilus*. These genera are associated with the first occurrence of *Xestoleberis, Mutilus, Loxoconcha, Leptocythere* s.l. This faunal community is exclusively brackish. The taxons succession reflects a gradual generic selection at the passage from a marine ecosystem to an ecosystem with reduced water salinity. The molluscs follow the same pattern showing the extinction of the last marine species and the persistence of the exclusively brackish faunas (*Cerithium, Syndesmya, Mactra, Cardium*).

A high quantitative (biomass) and qualitative (specific diversity) record is reached by the ostracods and molluscs fauna during the Bessarabian time. The beginning of the Kersonian time marks a steep decline of these features.

The Middle Sarmatian is characterised by a clayey facies dominated by the presence of the *Cryptomactra pes anseris* species in the lower part, followed by the exuberant development of the genus *Cardium* at the upper part.

The Upper Sarmatian (Kersonian; the time when Dacian Basin was paleogeographically outlined as a Paratethian Basin) is marked by rare ecological events as the extinction of the previous fauna and its replacement with a new typology of fauna (*Stanchevia, Loxocauda*). Moreover, a true explosive development of two species of small *Mactra* (out of several existing before) is taking place. At the same time, the *Limocardiids* and most of the gastropods (except for the pulmonates and the fresh-water ones) disappeared. The foraminifera are scarce or even absent. The Sarmatian *(s. l.)* sequence within the Dacian Basin ends with a fresh-water episode, with *Darwinulla, Ilyocypris, Cypris*.

Maeotian biostratigraphy. In the Dacian Basin the Sarmatian/Maeotian boundary is transgressive. This event was associated with important faunal changes (Fig. 1.6).

The fresh-water terminal Sarmatian *(s. l.)* is covered by a horizon with small *Congeria,* which is in turn followed by deposits with carinate congerians (morphologically close to some Pannonian species as *Congeria soceni, C. ringeiseni, C. scrobiculata, C. martonfii)*. They are overlaid by deposits with *Dosinia, Modiola incrassata minor, Ervilia minuta, Pirenella caspia, P. disjunctoides, Caspia latior*. The more frequent ostracods are *Maeotocythere sulakensis* and *Mutilus parabulgaricus*. This level has the quasi-marine Dosinia beds from the Euxinian Basin suggesting connection of this basin with the Dacian Basin for a short time.

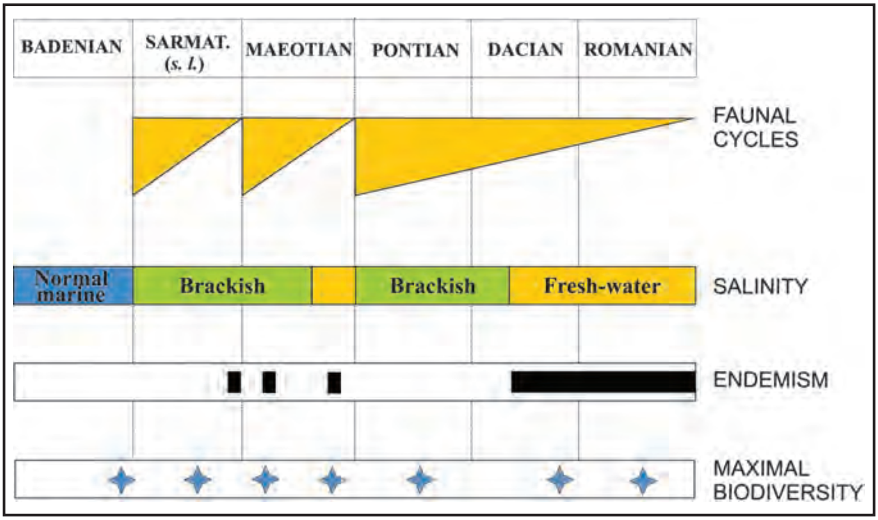


FIGURE 1.6. Main characteristics of the Dacian Basin bio-stratigraphic evolution

The Maeotian sequence continues with the so-called "ostracods marls" (*Hemicytheria, Loxoconcha, Callistocythere, Xestoleberis* including over 80 species).

A second level of small *Congeria* follows (*C. novorossica, C. navicula, C. panticapaea* and numerous morphologic variations of the genus *Hydrobia)*, ending the Maeotian biostratigraphic succession in the Dacian Basin

Pontian biostratigraphy. A new Dacian Basin biological cycle begins with the Pontian stage (Fig. 1.6), involving both molluscs and ostracods. At the base of the Pontian sequence, the *Limnocardiids* are dominant and the fauna is different from the late Maeotian. Paleontologically, the Maeotian/Pontian boundary is sharp and transgressive.

The Early Pontian sequence is mostly clayey, with *Paradacna, Congeria, Dreissena, Valenciennius*. The molluscan community enlarged during the Middle Pontian, especially the *Limnocardiids*. The *Arpadicardium* and *Caladacna* genera occur, as well as large *Congeria* (*C. rhomboidea)*. Among the ostracods, the *Tyrrhenocythere, Paraloxoconcha* genera emerged, and the number of *Euxinocytheres* species increased. The faunal uniformity suggests a unitary Pontian ecology of the Dacian Basin.

The upper part of the Pontian time marks a new faunal diversification. New *Phyllocardium, Dreissnomya* genera occur, the *Prosodacnae* species become frequent, and the first small *Stylodacnae* appear. The gastropods (*Viviparus, Melanopsis, Zagrabica*) are also into a process of diversification.

The three sequences described above have been assigned by Macarovici *et al.* (1965) to the three Pontian substages named Odessian, Portaferrian and Bosphorian.

Marinescu (1995) considered that the Dacian Basin water salinity progressively decreased during the Pontian time. This process is evident only in the western part of the basin, where the existence of an ostracods community with a small number of species (*Tyrrhenocythere filipescui* and large *Candonae*) together with the absence of the *Cytheridae* suggest water salinity in the lower part of the brackish range. In the central and eastern Dacian Basin areas, the Late Pontian ostracods community was dominated by the *Euxinocythere* and *Loxoconcha* group, while *Tyrrhenocthere* and *Cytherissa* are absent; this indicates a higher salinity and the connection with the Euxinian Basin.

Dacian biostratigraphy. The Dacian-time fauna developed gradually, with variants of the Pontian species. The terminal Pontian sequence with *Phyllocardium* is covered by yellowish sand with the first occurring *Pachydacnae* and very frequent *Prosodacnae*. Within this interval one can separate a lower part with *Pachydacna serena – cobălcescui*, small-size *Prosodacna rumana - munieri* and large-size *Stylodacna heberti*. For this interval Motaş (1965) coined the chronozone denomination Geţian.

Large-size *Prosodacnae* and *Stylodacna* gradually disappear in the upper part of the Dacian. Concomitently, the large-size *Viviparidae* (*V. rumana, bifarcinatus*) and small-size gastropods (*Hydrobia*, *Bulimus, Lithoglyphus*) occur with higher frequency, associated with coal deposits. For this Late Dacian stratigraphic sequence the name Parscovian, coined by Andreescu, was adopted (1972).

Conventionally the level with *Prosodacna neumayeri euphrosinae* is considered the boundary between Geţian and Parscovian chronozones. The upper limit of the Dacian stage is marked by the occurrence of the ornamented *Unio* morphotypes.

Romanian biostratigraphy. The last Pliocene stage of the Dacian Basin - the Romanian - is defined by a fresh-water fauna (unionids, viviparids and melanopsides) with regional endemic characteristics, as well as by the absence of the limnocardiids.

The faunal complex known as the "beds with *Viviparus bifacinatus*" (Lubenescu, 2004) represents the transitional episode between the Dacian and Romanian stages. A Dacian taxon, namely *Prosodacnomya sturi* (Macarovici *et al.,* 1961) was found occasionally at the base of the Romanian sediments. In addition, the *Unio (Rumanunio) rumanus* and *Viviparus rumanus* taxa disappeared and are missing from the Romanian sediments (Papaianopol, 2003).

Sedimentary units with a dominance of the ornamented species of *Unio* fauna are used as the boundary between the Lower and the Middle Romanian. The species *Potomida lenticularis* is dominant, together with *P. mojsvari*, *P. e.g. slavonica, Wenziella subclivosa, Viviparus structuratus* and *V. craiovensis*.

Andreescu (1981) pointed out the existence of the *Rugunio riphaei* zone, which marks the end of the Romanian biostratigraphic succession. The next stratigraphic zone, with *Unio apscheronicus* belongs to the Early Pleistocene stage. Papaianopol (1972, 1995) found, in the sub-Carpathian area, a clayey episode with *Helix* and *Cepaea,* which also records the begining of the Pleistocene time.

The outstanding morphologic variability of the *Unionids* fauna (25 genera and 112 species), the very large biomass of some of them and the massive shells of the most *Unionids* suggest a habitat and an ecologic environment rich in carbonates and nutrients, which generate both hyperthelic processes and an early reproduction. This means a neothenic development associated with isolation and a parathenogenetic reproduction.

The influence of the Euxinian Basin water was periodic during the Late Dacian and is recognized in the fauna from the eastern part of the Dacian Basin. A second Euxinian incursion, which occurred in the Middle Romanian time, reached the western part of the Dacian Basin (the Lupoaia and Jilț coal quarries). The ostracods fauna is of Caspian origin (*Cypris mandelstami, Eucypris famosa, Zonocypris membranae,* together with some endemic *Cypris* sp., *Cyclocypris* sp. and more *Candonae*). Pană *et al.* (2004) also evidenced the presence of gastropods with the same provenance (*Caspia* and *Baicalia* species).

The boundary between the Romanian and Pleistocene stage is marked by the occurrence of the species *Limnocythere jiriceki*, followed by *Ilyocypris caspiensis, Ilyocypris angulata angulata* and *Trajanocypris laevis* (in succession).

1.4. DACIAN BASIN STRUCTURAL FRAMEWORK [1]

The orogens and the platforms situated in their foreland are the main geotectonic features of the Romanian territory. Săndulescu (1984) (Fig. 1.7) distinguishes two orogenic areas which evolved throughout the Mesozoic and Tertiary (the Carpathian Orogen and the North Dobrogean Orogen) and a Cadomian Orogen (Central Dobrogean Green Schists). The eastern European Platform and the Moldavian Platform are older; the Precambrian foreland units and the Scythian and Moesian platforms are younger, Paleozoic in age. The foredeep and the intra-Carpathian depressions are the youngest structural units.

Two oceanic basins evolved in the Carpathian area during the Mesozoic period of extension: the Transylvanides (or East Vardar) and the outer Dacides trough (or Ceahlău-Severin) (*e.g.*, Săndulescu, 1988; Schmid *et al.*, 2008). The closure of the two oceanic basins began in the Cretaceous and concluded with a continental collision (Sarmatian, 10-11 Ma) recorded in the so-called Carpathians embayment, which is the eastward prolongation of the Ceahlău-Severin ocean (*e.g.*, Bala, 1987, Ustasewski *et al.,* 2008). Outer Carpathians or Moldavides (*sensu* Săndulescu, 1984) (Fig. 1.7) represent a complex nappe pile, emplaced over the slightly deformed foreland during the Miocene deformations (20–11 Ma, Săndulescu, 1984; Mațenco and Bertotti, 2000).

[1] Revised and amended by Liviu Mațenco

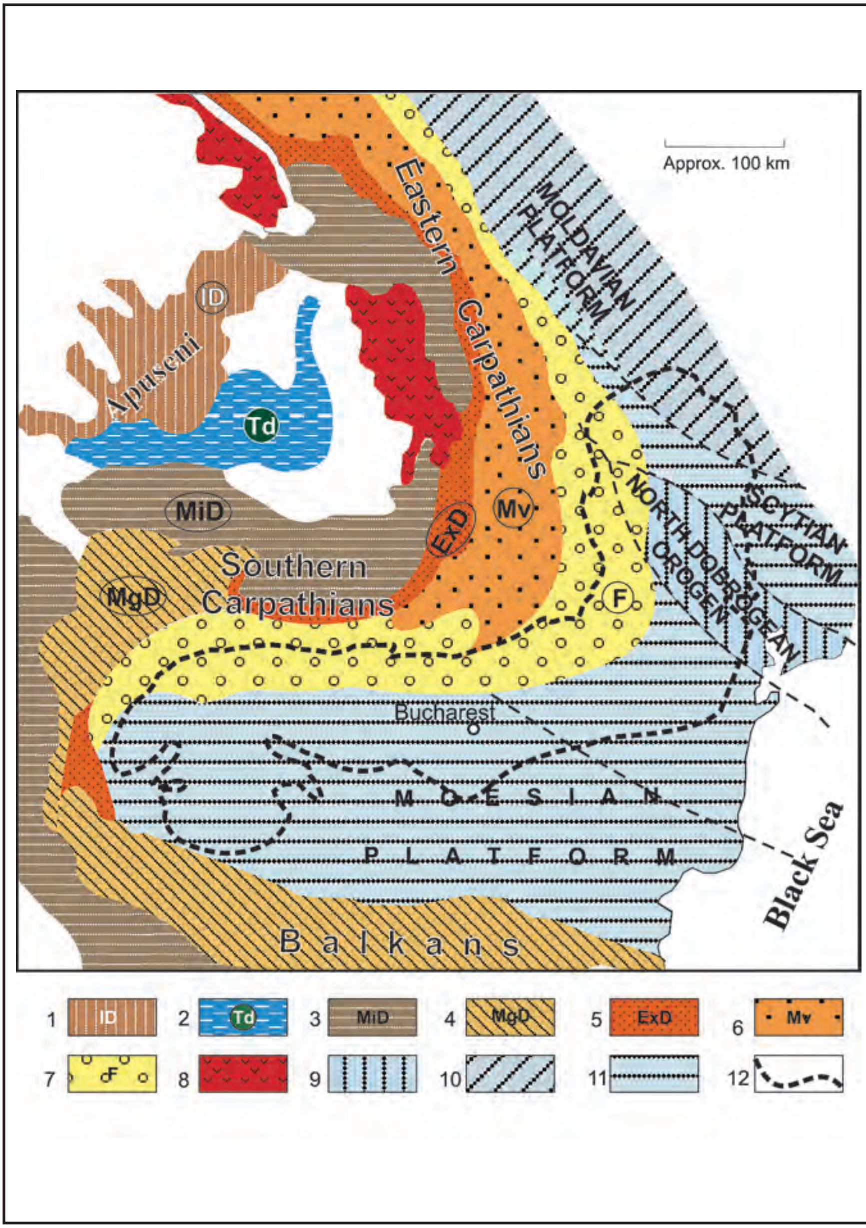


FIGURE 1.7. Tectono-structural sketch of Romania. Simplified and modified after Săndulescu (1984). **Legend:** 1. Internal Dacides. 2. Transylvanids. 3. Middle Dacides. 4. Marginal Dacides. 5. Outer Dacides. 6. Moldavides. 7. Foredeep. 8. Alpine igneous rocks. 9. North-Dobrogean Orogen. 10. Precambrian platforms. 11. Palaeozoic platforms. 12. Dacian Basin outline (based on the Maeotian paleogeographic map of Saulea *et al.*, 1969 and Hamor *et al.*, 1988)

The Eastern and Southern Carpathians tectonic activity culminated during the Sarmatian time (approximately 11 Ma), with subduction and continental collision between the East European-Scythian-Moesian foreland and the inner Carpathians Tisza-Dacia unit (Balla, 1986; Csontos, Vörös, 2004; Schmid *et al*., 2008). The Middle-Late Sarmatian (*sensu* Eastern Paratethys, see Vasiliev, 2006) is the moment when the Sub-carpathian Nappe was thrust on top of the sedimentary cover of the foreland platforms (Săndulescu, 1988; Maţenco, Bertotti, 2000). This event followed the Early and Middle Miocene nappe stacking, which led to the emplacement of the Internal Moldavides.

The latest Miocene-Quaternary post-collisional evolution also involved some limited deformation. The late orogenic evolution of the external part of the Romanian Carpathians and their foreland began after the Middle Sarmatian cessation of the major shortening (Leever *et al*., 2006), with a period of subsidence (Latest Miocene - Pliocene). Focşani Depression, located in the northern Dacian Basin, was the site of the highest subsidence values. The classically defined Wallachian compressional stage recorded in the SE Carpathians (*e.g*., Hippolite and Săndulescu, 1996) has been more recently quantified to 5 km of total shortening taking place along high-angle reverse faults cross-cutting the already locked nappes contacts (*e.g*., Leever *et al*., 2006). As a result, rapid exhumation took place in the Moldavides, being associated with continued subsidence in the Focşani foreland (*e.g.,* Maţenco *et al.,* 2007).

The post-collision foreland of the Romanian Carpathians is paleogeographically known as the Dacian Basin (*e.g*., Jipa, 2006 and references therein). Hence, the Quaternary uplift led to the erosional removal of a large part of the proximal Focşani foredeep.

Initially (Late Sarmatian *s. l*.), the Dacian Basin sedimentation was restricted mostly to the pre-existent foredeep area. During its subsequent development (especially during the Pontian time), the Dacian Basin sedimentation area extended southward, over the northern part of the Moesian Platform and a part of the Scythian platform (Fig. 1.7).

1.5. OVERVIEW OF THE DACIAN BASIN CYCLIC DEVELOPMENT

Three cycles of sedimentary and biological nature occurred during the development of the Dacian Basin (Jipa, Olteanu, 2006). The cyclic evolution is evident in the central and western part of the basin, where sedimentary sequences show contrasting lithology, from clay to sand and gravel.

The lithofacial, paleoenvironmental and paleontological data suggest the existence of the following development cycles:

- cycle 1, Sarmatian (*s.l.*);
- cycle 2, Maeotian;
- cycle 3, Pontian-Dacian-Romanian.

The Sarmatian (s.l.) cycle. In the western part of the Dacian Basin the Sarmatian (*s.l.*) sedimentary succession shows the transition from Volhynian fine-grained deposits (clay, silt and fine sands) to Bessarabian-Kersonian coarse-grained, sand and gravel fluvial deposits (Marinescu, 1978) (Fig. 1.8). Marinescu (1978) considers that the Maeotian deposits are transgressive on the coarse grain-size sequence of the Late Sarmatian from Valea Morilor.

In the Carpathian bend area, Pană (1968) showed that the Kersonian coarser-grained sediments overlay the clayey Bessarabian deposits, including the shell beds. During the Late Sarmatian (*s.l.*) sequence, the *Mactra* shell accumulations show clear littoral characters (Brustur *et al.*, 2005).

The Maeotian cycle. There are several places where the Maeotian sequence consists of a lower part dominantly clayey and an upper part sandy and/or gravely. The most complete cyclic development shows a continuous passage from lower

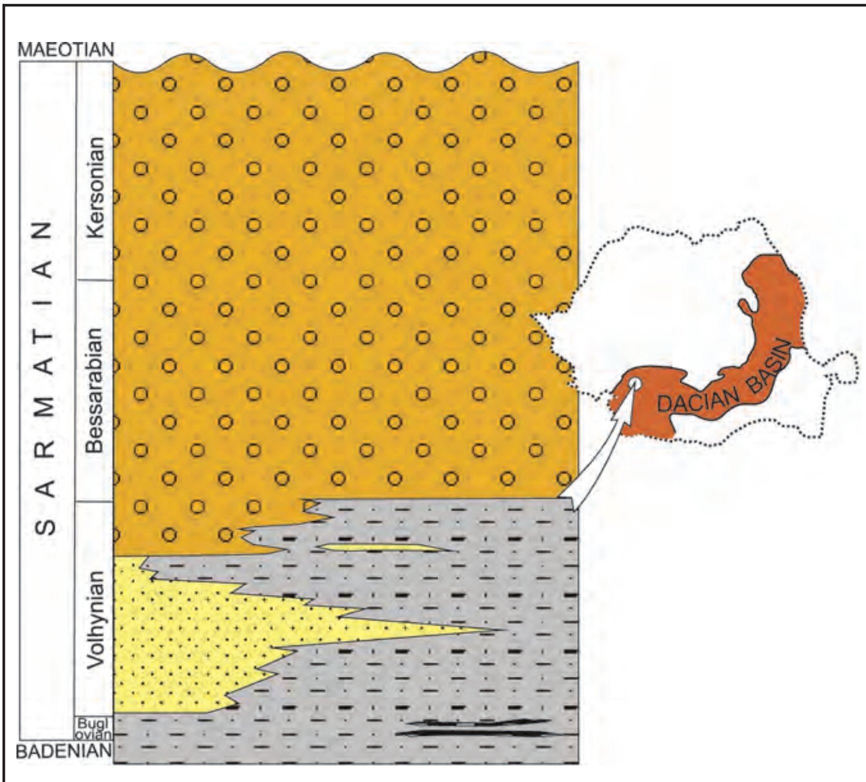


FIGURE 1.8. The synthetic litho-facies column of the Sarmatian (*s.l.*) deposits from the western part of the Dacian Basin. Simplified, from Marinescu (1978).

clayey facies (littoral with very low sediment supply?) to sandy deltaic facies and to fluvial sedimentation. This is observed on the right slope of the Luncavăț River (Cârstăneşti village, Vâlcea County), but the outcrops are discontinuous and partly covered. A large scale coarsening upward prevailing tendency appears at Lunguleţu geological section, followed by coarse-grained fluvial deposits (Fig. 1.9 A).

At the Bizdidel River section (Pucioasa, Dâmboviţa County) the Early Maeotian part of the section is tectonically missing. The lower part of the Late Maeotian, showing clear littoral (shore face and delta) features, is sharply overlaid by fluvial deposits (Fig. 1.9 B).

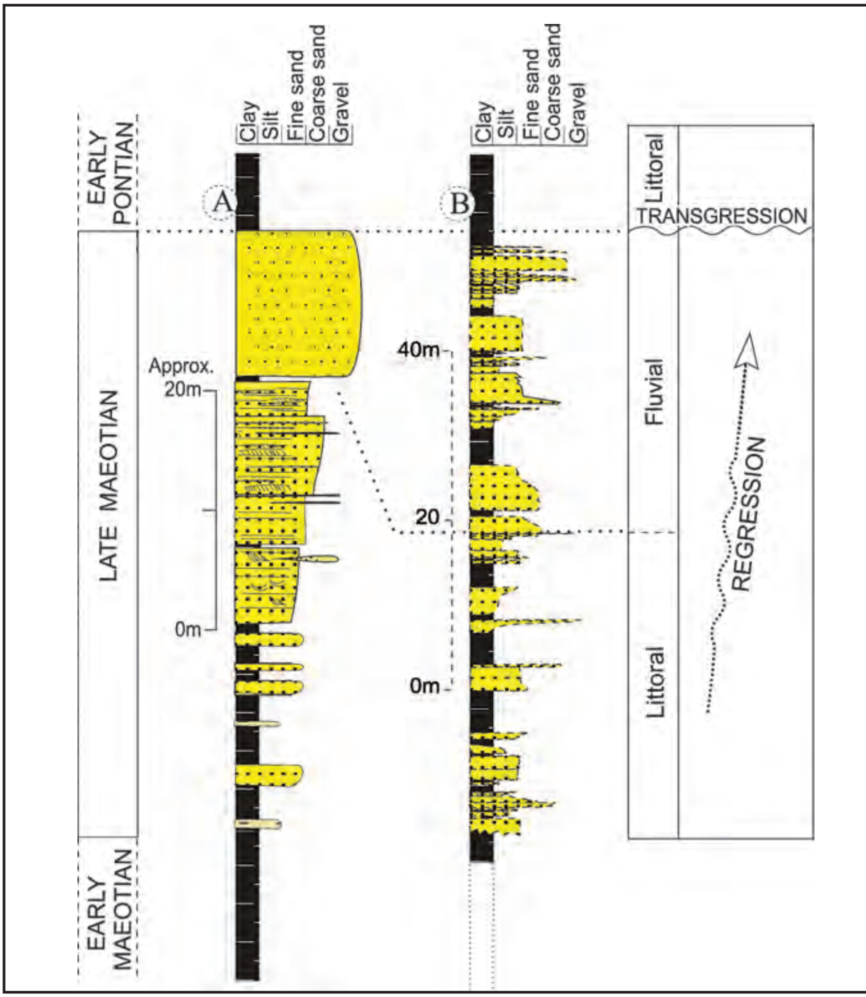


FIGURE 1.9. Main features of the upper part of the Maeotian sedimentary sequence. A. Bistriţa River, Lunguleţu village (Vâlcea County). B. Bizdidel River, Pucioasa (Dâmboviţa County).

On the Doftana River section (Câmpina, Prahova County), the coarser-grained top part of the Maeotian cycle displays features of the deltaic plain facies.

The Late Maeotian sediments cropping out on Bădislava River have a special facies, represented by fluvial, current transported gravel and coarse-grained sand, followed by muddy flood plain sediments with minor fluvial channels.

Regression is the dominant trend of the Maeotian cyclic sequence, manifested by the shallowing up (littoral to fluvial) tendency. The conglomeratic Late Maeotian deposits from the Bădislava River section are transgressively covering Middle Miocene deposits.

Fine grained, clay dominated Pontian deposits overlay the Late Maeotian sediments in all the geological sections discussed above. The Pontian transgression is of low intensity when the sequence begins with Early Pontian sediments (as in the Bizdidel River geological section). Sometimes the Pontian transgression is advanced and the Late Maeotian is covered directly by Late Pontian (Bosphorian) deposits (Bădislava River and other sections).

The Pontian-Dacian-Romanian cycle. The youngest Dacian Basin cycle is the best developed and the most significant. The basal deposits of the Pontian-Romanian cyclical sequence are transgressively overlaying the Late Maeotian fluvial sediments. During the Pontian and Dacian time, a shallowing up sequence developed, leading from Pontian clayey littoral deposits to Early Dacian deltaic deposits and to Late Dacian-Romanian fluvial sediment accumulation (Fig. 1.10). Continental sedimentation has been occurring since the Dacian time, earlier in the west and later in the eastern part of the Dacian Basin.

The cyclic sequences of the Dacian Basin have a transgressive-regressive character. Important faunal changes are associated with the cyclical events, which occurred during the Dacian Basin evolution (Jipa, Olteanu, 2006).

The terminal fluvial deposits of the three cycles may be interpreted differently. The littoral/fluvial sequences of the Sarmatian (*s.l.*) and of the Late Maeotian represent an input of thick detritus material at the edge of the basin. These fluvial deposits could not be present in the sedimentary sequence of the central Dacian Basin.

The Dacian-Romanian littoral and fluvial deposits have different sedimentary characters. Even though they are relatively thin, the Early Dacian littoral interval is identified on the entire western and central area of the Dacian Basin. The Late Dacian-Romanian fluvial term of the cycle extended on the entire area of the Dacian Basin. Unlike the two preceding cycles, the Pontian-Dacian-Romanian cycle reflects the filling out of the Dacian Basin and the passage to continental, fluvial environment.

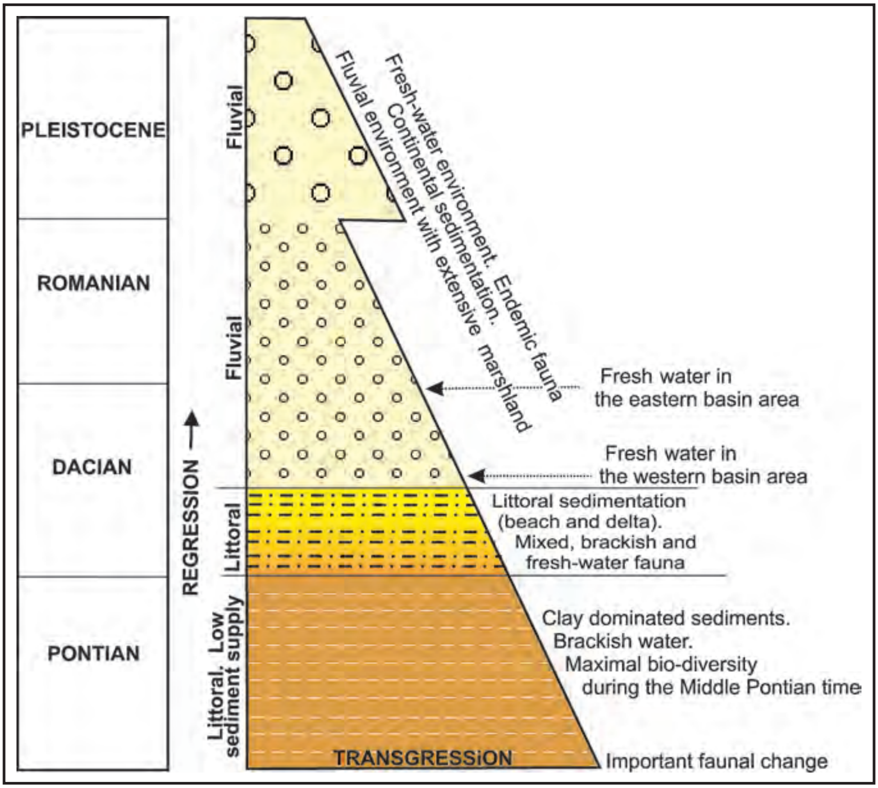


FIGURE 1.10. Main features of the Dacian Basin Pontian-Dacian-Romanian sedimentary cycle. Modified, from Jipa, Olteanu (2007).

1.6. NOMENCLATURE

The understanding of different Dacian Basin geological aspects is sometimes affected by terminology difficulties which might be confusing.

Areas within the Dacian Basin. There are several terms used to indicate limited areas which are parts of the Dacian Basin. The most frequently employed is the term "Getic Depression". This name refers to the Uppermost Cretaceous - Middle Sarmatian foredeep of the South Carpathians. In connection with the Dacian Basin, the name Getic Depression is used for the territory corresponding to the area formerly occupied by this tectonic unit (Fig. 1.11).

Focşani Depression is another name frequently occurring in connection with the Dacian Basin. This term is applied to the area in the northern part of the Dacian Basin (Fig. 1.11), which was affected by high subsidence during Late Neogene to Quaternary times.

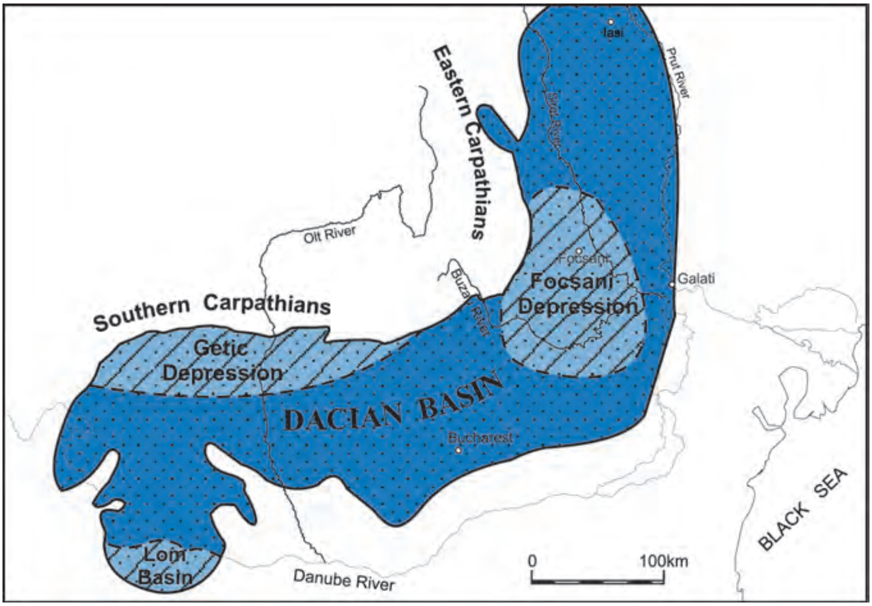


FIGURE 1.11. Selected areas of the Dacian Basin with specific names used by different authors

Basins within the Dacian Basin ? Terms like "Lom Basin" or even "Focşani Basin" also refer to different areas within the Dacian Basin (Fig. 1.11). When referring to Pliocene deposits, the name "Lom Basin" designates an area of the Dacian Basin located just south of the Danube River, in the northwestern Bulgaria and the north-eastern Serbia. "Focşani Basin" is sometimes used as an alternative denomination for "Focşani Depression". There is no reason to use the term "basin" for areas like Lom and Focşani, as they are included in the Dacian Basin.

Dacic vs Dacian. In scientific journals written in English, two names - Dacian and Dacic - are commonly used for the basin named after the Dacian people, ancestors of modern Romanians and who lived in the geographic region of Dacia. The English translation from the Romanian 'Bazinul Dacic', is Dacian Basin. Grammatical rules (Quirk *et al*., 1978) indicate that the use of 'Dacian' is preferred over 'Dacic' whereby

-(i)an is added chiefly to proper nouns to form personal nouns and non-gradable adjectives, meaning: 'belonging to…' ; 'pertaining to…', etc (as in: Indonesian, Parisian, Elizabethan, Darwinian) The suffix *-(i)an* "often corresponds to place nouns in *–(i)a*: Persia/Persian" (Randolph Quirk *et al*., 1978).

Also, Quirk *et al*. (1978) show that '-*ic* is used to form gradable or non-gradable adjectives often used for language names : « Celtic », « Arabic » (cf the nationality adjectives 'Arab, Arabian')'.

Moreover, *Britannica*, *Shorter Oxford*, *Webster*, *Bartelby.com* list 'Dacian' only as derivative from "Dacia".

Consequently, grammatically speaking, the correct rendering into English of the Romanian 'Bazinul Dacic' is the Dacian Basin.

Dacian time and Dacian Basin. Another nomenclature issue derives from the concurrent use of the name *Dacian* both for a *time unit* and for the *basin*. The same problem is connected with Pannonian, the *time span* and the *basin*.

The meaning of the word *Dacian* is usually understood, when considered in its context. However, to make things clear, in this book, the name Dacian is consistently associated with either the word *basin* or the word *time*.

Chapter 2

DACIAN BASIN PALEOGEOGRAPHY. SEDIMENTOLOGICAL INTERPRETATION

The analysis of the paleogeographic evolution represents an important approach for the investigation of the sedimentary history of a basin. Paleogeographic changes reflect the influence of factors (tectonic, climate), which also control the sediment provenance and sediment accumulation processes.

2.1. DACIAN BASIN PALEOGEOGRAPHIC EVOLUTION: ITS BEGINNINGS, DEVELOPMENT AND FILLING

2.1.1. Paleogeographic maps

The Dacian Basin paleogeographic analysis is based on local (Dacian Basin) and regional (Paratethys domain) paleogeographic maps.

Dacian Basin paleogeographic maps. At the beginning of the Dacian Basin paleogeographic studies, the accumulation of information was strictly constrained to the Romanian territory. The first atlas dealing with the Dacian Basin paleogeography was published as the 4th volume of the Lithofacies Atlas of Romania, dedicated to the Neogene time (Saulea *et al*., 1969). The atlas includes 13 plates, 11 of which are 1:2,000,000 scale lithofacies maps of the Aquitanian – Romanian (former Levantine) deposits. The 1969 issue is the second, final edition of the Neogene lithofacies maps. The first edition was published in 1964 with 1:500.000 scale maps.

The name "lithofacies atlas" does not correspond totally to the data available in the atlas. The maps produced by Saulea *et al*. (1969) include a rather large array of information. In addition to the lithological information, the atlas presents the paleogeographical extent of the sedimentary areas, including the continental areas (high altitude and low plains). Biostratigraphical data and paleoecological zones reflecting the paleosalinity were also mapped. The map for each interval shows the lithology and the sediment thickness (isopach map). The provenance of data used, mostly subsurface information, is marked on a special sheet of the atlas. The paleogeographic maps have been prepared at rather small time intervals (Fig. 2.1): Early-Middle Sarmatian (*s. l.*), Middle-Late Sarmatian (*s. l.*), Maeotian, Early Pontian, Late Pontian-Dacian and Romanian (Levantine).

The Saulea *et al*. (1969) Neogene paleogeographic atlas represents the basic framework required for any future project on Dacian Basin. However, the maps lack data in the areas where the Dacian Basin extends out of the Romanian territory, to the south of Danube River, offering an incomplete image of the basin.

Several years before the Neogene paleogeographic atlas of Romania of Saulea *et al*. (1969) was published, a similar collection of paleogeographic maps was drawn at the Research Institute of the Romanian Oil Ministry (Hristescu *et al*., 1962-1963)[1]. Unfortunately this atlas was not made available for public viewing, being in the format of a scientific report, and kept private.

The paleogeographic maps of Saulea *et al*. (1969) have been updated and developed by Papaianopol *et al*., 1987 and Marinescu and Papaianopol (1989, 1995, 2003). The new work advances the paleogeograhic knowledge of the Lower, Middle and Upper Pontian times of the Dacian Basin. New paleogeographic maps have been presented for the Dacian and Romanian times.

Connections of the Dacian Basin with marine bodies which could explain the calcareous nannoplankton occurrences have been studied by Mărunțeanu (2006).

Paratethys paleogeographic maps. The understanding of the Dacian Basin evolution within the Paratethys domain improved with the publication of the Central and Eastern Europe paleogeographic atlas (Hamor *et al*., 1988). The easternmost part of Paratethys (Caspian Basin and the Black Sea Depression) is not included in the Central and Eastern Europe atlas. Three paleogeographic maps display the Paratethys realm during the existence of the Dacian Basin (Fig. 2.1).

The paleogeographic image of the entire Paratethys domain is incorporated in the atlas of Peritethys (Dercourt *et al*., 2000). Only two maps are devoted to the time span of Dacian Basin existence (Fig. 2.1).

The lithologic - paleogeographic work of Popov *et al*. (2004) is dedicated to the Paratethys domain. Four maps (Fig. 2.1) of the Popov *et al*. (2004) paleogeographic atlas represent the Late Neogene time when the Dacian Basin was part of the Paratethys realm.

[1] Hristescu, E., Constantinescu, I., Micșa, L., Bosoancă, G., Grigorescu, M., Burlacu, A., Ichim, T., Vasilescu, E., Vasiliu, M., Cristodulo, D., Diaconescu, R., Dicea, M., 1962-1963. Atlasul hărților litologo-paleogeografice ale sedimentarului din R.P.R. Ministerul Industriei Petrolului si Chimiei, D.G.F.E.T.-T.E.G., Intreprinderea de Laboratoare Geologice. Unpublished report.

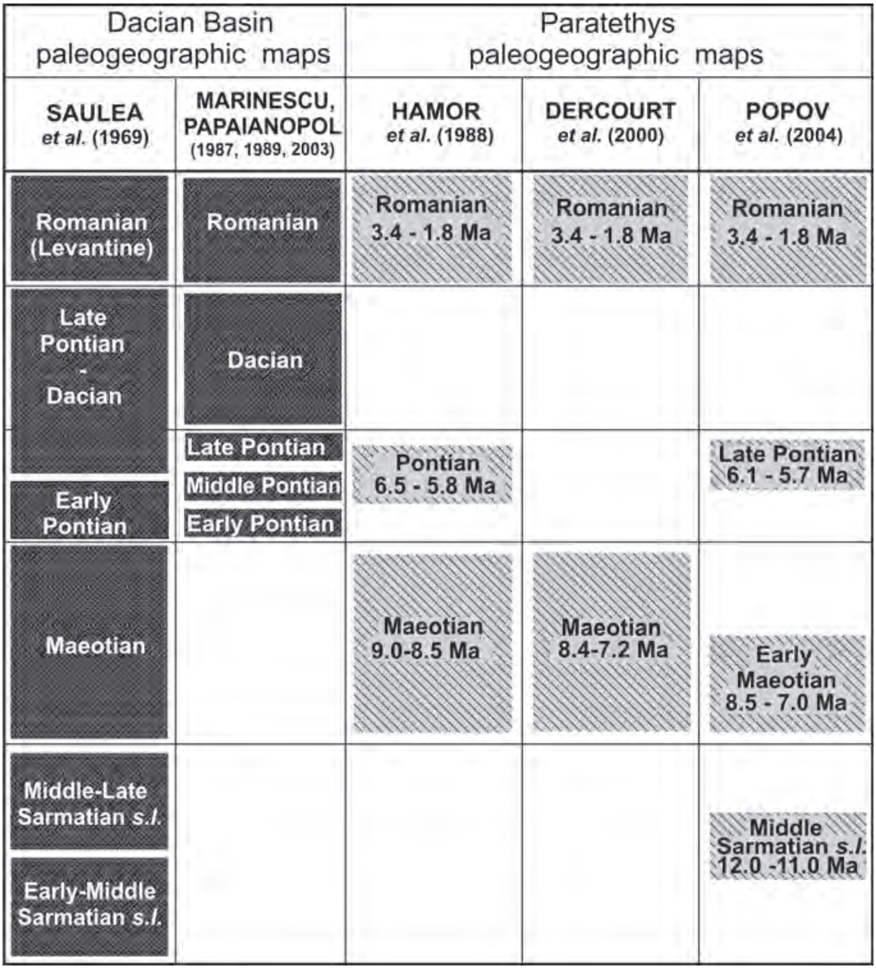


FIGURE 2.1. Paleogeographic maps used in this book for the investigation of the Dacian Basin evolution

2.1.2. Paleogeography before the existence of the Dacian Basin

The undivided Paratethys domain. According to Rögl (1999), during the Chattian time (29 - 24 Ma), after the initial isolation episode, Paratethys reverted to the open marine conditions due to the reconnection with the global ocean. The whole Paratethys appeared as an elongated epicontinental sea (Fig. 2.2A), with two deep-water basins (Carpathian Basin and Black Sea Depression). Between the deep basins there was the emerged Moesian land, but its presence did not obstruct the circulation of the Paratethys marine water (Popov *et al*., 2004). The Eggenburgian (20.5 - 19.0 Ma) paleogeographic map (Fig. 2.2A) shows the same undivided Paratethian sea.

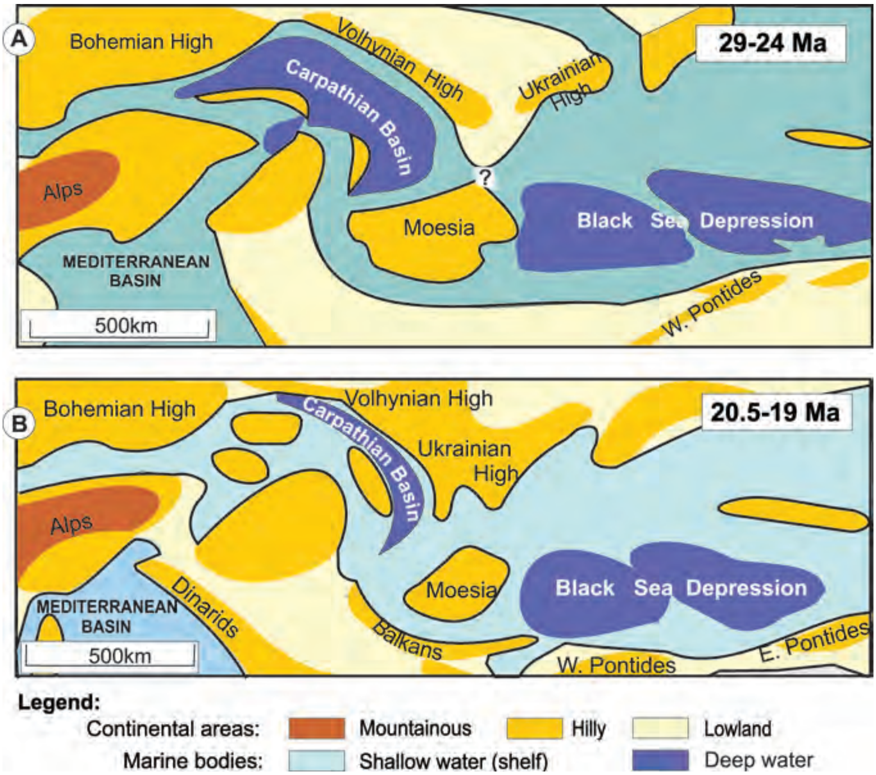


FIGURE 2.2. Paleogeography of the central part of the Paratethys domain during Chattian (29-24 Ma) (**A**) and Eggenburgian (20.5-19 Ma) (**B**). Simplified and modified after the paleogeographic maps in Popov *et al*. (2004)

Throughout this Paratethys stage the Dacian Basin did not exist.

Paratethys – a string of basins. Paratethys paleogeography changed from the beginning of the Badenian (Hamor *et al*., 1988; Popov *et al*., 2004). The fore-Alpine Basin, the westernmost Paratethian basin, closed. The rising Carpathians divided the western Paratethys, separating the Pannonian Basin area from the Carpathian foredeep (Fig. 2.3A). In the same time the Moesian – Dobrogean area emerged (Fig. 2.3A) and divided the Paratethys Basin into a large Oriental Paratehys domain (split in two, Euxinian and Caspian interconnected basins) and a much smaller western Paratethys (Pannonian Basin and the Carpathian foredeep) (Fig. 2.3 B).

During the Sarmatian (*s. l.*) time, the uplifted Carpathians separated Paratethys into two major parts (Fig. 2.3C). Situated in front of the rising mountain chain, the Carpathian foredeep belonged to the Oriental Paratethys basin.

The sedimentation basin outside the Carpathians during the Badenian – Early Sarmatian (*s.l.*) is the Carpathian foredeep (Fig. 2.3). The basin was shaped as a long trench adjacent to and in front of the Carpathians. It extended from the Southern Carpathians to the Western Carpathians. At the beginning of the Sarmatian (*s.l.*) time, the northern end of the foredeep closed and the trench extended only as far as the Galitzian Gulf.

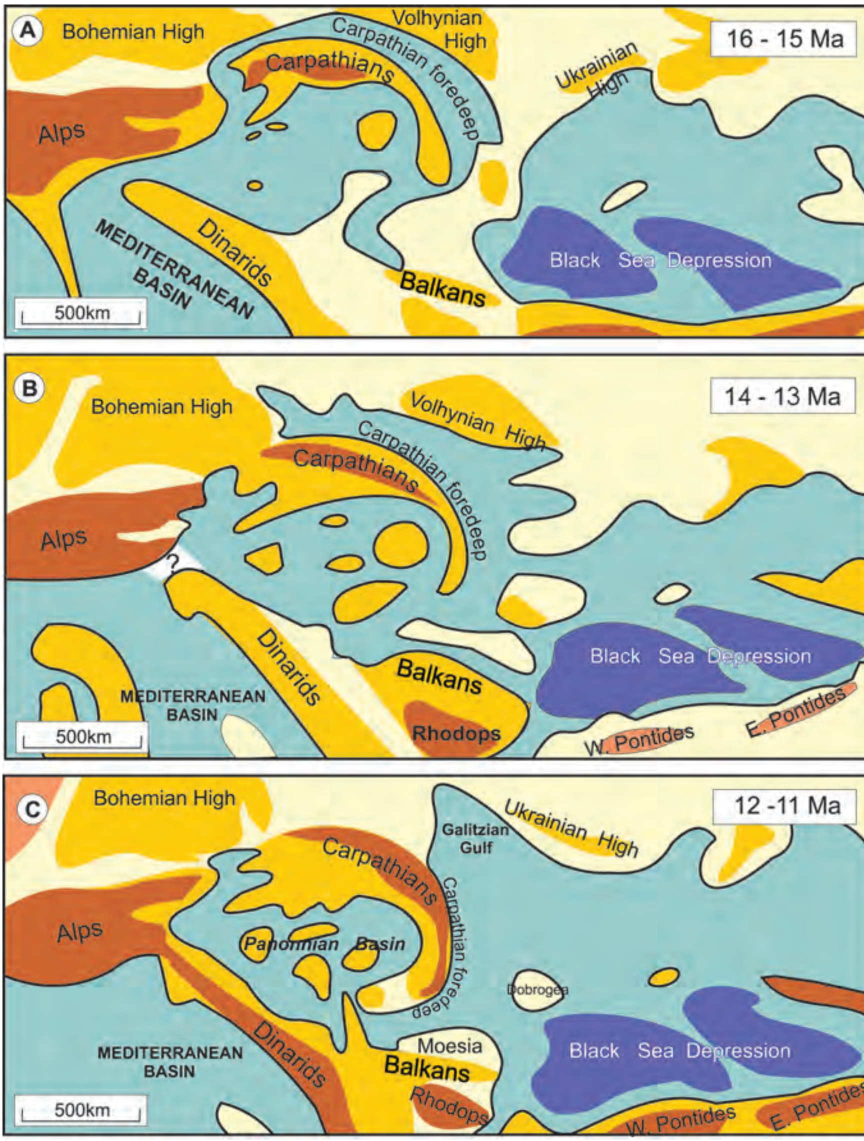


FIGURE 2.3. Paleogeography of the central part of the Paratethys domain during Early Badenian (16 - 15 Ma) (**A**), Late Badenian (14 - 13 Ma) (**B**) and Middle Sarmatian *s.l.* (12 - 11 Ma) (**C**). Simplified and modified after the paleogeographic maps in Popov *et al*. (2004). Legend at figure 2.2.

The brackish fauna characteristic to the Dacian Basin occurred also in the Carpathian foredeep since the Badenian – Early Sarmatian (*s.l.*). However, the Badenian – Early Sarmatian (*s.l.*) Carpathian foredeep and the Dacian Basin are quite different from the paleogeographic viewpoint. The Badenian Carpathian foredeep is a long basin extending from the southern Carpathians to the Bohemian High and becoming shorter during the Middle Sarmatian (*s.l.*) (Popov, 2004) (Figs 2.3 and 2.4). The Late Sarmatian (*s.l.*) Carpathian foredeep, or the Dacian Basin (Fig. 2.4) is a much smaller basin, about one third of the Badenian foredeep and one half of the Middle Sarmatian Carpathian foredeep. Consequently, the term Dacian Basin cannot be used for the Badenian-Early Sarmatian (*s.l.*) Carpathian sedimentation trench.

2.1.3. Dacian Basin formation

During the Sarmatian (*s.l.*) the collision between the Africans and Euro-Asian plates (Bala, 1987; Ustasewski *et al.*, 2008) generated the closure of the central and northern parts of the Carpathian foredeep. The southern segment of the foredeep, which continued to exist after the collision ceased, is the Dacian Basin. The geological moment of the Dacian Basin coming into existence was well outlined by Saulea *et al.* (1969). The formation of the Dacian Basin was demonstrated by preparing two Sarmatian (*s.l.*) paleogeographic maps at a very close time interval (Early and the lower part of the Middle Sarmatian, and upper part of the Middle to Late Sarmatian *s.l.*). The Early Badenian to Middle (lower part) Sarmatian (*s. l.*) Carpathian foredeep (Fig. 2.4A) was replaced by a smaller foreland basin in the Middle (upper part) Sarmatian (*s.l.*) (Fig. 2.4B). The newly formed basin is the Dacian Basin.

The continental collision between the East European/Scythian/Moesian foreland and the inner Carpathians Tisza-Dacia unit ended during Middle Sarmatian (*s.l.*) (see Chapter 1.4). The closure of the northern segment of the Carpathian foredeep was due to the Middle Sarmatian (*s.l.*) uplift which took place during and after the collision. A detrital continental facies with mammal remains (Saulea *et al.*, 1969) (Fig. 2.4B) occurred as a consequence of the uplift, contrasting with the brackish-marine deposits accumulated inside the basin, and making the northern limit of the Dacian Basin.

The Dacian Basin is the post-collision remnant of the Carpathian foredeep. As a consequence of the Sarmatian (*s.l.*) uplift, the Dacian Basin onset was associated with a significant regression (Saulea *et al.*, 1969). The Dacian Basin Late Sarmatian area was narrower compared to the Early Sarmatian foredeep (Fig. 2.4).

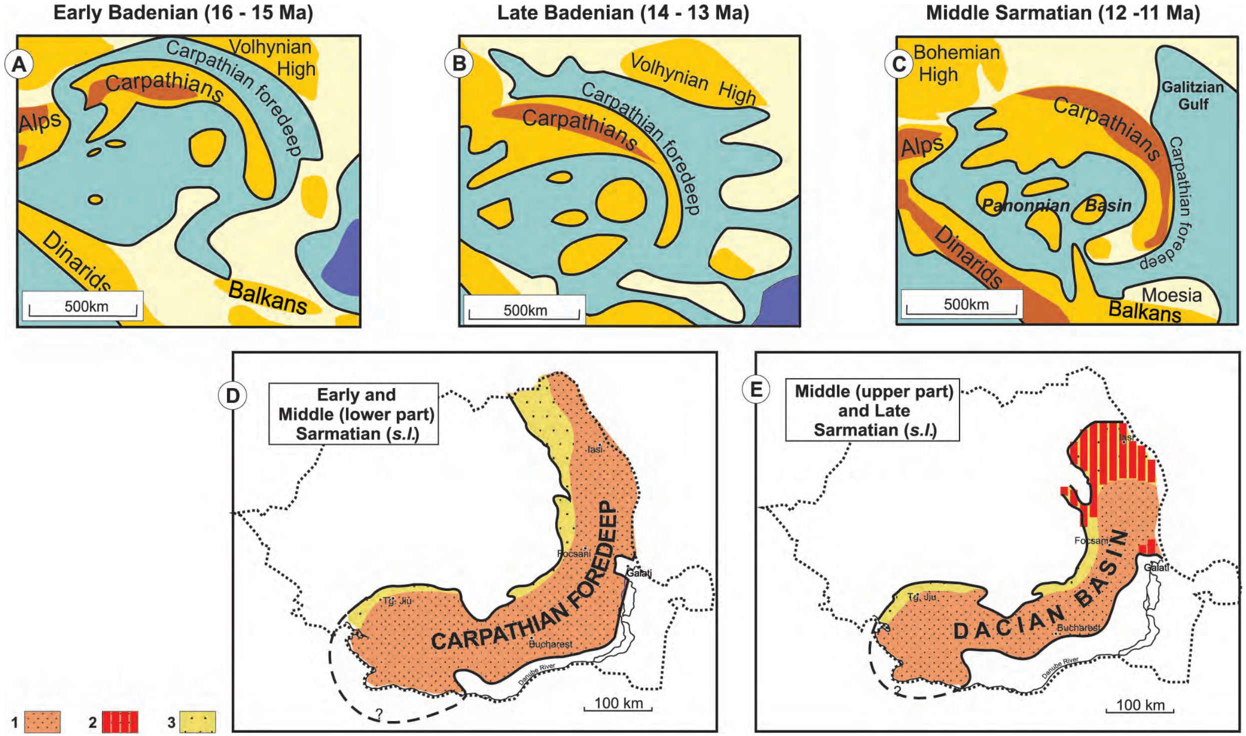


FIGURE 2.4. The Dacian Basin appearance as a distinct Paratethys unit. **A**, **B** and **C** – Carpathian foredeep evolution during the Badenian and Middle Sarmatian (*s.l.*). The western end of the foredeep shifted eastward. Simplified and modified after the paleogeographic maps in Popov *et al*. (2004). Legend at figure 2.2. **D** and **E** - Sarmatian (*s. l.*) paleogeographic evolution. During the Middle Sarmatian (*s.l.*), the foredeep area diminished to the size of the Dacian Basin. Paleogeographic data from Saulea *et al*. (1969). **Legend**: 1. Fine grained brackish facies. 2. Fine grained brackish to fresh-water facies. 3. Coarser-grained facies

2.1.4. The open sea Dacian Basin (Middle-Late Sarmatian *s.l.*)

The Middle-Late Sarmatian (*s.l.*) Dacian Basin was a sedimentary trench which received mostly fine-grained, silty-clayey detritus material (Fig. 2.5). Coarser-grained sandy sediments occured on the northern margin of the basin, in the proximity of the Carpathians. The largest amount of sand size sediments accumulated at the northern extremity of the basin. Based on faunal assemblages, Saulea *et al*. (1969) suggest the fresh-water (or with a tendency to become fresh-water) character of the coarser-grained deposits from the northern Dacian Basin (Fig. 2.5). The central and western part of the basin is characterized by brackish water faunas.

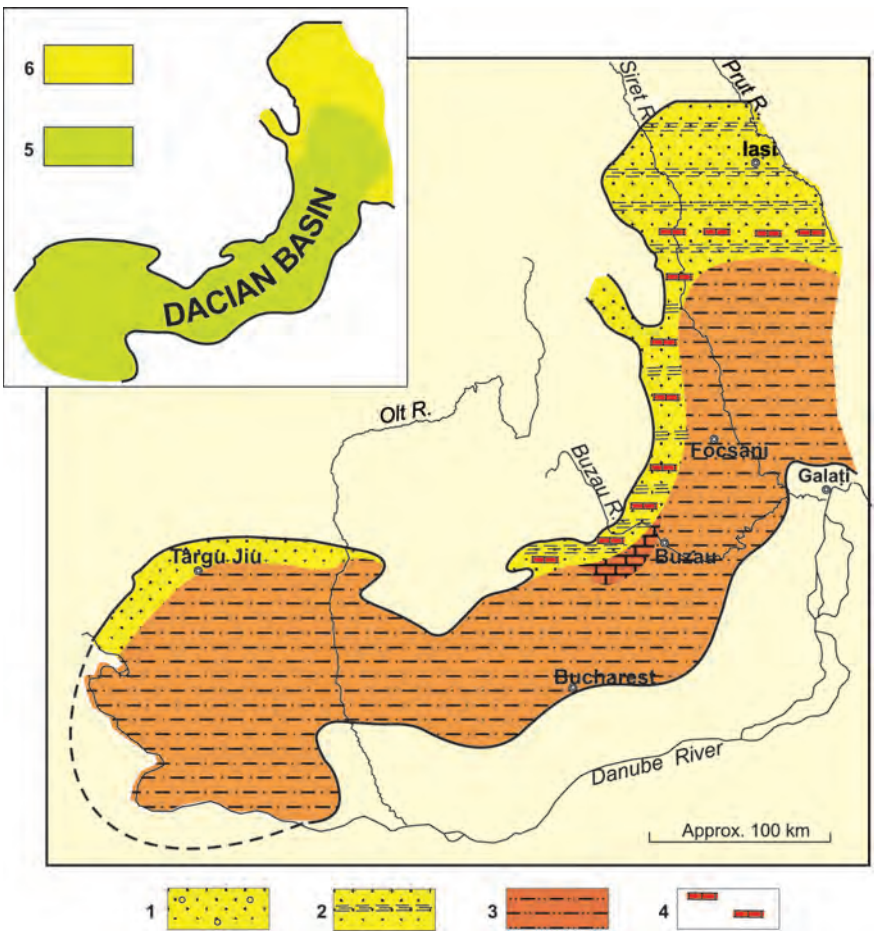


FIGURE 2.5. Dacian Basin during the Middle-Late Sarmatian (*s. l.*). Simplified and modified from Saulea *et al*. (1969). **Legend**: **1**. Sandy facies. **2**. Thick sandy units with clayey interbeds. **3**. Silty-sandy facies. **4**. Shell-beds. **5**. Brackish water environment. **6**. Fresh-water environment (or with a tendency to become fresh-water)

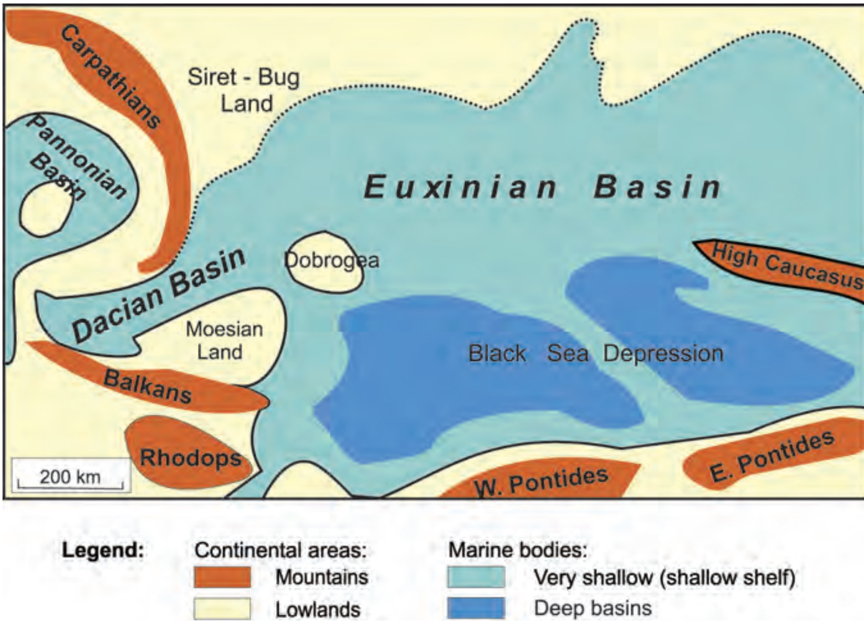


FIGURE 2.6. Paleogeographic sketch of the Dacian and Euxinian basins during Late Sarmatian (*s.l.*). Interpretation based on the Middle Sarmatian paleogeographic map (Paramonova *et al.*: in Popov *et al.*, 2004) and on the Early Maeotian map (Ilyina *et al.*; in Popov *et al.*, 2004). The northern limit of the marine area (dotted line) is tentatively marked out (by the authors of this book) at an intermediary position between the Middle Sarmatian and Early Maeotian limit.

Beginning with the Middle Sarmatian (upper part) and during the Late Sarmatian (*s.l.*), the Dacian Basin was largely connected to the east with the Euxinian Basin (the eastern part of the Oriental Paratethys) (Fig. 2.6) (Jipa, Olteanu, 2005). The Euxinian and the Dacian Basins were connected to the south and the north of the Dobrogean Island.

2.1.5. The semi-enclosed Dacian Basin (Maeotian-Early Dacian)

The general facies distribution existing in the Dacian Basin during the Middle-Late Sarmatian (*s.l.*) continued during the Maeotian time (Fig. 2.7). The marginal sub-Carpathian zone was also the site of sandy sediment accumulation. On the Maeotian paleogeographic map of Saulea *et al.* (1969) a silty-sandy facies is outlined in front of the Dobrogean dry land, but Papaianopol *et al.* (1987) does not confirm it.

After the Sarmatian phase when the Dacian Basin was connected with the Euxinian Basin through a wide area, the paleogeography changed considerably during the Maeotian time (Fig. 2.8). To the south of the Dacian Basin, a continental landmass has raised connecting Moesia and Dobrogea. The continental area named Siret-Bug Land by Popov *et al*. (2004) rose to the north of the Dacian Basin. As a result of these paleogeographic changes the connection between the Dacian and Euxinian basins was severely limited. Dacian Basin became a semi-closed water body (Jipa, Olteanu, 2005). Communication with the Euxinian Basin took place through a seaway located to the north of the present location of the town of Galați (named the "Galați passage" by Saulea *et al*., 1969 and by Marinescu, Papaianopol, 1989). This paleogeography setting is shown in the Maeotian paleogeographical map of Hamor *et al.*,1988), as well as in the paleogeographic map of Ilyna *et al*. (in Popov *et al*., 2004).

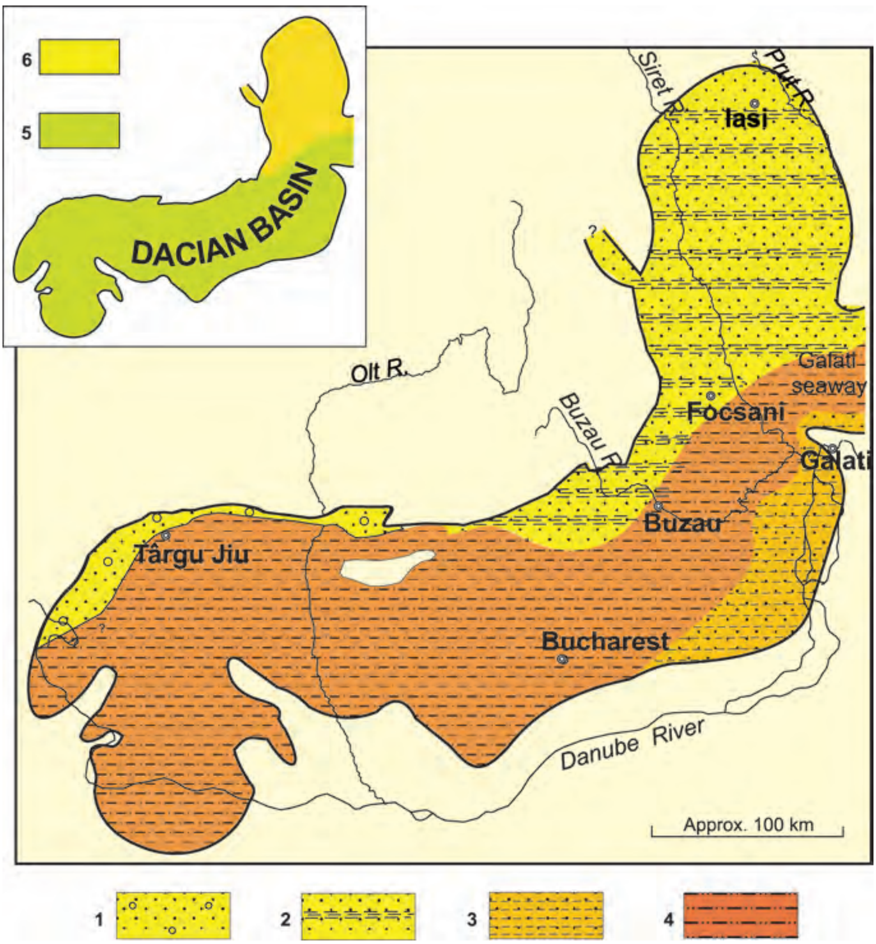


FIGURE 2.7. The Dacian Basin during the Maeotian time. Simplified and modified from Saulea *et al*. (1969). Southwestern limit of the basin from Hamor *et al*. (1988). **Legend**: **1**. Sandy facies with conglomeratic intercalations. **2**. Thick sandy units with clayey interbeds. **3**. Silty-sandy facies. **4**. Silty-clayey facies. **5**. Brackish water. **6**. Fresh water (or transition from brackish to fresh-water)

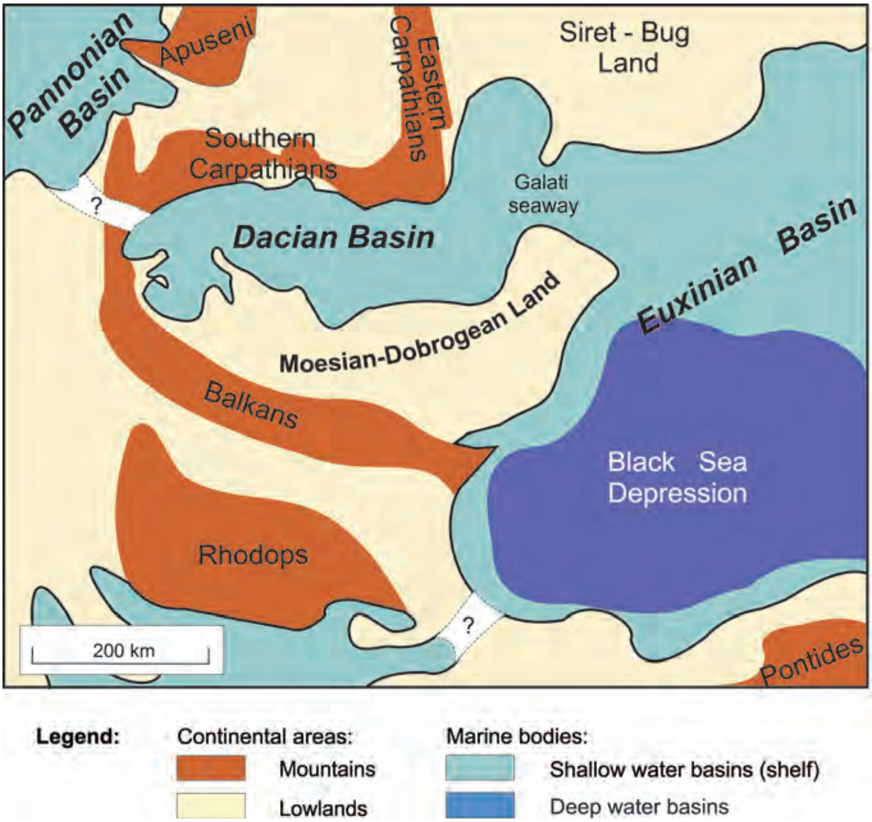


FIGURE 2.8. The Dacian Basin in the paleogeographic context of the Early Maeotian time (approx. 8.5 - 7 Ma). Simplified and modified after the paleogeographic map by Ilyina *et al*. (in Popov *et al*., 2004). The Dacian Basin after Saulea *et al*. (1969) and Hamor *et al*. (1988)

A similar paleogeography persisted during the Pontian interval. The narrow seaway connecting the Euxinian Basin and the Dacian Basin was located between the Dobrogean and the Volhynian Highs, to the north of the present day Galați Town.

The brackish-water conditions continued during the first part of the Dacian time (Jipa, 1997), and the semi-closed water body characteristic probably persisted during the Early Dacian time.

2.1.6. The closed Dacian Basin (Late Dacian-Romanian)

The brackish character of the Dacian Basin, persisted until the Early Dacian time in the western Dacian Basin. Beginning with the Middle Dacian period, the sedimentation in the Dacian Basin area became mostly fluvial, in contrast to the Euxinian Basin, which was still brackish-marine.

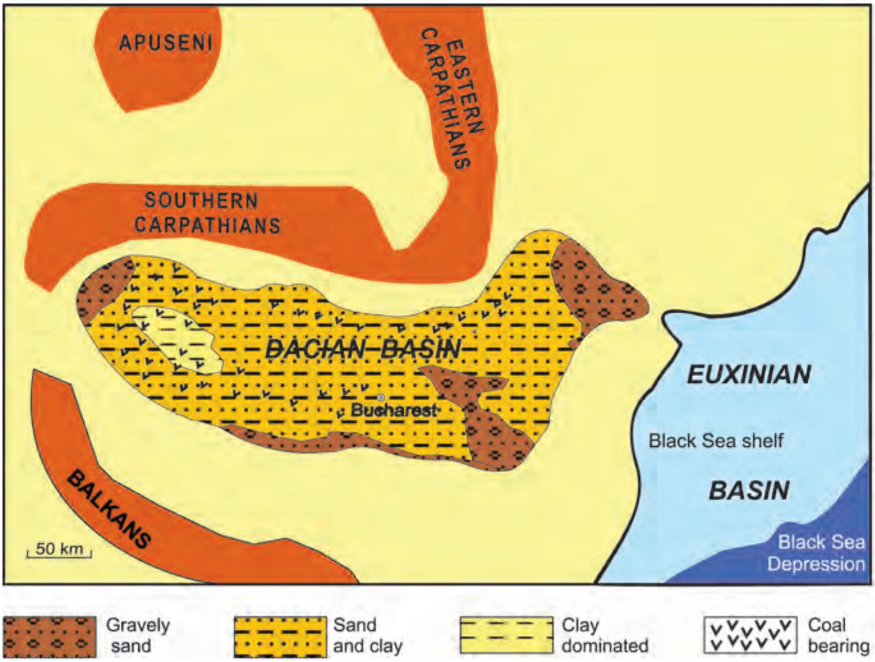


FIGURE 2.9. Paleogeography of the Dacian Basin during Romanian (3.4 - 1.8 Ma). Throughout this time, the basin was filled out and continental (fluvial) sediment accumulated on the area of the former basin. Modified after Papaianopol, Marinescu (2003)

The separation between the fluvial Dacian Basin and the brackish-marine Euxinian Basin (Fig. 2.9) is based on the preserved fauna. However, sediment transport existed between the two areas, mostly through the Paleo-Danube River discharge on the Black Sea shelf. Occasionally, during the Romanian time, Euxinian brackish water transgressed (invaded) the eastern part of the Dacian Basin area and sedimentary deposits accumulated with brackish fauna (see Chapter 12.2).

2.2. DACIAN BASIN PALEOGEOGRAPHIC CHANGES

The systematic paleogeographic investigation directed attention to significant changes of the Dacian Basin extent.

2.2.1. Sarmatian (*s.l.*) areal decrease

The formation of the Dacian Basin (upper part of Middle Sarmatian *s.l.*) was accompanied by a significant decrease of the sediment accumulation area (Saulea *et al.,* 1969) (Figs. 2.4 and 2.10). The Dacian sedimentary trench became narrower as compared to the earlier (Early-Middle Sarmatian *s.l.*) foredeep.

The reverse process, the basin enlargement and the widening of the depositional area started from the Late Sarmatian (*s.l.*) time (Saulea *et al*., 1969).

2.2.2. Dacian Basin extent during Maeotian-Pontian

The paleogeographic maps (Saulea, 1969; Papaianopol *et al*., 1987; Marinescu and Papaianopol, 1989) point out the Dacian Basin (Figs. 2.10 and 2.11) extended southward during the post-Sarmatian (*s. l.*). Considering the present-day course of the

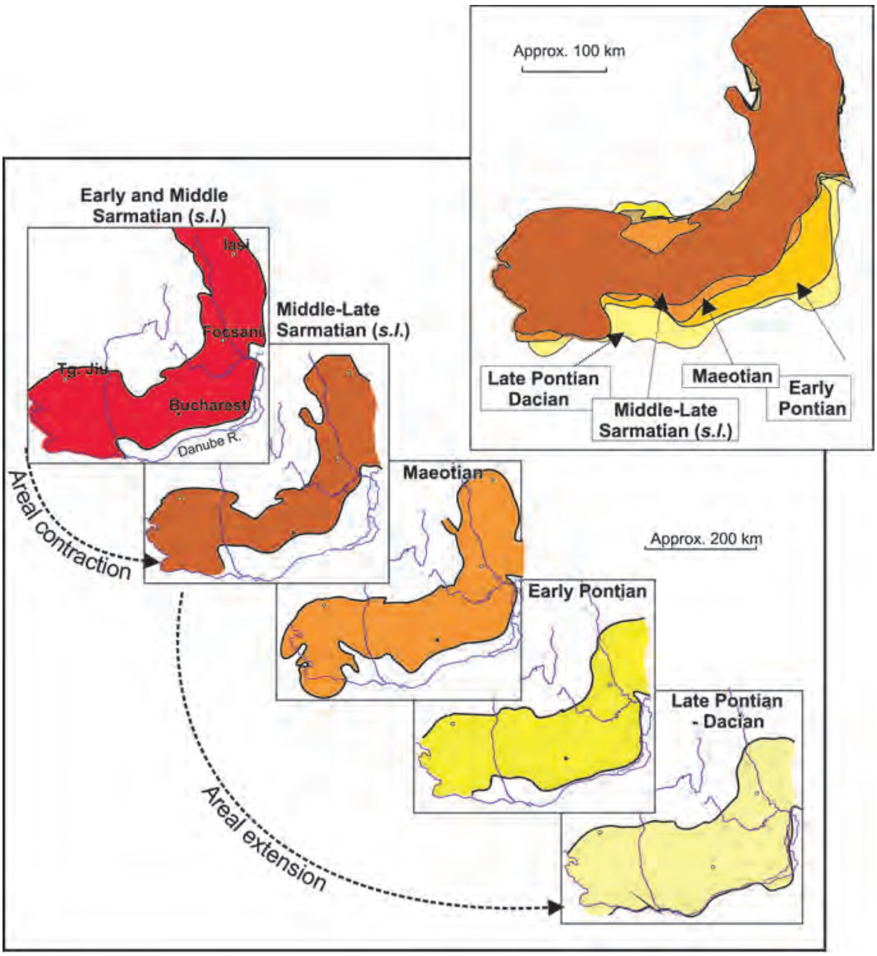


FIGURE 2.10. Areal evolution of the Dacian Basin sediment accumulation space during the Late Neogene. Note the progressive shift of the southeastern boundary of the basin, from Late Sarmatian (*s. l.*) to Late Pontian (modern Danube River course for marker). Right-up corner: superposed maps to make evident the time-continuous enlargement of the Dacian Basin. Paleogeographic sketches simplified after Saulea *et al*. (1969). The southwestern limit of the Dacian Basin after Hamor *et al*. (1988)

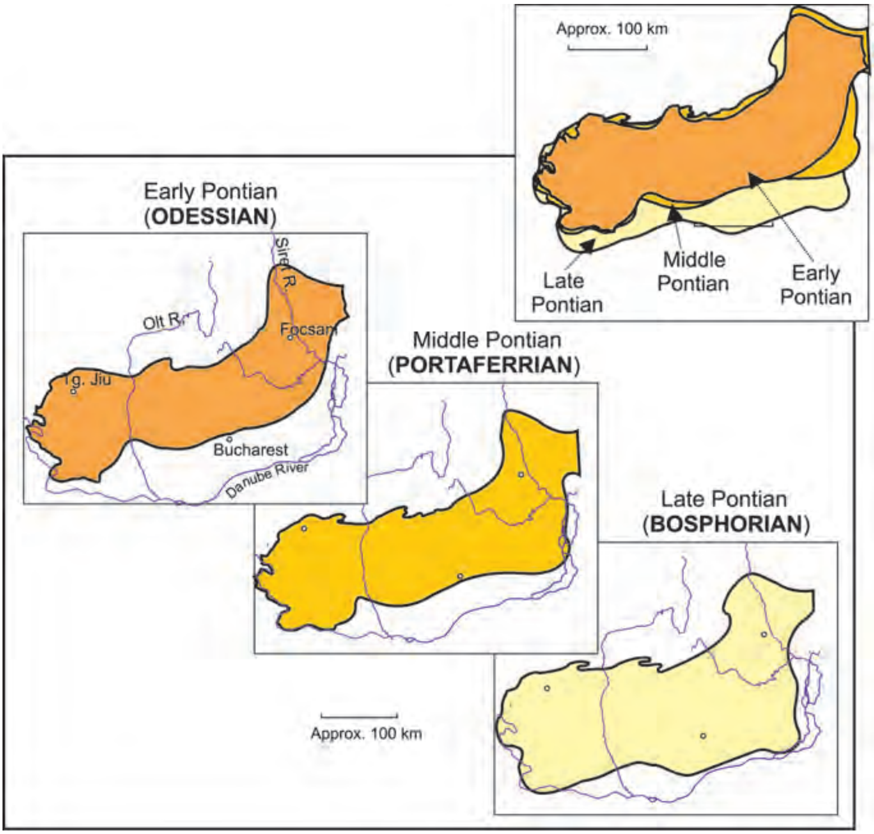


FIGURE 2.11. Area evolution of the Dacian Basin during the Pontian time. Right-up corner: superposed maps to emphasize area extension. Paleogeography sketches simplified from Papaianopol *et al*. (1987)

Danube River as a marker (Fig. 2.10), the Dacian Basin during the Middle-Late Sarmatian (*s. l.*) maximum extent was north of the Danube River. During Maeotian the southern limit of the Dacian Basin shifted toward the south, but still north of the modern Danube River. The Early Pontian Dacian Basin extended to the Danube River marker and the southern Late Pontian–Dacian boundary was beyond the present-day course of the Danube River. Consequently, according to the paleogeographic maps of Saulea *et al*. (1969) it appears the Dacian Basin continuously extended toward the south during its evolution.

The trend of southern extension is also revealed by the Dacian Basin paleogeographic maps prepared by Papaianopol *et al*. (1987), and Marinescu and Papaianopol (1989) (Fig. 2.11), but the extension looks different. According to these maps the southern margin of the Dacian Basin migrated small distances during the Early and Middle Pontian, and larger distances during the Late Pontian.

Both sets of paleogeographic maps indicate that only the central and central-eastern parts of the southern Dacian Basin limit are subject to migration. In contrast the southern shift is not apparent in the southwestern part of the Dacian Basin.

Sediment thickness distribution. The sediment thickness (isopach maps) from the initial stage of existence of the Dacian Basin indicates that the accumulation of detrital material was more active in the eastern part of the basin, less active in the western part, while the area in between was sediment-starved (Fig. 2.12).

Starting from the Maeotian at the southern periphery of the basin an area with low sedimentation rate and reduced sediment thickness appeared. During the Maeotian time this area was narrow and apparently insignificant, but its width became several times larger during the Early Pontian and Late Pontian-Dacian time. Taking into consideration the southern migration of the basin, as previously discussed, we believe that the thin-sediment area from the southern periphery of the basin (hatched in Fig. 2.12) represents the region of southward extension of the Dacian Basin. Following the southward widening trend of the basin, the area with thin sediment extended only in the central and central-eastern periphery of the basin.

Paleoenvironment in the Late Pontian Dacian Basin. According to Saulea *et al.* (1969), during the Late Pontian-Dacian in the northern, sub-Carpathian area of the Dacian Basin the cardiid shells are characteristically thick and large. In contrast, in the southern part of the basin, the mollusks associations consist of numerous small size specimens, with thin shells. These features indicate a shallow water environment with low relief coast and lower energy for the southern area of the Dacian Basin.

2.2.3. Nature of the southward extension process

Previous interpretations considered the southward enlargement of the Dacian Basin as common transgression (Saulea *et al*., 1969; Papaianopol *et al*., 1987; Marinescu and Papaianopol, 1989). Here we discuss possible alternative interpretations.

Processes of transgression. Transgressive events affected the Dacian Basin during the Late Neogene time. The sub-Carpathian coast of the Dacian Basin exhibits clear evidences for these processes. Late Neogene sedimentary deposits overlie directly Early Miocene or Paleogene deposits. The transgressive episodes are restricted to short periods of time, like Late Maeotian and Late Pontian (see Chapter 1.5).

Based on information offered by the paleogeographic maps (Saulea *et al*. 1969) (Fig. 2.10), the southward enlargement of the Dacian Basin may be viewed as a long-term process, which progressed through the whole time-span of existence of

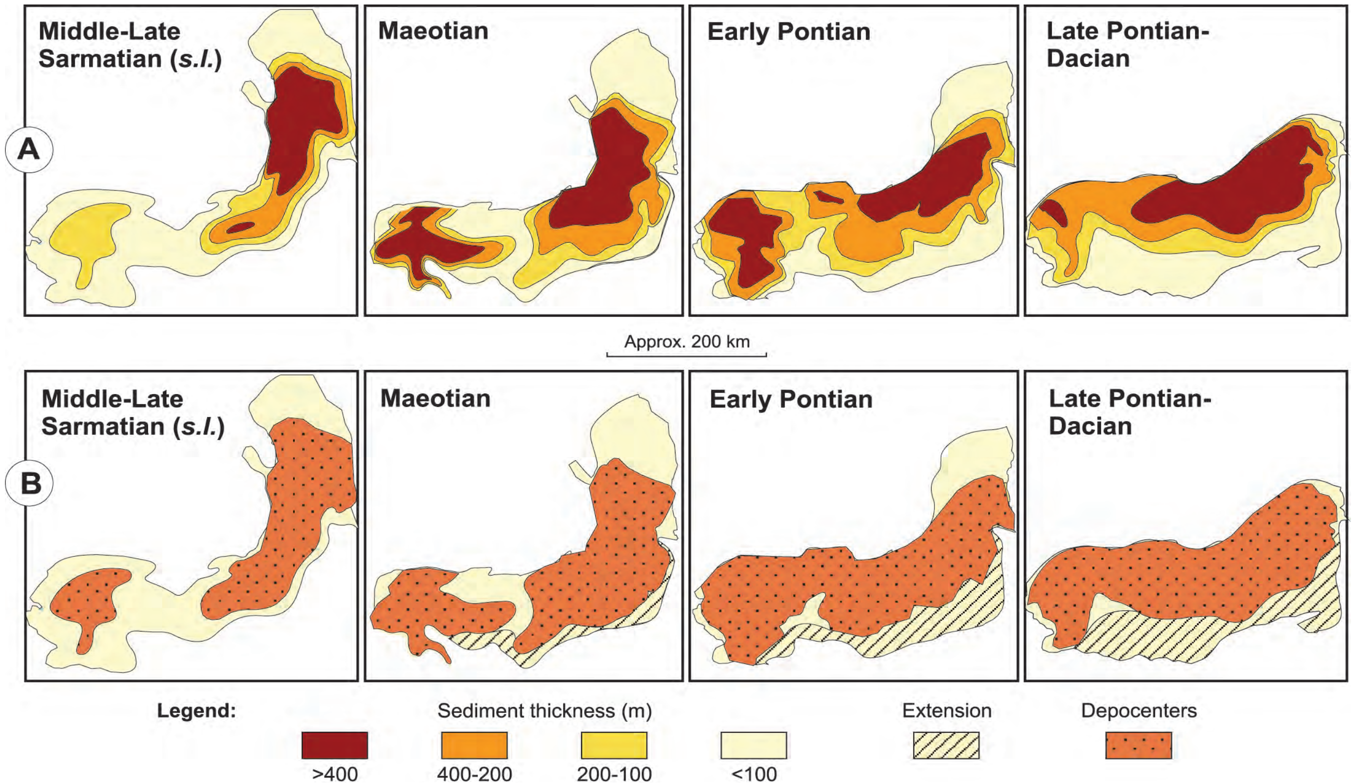


FIGURE 2.12. Sediment thickness distribution during the process of southward extension of the Dacian Basin area. **A**. Sediment thickness distribution. **B.** Depocenters *vs*. extension zone. Isopachs simplified from Saulea *et al*. (1969). Southeastern part of the areas with thinner than 100 m sediments is marked as extension zone. Areas with thicker than 200 m sediments are considered (for the present purpose) as depocenters

the brackish basin. This long timescale indicates that the southward extension of the Dacian Basin was not of an usual transgressive nature.

The paleogeographic maps of Papaianopol *et al*. (1987) and Marinescu and Papaianopol (1989) suggest that the southward enlargement of the pre-Bosphorian Dacian Basin was of low magnitude. In contrast, the Late Pontian (Bosphorian) extension to the south of the Dacian Basin limit was an important event. According to this data the transgressive process hypothesis becomes more applicable to explain the southward widening of the Dacian Basin. However, the regressive characteristic of the terminal Bosphorian-Early Dacian sediment sequence from the central and western area of the basin is opposed to the transgression interpretation. This Bosphorian-Dacian sequence indicates the passage from a clayey Bosphorian environment to a sandy, deltaic sedimentation.

Depocenter migration. Shifting of the sediment accumulation area (depocenter) is a possibility which requires consideration when looking for an explanation of the southward migration of the Dacian Basin limit.

The distribution of the thicker than 200 m sediments, which may be considered to represent the basin depocenter, was emphasized on the Fig. 2.12 B. Starting with the Maeotian time the northern limit of the sediment depocenter was adjacent to the sub-Carpathian margin of the Dacian Basin. As the Fig. 2.12 suggests, the southern limit of the depocenter was almost the same for the entire Maeotian to Early Dacian period. This strongly suggests that the main area of sediment accumulation did not suffer a systematic shifting southward. Consequently, the southward enlargement of the Dacian Basin cannot be attributed to a depocenter migration process.

Paleo-morphology control. Fine-grained lithology, smaller and thinner mollusc shells and reduced sediment thickness are important features of the southern marginal deposits of the Dacian Basin. These characteristics indicate that this marginal zone (central and southeastern area; not the western part) represented a low energy, shallow-water area in front of a low relief coastal dry-land. Due to its location at the foot of the Carpathians, the northern margin of the basin was exactly the opposite type of coastal area, with different relief, shoreline morphology and sedimentary dynamics.

On account of the pronounced morphologic asymmetry – north *versus* south – of the Dacian Basin coastal area, the southern large scale and long time extension of the basin could be explained as a process developed under relief morphology control. The existence of a dominant long and gentle slope on the southern part of the basin (Fig. 2.13) would determine a continuous shift of the basin limit. During infilling of the basin by sediments, the upper surface of the accretionally accumulated detrital material would reach the bottom up-slope at locations situated more and more to the south. In the paleo-morphology control concept this process is not a transgression, because the shift of the sediment accumulation area is not due to a landward influx of the sea water.

In the south-western part of the Dacian Basin, the basin limit did not suffer any significant shift to the south. This was due to the distinct morphology of this western Dacian Basin area, which represents a depressional accumulation zone, the deepest part of the basin (Leveer, 2007; see Chapter 4 for discussion).

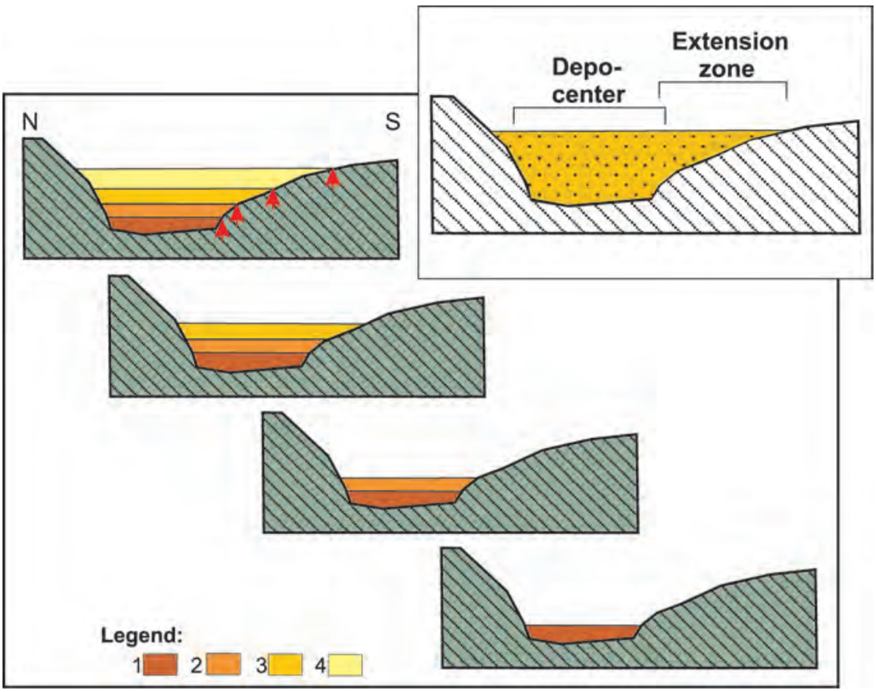


FIGURE 2.13. Graphic presentation of the hypothesis of morphologic control of the Dacian Basin southward extension. As the upper surface of the sediment accumulation was reaching a higher elevation (by sediment accretion), the southern limit of the basin moved upslope and the basin limit shifted southward. The red arrows point out the passive southern expansion of the Dacian Basin sedimentation area. Not to scale. **Legend**: **1**. Sarmatian (*s. l.*). **2**. Maeotian. **3**. Pontian. **4**. Dacian (time).

2.2.4. Northern extent of the Dacian Basin

Facies and paleo-geomorphology maps of Saulea *et al.* (1969) for the northern area of the Dacian Basin (Fig. 2.14), suggest a southward shifting (between 50 and 100 km) of the basin limit. The database for the interpretation of the northernmost boundary of the basin is rather limited, especially for the Pontian maps (Fig. 2.14 B, C and D).

The process in discussion is not related to the areal changes in the southern part of the basin. The areal decrease at the northern end of the Dacian Basin could be attributed to the uplift in the northern part and/or to the subsidence in the south.

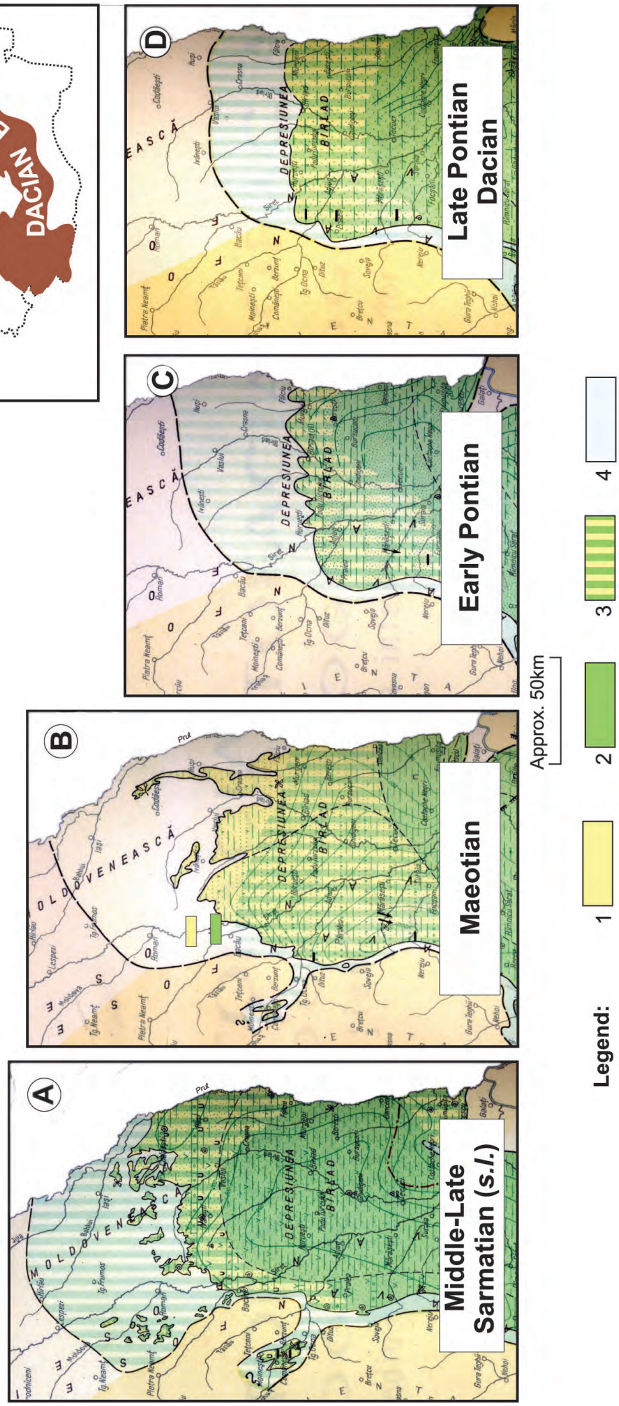


FIGURE 2.14. Paleogeography and facies at the northern end of the Dacian Basin. From Saulea *et al.*, (1969). **Legend**: **1**. Fresh-water facies. **2**. Brackish-water facies. **3**. Brackish facies with a tendency to become fresh-water. **4**. Eroded deposits at the sub-Carpathian margin of the Dacian Basin. Index map in the right-up corner showing the location of the study zone in the Dacian Basin.

Some facies entities are also involved in the changes at the northern ending area of the Dacian Basin. From Middle-Late Sarmatian (*s.l.*) to Maeotian time the fresh-water and fresh-water influenced fauna and facies appear to have suffered a distinct southward migration (Fig. 2.14 A and B). The same shifting process was active during the Early Pontian time (Fig. 2.14 C), but over a reduced area.

2.3. WAS THE DACIAN BASIN A LAKE OR A SEA ?

In addition to "river", the terms "lake" and "sea" represent some of the most used, trivial but vital, physico-geographical notions of human activity.

2.3.1. Modern lakes and seas. How are they dissimilar ?

For the characterization of the terms "lake" and "sea" the size, delimitation, and salinity of the bodies of water are essential.

Main criteria. In the scientific literature but also in the perception of people, the deepest rooted way of defining lakes or seas is based on the size of the water body. Everybody agrees that the lake is larger than a small pond, but smaller than a sea, which in turn has a smaller surface than the ocean.

A frequently used lake – sea discrimination standard is based on the areal relationships between water and land. It is largely accepted that lakes are completely surrounded by dry land (landlocked) and the seas are not entirely surrounded by land.

Water salinity represents a very significant attribute in differentiating the lake from the sea. Continental running waters and lakes have very reduced salinity (fresh-water; less than 5 ‰). By contrast, marine water is salty, with an average salinity between 31 ‰ and 36 ‰.

Exceptions to the rule. The validity of the three lake *vs*. sea discrimination criteria discussed above is weakened by multiple exceptions. Along the human history, the lake or sea denomination was applied according to local conceptions, opinions or understanding and sometimes directly reflecting local myths and folklore.

There are no numerical values to limit the size of lakes, seas or oceans. That is why some very large water bodies are called lakes (for example the Caspian Lake), or some large lakes are named sea (Dead Sea; the Aral Lake is also known as Aral Sea).

The land-enclosing feature should have been rather easy to observe in defining the lacustrine water bodies. However, some coastal water bodies are called lakes although they do not have an inland setting and have marine outlets (like Lake Maracaibo, Chilka Lake and others). In the dominantly accepted meaning, the sea should not be landlocked but should be always in communication with the global ocean. Nevertheless, there are marine bodies (inland seas) which evolved to become landlocked (the Caspian Sea). Some seas are not completely landlocked, having restricted communications with other marine bodies (the Black Sea, the Mediterranean Sea, the Baltic Sea and others).

The salinity rule also has exceptions, as some aquifers called lakes have relatively higher water salinity (the Caspian Sea, the Aral Sea, the Lake Balkhash), sometimes higher than the normal marine salinity (the Great Salt Lake, the Dead Sea).

"Marginal sea" is a term only vaguely connected to the main lake-sea classification principles. When there are features allowing the separation of a marine body within an ocean or a larger sea, that marine body is known as a "marginal sea". All modern oceans include internal seas (like the Barents Sea in the Arctic Ocean, the Celtic Sea in the Atlantic Ocean, or the Andaman Sea in the Indian Ocean). Although it is only a sea, the Mediterranean is divided into a number of marginal seas (the Adriatic Sea, the Aegean Sea, the Alboran Sea, the Ionian Sea, the Ligurian Sea, the Tyrrhenian Sea and others).

2.3.2. A paleogeographic approach to the lake and sea classification

Following the geographic patterns, paleogeography encountered major difficulties in discriminating between the lacustrine and the marine nature of an ancient basin. Paratethys paleogeography offers an adequate image of this situation, and the Dacian Basin is a good example.

Based on the geographic and oceanographic classification of the present-day bodies of water, a lake/sea classification which can be used in geological studies was prepared and is here presented (Fig. 2.15). The main new aspect of this classification is the unambiguous definition of the types of water bodies. This was possible by recognizing and introducing in the classification the types representing exceptions to the rules that could be applied in geological studies.

An important way of thinking in drawing up the classification (Fig.2.15) is the geological perception. The modern lake and sea types are characterized in accordance to a very limited evolution time of the respective water bodies. Paleogeography might change in time. This makes possible to realize in which way a basin has been formed, and how it evolved.

In the classification we propose for geological application, the three main physical-geographic criteria create the framework of the lake/sea/ocean portrayal: (1) the size of the water basin, (2) the water salinity and (3) the land-water relationship (the location and delimitation of the water basin).

A numeric limit value between the size of lakes and seas is compulsory in order to make this criteria work. The world's largest lake is the Lake Superior, with a surface of approximately 82,000 sq. km. Consequently, we propose the 100,000 sq. km limit between lake and sea surface, in round numbers.

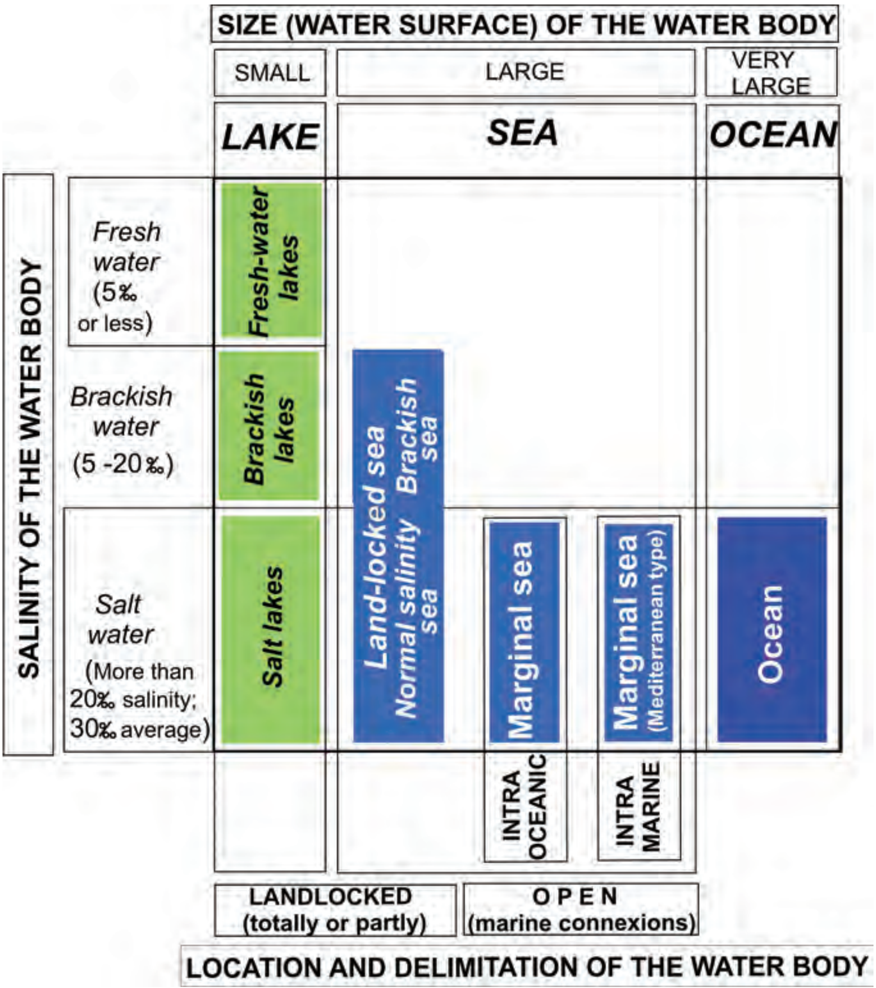


FIGURE 2.15. Classification of standing water bodies in the paleogeographic perspective

The salinity criterion used in the classification is the same scale dividing the paleo-basins into fresh water, brackish water, normal marine water or hyper saline (Fig. 2.15). The lacustrine water bodies can be affiliated to any of the three types. The sea bodies usually show normal water salinity, but brackish marine bodies also exist (the Baltic Sea - less than 15‰ salinity; the Black Sea - 17‰ salinity in the surface water).

Location and delimitation is the third classification criterion. Two main water bodies categories are separated in this classification (Fig. 2.15): landlocked (surrounded by land) and open (connected to the global ocean). The landlocked category is shared by both lakes and seas. All the lakes are land-enclosed water bodies. The sea could be both, an inland or an open basin.

The inland seas are usually semi-enclosed, having some restricted waterways to communicate with other marine basins. We do not exclude the possibility that some marine basins become completely landlocked, as marine connections could be cut and re-established during the evolution of a marine basin. Sometimes a sea turns out to be landlocked when reaching a final stage of its evolution (the case of the modern Caspian Sea). We believe that such a landlocked body becomes an authentic lake when the lacustrine features dominate: the salinity drops toward or within the fresh-water standard, but mostly when its water surface decreases drastically through sedimentation and/or evaporation.

The seas are usually opened toward other marine basins. Open seas water shows a normal marine salinity. Inland seas could fall into the category of brackish water basins.

Beside the common open marine basins, sometimes intra-oceanic and intra-marine bodies can be separated. Marginal seas (such as the Caribbean Sea, the Arabian Sea, China Sea, and Japan Sea) are sections of an ocean. The classification we are presenting (Fig. 2.15) also include the marginal seas of Mediterranean type, corresponding to parts of a larger sea (such as the Ionian Sea, the Aegean Sea, the Tyrrhenian Sea, the Adriatic Sea and the Ligurian Sea from the Mediterranean Sea). Discontinuous presence of emerged land or submerged at small depths (islands, archipelagoes, or peninsulas or corresponding submerged relief) are the elements that help delimit the marginal seas *versus* the enclosing ocean or large sea.

An important knowledge for discriminating between lake and sea is provided by the communicating water bodies. A lacustrine paleo-basin is not supposed to exchange water with a marine basin. The analyzed paleo-basin is itself a marine body if it is directly and for a long-time connected to a paleo-water basin with definite marine characters.

2.3.3. Applying the lake - sea classification criteria to the Dacian Basin

The physico-geographical criteria adapted for the study of ancient basins (Fig. 2.15) are adequate for the analysis of the lacustrine *vs*. marine character of the Dacian Basin.

Size of the Dacian Basin body of water. Using the paleogeographical maps edited by Saulea *et al*. (1969), we measured the area of the Dacian Basin during the Middle and Late Sarmatian (*s. l.*), the Maeotian and the Early Pontian time. The data obtained shows the Dacian Basin aquifer area had a surface ranging between 98,000 and 110,000 sq. km (based on the extent of its deposits). These numbers represent the minimal value of the basin surface, because most of the marginal deposits have been eroded during the Carpathian uplift (Saulea *et al*., 1969; Leveer *et al*., 2006).

Dacian Basin location and delimitation. As previously discussed in this book (Chapters 2.1.5 and 2.1.6), according to the existing paleogeographic data (Saulea *et al.*, 1969), the Dacian Basin displayed characters of an open water basin during the Middle and Late Sarmatian (*s. l.*) time (Fig. 2.6). While functioning as a Middle and Late Sarmatian (*s. l.*) open basin, the Dacian Basin was in wide direct contact with the Euxinian Basin, exchanging water both northward and southward of the Dobrogean dry land.

Surrounded on three sides by the Carpathians and Moesia, and with the Dobrogean island/peninsula to the east, the Dacian Basin was a semi-enclosed basin (Fig. 2.8) during the Maeotian to Early Dacian. The basin was not completely landlocked because it maintained a permanent connection with the Euxinian Basin and also had episodic connections with the Pannonian Basin (Figs. 2.7 and 2.8).

Salinity of the Dacian Basin water body. As a consequence of isolation and internal division into distinct sub-basins, brackish conditions established throughout the Paratethys realm, starting from the Badenian (Rögl, 1999). Following the evolution of the Paratethys domain, the Dacian Basin was brackish since it has been formed. Based on the fauna in the western part of the Dacian Basin (the Valea Morii profile), Marinescu (1978) concludes that the Sarmatian water had a salinity of 16 – 18 ‰. Pană (1966) and Saulea (in Saulea *et al.*, 1969) reached similar results in the northern part of the Dacian Basin. Papaianopol (in Papaianopol *et al.*, 1995) indicates that the Sarmatian fauna from the central part of the basin (Buleta, Râmnicu Vâlcea area) suggest water salinity of approximately 14 ‰.

Papaianopol *et al.* (1995) point out the oscillating character of the water salinity during the Maeotian time. A low salinity level (5 – 10 ‰, Marinescu, 1978) is recorded in the lowermost interval, rich in *Congeria* fossils. The upper part of the Early Maeotian (Oltenian), with *Dosinia* fauna, represents a high salinity episode (approximately 18 ‰, Marinescu, 1978). Brackish, but mostly fresh-water fauna occur in the Late Maeotian (Moldavian) deposits.

During the Pontian, the Dacian Basin water salinity was 7 – 8‰ (the level of *Congeria rhomboidea* of the Bengeşti fauna) (Papaianopol *et al.*, 1995). The salinity value dropped to 5 – 6 ‰ and occasionally reached nearly 3 ‰ during the deltaic Early Dacian.

The general picture portrayed by the data presented above is that the Dacian Basin water salinity evolved from a high-brackish value (18 ‰) at the beginning of the basin history to fresh-water at the terminal stage of the Dacian Basin existence (since Middle Dacian time). The salinity values decreased and oscillated during the Maeotian and continued to decrease during the Pontian.

The paleo-salinity data presented above come from the area at the northern border of the Dacian Basin, where the salt content of the littoral waters could be significantly lower than the water salinity in the central part of the basin. A similar salinity variation was observed in the modern Black Sea, where the western part is less saline due to influx of fresh-water from the Danube, the Dniestr and the Dniper Rivers.

Dacian Basin – Euxinian Basin connexion. During its existence as a brackish basin, Dacian Basin was connected with the adjacent Paratethys basins (Fig.1.3). The connection with the Euxinian Basin was permanent.

The connectivity between the Dacian and Euxinian basins is revealed by similar faunal assemblages, indicating water exchanges between the two basins. Communication between the Dacian and Euxinic basins was made by a strait (the Galați waterway; Saulea *et al*., 1969) that was indicated on paleogeographic maps (Hamor, 1988, Rögl, 1998a, Popov *et al*., 2004, Dercourt *et al*., 2005).

In order to define the salinity of the Dacian Basin, it is essential to know the salinity of the Euxinian Basin, the larger basin linked to the Dacian Basin.

The Euxinian Basin surface is seven to eight times larger than the Dacian Basin surface. This makes the Euxinian Basin a marine unit, according to the lake/sea size classification presented (Fig. 2.15). The Euxinian Basin salinity was brackish starting with Badenian time, showing a gradual decrease toward the end of the Pliocene (Ilyina *et al*., 1976). The inland character of this basin is indicated on the Paratethys paleogeographic maps (Popov *et al*., 2004), but in time this changed to become a semi-enclosed basin during the Late Neogene. Taking into consideration all these features, it appears that the Euxinian Basin, that was permanently connected with the Dacian Basin, was a large, inland brackish sea.

2.3.4. The Dacian Basin: lake or sea?

The size of the Dacian Basin surface corresponds to a very small sea, but is very close to the largest lake surface. After being an open basin during its initial development stage, the Dacian Basin became semi-enclosed, with restricted water connections. The Dacian Basin salinity was brackish, with important short time salinity variations (at least, in the littoral zone). During its evolution, the Dacian Basin brackish salinity decreased and became fresh water after the closure of the basin (Middle Dacian-Romanian).

A significant feature for its classification as lake or sea is the fact that throughout its existence the Dacian Basin was in permanent communication with the large brackish-marine Euxinian Basin.

Most of the characters revealed by the lake/sea classification criteria suggest that Dacian Bassin was a small brackish, inland sea. The permanent connection with a large sea strongly argues against the lacustrine nature of the Dacian Basin.

The Dacian Basin size is close to that of the smallest marginal seas which are part of the Mediterranean Sea. The Dacian Basin in the open sea stage (Middle – Late Sarmatian *s.l.*) is comparable to the Thyrrenian and Ionian Seas, which have a large marine frontier towards the central Mediterranean Sea. The semi-enclosed Dacian Basin (Maeotian, Pontian, and Early Dacian) had the shape of the Adriatic Sea, which communicates through a narrow marine frontier with the Ionian Sea.

The Dacian Basin is a component unit of the Oriental Paratethys. As suggested by its location – peripheral and partly detached – the Dacian Basin has the characters of a marginal sea (Mediterranean type) within the major Euxinian Basin marine body. The island (later peninsula) represented by the Dobrogean High, marks the basin limit of the Dacian Basin as a marginal sea.

2.4. CONCLUSIONS

Paleogeographic evolution. The Dacian Basin formed as a geographically distinct basin during the upper half of the Sarmatian (*s. l.*) (Saulea *et al*., 1969), as a remnant of the Carpathian foredeep.

During its initial evolution (Late Sarmatian *s. l.*), the Dacian Basin displayed the characteristics of an open marginal sea, and the connection with the eastward Euxinian Basin was wide.

During the second paleogeographic phase (Maeotian-Pontian-Early Dacian), the Dacian Basin evolved as a semi-enclosed sea, and the connection with the Euxinian Basin was through a narrow strait (Galați seaway).

The final closed basin paleogeographic phase (Late Dacian-Romanian), with dominant fluvial sedimentation, established after the sediment infill of the brackish Dacian Basin.

Dacian Basin extent. Dacian Basin varied in extent through time. The most abrupt change was during post-Sarmatian (*s. l.*) with significant southward enlargement of the basin area, which affected the central and central-eastern parts of the southern basin.

The southward area enlargement appears as a continuous Maeotian-Early Dacian migration according to Saulea *et al*. (1969) paleogeographic maps. The paleogeographic maps of Papaianopol *et al*. (1987), and Marinescu and Papaianopol (1989) suggest that only during the Late Pontian the southern shift was significant.

Paleo-morphology factors might have controlled the southward Dacian Basin enlargement.

Dacian Basin: lake or sea. The relevant characters pointed out by the lake-sea classification criteria (Fig. 2.15) suggest that the Dacian Basin was a small brackish, inland water body. Being part of the larger marine basin of the Oriental Paratethys and because it was permanently connected to the Euxinian Basin, Dacian Basin is to be considered itself a sea.

The permanent connection with a large sea strongly argues against the lacustrine nature of the Dacian Basin. From its – peripheral and partly detached – placement, the Dacian Basin appears as a marginal sea of Mediterranean type, located at the periphery of the Euxinian large sea.

Chapter 3

SEDIMENT THICKNESS DISTRIBUTION IN THE DACIAN BASIN

Quaternary deposits cover the central and outer part of the Dacian Basin (Fig 1.2), as already mentioned. For the study of sedimentology, the image of the sediment thickness distribution offers a precious opportunity to get information regarding the entire area of the Dacian Basin. This is the reason why so much importance is given to the presentation and interpretation of the Dacian Basin isopach maps.

3.1. DATA SOURCES

Researchers studying the Dacian Basin benefit from several sources of data regarding the distribution of sediment thickness (Fig. 3.1). Two of the sources (Fig. 3.1 A and B) are atlases of lithologic-paleogeographic maps with different types of information including isopach maps. These maps cover the entire Dacian Basin. The other sources of sediment thickness data (Fig. 3.1 C, D and E) are isopach maps drawn for restricted areas within the Dacian Basin.

3.1.1. Lithofacies Atlas of Romania

The Neogene lithofacies atlas of Romania (Saulea *et al.*, 1969) includes isopach maps at several stratigraphic levels (Figs. 3.2; 3.3; 3.4; 3.5; 3.6), as presented in chapter 2.1.1. The existence of Neogene sediment thickness for the whole basin extent, proved to be very important for the sedimentogenetic evaluation of the Dacian Basin deposits. The isopachs were drawn at the 100m interval. The isopach maps are based on outcrop data, but mostly, on information from 80 – 100 boreholes. The distribution of the sediment thickness accumulated in the Dacian Basin is presented by Saulea *et al.* (1969) for the following time intervals: Middle and Late Sarmatian (*s.l.*), Maeotian, Early Pontian, Late Pontian-Dacian and Romanian (formerly Levantine).

FIGURE 3.1. Dacian Basin isopach maps; authors, areal and stratigraphic targets

3.1.2. The Lithologic-Paleogeographic Atlas of Romania

A similar scientific project, the Atlas of the Lithologic-Paleogeographic Maps of the Sediments from Romania (Hristescu *et al*., 1962-1963), was carried out as an internal project by the Geology Laboratory Enterprise of the Petroleum Ministry in Bucharest. Based on the surface (outcrops) and subsurface data (over 100 boreholes), this atlas includes Dacian Basin maps for the Maeotian, Pontian, Dacian and the Romanian deposits (Fig 3.7). On each lithologic-paleogeographic sheet, an isopach map was included. A short time period – only two years – was allocated for the completion of the project. The maps were not published. A limited number of Atlas copies were distributed to geological institutions like the Geological Institute of Romania, the University of Bucharest and others.

The possibility to compare the two sources of information covering the entire area of the Dacian Basin is unique and extremely useful for the sedimentological investigation. There are numerous detail differences between the isopach maps in the lithologic - paleogeographic atlases edited by Saulea *et al*. (1964; 1969) and Hristescu *et al*. (1962-1963). However, the Dacian Basin images of the sediment thickness distribution achieved by the two teams of authors show similar major patterns.

3.1.3. Recently published isopach maps

A detailed isopach map was prepared by Damian (1996), regarding Pontian deposits from the area at the south and east of Buzău town (Fig. 3.8). Borehole data are presented and located, making the isopach map clear and logical. Seismic sections have also been used for the construction of the isopach map.

In recent years, the Focşani Depression, an area affected by high subsidence and located in the northern part of the Dacian Basin, was the object of advanced structural studies, promoted by the Tectonics Department, Faculty of Earth and Life Sciences at Vrije Universiteit, Amsterdam. Two isopach maps have been produced within these investigation projects (Tărăpoancă, 2004; Leveer, 2007). Based on thickness data resulted from seismic sections these maps cover a restricted surface focused on the Focşani Depression area.

3.2. DACIAN BASIN SEDIMENT THICKNESS DISTRIBUTION

Having a good stratigraphic background and an advanced and checked up paleogeographic presentation, the isopach maps drawn by Saulea *et al*. (1969) are our main source of sediment thickness data. The other isopach maps offer data to confirm (or not) the Saulea *et al*. sediment thickness information (since the maps have been conceived four decades ago) and provide complementary details when necessary.

3.2.1. Thickness of the Middle- Late Sarmatian (*s.l.*) sediments

According to the Saulea *et al*. (1969) isopach map (Fig. 3.2), for the Middle (upper part) and Late Sarmatian (*s.l.*) time interval, the sediments accumulated in the Dacian Basin are distributed within two areas of unequal extent.

The most important area of sediment accumulation is in front of the Eastern Carpathians, in the northern extremity of the Dacian Basin (Focşani-Buzău area) up to the bend zone of the Carpathians. The thickest (400m) sediments occur in the central part of the basin sedimentary area. This thickness of sediments decreases to zero toward the southern and eastern limit of the basin.

The second area of sedimentary accumulation is delineated in the western extremity of the Dacian Basin, Saulea *et al*. (1969) marking the thickness of the deposits in this area by isopachs of 100 m and 200 m. The two isopach lines appear in the middle of the sedimentary area, and the 200 m thickness line is in the central part. The sedimentation area extends southward along a narrow zone.

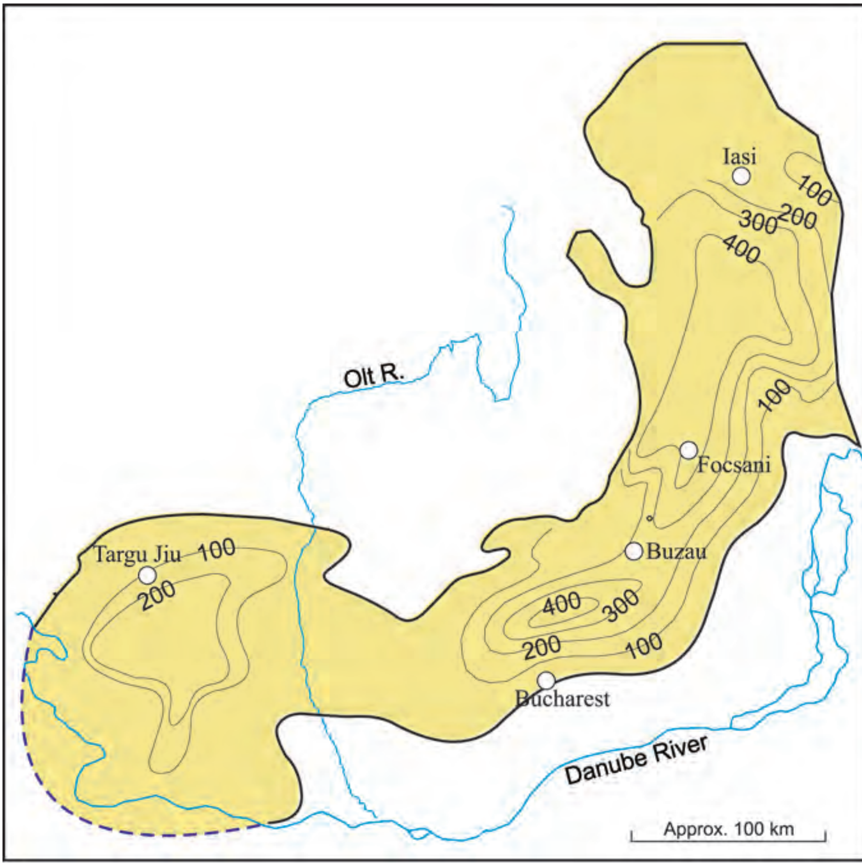


FIGURE 3.2. Dacian Basin sediment thickness distribution during the Middle and Late Sarmatian (*s.l.*) time. Isopach map from Saulea *et al*. (1969). Thickness values in meters.

3.2.2. Thickness of the Maeotian deposits

On the Maeotian lithofacies map (Saulea *et al.*, 1969) (Fig. 3.3), the isopach pattern reveals the existence of two separate areas of sediment accumulation. The presence of these two areas is similar to the situation from the Middle and Late Sarmatian, but the two Maeotian depocenters are larger and closer to each other.

The eastern isopach pattern shows a maximum thickness (1200 m) located in the northern part of the Carpathian bend. Unlike the Middle-Late Sarmatian (*s. l.*) conditions, the thickest zone of sediments occurs by the Carpathian side of the basin. From this, the sediment thickness decreases toward the north, east and south-east to less than 100 m.

In the western Maeotian depocenter, the isopach lines reveal the enlargement of the area of sedimentation as compared to the western Middle and Late Sarmatian (*s. l.*) depocenter. The isopachs describe three lobes, the eastern and the southern ones showing more stretched-out surfaces. This pattern suggests that sediment accumulation was also controlled by other factors, probably of tectonic nature. The maximum sediment thickness (600 m) of the western depocenter area appears in the center and in the northern extremity of the area. The deposits are thin toward the east, south-east and south-west.

3.2.3. Thickness of the Early Pontian deposits

The image created by the Early Pontian isopach map of Saulea *et al*. (1969) reveals two distinct depocenters. The pattern has similarities with the Sarmatian and Mae-

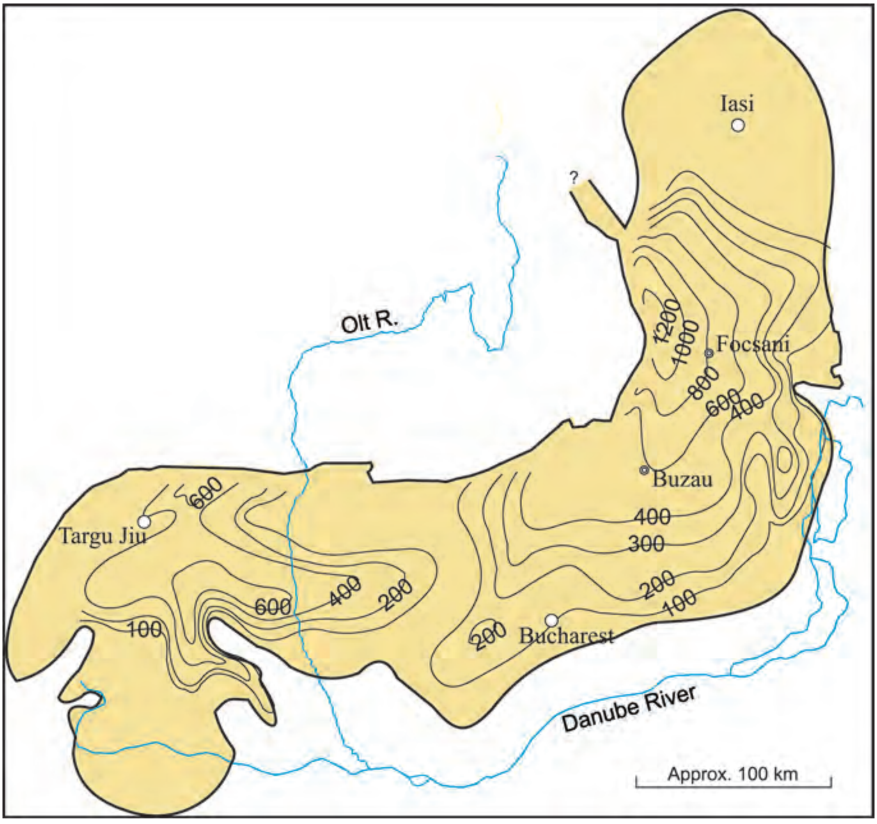


FIGURE 3.3. Dacian Basin isopach map of the Maeotian deposits. From Saulea *et al*. (1969). Sediment thickness in meters.

otian conditions. The two Early Pontian depositional areas are more extended and became closer to each other. Moreover, the 100 m isopach line is common to both sedimentary areas.

In the eastern area, the 100 m and 200 m isopach lines are lobed, delineating several secondary sediment thickness centers. In front of the Carpathian bend zone, in the Buzău - Focşani area, Saulea *et al*. (1969) did not trace isopach lines for sediments thicker than 500 m. However, the pattern in this area clearly suggests that the sediments are getting thicker toward the Carpathians. According to the Pontian isopach map of Hristescu *et al*. (1962-1963), the sediments reach 1200 m thickness in this region (Fig. 3.4).

The western sedimentation area is defined by concentric isopach lines. The maximal thickness line in this western area is of 800 m. The thickest sediments occur in the northwestern part, close to the Carpathians. Several lobes are shown by the 200-500 m isopach lines, but not as developed as shown on the Maeotian map in the corresponding area.

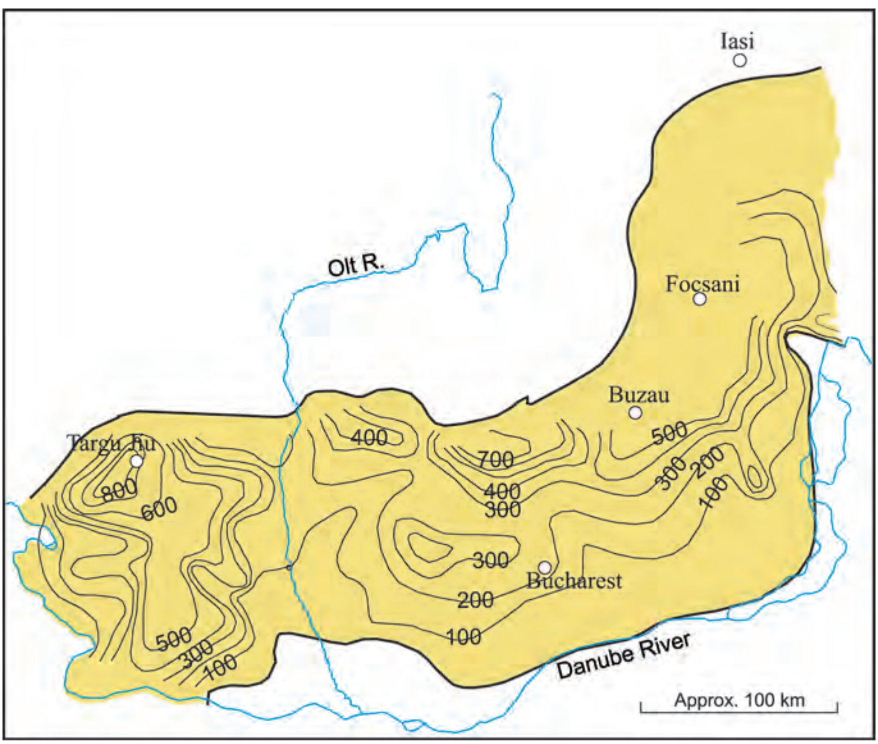


FIGURE 3.4. Dacian Basin sediment distribution during the Early Pontian time. Isopach map from Saulea *et al*. (1969), sediment thickness in meters.

3.2.4. Thickness of the Late Pontian-Dacian deposits

On the Late Pontian to Dacian isopach map (Saulea *et al*., 1969), two discrete sediment thickness areas, located in the eastern and western parts of the Dacian Basin, can also be noticed (Fig. 3.5). The degree of mixing of these depocenters is more advanced and two thickness isolines (100 and 200 m) are shared by the two areas.

The eastern area of Late Pontian-Dacian sediment distribution expanded significantly toward the west, occupying the center of the Dacian Basin. More than one nucleus of relatively higher sediment thickness can be identified. The thickest sediments occur in the Focşani area, adjacent to the Carpathians. As in the case of the Early Pontian lithofacies map, Saulea *et al*. (1969) did not trace isopach lines over 900 m sediment thickness in the Buzău - Focşani area (Fig. 3.5).

The sediment accumulation area in the western extremity of the Dacian Basin, very distinct in the time periods previously discussed, has a small extension and is marked by rather low sediment thickness. Its identity is defined by the strong southern lobes of the 100 m and 200 m isopach lines. The only isoline particular to

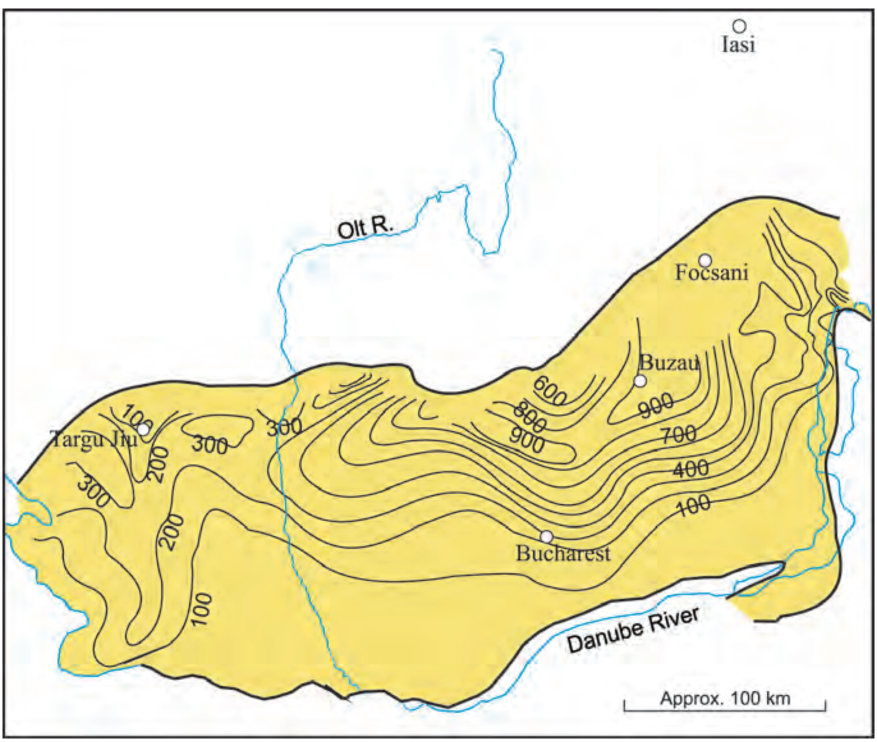


FIGURE 3.5. Dacian Basin sediment distribution during the Late Pontian - Dacian time. Isopach map from Saulea *et al*. (1969), sediment thickness in meters.

the extreme western area is the 300 m one (the maximum thickness in this zone), while the other isopach lines are common to both Late Pontian-Dacian sedimentary areas.

3.2.5. Thickness of the Romanian deposits

Saulea *et al*. (1969) present only the general trends of the Romanian sediment thickness distribution in the Dacian Basin (Fig. 3.6). All along the basin, the relatively thicker sediments make up a zone adjacent to the Carpathians. Within this zone, the thickest sediments occur in the eastern part of the basin, close to the Carpathian bend, in the Buzău - Focşani area.

According to Hristescu *et al*. (1962-1963), sediments up to 3000 m thick accumulated in this Buzău - Focşani area, which is about twice the amount of sediments collected in each of the preceding time intervals (Maeotian to Dacian). A smaller sub-Carpathian area with thick sediments (2000 m) is delineated in the central part of the basin.

Both Saulea *et al*. (1969) and Hristescu *et al*. (1962-1963) indicate that the sediments in the western part of the Dacian Basin are comparatively thinner, less than 400 – 500 m thick.

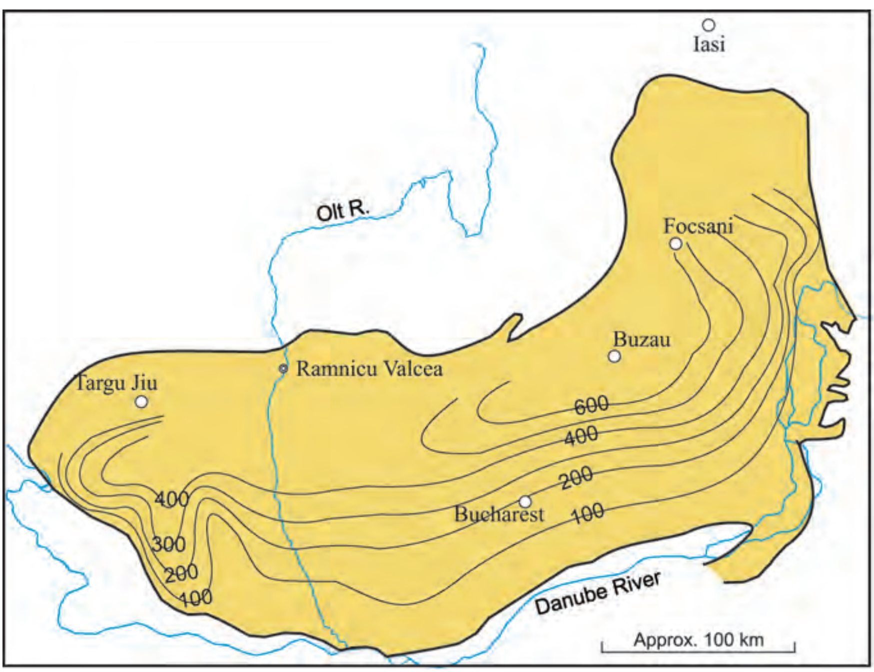


FIGURE 3.6. Dacian Basin sediment distribution during the Romanian time. Isopach map from Saulea *et al*. (1969), sediment thickness in meters.

The Romanian sediment thickness distribution shows an integrated pattern. Except for the high thickness nuclei, the isopach lines are continuous from the north to the west of the Dacian Basin area. This feature allows the isopach map to evidence the sediment thinning out trend toward the external (eastern and southern) limit of the basin.

3.3. SEDIMENT THICKNESS IN THE EASTERN DACIAN BASIN DEPOCENTER

Sediment thickness distribution maps indicate an area of high sedimentation in the eastern part of the Dacian Basin. In the western part of the basin, there is another area of high sedimentation, but the eastern area is the largest and the most constant depocenter of the Dacian Basin. It corresponds to the Focşani Depression, singled out by its high subsidence. This sediment accumulation area played an important part in the basin evolution. For unknown reasons (possibly of stratigraphic nature) some of the isopach maps edited by Saulea *et al*. (1969) do not present the complete picture of the thickness distribution within the eastern depocenter. Supplementary data are available and can help to complete the information on this subject.

The picture of the eastern Dacian Basin sediment accumulation area during the Maeotian time by Saulea *et al*. (1969) (Fig. 3.9A) is corroborated by Hristescu *et al*. (1962-1963) (Fig. 3.9B) and by Tărăpoancă (2004) (Fig. 3.9C). According to these data sources, the sediment thickness in the eastern area reaches about 1200-1300 m. The eastern depocenter is situated in the Focşani zone, with a southern extension to the Buzău locality.

As revealed by Hristescu *et al*. (1962-1963) (Fig. 3.10B) and Tărăpoancă (2004) (Fig. 3.9C), the amount of accumulated sediments and the areal location of the eastern Dacian Basin depocenter during the Pontian time are practically the same as in the Maeotian time.

The development of sedimentary deposits in the eastern Dacian Basin during the Dacian is not well documented. The maps supplied by Saulea *et al*. (1969) and by Hristescu *et al*. (1962-1963) are in disagreement, possibly because of the different stratigraphic background.

The isopach map prepared by Hristescu *et al*. (1962-1963) (Fig 3.7) suggests that the eastern sediment accumulation area became more active during the Romanian, with sediment thickness of up to 3000 m.

All the isopach maps indicate the high sediment thickness nucleus of the eastern Dacian Basin depocenter maintained about the same location (corresponding to the Focşani – Buzău zone) during the Maeotian – Romanian interval.

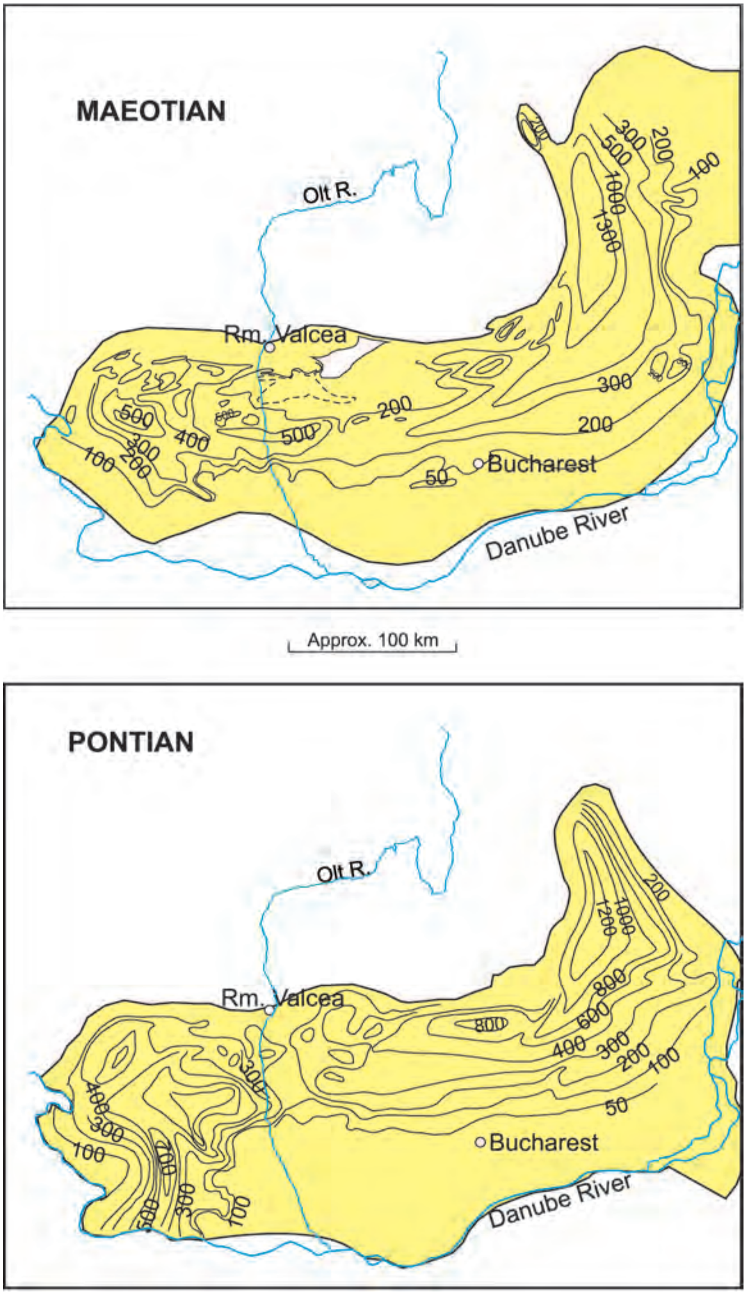


FIGURE 3.7. Isopach maps of the Dacian Basin during Maeotian and Pontian prepared by Hristescu *et al*. (1962-1963). Sediment thickness in meters.

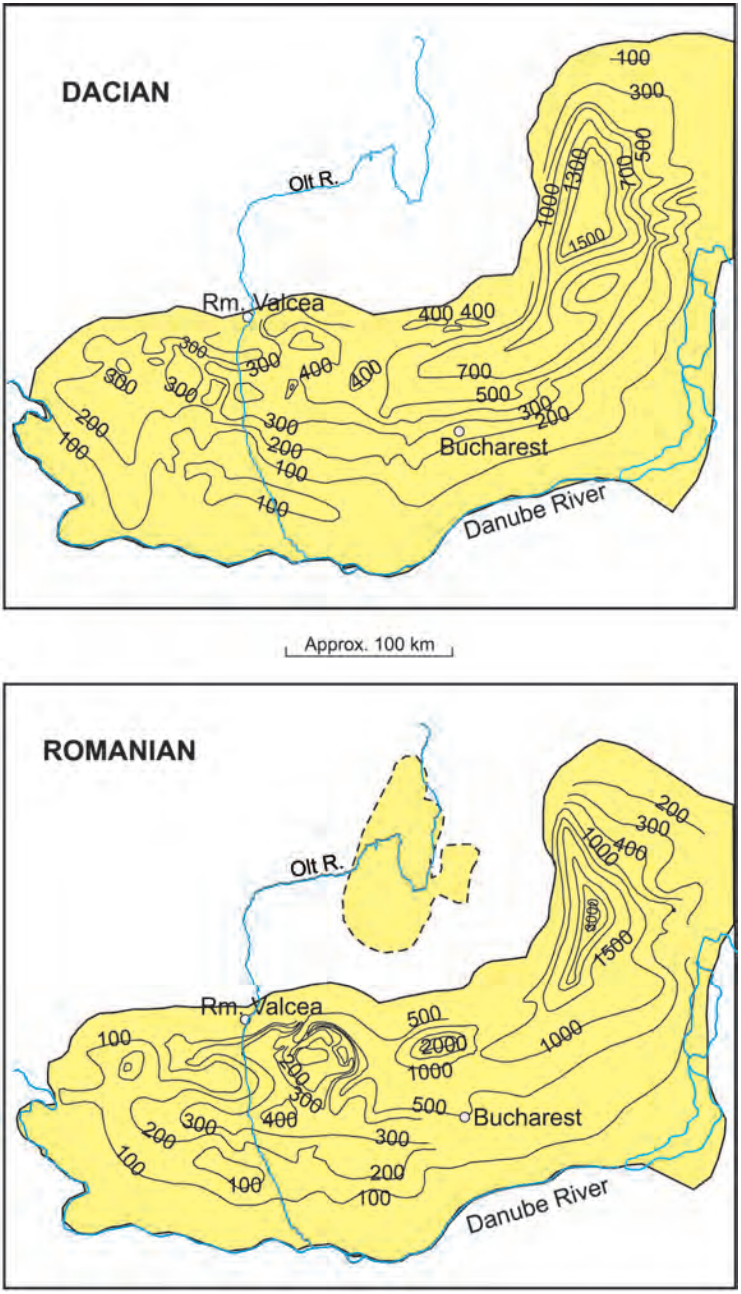


FIGURE 3.7. Isopach maps of the Dacian Basin during Dacian and Romanian prepared by Hristescu *et al*. (1962-1963). Sediment thickness in meters.

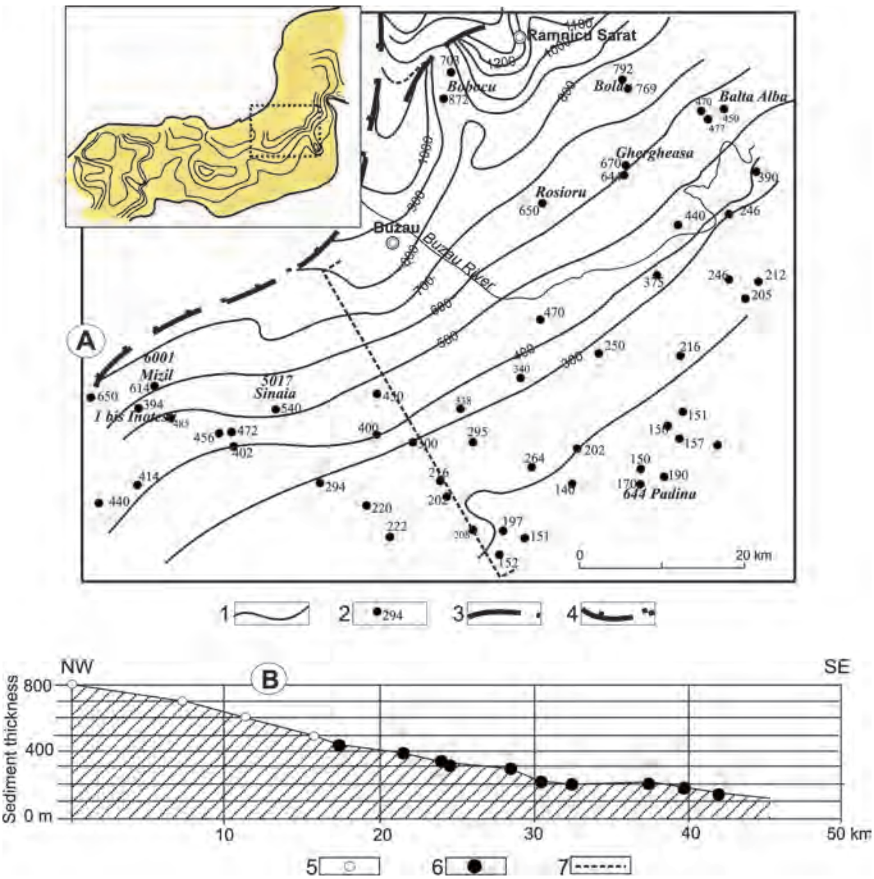


FIGURE 3.8. Isopach map of the Pontian deposits (**A**) in the marginal, southeastern part of the Dacian Basin. Redrawn from Damian (1996). **B**. Sediment thinning-out trend. Upper left corner: index map with location of the Damian map on the Early Pontian isopach map of Saulea *et al*. (1969). **Legend**: **1**. Isopach line (thickness in meters). **2**. Borehole location and local Pontian sediment thickness (in meters). **3**. Fault. **4**. Peri-Carpathian line (underground outline). **5**. Sediment thickness based on isopach line value. **6**. Borehole sediment thickness data. **7**. Section line

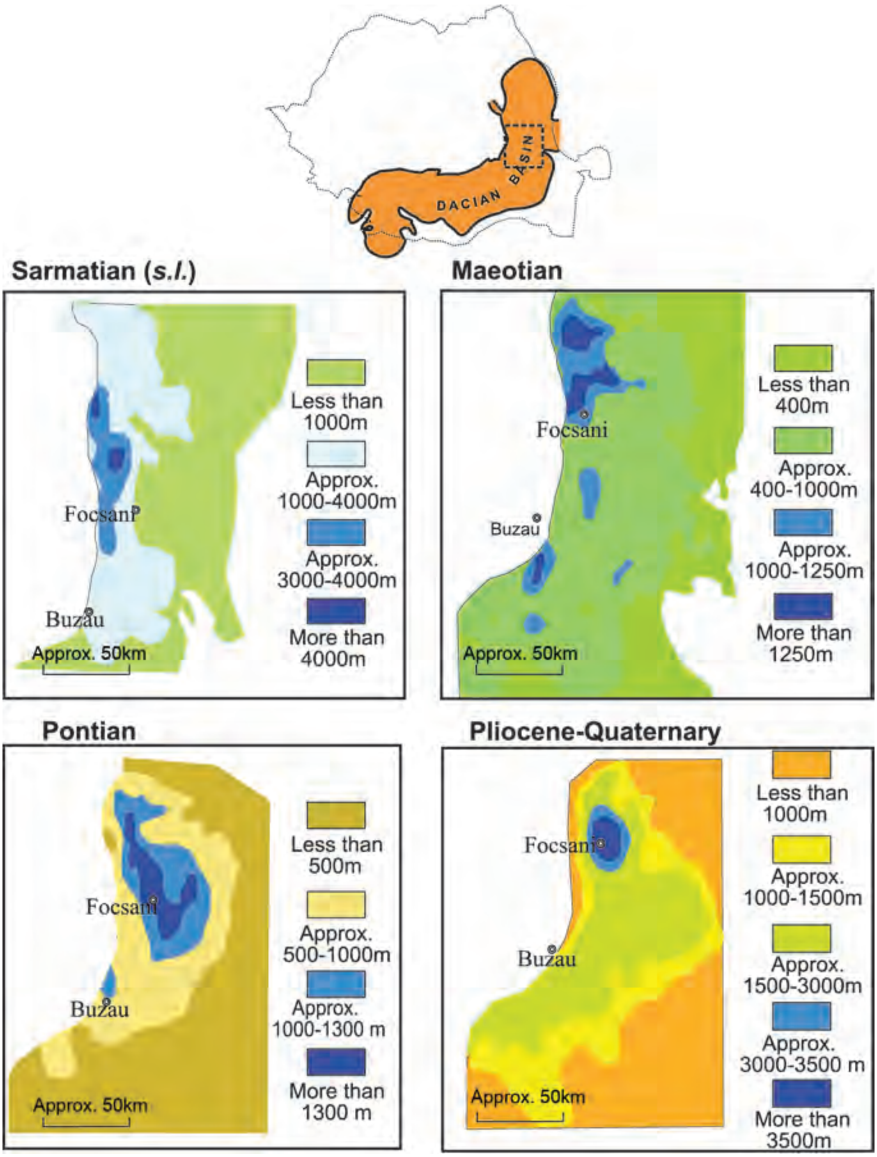


FIGURE 3.9. Sediment thickness maps of the Late Neogene deposits in the Focşani-Buzău area, based on seismic data. Redrawn after Tărăpoancă (2004)

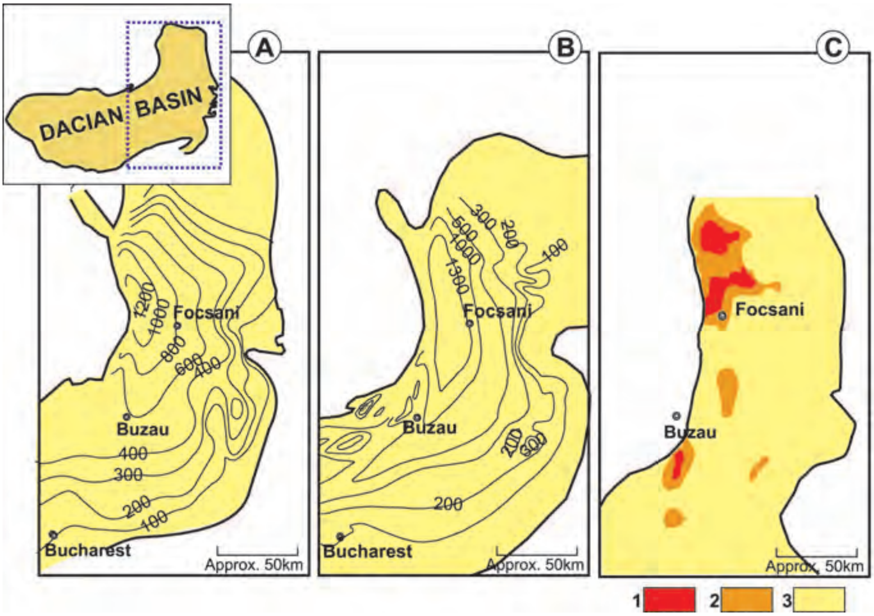


FIGURE 3.10. Location of the thickest Maeotian sediments in the eastern part of the Dacian Basin, according to different authors. **A**. Isopach map by Saulea *et al*. (1969). **B**. Isopach map by Hristescu *et al*. (1962-1963). **C**. Thickness map from Tărăpoancă (2003). **Legend** for sediment thickness: **1**. More than 1250 m. **2**. Approx. 1000-1250 m. **3**. Approx. 400-1000 m

3.4. SEDIMENT THINNING-OUT AT THE SOUTHERN EDGE OF THE DACIAN BASIN

All the examined isopach maps indicate that the Dacian Basin sediments thin toward the outer, southern and eastern boundaries of the basin. An isopach map drawn by Damian (1996) presents the detailed thinning-out structure of the basin.

The detailed isopach map (Fig. 3.8A) confirms the image conveyed by Saulea *et al.* (1969) and Hristescu *et al*. (1962-1963) isopach maps on the basin-scale thinning of sediments toward the margins of the Dacian Basin. The slope of the thickness/distance graph (Fig. 3.8B) of the Pontian sediments exhibits small irregularities. It shows a constant sediment accumulation trend. This feature brings more information about the continuity of the process which determined the southward advancement of the sediment accumulation front at the periphery of the Dacian Basin (see Chapter 2.3).

3.5. CONCLUSIONS

Examination of the sediment thickness distribution in the Dacian Basin reveals several features directly related to basin architecture and evolution:

- the Dacian Basin sediments are thicker in the sub-Carpathian area and thin out away from the Carpathians, toward the southern and eastern basin margin;
- two main nuclei of high sediment thickness, located in the eastern and the western parts of the Dacian Basin, were extant during the basin evolution;
- during the early stage of basin development, these high sediment thickness nuclei were initially distinct from each other, but over time enlarged and merged to form an integrated area of sedimentation;
- the intense sediment accumulation in the eastern depocenter was relatively constant during the Maeotian to Dacian period, the accumulation becoming more active during the Romanian;
- the western depocenter was more dynamic during Maeotian and Early Pontian time, but its importance as a sedimentary accumulation area declined in the second part (Dacian-Romanian) of the Dacian Basin evolution.

Chapter 4

DACIAN BASIN PHYSIOGRAPHY

Sedimentation in the brackish–water Dacian Basin came to an end in the Middle Dacian time (4.5 Ma). During the Late Pliocene and the Quaternary, the sedimentary sequence of the Dacian Basin did not undergo significant tectonic deformation events. Consequently, the major morphologic elements can be identified from the modern extent of the Dacian Basin deposits.

Depression and flexure of the continental crust which shaped the Carpathian foreland basin induced the major morphologic features characteristic of this type of sedimentary basin. These features have been also taken over by the Dacian Basin. Some new morphologic characteristics also occurred during the basin paleogeographic evolution and influenced its original shape. Synsedimentary tectonics, mainly subsidence, was in competition with sedimentary accumulation process influencing the basin morphology.

4.1. TECTONIC EFFECTS ON THE DACIAN BASIN PHYSIOGRAPHY

According to its structural setting, the Dacian Basin is a foredeep – or a foreland – unit. The Carpathian foredeep, suffered a long time shrinking process (Fig. 4.1). The Dacian Basin is the remnant of the Carpathian foreland, after the Sarmatian tectonic climax.

As a foreland unit, the Dacian Basin inherited the following morphologic attributes from the antecedent foreland basin: (1) elongated shape, (2) depressed bottom relief and (3) asymmetry of the relief of its coastal zones.

The elongated morphology of the Dacian Basin is a tectonically generated feature, specific to the foredeep basins. Excepting the very first moment of its appearance as a distinct Paratethys unit during the Middle Sarmatian (*s.l.*), the Dacian Basin experienced a continuous enlargement during its geological history. This process inflicted significant changes on the basin geometry.

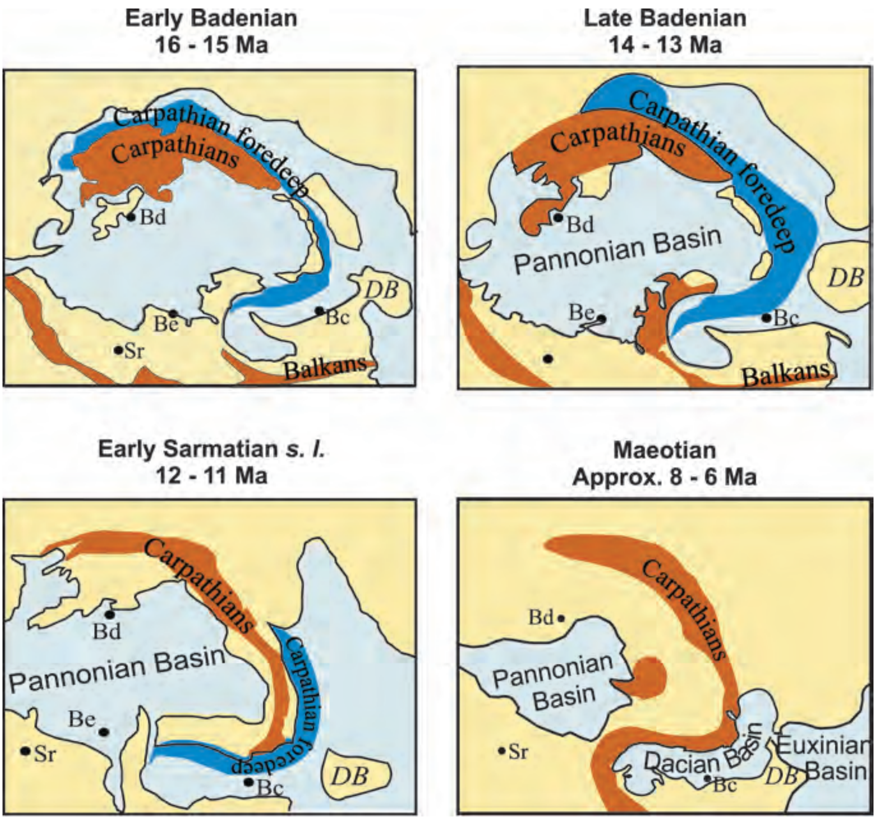


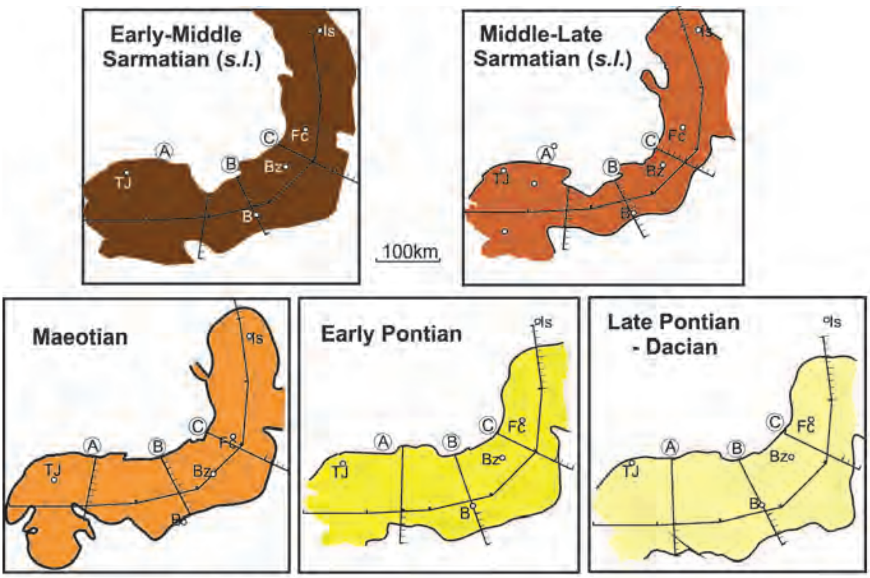
FIGURE 4.1. Evolution of the Carpathian foredeep during Badenian - Maeotian time. Paleogeographic sketches with data from Hamor *et al*. (1988), Popov *et al*. (2004) and Saulea *et al*. (1969). **Bc** - Bucharest. **Bd** - Budapest. **Be** - Belgrade. **Sr** - Sarajevo. **DB** - Dobrogean High

The Dacian Basin diminished in length from about 630 km, during the Middle-Late Sarmatian (*s.l.*), to around 570 km (Pontian and Dacian time) (Fig. 4.2), amounting to a 10% shortening.

The first change of the Dacian Basin width occured during the Middle Sarmatian (*s.l.*), probably representing a tectonically imposed adjustment. On this occasion, the basin narrowed by more than 30% in comparison with the preceding Early-Middle Sarmatian (*s.l.*) basin (Figs. 3.4 and 4.2).

The enlargement of the Dacian Basin was the result of a large-scale process operating over relatively long-time scales (see Chapter 2.2.2). The mean width in the central part of the basin increased from about 67 km, during the Middle-Late Sarmatian (*s.l.*), to 100 – 118 km, in the Pontian – Dacian interval (*i.e.*, 49 to 76% basin enlargement).

The simultaneous length and width changes experienced by the Dacian Basin during the brackish-marine development produced a change of its geometric areal configuration. The elongation of the Dacian Basin, expressed by a width/length ratio of 1/9.4 during the Middle Sarmatian (*s.l.*), was altered to a width/length ratio amounting to 1/4.8 - 1/5.7 during the Pontian-Dacian stage (Fig. 4.2).



	Basin length (km)	Basin width (km)					W/L
		A	B	C	Mean	Max.	
Early-Middle Sarmatian (*s.l.*)	*More than 700*	80	90	110	**93**	140	
Middle-Late Sarmatian (*s.l.*)	*630*	65	65	70	**67**	90	1/9.4
Maeotian	*620*	90	100	110	**100**	125	1/6.2
Early Pontian	*570*	120	125	110	**118**	140	1/4.8
Late Pontian - Dacian	*570*	150	130	120	**100**	165	1/5.7

FIGURE 4.2. Evolution of the Dacian Basin geometry, expressed by comparing the shape parameters. Paleogeographic sketches based on Saulea *et al.* (1969). **A**, **B**, **C** - transects for the basin width measurement

Presently, we have no data concerning the transversal shape of the Dacian Basin. The large-scale concave form of the Dacian Basin basal section should be another tectonically inflicted geometric feature of the basin, as a direct effect of the lithosphere depression and flexure. The trench pattern of the Dacian Basin is also suggested by the dominant longitudinal trend of the paleocurrents (see Chapter 10.2). Paleocurrent trends, being characteristics of foreland basins, are imposed by their elongated – trench like – shape.

As a result of its location adjacent to the Carpathians, costal relief of the Dacian Basin is asymmetric. On the internal, mountain facing side, the coastal zone of the Dacian Basin had a higher relief. The external, southern and eastern sides of the basin were a low relief coast.

4.2. DACIAN BASIN SHELF AND TROUGH

The isopach maps drawn for several successive time slices point out the development of a southern zone with very thin sediments (Fig. 2.12; marked as Sh in figure 4.3) during the Pontian and Dacian. In opposition, on the internal, sub-Carpathian side of the Dacian Basin, there are always thick deposits.

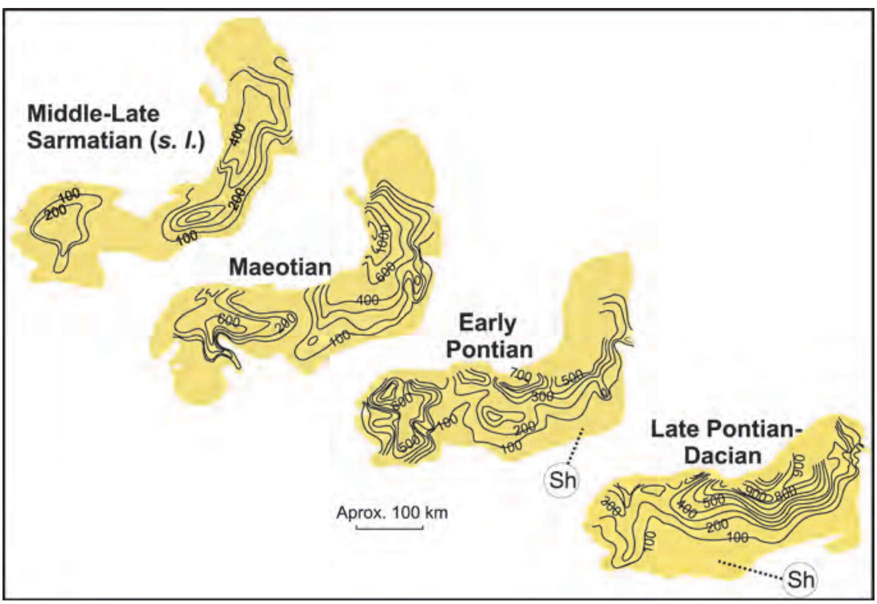


FIGURE 4.3. Sediment thickness distribution during the Dacian Basin evolution. The southern area (Sh) with very thin (and fine grained) sediments became evident during the Pontian and Dacian time. This area is interpreted as the shelf zone of the Dacian Basin. Isopach maps from Saulea *et al*. (1969). Sediment thickness in meters

The two above-mentioned sediment thickness zones have been interpreted as the shelf area and the deeper, trough area of the Dacian Basin (Fig. 4.4). The lithology and some of the faunal characteristics indicate that the southern zone, with its thin sediments, represents a quiet brackish marine environment, probably close to the coastline. Analyzing the nature of the southern Dacian Basin enlargement (Chapter 2.2.2), the paleo-morphology control theory appears the most balanced. The development of the southern thin sediment extension of the basin reflects the progressive accumulation of a thin sediment blanket, on a gentle sloping area from the external, low relief side of the basin. This is also the rational behind the interpretation of the southern zone with its thin sediments, as the shelf area of the Dacian Basin.

The Dacian Basin southern shelf area corresponds to Porebski and Steel's (2003) morphological definition of a shelf, as a shallow-marine platform located at the margin of a basin. The southern shelf represents a submerged area, which has been progressively covered with sediments. Sediments that accumulated on this shelf did not come from the coastal zone of the shelf hinterland, but especially from a relatively distant Carpathian source.

The internal, sub-Carpathian zone of the Dacian Basin is the area where the bulk of sediments accumulated. It represents the deeper part of the basin, the trough which directed the influx of the detrital material. In this book, the Dacian Basin trough area is not characterized as the site of the largest sediment accumulations, a feature controlled by subsidence. The trough zone is defined by the distribution of the main body of sediments and by the contrast with the thin sediment blanket in the southern part of the basin.

The rather abrupt passage from the southern thin sediment area and the northern (and central) thick sediment accumulation zone (Fig. 4.4) suggests that there was a shelf edge, and a steeper slope in between the Dacian Basin shelf and trough areas.

There is no indication concerning a possible shelf area in the sub-Carpathian margin of the Dacian Basin. Taking into account the pre-sedimentary morphologic difference which existed between the two coastal margins of the basin, it is possible that the shelf zone did not exist in the internal, sub-mountainous marginal area. If a narrow shelf existed on the internal part of the basin, it could have been eroded during the Carpathian uplift. Such a zone of erosion was sketched by Saulea *et al.* (1969) (Fig. 2.14) and documented by Leveer *et al.* (2006) in the northern part of the Dacian Basin.

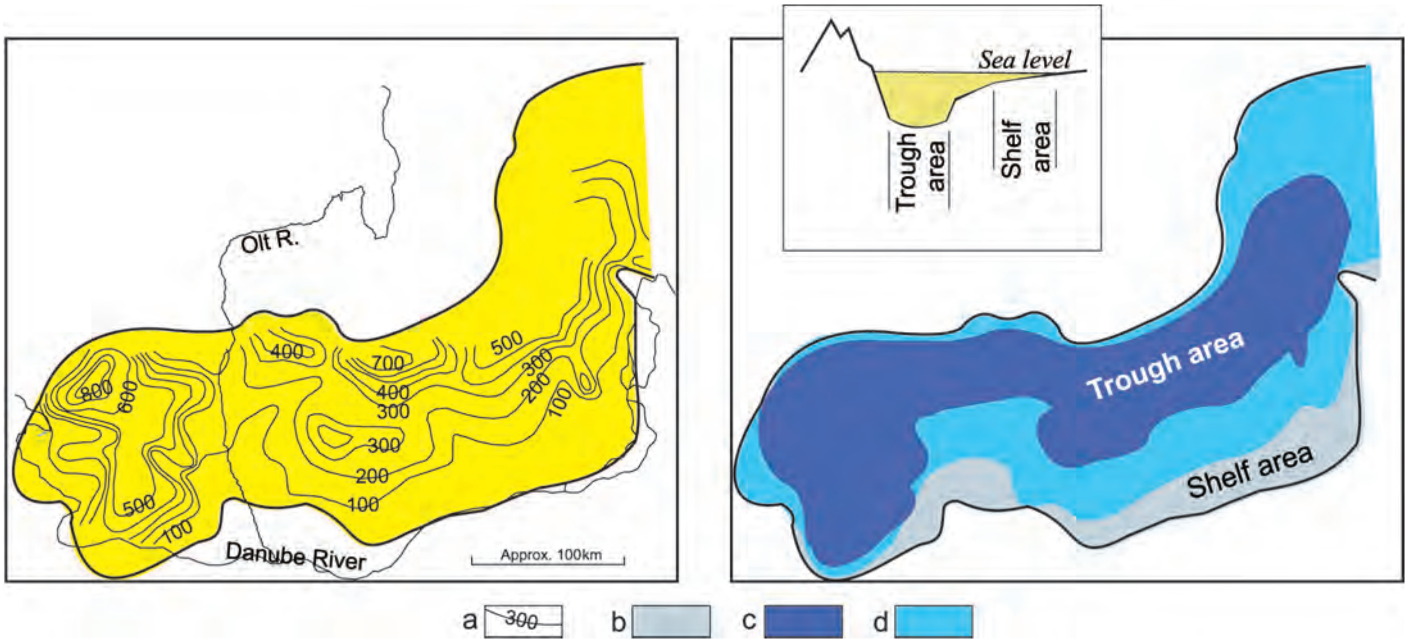


FIGURE 4.4. Physiographic significance of the Dacian Basin major sediment-thickness accumulation zones. **Legend**: **a** - Early Pontian isopach lines (thickness in meters) (from Saulea *et al*., 1969); **b** - zone with very thin sediments, interpreted as shelf area; **c** - zone with the thickest sediments, interpreted as trough area; **d** – intermediary zone between shelf and trough

4.3. DACIAN BASIN SEDIMENTATION DEPTH

Estimation of the sedimentation depth in the Dacian Basin brackish-sea, have always been a subject of utmost importance for the Dacian Basin enthusiasts. The reduced possibility to compare data resulted from deposits on the margins and in the central part of the basin was – and still is – a factor limiting the understanding of the subject. We are going to approach the sedimentation depth problem with data coming from the two end zones of the Dacian Basin area.

The northern end zone of the Dacian Basin is singled out by Saulea *et al*. (1969) as the area of the basin where extensive fresh-water or fresh-water influenced deposits have been observed (Fig. 4.5). A Late Sarmatian (*s. l.*) detrital-continental facies with mammal remains (*Ichtiterium, Hipparion* near the town of Iasi) is mentioned by Saulea *et al*. (1969). The brackish character (with *Limnocardium*) developed in the northernmost Dacian Basin area during the Early Pontian, but the continental facies appeared again during the Late Pontian.

The shallow water characteristic of the deposits in the northern part of the Dacian Basin near Focşani is substantiated by the fluvial facies of the sediments. Sand beds, several meter thick and fining upward with erosional bottom features are intercalated in homogeneous (showing no bedding) silty clay, with rare fresh-water fossils. This aspect dominates the area at the west of Focşani, but southward of Buzău the homogeneous silty clay are progressively replaced by littoral brackish sand and clay sequences with wave ripples.

A fine-grained sand and silt sequence with large scale inclined bedding (clinoforms) developed at the western margin of the Dacian Basin. The prograding facies was mentioned by Tărăpoancă (2004) and further investigated by Leveer (2007) (Fig. 4.6). The sequence is significant for the assessment of the sedimentation depth, as the thickness of the genetically unitary clinoform sequence indicates the minimal sediment accumulation water depth. On this base, a sedimentation depth of several hundred meters (around 300 m; Tărăpoancă, 2004; Leveer, 2007) can be appreciated for the Meotian-Pontian clinoform sedimentary succession.

The evaluation of the sedimentation depth presented above suggests the image of a Dacian Basin brackish-marine trough which is fluvial to very shallow in the northern basin extremity, but shows a considerably deeper water depth at the opposite, western end (Fig. 4.7). The dominant longitudinal and southward flowing, paleocurrent trend, together with the sedimentation depth evaluated at the two extremities of the basin, are indications leading to the image of a Dacian Basin trough getting deeper and deeper from a fluvial environment in the north to a several meter depth marine setting in the western part.

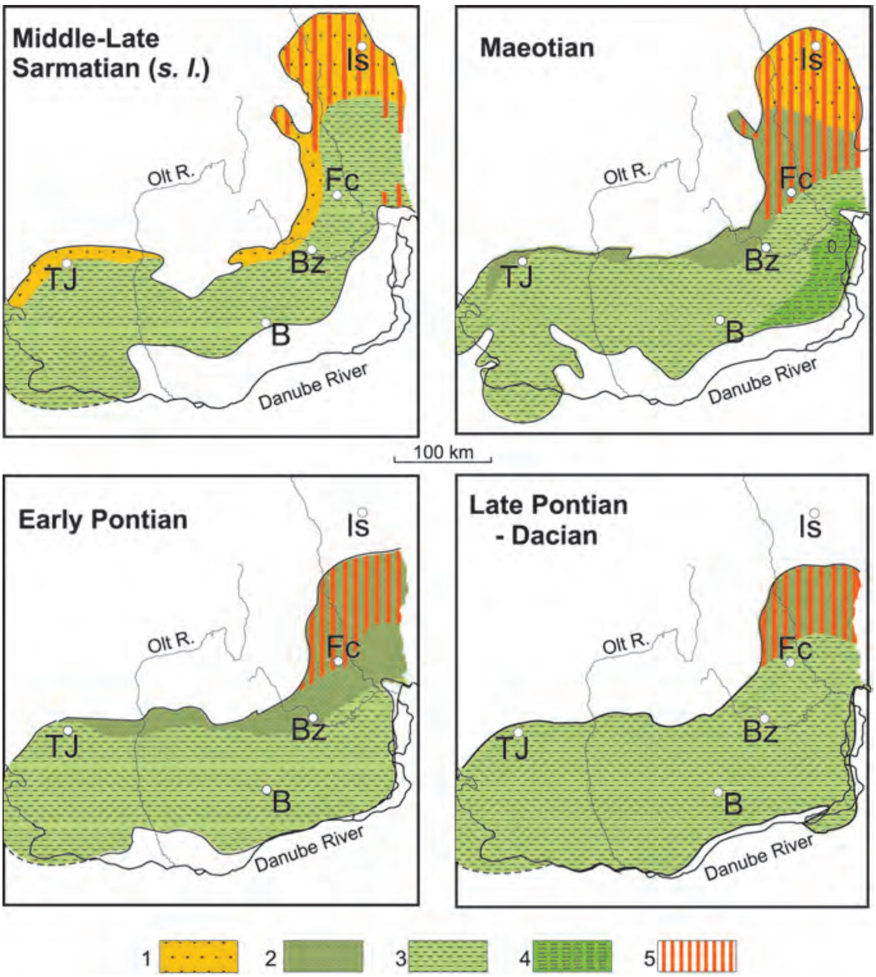


FIGURE 4.5. Main Dacian Basin fresh-water areas. Simplified and modified from Saulea *et al.* (1969). **Legend**: **1**. Littoral sandy facies. **2**. Brackish-water sandy facies. **3**. Brackish-water silty-sandy facies. **4**. Brackish water clayey-silty facies **5**. Fresh water facies (or tending to become fresh-water) in the northern end area of the Dacian Basin

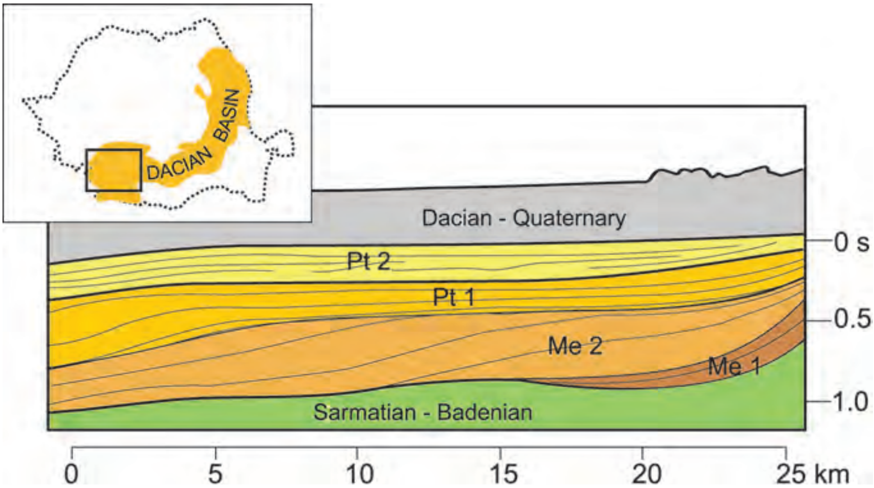


FIGURE 4.6. Large-scale inclined bedded deposits from the western area of the Dacian Basin. The index map in the upward-left corner indicates the location of the occurrence area. Interpreted seismic section, simplified and modified from Lever (2007). **Me1** and **Me2** = upper/lower parts of the Maeotian sedimentary sequence. **Pt1** and **Pt2** = upper/lower parts of the Pontian sedimentary sequence

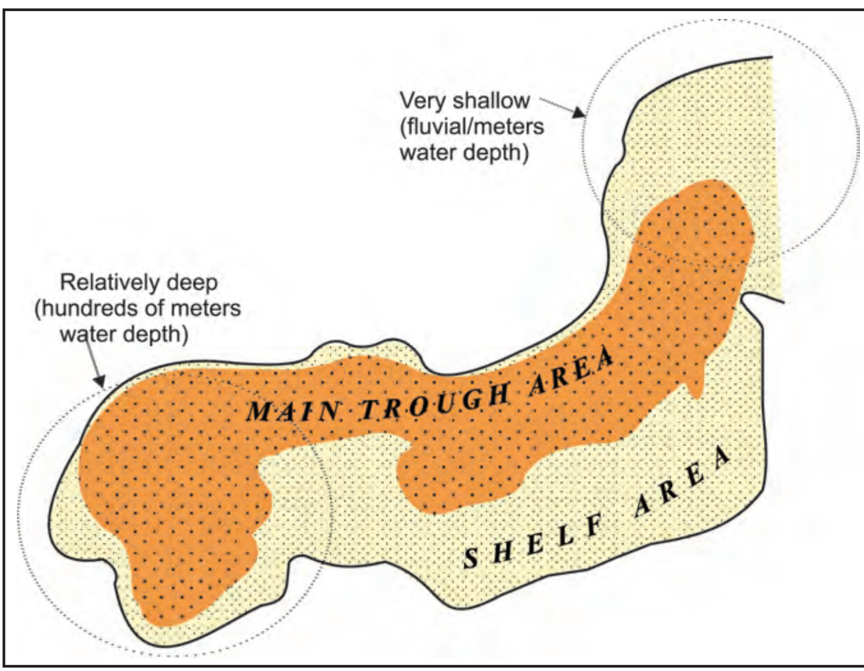


FIGURE 4.7. Sedimentation depth of the Dacian Basin during the brackish-marine development. The water depth evaluation is based mainly on the sedimentation environment data from the two end areas of the basin. See comments in text

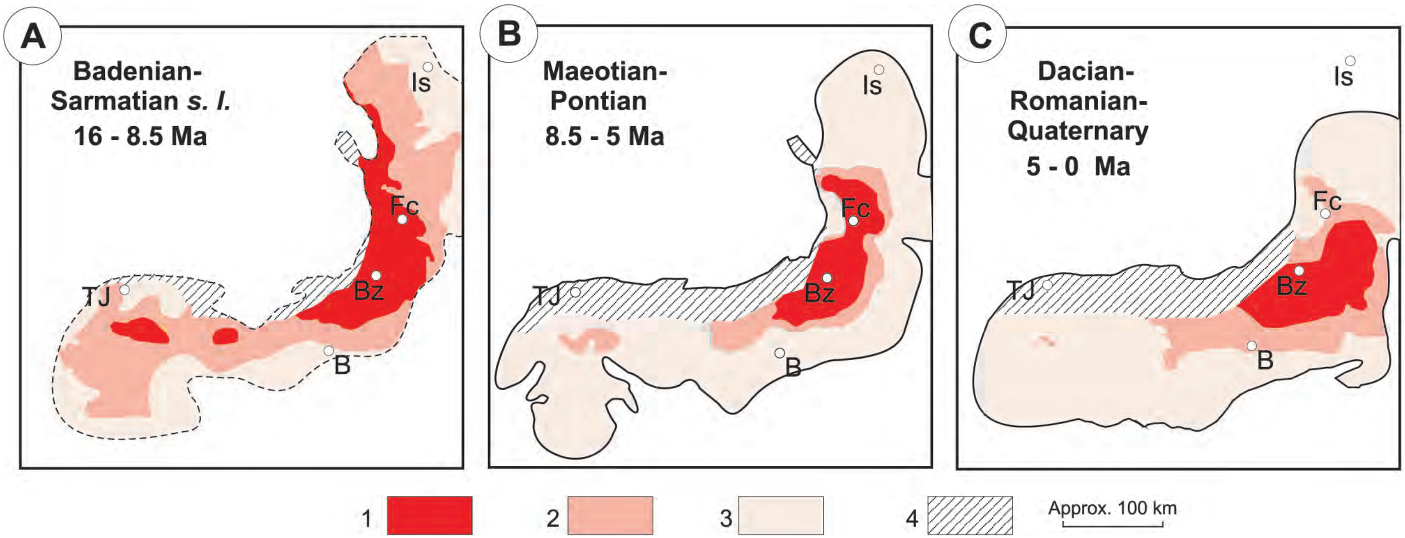


FIGURE 4.8. Location of the highly subsiding areas during the Dacian Basin evolution. Simplified and modified from Bertotti *et al*. (2003). Dacian Basin outline from Saulea *et al*. (1969), with elements from Hamor *et al*. (1988). **Legend**: **1**. High subsidence. **2**. Moderate subsidence. **3**. Low subsidence or no subsidence. **4.** No subsidence data. **B** - Bucharest. **Is** - Iaşi. **Fc** - Focşani. **Bz** - Buzău. **TJ** - Târgu Jiu

4.4. SUBSIDENCE AND BASIN MORPHOLOGY

The Dacian Basin was an area of strong subsidence. This subsidence started during the Badenian and continued until the Quaternary (Bertotti *et al*., 2003). During the Sarmatian (*s.l.*), synchronous with the tectonic climax of the Carpathian Orogen, the subsidence attained a maximum in strength and extension (Fig 4.8A). According to Bertotti *et al*., 2003 after the lithospheric collision, Pontian-Quaternary subsidence continued to act, but only within a restricted zone from the northern part of the Dacian Basin (Focşani-Buzău area, named the Focşani Depression) (Fig 4.8 B and C).

Since strong subsidence coincided in time with active uplift and erosion in the Carpathians, a large amount of detrital material was accumulated in the Focşani Depression. In cases such as these, the unbalance between subsidence and sedimentation may possibly produce changes in basin morphology.

The Late Sarmatian-Early Dacian sedimentary environment in the sediment sequence of the Focşani Depression appears to be rather uniform. This indicates equilibrium between subsidence and sediment accumulation. However, at the scale of the entire basin, the sedimentary facies in the Buzău-Focşani area is different from the major facies of the central and western Dacian Basin sediments. Moreover, the northern part of the basin acted differently from the rest of the basin during certain moments of evolution. This raises the question whether the Focşani Basin occasionally did operate with a restricted independence within the Dacian Basin. This situation could have been generated by a phase of subsidence dominating the sedimentation rate and therefore could induce morphologic changes within the basin. It is difficult to answer such a question, because there are also major features which indicate that most of the time, the sediment accumulation activity in the northern area was part of the general pattern of the Dacian Basin sedimentation.

4.5. CONCLUSIONS

The Dacian Basin exhibits the principal physiographic characters of a foreland depression and acted as an elongated sedimentation trough, adjacent to the Eastern (the southern part) and the Southern Carpathians.

The basin shelf, located in the southern part of the Dacian Basin, was covered by a relatively thin blanket of sediments. The main trough of the basin, including most of its accumulated sediments, corresponds to the northern (sub–Carpathian) and the axial area of the Dacian Basin.

The basal section of the Dacian Basin sedimentary trough deepens towards the west. The deepest area of the basin was at the western end, with a water depth evaluated at several hundreds of meters. Fluvial and very shallow water environments prevailed at the northern extremity of the basin.

Chapter 5

LITTORAL SEDIMENTARY ENVIRONMENT IN THE DACIAN BASIN

Littoral deposits are frequently cropping out in the Dacian Basin area. The paleoenvironmental analysis of the littoral sedimentation in the Dacian Basin began in 1991, when the American sedimentologist Thomas Ryer recognized shoreline sequences in the Pontian deposits from Tigveni zone (east of Curtea de Argeş town, Argeş County). The first sedimentological study dedicated to littoral sediments was carried out by N. Anastasiu and L. Iordache (1993). The authors described Late Neogene sediments accumulated in shoreline and fluvial-deltaic environments, from the area in between Topolog River (Tigveni locality) and Olt River.

5.1. CRITERIA FOR THE PALEOENVIRONMENTAL RECONSTRUCTION OF THE DACIAN BASIN LITTORAL DEPOSITS

The outcrop-based sedimentological investigations used the following two criteria to recognize Dacian Basin littoral sedimentary paleoenvironments:

- sedimentary structures with paleo-environmental significance (wave and storm generated) and
- vertical grain size sorting

When the identification of the littoral units is based on well logs, the analysis depends only on sedimentary features suggested by the shape of the geophysical logs. Consequently, the paleo-environmental reconstruction relies on the grain size trend aspects.

In both cases (outcrop or subsurface data), the main paleo-environmental criteria are supplemented with additional observations:

- lithofacies, suggesting the level of the depositional energy;
- sedimentary unit thickness, indicating the magnitude of the clastic sediment influx.

Littoral sedimentary structures. The presence of the sedimentary structures generated by waves or by storm represents the most used criterion for the identification of the littoral sedimentary environment. This standard is most powerful for the evaluation of the shoreline environment when both types of sedimentary structures – produced by wave and storm – are simultaneously present in the outcrop.

Vertical grain size sorting. At the present-day state of knowledge, the sediments coarsening upward is interpreted as resulting through progradation of the sediment accumulation area. During progradation the coarsest particles accumulate in the upper part of the advancing frontal surface of the sediment body, while the fine grained detrital material is deposited towards the base of the frontal slope. The resulting sedimentary unit is coarsening upward. The successive basinward shifting of the accumulation front is a common process in the littoral environment.

The littoral connotation of the coarsening upward feature is sometimes exaggerated, especially when the evaluation depends exclusively on well log data. Other types of vertical grain sorting can occur in the littoral environment (Fig. 5.1). Also, the fluvial (crevasse splay) deposits could show coarsening upward. The confidence of the littoral paleoenvironmental reconstruction in the Dacian Basin deposits is higher when based on the coexistence of both wave/storm structures and coarsening upward feature.

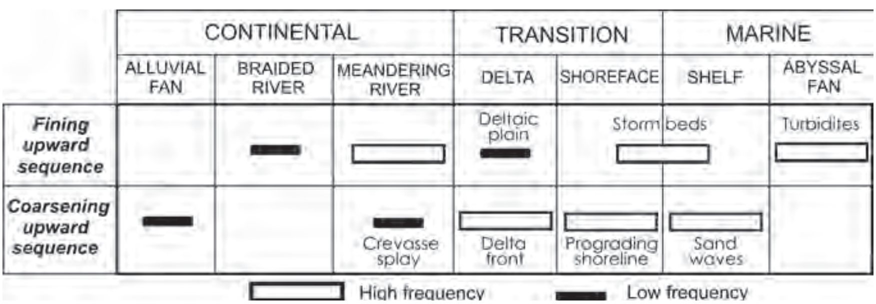


FIGURE 5.1. The environmental distribution of the vertical grain-size sorting units

5.2. SHORELINE SEDIMENTATION ENVIRONMENT IN THE DACIAN BASIN

Dacian Basin shoreface deposits show a variety of sedimentary features. Most frequently these features point out that the beach sedimentation has taken place in fair-weather conditions, but the storm-controlled shoreline deposits are also present. The beach environment may be singled out by the dominance of special sedimentary structures, like parallel laminated sequences or shell accumulations. Many Dacian Basin shoreline sequences are fine-grained and the silty or fine grained sandy interbeds with shoreface structures are very thin, indicating the lower energy level of the sedimentation process. Less frequent are the thicker shoreline sedimentary units, usually with prograding characteristics.

5.2.1. Wave-controlled shoreline environment

All littoral sediment accumulation showing frequent wave-generated structures have been attributed to the wave-controlled shoreline environment.

Wave ripples. Small scale asymmetrical ripples occurring in the Dacian Basin sediments are best observed in the vertical section. The morphology parameters of the wave ripples profile are moderately variable (Fig. 5.2), indicating two dimensional types of ripples. The smaller ripples are defined by 5-8 mm height (H; crest to trough) and 73 – 83 mm wavelength (L; crest to crest). The height reaches 11 – 13 mm for the larger ripples and their wavelength is 123-143 mm. The size variability is mostly between trains of wave ripples. Sometimes, even within an individual ripple train there are variations of the height of the crest (Figs. 5.2 and 5.5 C), lower and higher ripples alternating at random.

The sharp crests are characteristic of the wave ripples observed in the Dacian Basin deposits (Fig. 5.2 C, E, and G). Round crested wave ripples are also occurring (Fig. 5.2 A, B, D, F), indicating a higher dynamics of the water. Occasionally, the crest roundness varies in between ripples from the same train (Fig. 5.2 G).

Wave ripples are roughly parallel (Fig. 5.3 A), but they also show crest forking, small scale sinuosity and crest terminations (Fig. 5.3 B). In the infrequent occasions when it was possible to observe trains of wave ripples on superposed beds (Fig. 5.3), the general orientation of the successive ripple sets did not show significant differences. Interference ripples are relatively frequent in the littoral sediments from the Dacian Basin (Figs. 5.4; 5.3 A).

The majority of the wave ripples examined in the Dacian Basin sediments display the characteristic internal structure of the symmetrical ripples (Boersma, 1970), consisting of sets of laminae dipping almost symmetrically in opposite directions (Fig. 5.5A).

A number of departures from the typical aspect of the wave ripples occur in the Dacian Basin littoral sediments. In some cases, the superimposed chevron lamination is replaced with laterally extended sets of cross laminae (Fig. 5.5 B), but the characteristic presence of the oppositely inclined bundles of laminae persists.

Usually, the wave-formed ripples observed in the Dacian Basin deposits are related to thin sandy accumulations (Fig. 5.5). There are cases when the sandy accumulation with divergently inclined sets of laminae are much thicker (Fig. 5.6), indicating a higher aggradation rate.

Rarely, sets of continuous laminae climbing over common wave ripples have been observed (Fig. 5.7). The truncated ripples (Fig. 5.8) represent another rare ripple variety from the littoral sediments in the Dacian Basin.

A special feature was observed among the waves rippled Late Dacian beds from Bădislava River, when the undulated top surface covers (erosionally?) a single set of inclined and largely undulated laminae (Fig. 5.5 D).

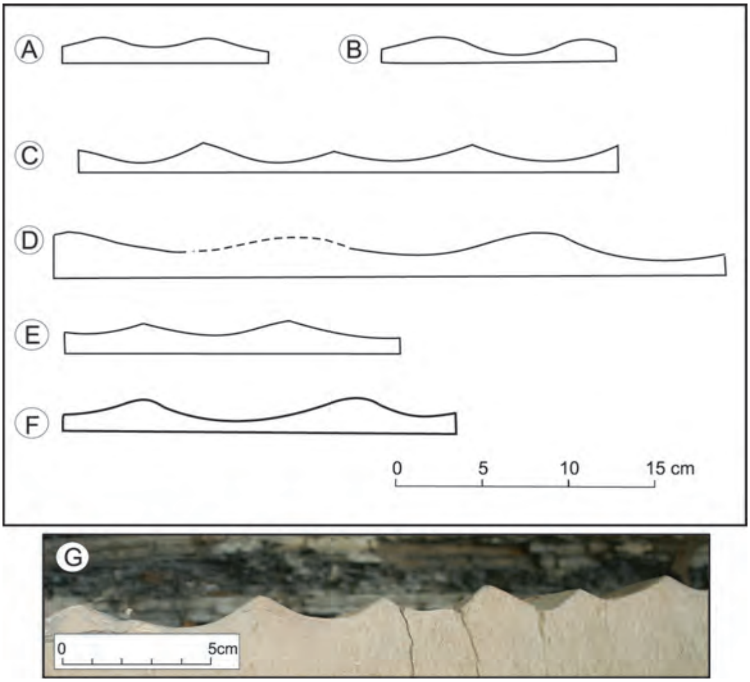


FIGURE 5.2. Cross section morphology of the wave ripples from the Dacian Basin deposits. **A** - Middle Pontian, Slănicu de Buzău River (Buzău County). **B** - Middle Pontian, Râmnicul Sărat River (Vrancea County). **C** - Maeotian, Râmnicu Sărat River (Vrancea County). **D** - Middle Pontian, Râmnicu Sărat River (Jitia de Jos, Vrancea County). **E** - Middle Pontian, Slănicu de Buzău River (Buzău County). **F** - Late Pontian, Bădislava River (Argeş County). **G** - Late Sarmatian (*s. l.*), Râmnicu Sărat River (Vrancea County)

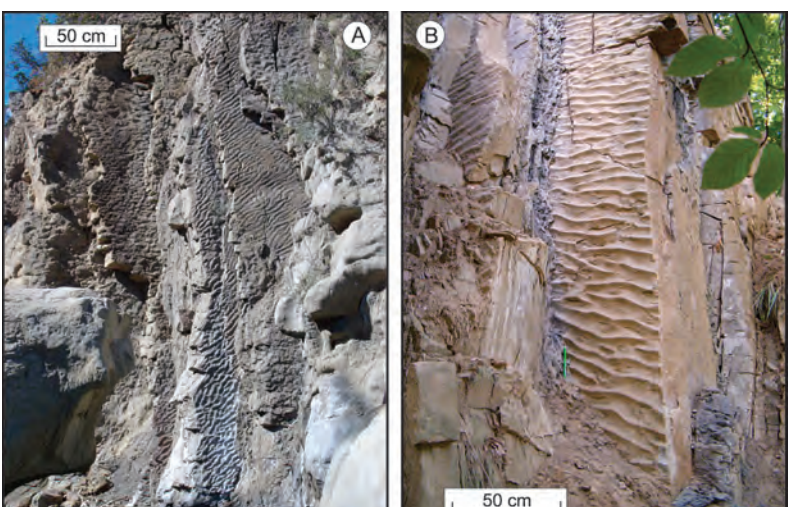


FIGURE 5.3. Crest pattern of the wave ripples from the shoreface Dacian Basin sediments. **A** - Late Maeotian. **B** - Late Sarmatian (*s. l.*). Râmnicu Sărat River (Jitia de Jos village, Vrancea County)

FIGURE 5.4. Interference wave ripples. Late Maeotian, Râmnicu Sărat River (Jitia de Jos, Vrancea County)

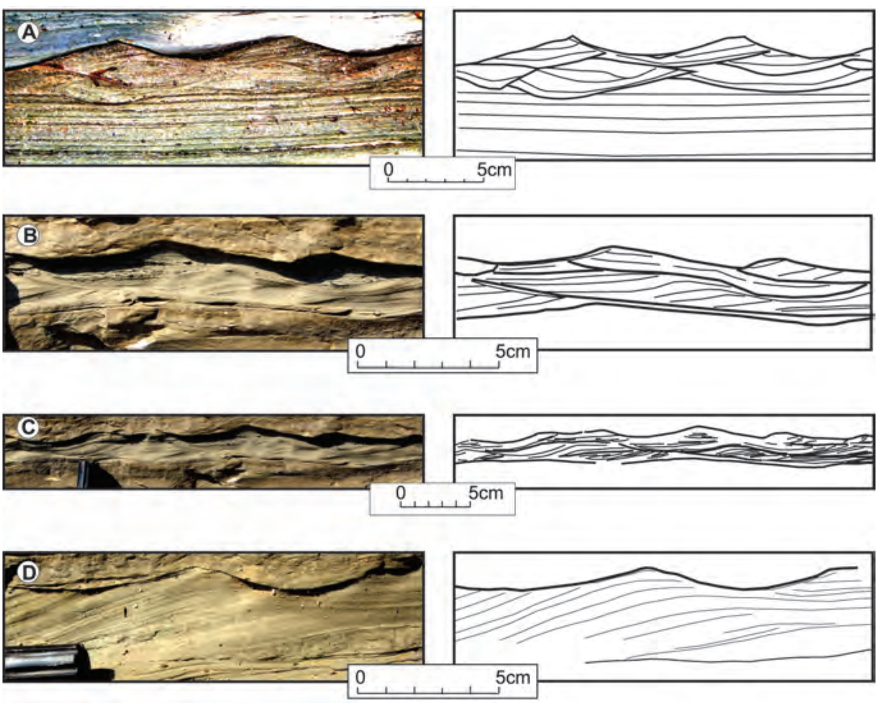
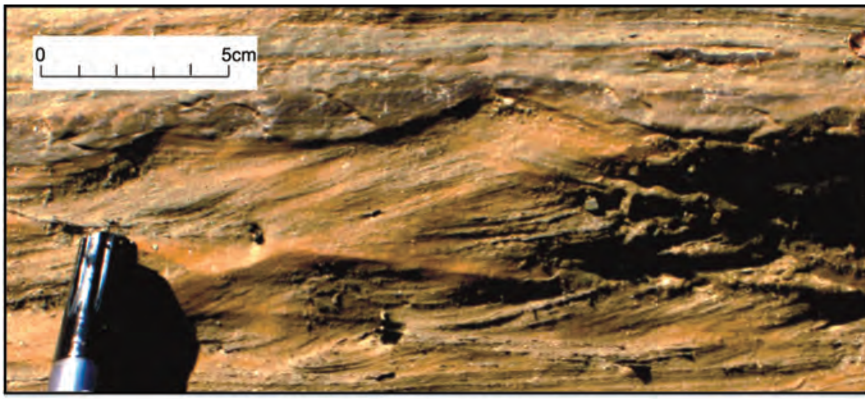


FIGURE 5.5. Wave ripples internal structure. Early Dacian, Bădislava River (Bălileşti village, Argeş County)



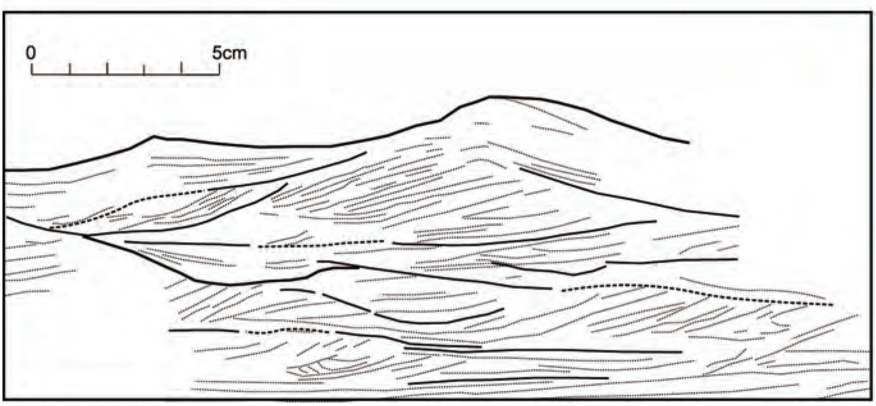


FIGURE 5.6. Aggraded wave ripples with complex internal lamination. Early Dacian, Bădislava River (Băileşti village, Argeş County)

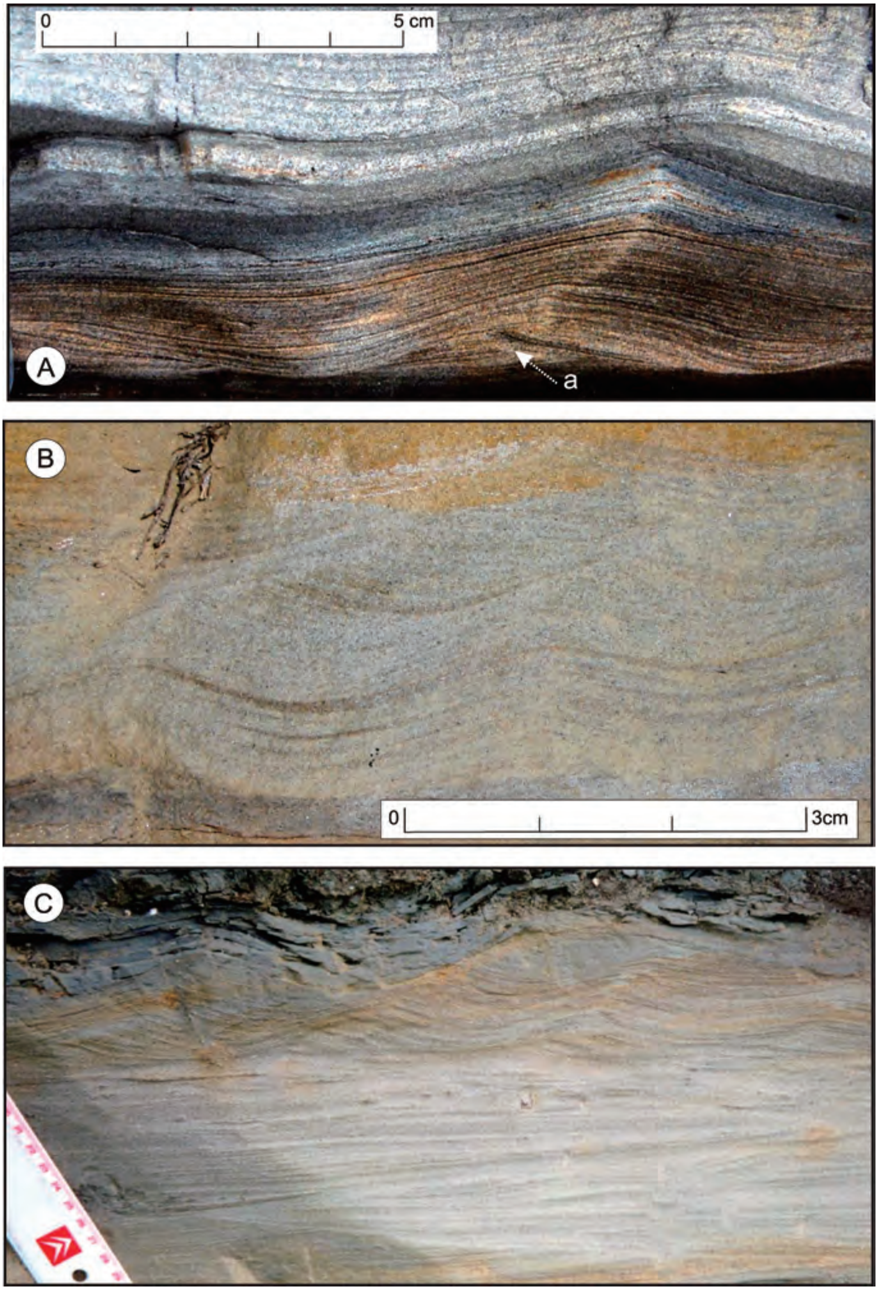


FIGURE 5.7. Wave ripples with continuous, climbing laminae. In picture A, at the base of the climbing set, there is a ripple with laminae dipping in opposite directions (a). **A** - Late Maeotian, Râmnicu Sărat River (Jitia de Jos village, Vrancea County). **B** - Pontian, Slănicul de Buzău River. Gura Dimienii village (Buzău County). **C** - Late Maeotian. Bizdidel River, Pucioasa (Dâmbovița County). Possible hummocky cross lamination under the wave ripples.

FIGURE 5.8. Truncated wave ripples in the Late Maeotian littoral sediments from Râmnicu Sărat River (Jitia de Jos village, Vrancea County)

Sedimentary dynamics in the wave-controlled shoreline environment. The waves were not the only transport and sedimentation agent acting in the sub-Carpathian shoreline of the Dacian Basin. The part played by normal, bottom currents is indicated by rather frequent sedimentary features.

Erosion was not a predominant process in the wave-controlled shoreline environment. A small size erosion channel was observed on Bădislava River valley, in the Early Dacian sediments (Fig. 5.9). This shows an erosion episode in the dominantly bidirectional transport and sedimentation environment. The climbing ripples (Fig. 5.10) visible in the same area point out an off-shore directed, very active sediment transport. Wave ripples occur subsequently to the high rate sediment accumulation with climbing ripple structure (Fig. 5.10).

The wave action was sometimes supplemented or succeeded by unidirectional flow. This is indicated by sedimentary structures illustrating the conversion of the symmetrical ripples into asymmetrical ripples, due to subsequent unidirectional flow and lee side sediment accumulation (Fig. 5.11). Symmetrically shaped ripples with current lamination (Fig. 5.12) have also been observed.

Low energy wave-controlled shoreline environment. The Dacian Basin shoreline sediments accumulated under the hydrodynamic domination of the waves can be classified according to the characteristic of their sedimentary succesion.

Clayey sediments are the prevailing lithologic feature of all the shoreline sequences in the Dacian Basin. According to the thickness development of the sandy units, a separation can be made between lower energy and higher energy wave-dominated shoreline environment.

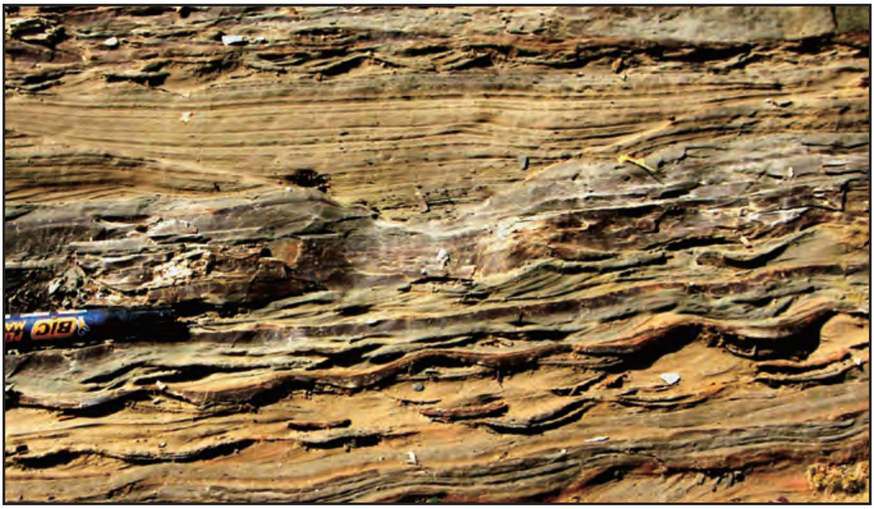


FIGURE 5.9. Erosion channel in the wave-dominated shoreface environment. Early Dacian, Bădislava River (Bălilesti village, Argeş County)

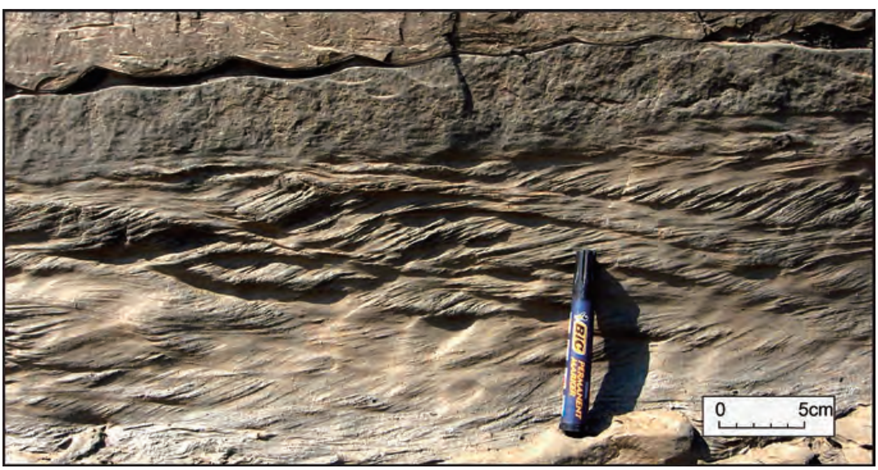


FIGURE 5.10. Climbing ripples associated with wave ripples in the shoreface sediments of the Dacian Basin. Early Dacian, Bădislava River (Bălilesti village, Argeş County)

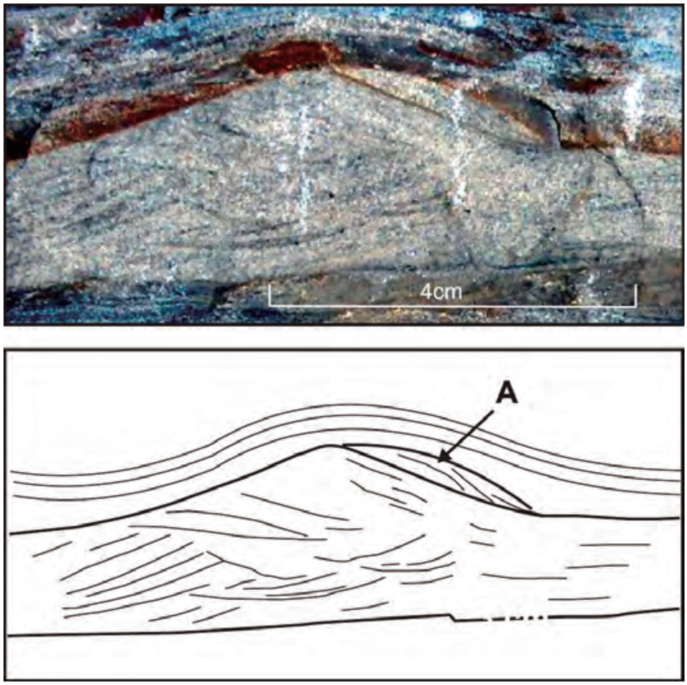


FIGURE 5.11. Conversion from symmetrical to asymmetrical ripple, through subsequent sediment accumulation (A). Late Pontian, Râmnicu Sărat River (Dumitreşti, Vrancea County)

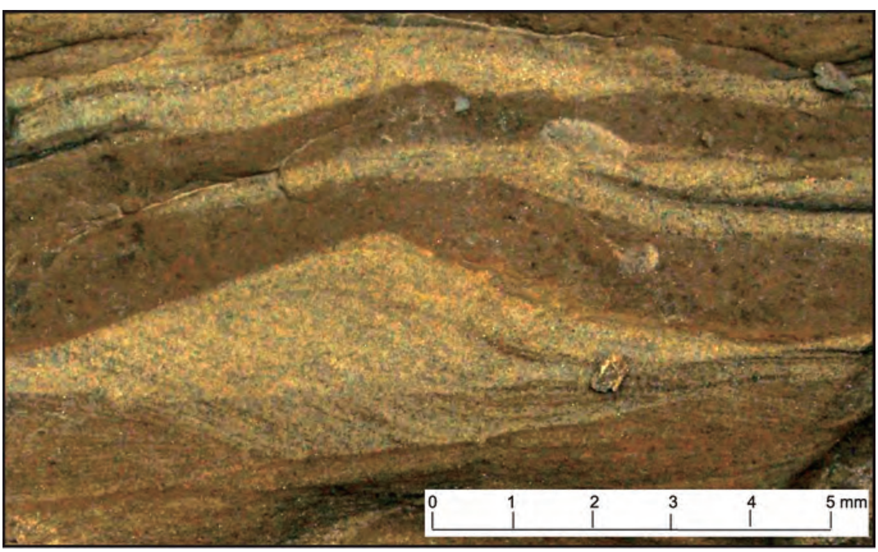


FIGURE 5.12. Symmetrical-shaped ripple with current lamination internal structure. Late Maeotian shoreface sediments from Râmnicu Sărat River (Jitia de Jos village, Vrancea County).

Some of the clayey sedimentary sequences include thin fine grained sand interbeds, with wave ripples. In the Bădislava River Late Pontian succession (Fig. 5.13 C), many of the thin sandy intercalations show wave ripples. These sandy units with symmetrical ripples are several centimeters thick. No clear vertical grain size sorting can be distinguished within the thin sandy intercalations. Thicker sandy beds (10 – 20 cm) occur also, but they represent a minority. A hummocky cross stratification structure was observed in one of the thicker beds.

In accordance with the limited sandy sediment accumulation rate the sequences with the characteristics presented above belong to the low energy shoreface category.

High energy wave-controlled shoreline environment. The higher energy shoreline environment is marked by the presence of better developed, thicker sandy units (Fig. 5.13 B, C, D). The most representative of these sandy units are 1-2 m thick units with distinct coarsening upward trend (Fig. 5.14). Wave ripples are observed in the basal part of the coarsening upward units, but they are replaced with current structures at higher levels of the sequence (Fig. 5.15). In the shoreline sedimentary section from Chiojdeni (Râmnicu Sărat River) (Fig. 5.15), a hummocky type structure occurs. The size of the cross lamination structures is larger to the upper part of the coarsening up unit. The sediment succession is topped by symmetrical ripples.

The sediment sequences attributed to the lower or higher energy shoreline might also represent sediment accumulation in the lower or middle shoreface area. The rate of sediment influx could also control the character of the two types of shoreface sequences.

Parallel lamination shoreline environment. The high energy Dacian Basin shoreline sequences also include sandy units with parallel lamination (Fig. 5.13 B, C, and D). At the Chiojdeni geological section (Râmnicu Sărat River) (Fig. 5.16), the parallel laminated interval consists of three units, summing up a thickness of two meters. Two of the three units show trough cross-lamination at the upper part. Wave ripples occur at the top of the upper unit, as well as a deformation structure.

The whole parallel laminated sequence appears to represent a very high energy shoreline environment, which was getting more tranquil at the end of the event.

5.2.2. Storm-controlled shoreline environment

The littoral units in the Dacian Basin incorporate occurrences of storm generated sedimentary structures (Fig. 5.17). The frequency of this type of structure is low, indicating that storm currents did not influence significantly the Dacian Basin shoreline or near-shore sediment accumulation. The only storm-controlled shoreline sediments sknown in the Dacian Basin are Maeotian in age and crop out in the geological section of the Bizdidel River, east of Pucioasa town, in the Dâmbovița County.

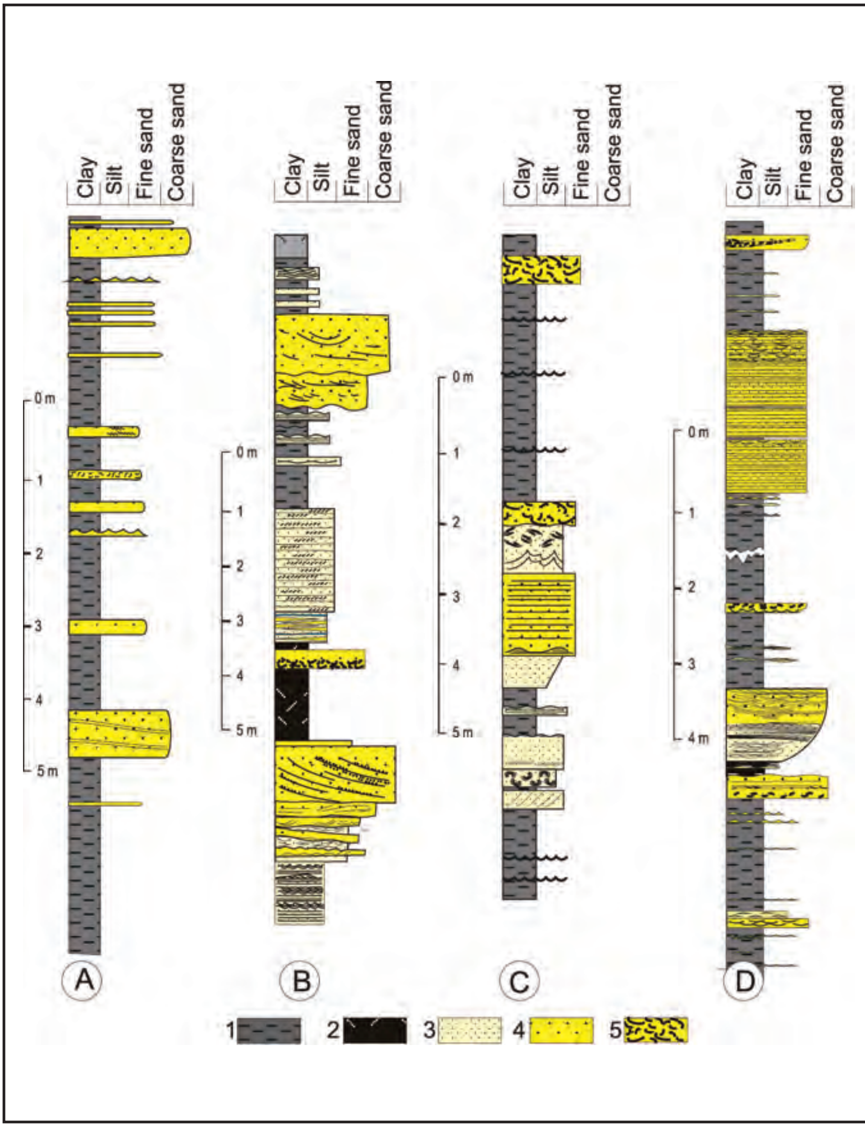


FIGURE 5.13. Dacian Basin shoreface sedimentary successions. **A** - Maeotian, Râmnicu Sărat River (Jitia de Jos village, Vrancea County). **B** - Late Pontian (basal part), Bădislava River (Vlădeşti village, Argeş County). **C** - Late Pontian (upper part), Bădislava River (Bălileşti village, Argeş County). **D** - Late Pontian, Râmnicu Sărat River (Chiojdeni village, Vrancea County). **Legend**: **1**. Brackish, bedded clay. **2**. Fluvial, homogeneous clay. **3**. Silt. **4**. Sand. **5**. Breccia

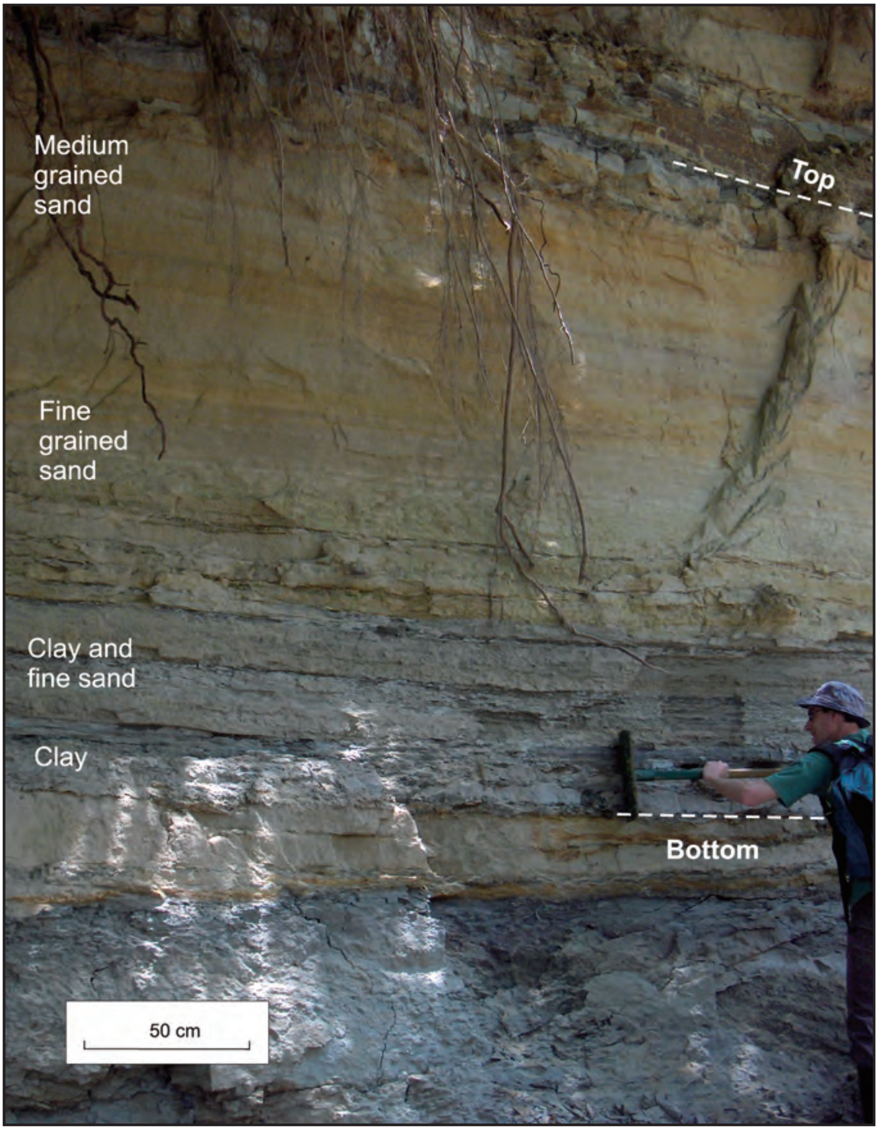


FIGURE 5.14. Coarsening upward trend in sediments of high energy shoreline. Wave ripples occur in the fine-grained basal part. Lowest part of Late Pontian, Bădislava River (Vlădeşti village, Argeş County)

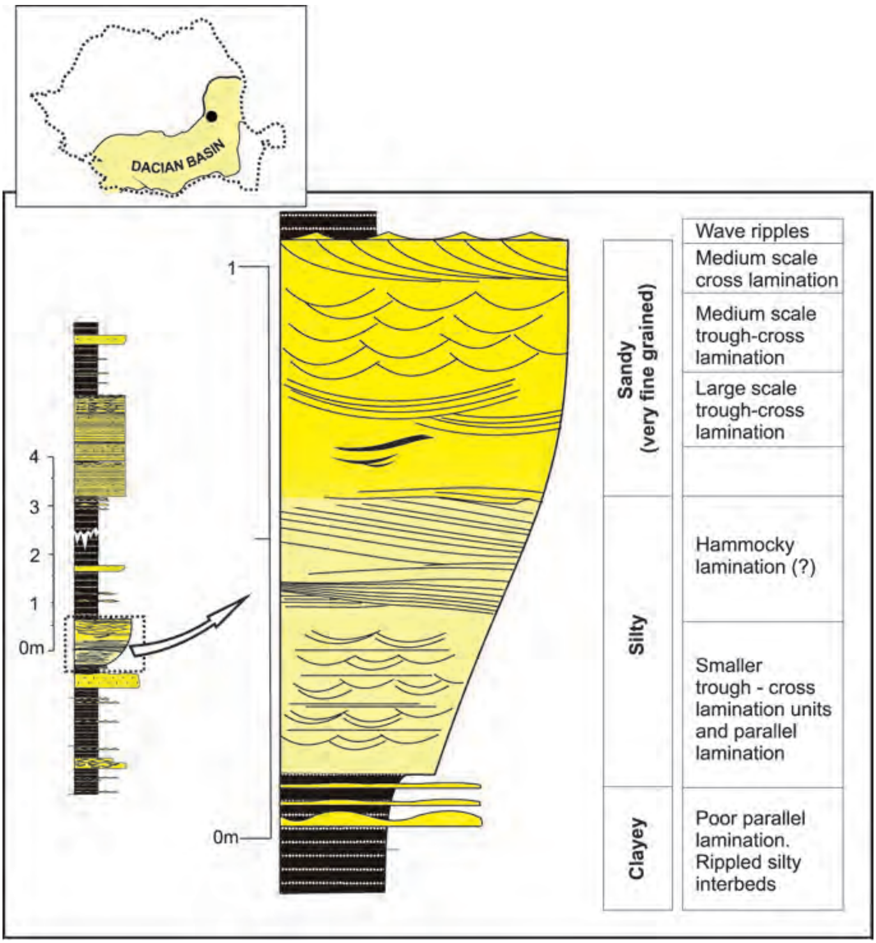


FIGURE 5.15. Shoreface sequence in the Late Pontian deposits from Râmnicu Sărat River (Chiojdeni, Vrancea County). Upper-left corner: index map with location of the geological section in the Dacian Basin area and in Romania

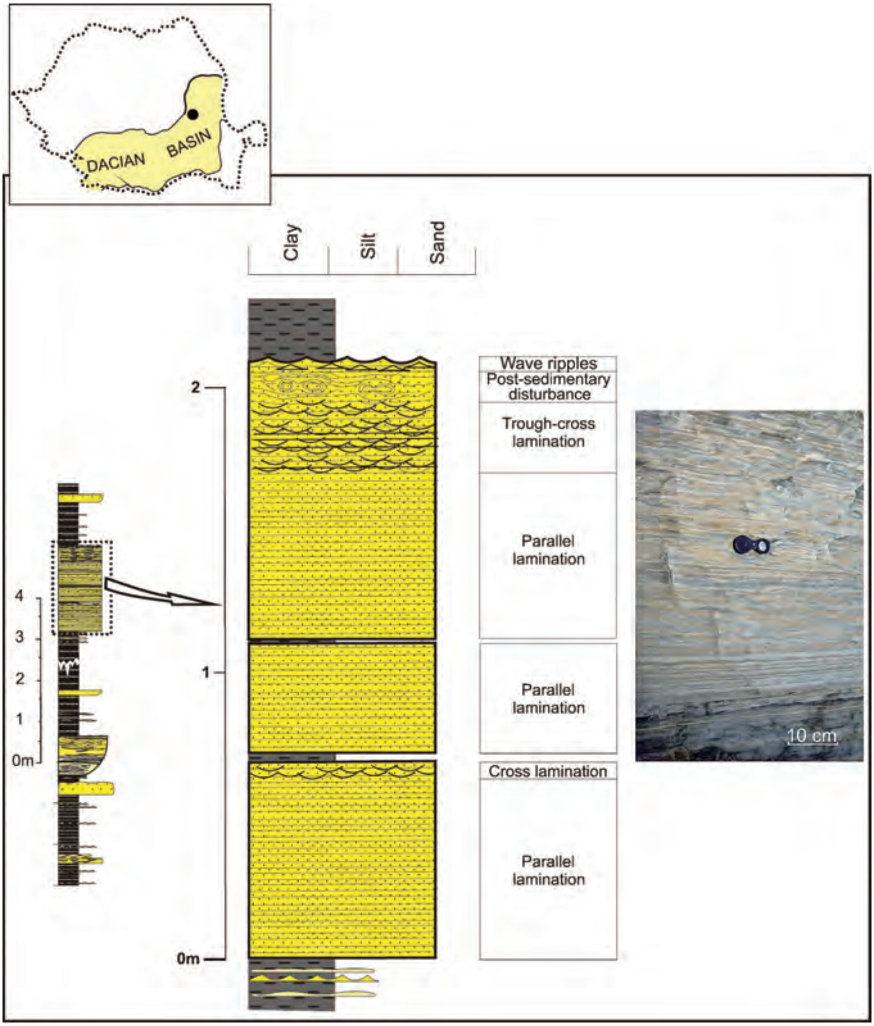


FIGURE 5.16. Parallel lamination facies of the wave-dominated shoreface environment. Late Pontian, Râmnicu Sărat River (Chiojdeni, Vrancea County)

FIGURE 5.17. Hummocky cross-lamination and wave ripple lamination in the Late Pontian deposits from Topolog River (right slope), north of Tigveni (Arges County)

The shoreface deposits from the Bizdidel River section belong to the lower part of the Late Maeotian (Fig. 5.18). Seven sedimentary storm events units occur in the 36 m thick Late Maeotian shoreline deposits. The hummocky type structure occurs in various situations. The graphic in figure 5.18 A shows three of these situations:

- single hummocky cross-lamination unit in a fine-grained, non-graded sand, with wave ripple lamination on top (sequence A1);
- complex coarsening upward sequence with wave ripple lamination at the base, multiple hummocky lamination units with three intercalated levels of wave ripple lamination and medium-scale cross-lamination on top (sequence A2);
- fining upward sequence with hummocky lamination (several units) ending with wave ripples on top (sequence A3).

Some of the sedimentary succesions with hummocky cross-lamination are apparently non-graded, homogeneous in regard to the grain size (Fig. 5.18 B and C).

The three types of sequences (Fig. 5.18) point out the participation of the storm generated sediment accumulation in different shoreline processes: (1) shoreline progradation (with coarsening upward record) and (2) stable, shoreline aggradation (the non-graded succesions). The fining upward unit shows the character of an accumulation entirely controlled by the storm process.

A significant feature of the storm influenced units is the alternation of hummocky cross-lamination and smaller structures, probably wave ripple lamination (Figs. 5.18 and 5.19). This reflects the fluctuation of storm and fair-weather conditions.

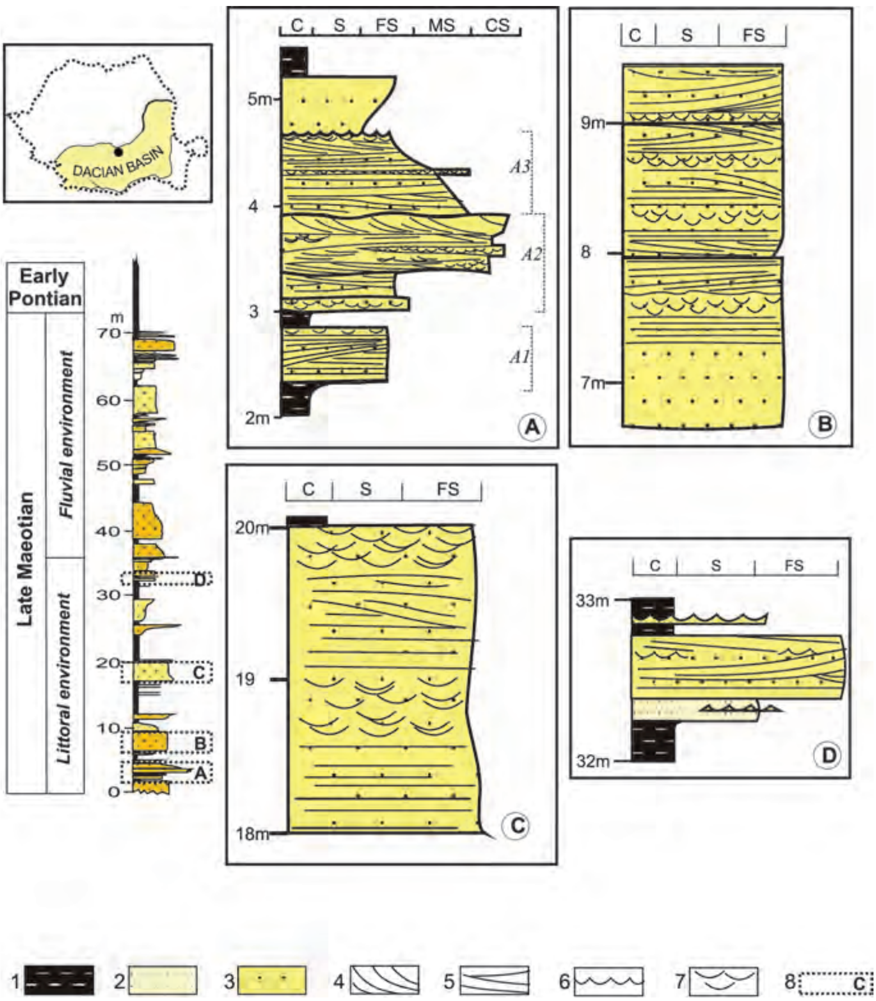


FIGURE 5.18. Storm-dominated littoral accumulation in the Late Maeotian sequence from Bizdidel River (Pucioasa, Dâmbovița County). **A** to **D** - Internal sedimentary structure at several moments of storm domination. Left side – stratigraphic column of the Maeotian deposits. Upper left - index map showing location of the Bizdidel River section in the Dacian Basin area and in Romania. **Legend**: **1**. Clay. **2**. Silt. **3**. Sand. **4**. Current cross-lamination. **5**. Hummocky cross-lamination. **6**. Wave ripples. **7**. Internal lamination of the wave rippled units. **8**. Location in the general stratogram. **C**. Clay. **S**. Silt. **FS**. Fine-grained sand. **MS**. Medium-grained sand. **CS**. Coarse-grained sand

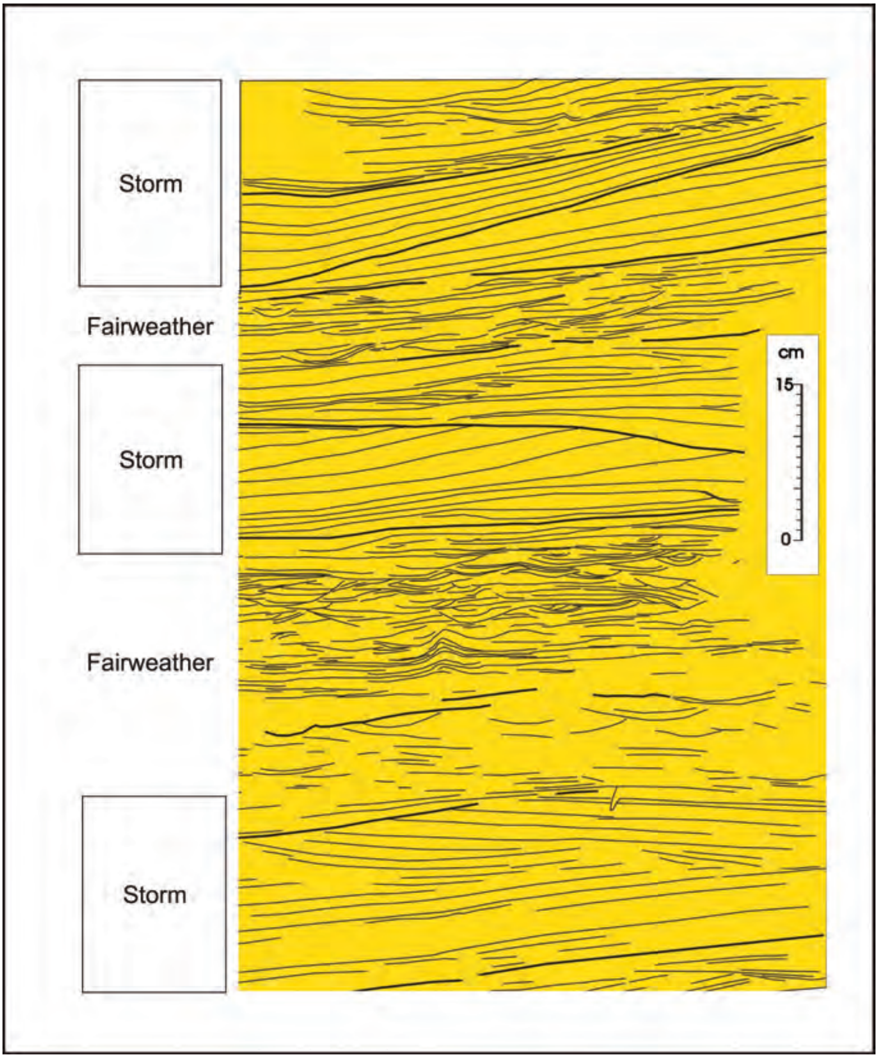


FIGURE 5.19. Hummocky cross-lamination structures alternating with smaller-size sedimentary structures, suggesting alternating weather conditions. Drawing after a picture. Late Maeotian, Bizdidel River (Pucioasa, Dâmbovița County)

5.2.3. Shell beds in the Dacian Basin shoreline environment

In the northern Dacian Basin area, between Putna River and Prahova River, on the sub-Carpathian margin of the basin, the presence of a distinctive Late Sarmatian (*s. l.*) calcareous deposit was signaled by Pană (1966) and Saulea *et al*. (1969). It consists of accumulations of *Mactra* shells, making up layers of various thicknesses, associated with claystone and sandstone beds. Brustur *et al*. (2005) specify that the accumulated shells belong to the same taxonomic unit or even to the same species of bivalve mollusk.

Shell accumulations from the Late Sarmatian (*s. l.*) deposits have been investigated at the Râmnicu Sărat River geological section (north of the Jitia de Jos village). The shell beds consist of mostly unbroken *Mactra* shells included in a sandy matrix. In some cases the bedding is evidenced by alternating bands of sand and shells. In the outcrop at the north of Jitia de Jos, the thickest shell layer displays an internal inclined bedding (Fig. 5.20). The single *Mactra* shells show a preferential orientation with the convex side of the shells pointing upward. This orientation and the inclined sedimentary structure indicate that the shell accumulation is of detrital origin, resulting articulated current transport. The presence of *Mactra* specimens with the two valves articulated, in the living position, indicates that the shells have not been carried for long distances.

In the outcrop area located on Râmnicu Sărat River, the internal current structure of the shell layers consists of a single set of inclined beds. Therefore, the entire mass of shells was displaced during a single transport episode. Considering the shell bed thickness of several tens of centimeters, the shell accumulation required a high energy transport agent.

Several sandstone beds with wave ripples (Fig. 5.3 B) have been observed in the sedimentary succession which includes the investigated shell layer. This is a clear indication of the shoreface or nearshore environment of the shell accumulation. It is likely that storm-generated currents have been the agent able to transport, concentrate and accumulate the shells. The inclined internal structure of the shell beds (Figs. 5.20 A and B) could also represent a storm generated feature.

The sandy matrix of the Late Sarmatian (*s. l.*) shell beds from the Râmnicu Sărat River (Fig. 20 D and E) occurs in variable quantity. It has been observed that, practically, all shells from low matrix shell beds are orientated with their convex side up (Fig. 20 D). In contrast, in the layers with abundant sandy matrix, the shells display variable positions. Consequently, it appears that the amount of matrix could indicate the relative energy level of the currents which transported and concentrated the shells.

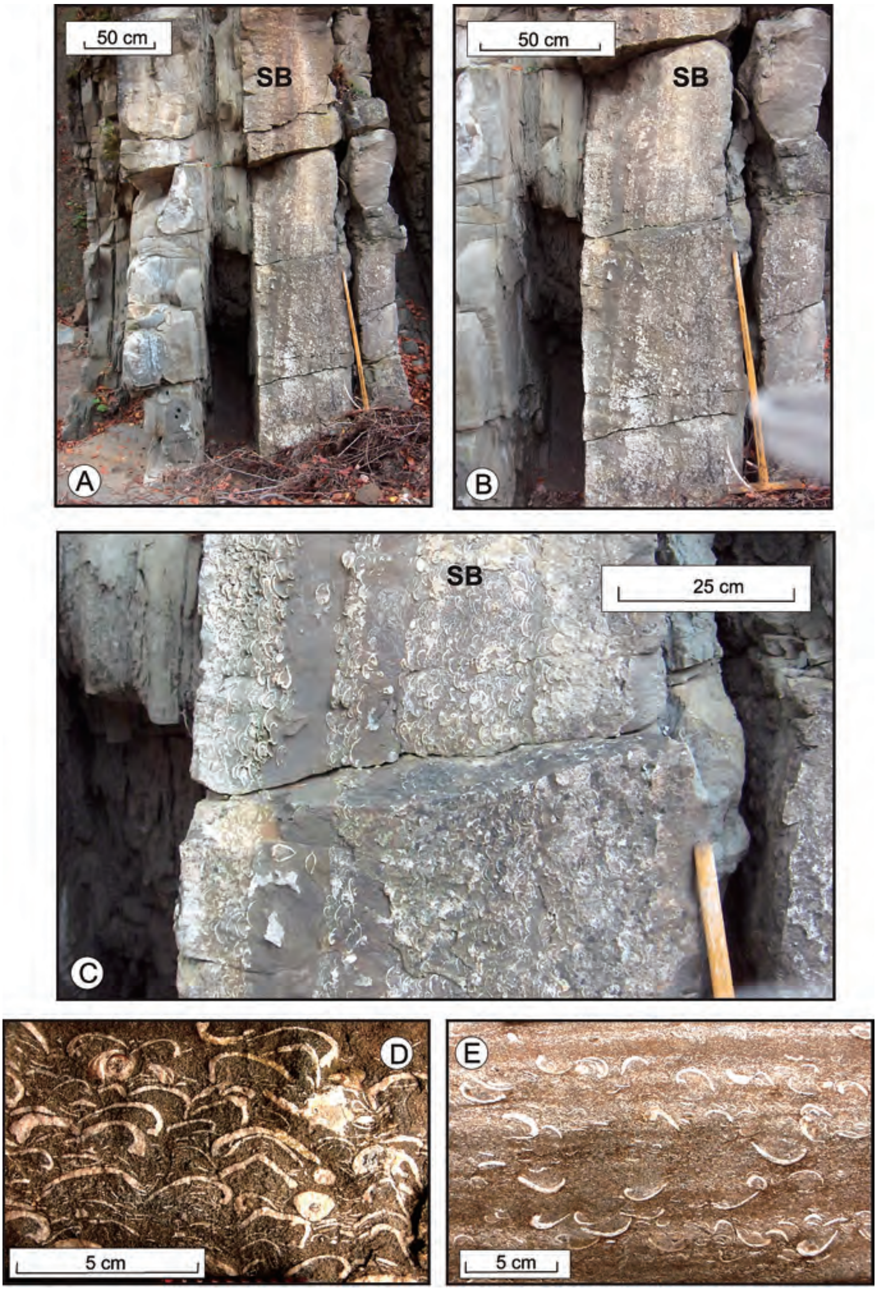


FIGURE 5.20. Late Sarmatian (*s. l.*) shell bed (**SB**) cropping out on the right bank of the Râmnicul Sărat River, north of the village Jitia de Jos (Vrancea County). The pictures **A**, **B** and **C** show the same shell bed at increasing enlargements. **D**. Shell bed with a smaller amount of matrix. **E**. Shell bed with largely dominant sandy matrix

5.2.4. Biological features of the Bizdidel River littoral deposits

The Late Maeotian littoral deposits from the Bizdidel River section (Pucioasa, Dâmbovița County) have been investigated from sedimentological and micropaleontological viewpoints.

The micropaleontological study, carried out through the ostracod analysis, was completed by Radu Olteanu (in Jipa, Olteanu, 2005). The results obtained by Radu Olteanu (Fig. 5.21) are the following:

- Sample 1 (number of specimens in brackets): *Ilyocypris* aff *bradyi Sars* (5), *Candona* aff *compressa* Koch (4), *Pseudocandona albicans* (Brady) (4), *Candona danubiana* Stanceva (8), *Candona* sp. 2, *Hemicytheria* aff. *parva* Stanceva (2), *Chartocythere* aff. *minor* Krstic (3), *Cyprideis* sp. (11). The ostracod community represents a fresh-water biotope, possibly a littoral plain. The presence of five fresh-water species together with brackish-oligohaline species strongly indicate the confluence of two contemporaneous biotopes, a fluvial-lacustrine one and a basinal one;
- Sample 2 (number of specimens in brackets): *Loxoconcha aspera* Olteanu (2), *Candona* aff *dunaviensis* Stanceva (3), *Cyprideis s*p. with tuberculate ornamentation (22 adult and juvenile specimens). The high frequency of the *Cypreides* taxon together with a species of *Loxoconcha* and two species of *Candona* (typologically from the group *C. angulata* G.W. Muller and *C.* ex gr. *caudata* Kaufmann) suggest a fresh-water biotope. The tuberculate ornamentation of *Cyprideis* and presence of juvenile specimens are suplementary indication on the fresh-water nature of the biotope. The mentioned species are common to the limnic facies (Devoto, 1965);
- Sample 3: *Loxoconcha irregularis* Olteanu (1 valve), *Candona* aff. *perrara* Stanceva (8 juvenile valves), explosion of *Cyprideis* (non-tuberculate valves). These Late Maeotian species point to the diminishing of the water salinity;
- Sample 4 (number of specimens in brackets): *Cyprideis* sp. (54 adult valves şi 88 juvenile, non-tuberculate valves), *Loxoconcha aspera* Olteanu (27), *Loxoconcha ovala* Olteanu (18), *Loxoconcha irregularis* Olteanu (5), *Loxoconcha arabesca* Olteanu (3), *Chartocythere intima* Olteanu (4), *Leptocyhere* sp. A (ex gr *Callistocythere (?) negotini* Krstic). The dominance of the Cytheridae and the absence of any fresh-water faunal element indicate a littoral community exclusively brackish;
- Sample 5: eroded valves of *Cyprideis* sp. (non-tuberculated specimenes), *Candona* aff. *danubiana* (one valve);
- Sample 6: *Loxoconcha aspera* (4 adult valves), *Loxoconcha irregularis* (3), valve de *Cyprideis* sp. (50 non-tuberculated valves, adult and juvenile specimens). This is a restrictive community with two survived „opportunistic" species characterized by large ecological tolerance. The high frequency of *Cyprideis*

genus and cohabitation with two *Loxoconcha* species (but no species from the *Leptocythere* group) reveal a dramatic drop of the water salinity. This conclusion is supported by the diminuation of the external ornamentation, of the valves (Olteanu, 1989);

- Sample 7: population exclusively of *Cyprideis* sp. with non-tuberculated valves, suggesting a fresh-water biotope;
- Sample 8: almost similar with sample 7.

All the eight samples collected from the littoral Late Neogene sequence cropping out on Bizdidel River, are charaterized by a tuberculate/non-tuberculate ratio of 12/1. This ratio indicates an unstable biotope, at the limit between liminic and brackish environments.

The biological environment evidenced the ostracod analysis carried out by Radu Olteanu, and confirms the littoral environment outlined through sedimentological investigation. The shoreline is realistically illustrated as the biotope at the limit between the brackish and fresh-water environments.

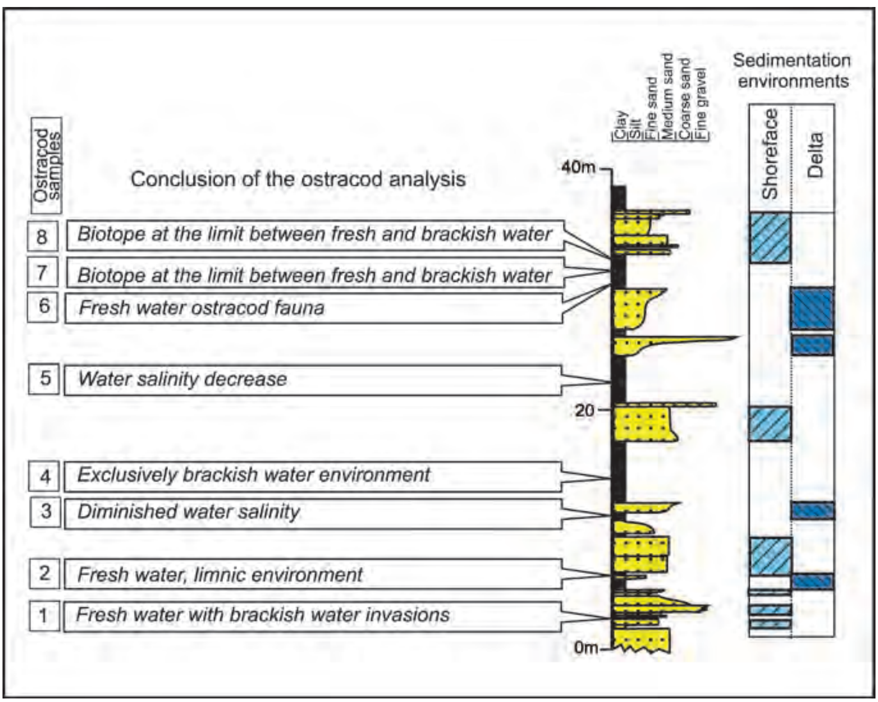


FIGURE 5.21. Sedimentary littoral environments and their biologic features. The paleobiological characteristics are based on the ostracod analysis carried out by Radu Olteanu (in Jipa, Olteanu, 2005). Late Maeotian deposits from Bizdidel River, Pucioasa (Dâmbovița County)

5.3 DELTAIC ENVIRONMENT IN THE DACIAN BASIN

An important part of the deltaic sedimentation is taking place in the shoreface area. The two environments are sometimes difficult to be clearly separated in old rocks. Treating the subject of littoral environment in the Dacian Basin, the shoreline and deltaic paleoenvironments have been delimitated on the following pragmatic basis:

- the sediment accumulation displaying features determined by wave and storm action have been attributed to the shoreline environment;
- deposits with progradation characteristics but without sedimentary structures produced by basinal agents (waves and storms), have been considered as fluvial-dominated delta-front sediment accumulation;
- a third environmental type is represented by sedimentary sequences with both fresh-water and brackish-marine features. This kind of sediment accumulation has been interpreted as representing the deltaic plain environment.

5.3.1. Delta front sedimentation

When it is associated with the absence of wave or storm sedimentary structure, the coarsening upward grain size trend is the main feature of the Dacian Basin sediment bodies interpreted as deltaic units. This is the major argument on which the assignment of these units to the delta front sedimentation environment is based.

Deltaic coarsening upward units. Both surface, outcrop observations and subsurface, well logs examination produce data concerning the deltaic coarsening upward. The direct, outcrop observations point out the variable grain size range of the coarsening upward deltaic bodies. Some deltaic units are fine-grained and evolve from silty sand in the base, to fine or medium-grained sand at the terminal part (Fig. 5.22). Other Dacian Basin deltaic sequences show a large grain size variation, from silt or very fine sand at the base, to fine-grained gravel on top (Fig. 5.23). Even if the top of the sequence is not much coarser-grained as compared to the grain size at the base, the coarsening upward trend is sometimes emphasized by small pebbles (clay but also quartzite) and shell fragments occurring at the terminal upper part of the unit (Fig. 5.22 B).

The grain size variation of the Dacian Basin deltaic units can also be expressed by the thickening upward of the sand beds (Fig. 5.24). In this way, the sand/clay ratio is changing and the sedimentary unit is getting coarser-grained toward the top.

Coarsening upward sequences are confidently observed on the well logs (Fig. 5.25). The geometry of the deltaic unit is sometimes more completely and suggestively presented by the borehole geophysical logs. The Dacian Basin deltaic units are usually multiple, consisting of a succession of coarsening upward units. Each unit display a coarsening upward pattern (Fig. 5.25 B).

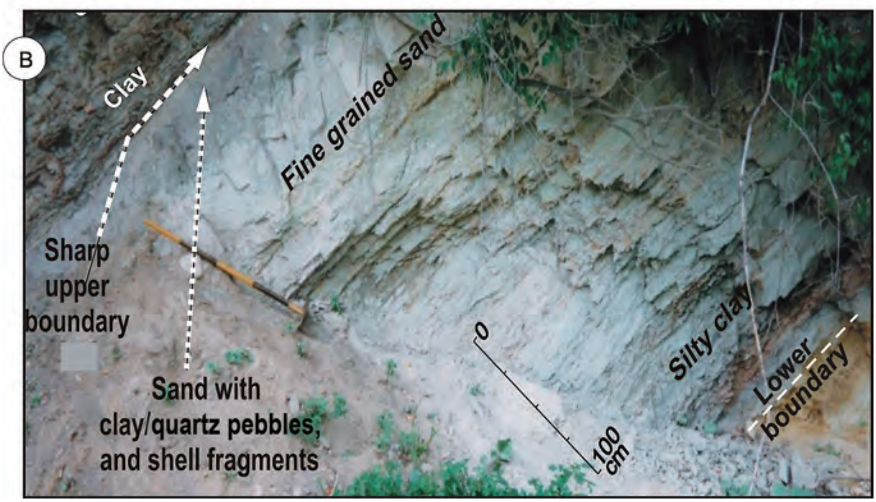


FIGURE 5.22. Coarsening upward, fluvial dominated deltaic sequences. **A** - Early Dacian, Prahova River, right slope (Bobolia village, Prahova County). From Jipa *et al.* (2007). **B** - Late Maeotian, Bizdidel River (Pucioasa, Dâmbovița County)

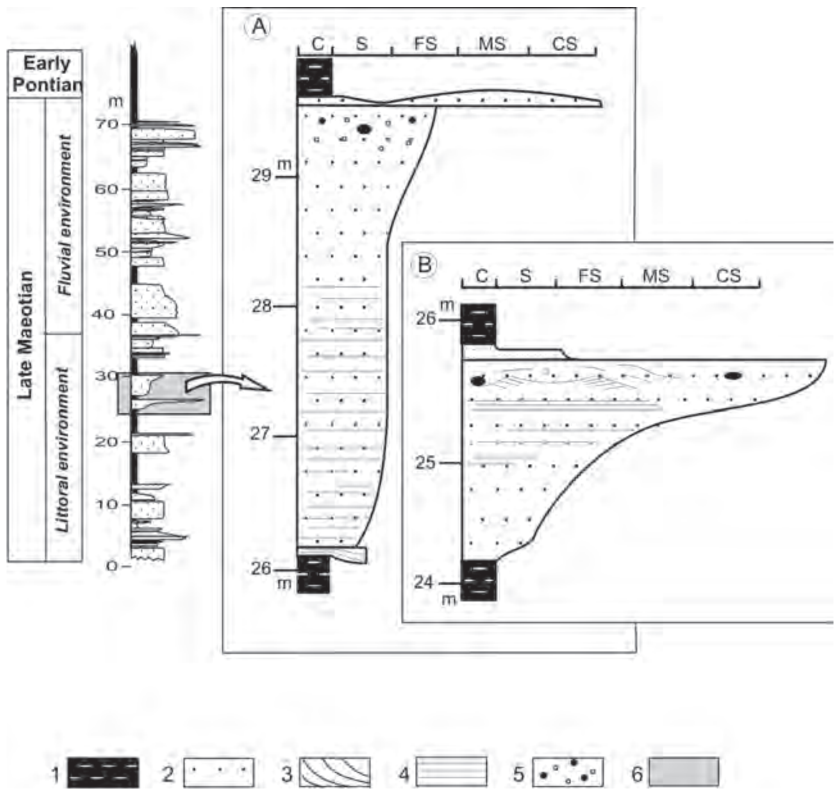


FIGURE 5.23. Coarsening upward, fluvial dominated deltaic units in the Early Dacian. Late Maeotian, Bizdidel River (Pucioasa, Dâmbovița County). From Jipa *et al.* (2007). Left side - stratigraphic column of the Maeotian deposits. The coarsening upward unit **A** is also presented in figure 5.22 B. **Legend**: **1**. Clay. **2**. Sand and silt. **3**. Cross lamination. **4**. Parallel lamination. **5**. Hard and soft pebbles. **C** - Clay. **S** - Silt. **FS** - Fine-grained sand. **MS** - Medium-grained sand. **CS** - Coarse-grained sand

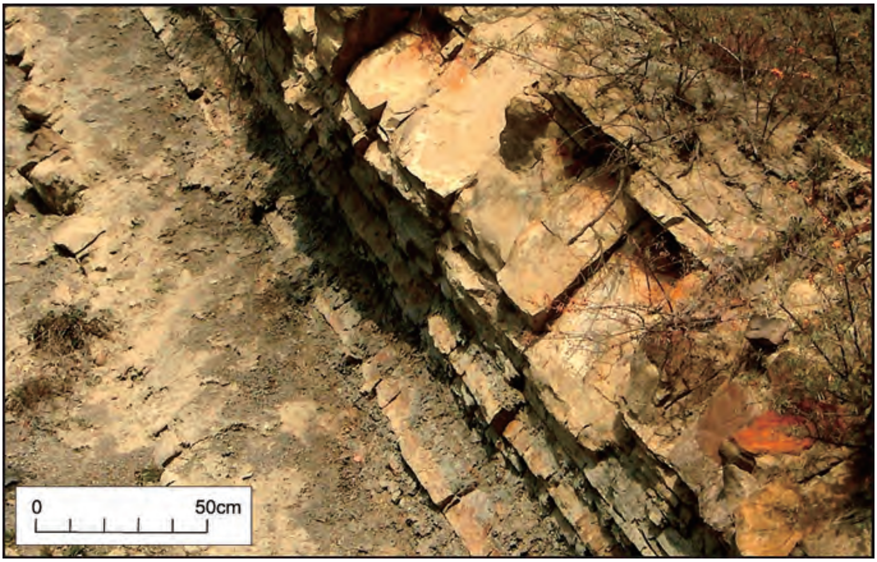


FIGURE 5.24. Coarsening upward trend expressed by the thickening-upward of the sandstone beds. The alternating claystone beds are implicitly thinning upward. Maeotian, left bank of the Slănicu de Buzău River, at Mânzăleşti (Buzău County)

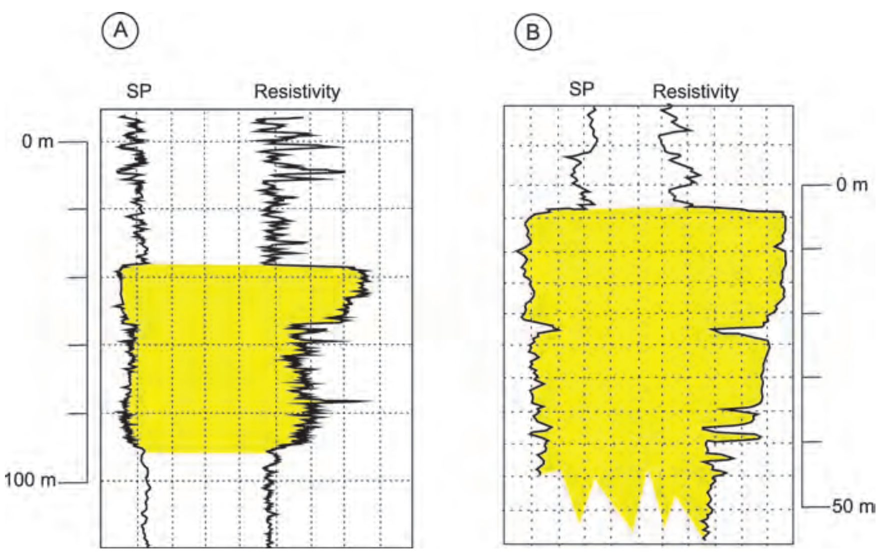


FIGURE 5.25. The well log image of the Early Dacian deltaic sedimentary bodies

The sharp upper limit is a typical feature of the Dacian Basin deltaic, coarsening upward bodies. This character is distinct on well logs (Fig. 5.25) and in outcrops (Fig. 5.26).

Some of the observed deltaic units, especially the finer-grained ones, are not showing internal sedimentary structures, except some vague lamination (Fig. 5.26 A). Intense bioturbation (Fig. 5.27) could be one of the causes of the apparent homogeneity. Bedding is clearly indicated in some instances (Fig. 5.22 A), with alternation of sediments with not very different grain size. Current lamination is frequent, mostly for deltaic units with medium or coarse-grained sand at the upper part of the units. Current ripples, sometime at large scale (Fig. 5.28), occur at the top limit of the Dacian Basin coarsening upward deltaic bodies.

The mass transport delta. A special type is the deltaic body with delta-front sediment mass transport. This type of delta was documented at the Bădislava geological section (Jipa *et al*., 1996), where it displays three succeeding facies (Fig. 5.29):

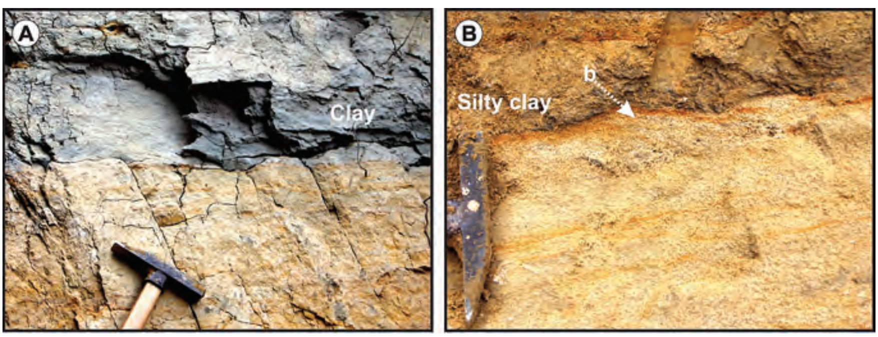


FIGURE 5.26. Sharp limit at the top of the deltaic bodies. **A**. Top part of a fine grained (fine sand) deltaic body. **B**. Middle to coarse grained sand at the upper boundary of a deltaic body. Note the current ripples at the very top (**a**). Early Dacian, Prahova River, right slope (Bobolia village, Prahova County). From Jipa *et al*. (2007)

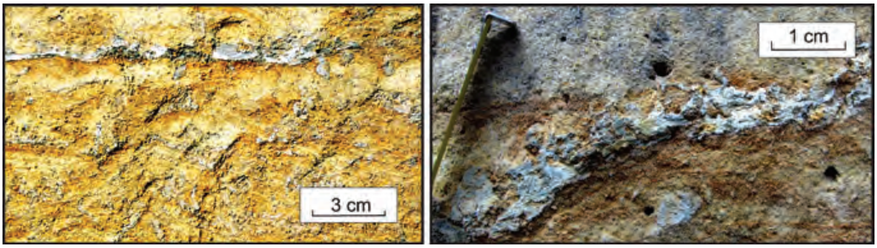


FIGURE 5.27. Sediments of the coarsening upward deltaic units displaying advanced bioturbation. Early Dacian, Prahova River, right slope (Bobolia village, Prahova County)

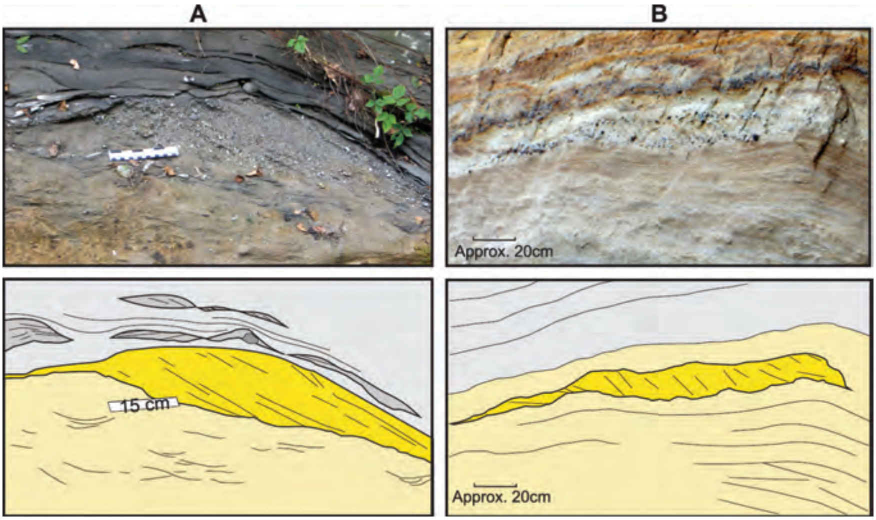


FIGURE 5.28. Large scale current ripples at the top of the Dacian Basin coarsening upward deltaic units. **A**. Late Pontian, Bădislava River (Bălileşti, Argeş County). **B**. Early Dacian, Prahova River, right slope (Bobolia village, Prahova County)

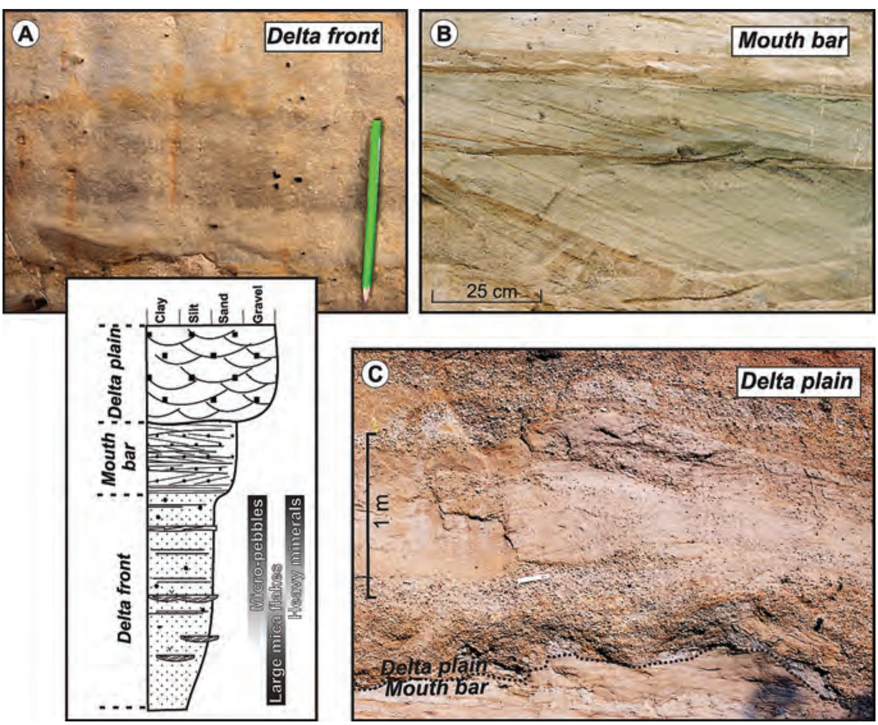


FIGURE 5.29. Bădislava River deltaic body, with sediment mass-transport in the delta front unit. Note the erosional contact at the base of the delta plain sediments, as well as the large intra-depositional clay pebbles. The darker colored spaces in the picture **A** are heavy minerals concentrations

- fine and very fine sand with large mica flakes in the lower part and scattered micro-pebbles in the upper part of the interval (Fig. 5.29 A);
- tabular cross-laminated fine and medium-grained sand (Fig. 5.29 B);
- pebbly sand with large scale trough cross-lamination (Fig. 5.29 C).

In accordance with its gravitational characteristic, marked by the presence of the small quartzitic pebbles randomly distributed in a dominant sandy matrix, the lower fine-grained sand facies was attributed to the delta front environment.

The upper gravelly unit was ascribed to the delta plain environment. This interpretation relies on the pebbly sand sedimentary unit displaying the characteristic features of the fluvial sediment accumulation.

Just because it occurs in between delta front and delta plain deposits, the tabular cross laminated sand was interpreted as a mouth bar accumulation.

Delta front heavy mineral concentrations. A special feature of the gravitational delta discussed above is the presence of heavy mineral concentrations (Fig. 5.29 A) at the upper part of the facies interval interpreted as delta front environment.

The heavy minerals accumulations are hommogeneous or laminated. The homogeneous aspect is related to the absence of clear bedding. Small (mostly up to 5 mm in diameter) quartzitic pebbles, distributed at random into the fine-grained sandy matrix, coexist with the heavy minerals. Bioturbation structures have been observed. The heavy mineral rich bands (Fig. 30 A) are sometimes showing the bedding.

The laminated aspect (Fig. 5.30 B) is characterized by parallel and trough-like laminae with concentrated heavy minerals.

Abundant mica grains, some of them as large flakes (2 – 4 mm) occur at the lower part of the delta front facies interval. The muscovite flakes are distributed in the mass of the very fine-grained sand, or concentrated in cross lamination troughs.

The presence of the two superposed intervals, heavy minerals and muscovite-rich, is here interpreted as an indication of a differential sedimentation process, which took place on the delta front slope. The heavy minerals settled down first, together with the small pebbles, on the upper slope of the delta front, due to their higher specific gravity. The random distribution of the pebbles and irregular shape of the heavy mineral bands (Fig. 5.29 A) suggest the particles have been transported by mass transfer. The mica particles have been further maintained in suspension, in view of their lower settling velocity and higher floating capacity, and settled down on the lower part of the slope.

On the delta front slope, the sediment transport was discontinuous. In between two mass flow events, weak currents reworked the heavy mineral-reach deposit and concentrated the heavy minerals as parallel and concave laminae.

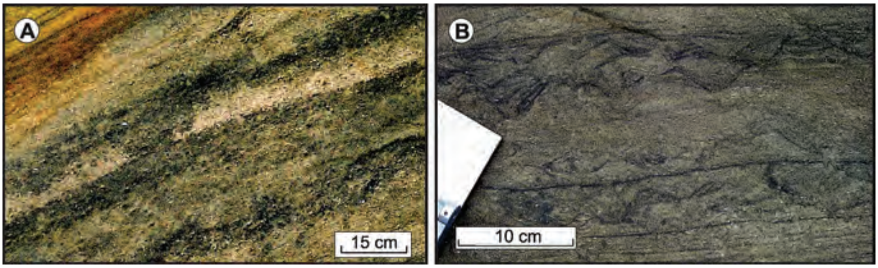


FIGURE 5.30. Types of heavy minerals occurrence in the deltaic deposits from Bădislava River geological section (Bălileşti, Argeş County). **A** - The homogeneous aspect. The darker colored irregular bands are rich in heavy minerals. Note the frequent small pebbles. **B** - The laminated aspect. The dark lamineae are heavy minerals-rich.

Thickness of the deltaic sedimentary bodies. The thickness of most of the Dacian Basin coarsening upward deltaic units studied in outcrops varies in the 5 to 15 meters range. The subsurface data, based on measurements in 73 boreholes (Jipa *et al*., 2007), indicate deltaic bodies thickness ranging between 23 meters and 85 meters (see Chapter 11).

Significant thickness variation within a unitary deltaic body has been observed. In Bădislava River area (Fig. 5.31), a coarsening upward sedimentary unit displays lateral variations from less than 10 m to more than 15 m thickness. The upper, gravely unit of the studied deltaic body occurs discontinuously.

5.3.2. Delta plain sedimentation

In the previous 5.3.1 chapter, a gravely upper facies from Bădislava River area has been attributed to the delta plain environment. The premises for this interpretation are very limited. The Middle Pontian deposits cropping out on Slănicu de Buzău River at the Sârbeşti village, which are here presented as belonging to the delta plain environment, offer a relatively large array of sedimentary features (Fig. 5.32). This makes up a solid ground for a rational sedimentary paleoenvironment reconstruction.

The main outcome of the Middle Pontian sediment investigation refers to the coexistence of brackish-marine and continental-fluvial sediment accumulation processes. The picture which emerges out of this study is that of a fluvial network (distributary channels and their flooding plain), which was laterally switching by avulsion and allowed brackish-marine shoreline sediments to accumulate in the same area. This is an example of the interplay between the wave energy and the fluvial input.

The Middle Pontian sedimentary sequence, cropping out on Doftana River (near Câmpina, Prahova County; not very far from Sârbeşti), displays only delta front sedimentary features. The Doftana and Sârbeşti units could be parts of a Middle Pontian deltaic environment of the Dacian Basin. The fluvial channels documented by the Sârbeşti study could represent the distributaries which carried sediment and built up deltaic lobes, with delta front sediments like those observed in the Doftana outcrops. The modern erosion probably exposed either the frontal part of the deltaic system (Doftana River geological section) or the rear area of the system (the delta plain sediments from Sârbeşti).

In the area where the Sârbeşti Middle Pontian deposits have been investigated, the brackish-marine sediments are represented by clayey sequences with sand bed intercalations. Some of the sand interbeds, with current lamination and sporadic wave ripples, are coarsening upward (Fig. 5.33 A, B, C). There are also thinner sand interbeds with wave ripples (Fig. 5.34 A and B).

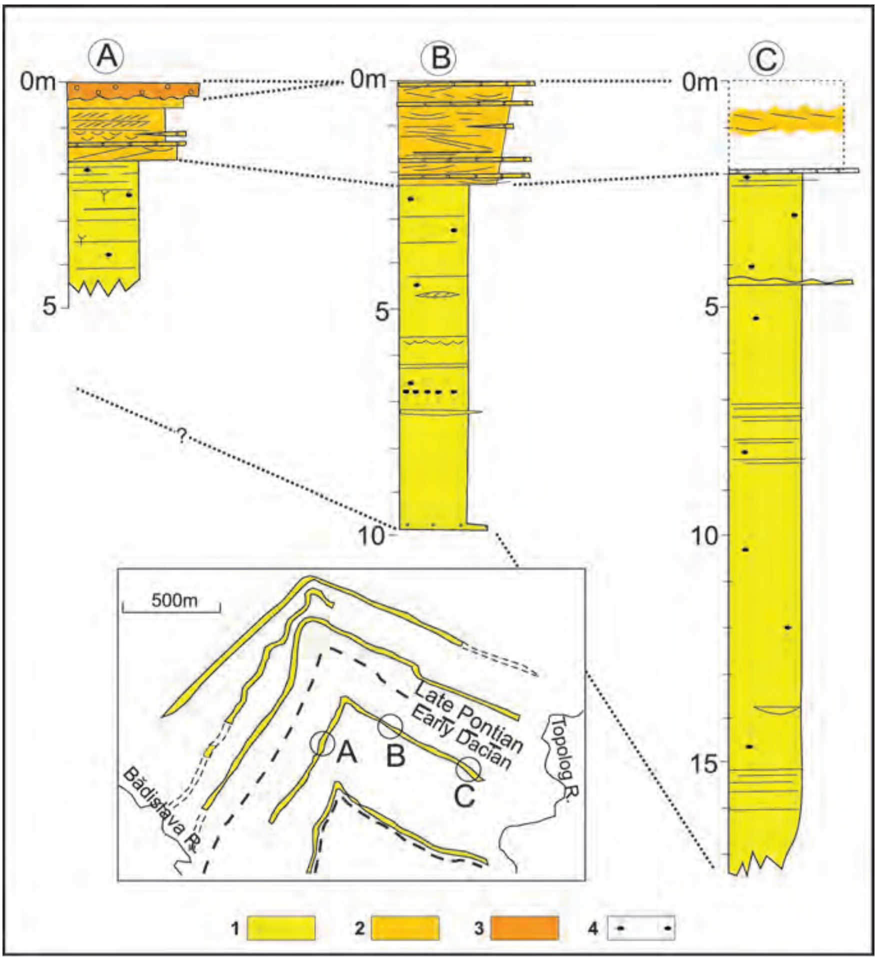


FIGURE 5.31. Lateral variation of a deltaic body. Early Dacian,Tigveni (between Bădislava and Topolog rivers), Argeş County. **Legend**: **1**. Fine and very fine grained sand. **2**. Medium and coarse grained sand. **3**. Fine grained gravel. **4**. Micro-pebbles

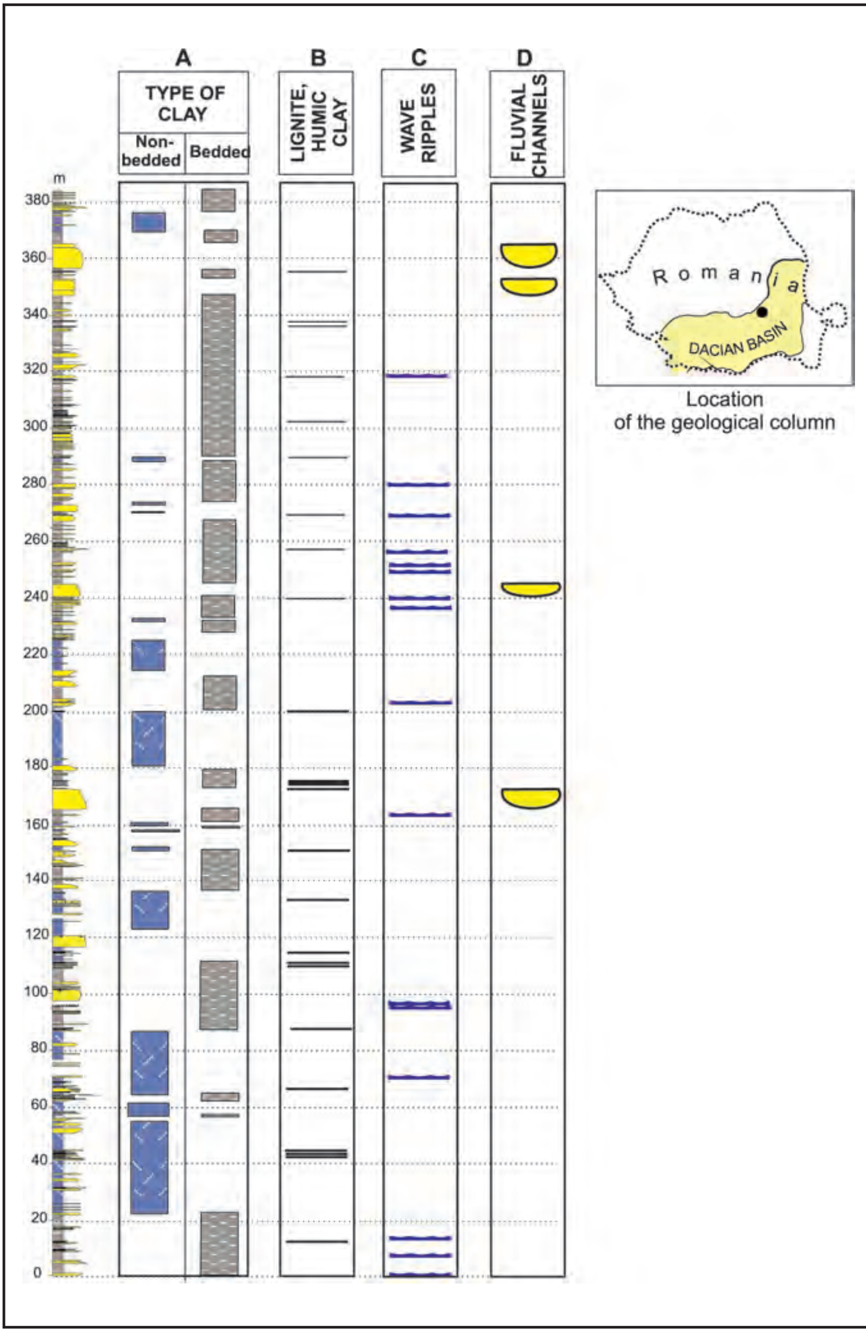


FIGURE 5.32. Sediment succession and the main facies features of the Middle Pontian deposits from Slănicu de Buzău River (Sârbeşti, Buzău County)

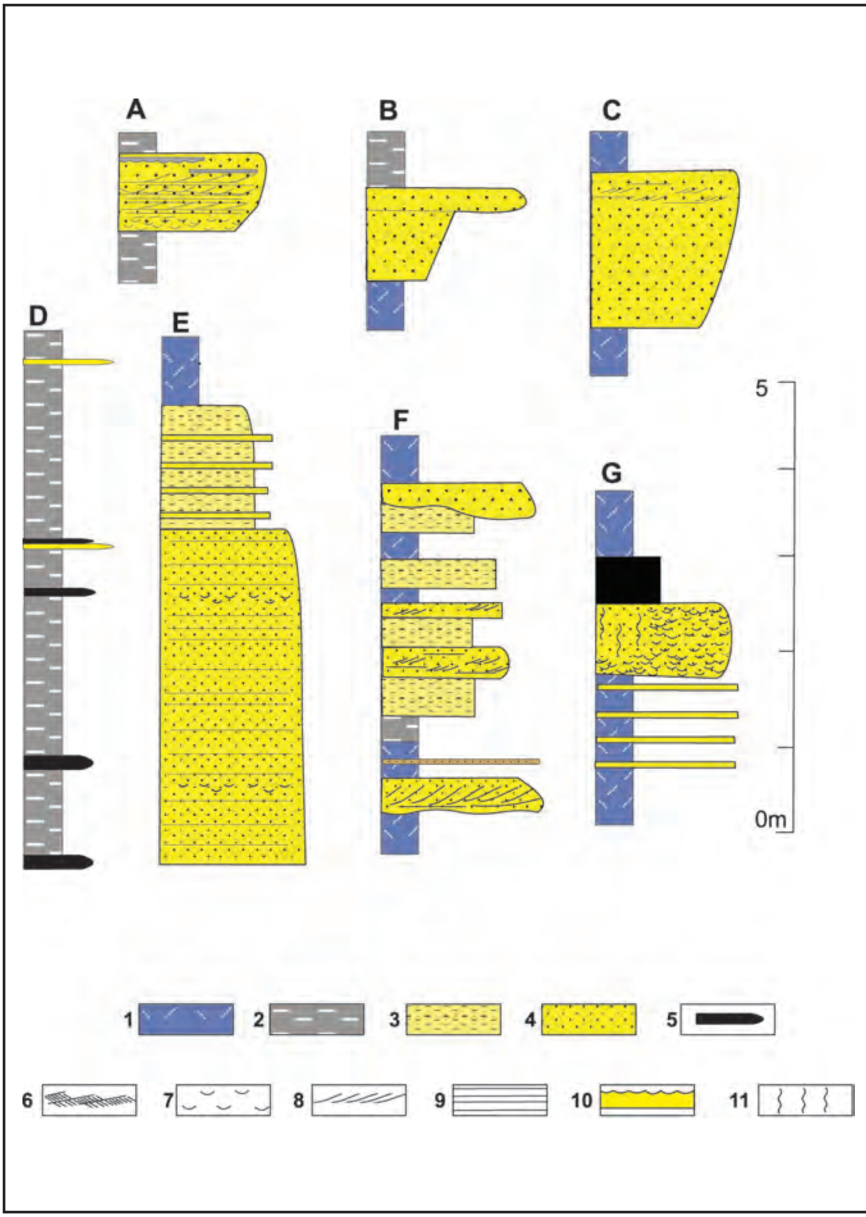


FIGURE 5.33. Main types of genetic sedimentary units in the Middle Pontian delta plain environment. **A**, **B** and **C** - Brackish marine sequences. **D** - muddy floodplain environment. **E** - Fluvial channels. **F** and **G** – Sheet-flood sequences. Middle Pontian, Slănicu de Buzău River, Sârbeşti village, Vrancea County. **Legend**: **1**. Homogeneous clay. **2**. Bedded clay. **3**. Silt. **4**. Sand. **5**. Coal and humic clay. **6**. Climbing ripple lamination. **7**. Trough cross-lamination. **8**. Tabular cross-lamination. **9**. Parallel lamination. **10**. Wave ripples. **11**. Fossil traces.

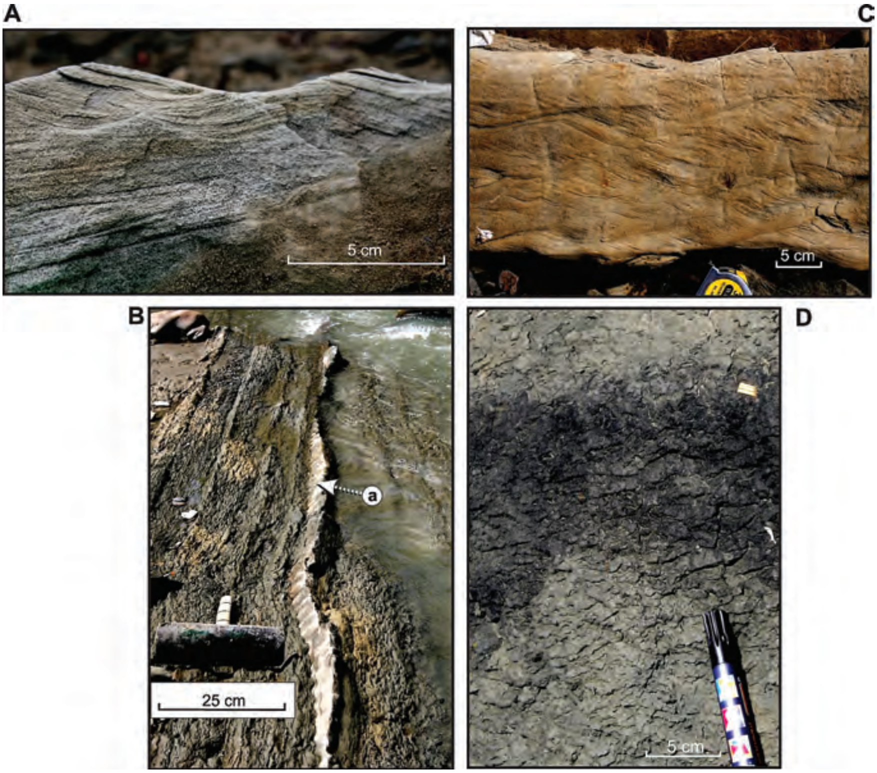


FIGURE 5.34. Sedimentary aspects of the delta plain environment. **A**. Wave ripples. **B**. Brackish marine sequence with a wave-rippled bed (a). **C**. Sheet-flood, climbing laminated sediments. **D**. Muddy flood plain sediments. Note the gray non-bedded clay and the dark humic clay

The muddy floodplain sediment with humic clay or lignite intercalation (Figs. 5.33 D; 5.34 D), are the fluvial genetic unit with large occurrence in the Middle Pontian sedimentary sequence from Sârbeşti.

The fluvial channels are a very important feature in the structure of the Sârbeşti continental system. The channel fills are fining upward sand accumulations, with frequent current lamination internal structures (Fig. 5.33 E). Their thickness is usually around 4-5 m, but occasionally reaches more than 10 m. The width of one of the largest channel unit is more than 60 m.

The fluvial sedimentary succession studied at Sârbeşti includes sand interbeds, usually thinner than 1m (Figs. 5.33 F and G). Their internal sedimentary structures are current generated, but the medium scale cross lamination appears to be characteristic. Climbing ripples have been observed in several cases (Fig. 5.34 C). The sheet-like geometry of some of these sand beds has been documented, tracking the sand unit on several tens of meters (Fig. 5.35). In accordance with its features, this type of sediment body was attributed to the sheet-flooding process (Fisher *et al*., 2007).

The presence of fluvial crevasse splay sediments was not evidenced during the study of the Sârbeşti Middle Pontian sequence. It is possible that some of the thinner coarsening upward sand beds that we ascribed to the brackish-marine system represent in fact fluvial crevasse splay sediments.

FIGURE 5.35. Tabular cross-laminated sand beds with large extent (pointed out by arrows) attributed to the sheet-flood facies. Middle Pontian, Slănicu de Buzău River, Sârbeşti village (Buzău County)

5.4. SOFT SEDIMENT DEFORMATION IN THE LITTORAL DEPOSITS

Soft sediment deformation structures are present in the littoral successions from the Dacian Basin. According to the relationships with the undeformed sediments below and above (Fig. 5.36), the structures are intraformational and syndepositional.

Some distortions are soft-sediment coherent deformations (Fig. 5.36 A). In some cases (Fig. 5.36 B), the aspect of the deformed structure might be the result of several processes (Horne, 1968):

- initially the bedded sediment was folded, probably by down-slope movement;
- the folded sediment suffered post-sliding erosion, which cut the anticline part of the folds and the synclinal parts became discontinuous;
- the sedimentation which took place after the slumping and erosion covered discordantly the deformed sediments.

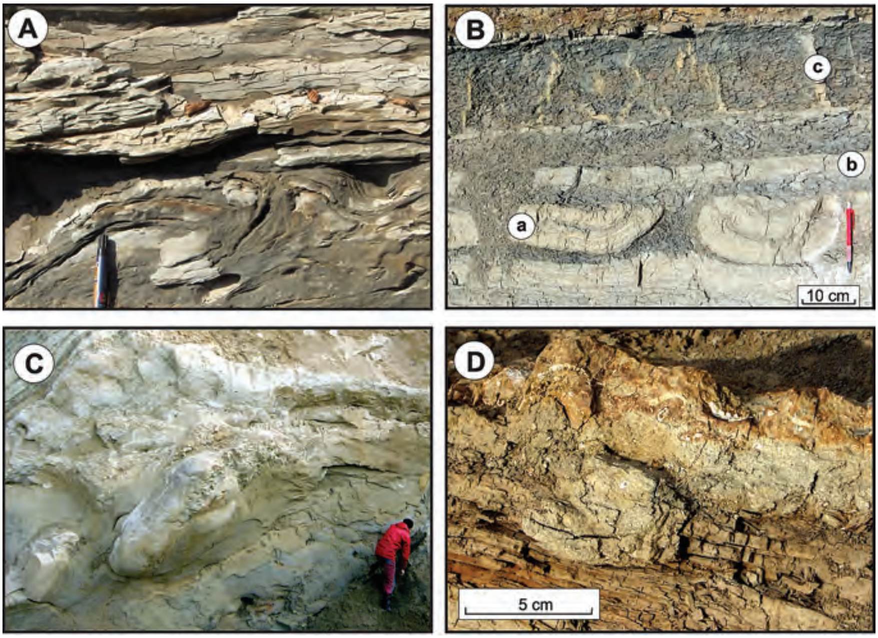


FIGURE 5.36. Sediment slumping structures in the littoral deposits from the Dacian Basin. **A**. Coherent syn-depositional deformation. Early Dacian, Bădislava River, Bălileşti village (Argeş County). **B**. Syn-depositional distortion (a), followed by erosion before the accumulation of the covering, undeformed sediments (b). Note clastic dykes (c), showing little or no compaction. Early Dacian, Râmnicu Sărat River, Chiojdeni village (Vrancea County). **C**. Large scale mass-transport breccia. Early Dacian, Râmnicu Sărat River, Chiojdeni village (Vrancea County). **D**. Mass-flow breccia consisting of shells and fragments of shells in a silty matrix. Early Dacian, Râmnicu Sărat River, Chiojdeni village (Vrancea County)

Clastic dykes can be observed in the undeformed sediments just above the slumped beds. The geometry of the dykes suggests that post-slumping compaction was not significant.

In contrast with the coherent deformations, in the littoral deposits syndepositional, highly destructed deposits have been also noticed. They probably represent the mass-flow events triggered by sediment sliding. The mass-transported sediment consists of fragments of rocks, hard and soft pebbles and shells, embedded in a fine-grained matrix. This type of breccias occurs either at a large scale (Fig. 5.36 C) or at a small scale (Fig. 3.36 D).

5.5. DACIAN BASIN SEDIMENTARY ENVIRONMENT BELOW THE FAIRWEATHER WAVE BASE

The sedimentary environments analysis depends a great deal on the interpretation of the sedimentary structures and implicitly on outcrop observation. Most of the Dacian Basin extent is covered with Quaternary deposits (Fig. 1.2). Practically, all the good outcrops are located in the sub-Carpathian proximal (littoral) zone of the basin. This is why at the present time we know very little about the sediment accumulation environments of the axial and external parts of the Dacian Basin.

5.5.1. Deeper-water sediment accumulation in the Dacian Basin

The western end of the Dacian Basin is the only area where there are arguments for deeper-water sedimentation depth. This is based on the presence of a large scale progradation structure (Fig. 4.6), whose thickness approximates the sediment accumulation water depth. On this basis, Leever (2007) appreciates the minimal water depth in the western Dacian Basin to 300 m. The deeper-water sediments accumulated in the western part of the Dacian Basin are fine-grained. The well logs and the drill cuttings of the Băleni 1 well (Mehedinţi County) (Fig. 5.37) show that Maeotian-Pontian sediments consist of clay or silty clay, with very thin fine-grained sand (or silt) intercalations.

The persistent absence of any wave or storm sedimentary structure within a Dacian Basin littoral sequence is regarded as a possible indication of an environment placed under the fair-weather wave and storm base. However, a supplementary indication is necessary to validate such interpretation.

This reasoning was applied to a sand dominated facies investigated in the Olteț River geological section (Cireşu village, Vâlcea County).

One of the facies of the Maeotian deposits cropping out along the Olteț River consists dominantly of sand, with thin clayey intercalations (Fig. 5.39). Some of the sand beds are lens-like and their bottom limit cuts discordantly the underlying thin clay and sand beds. Other sand beds are tabular and extensive. The internal structures of the sandy Maeotian facies are current generated. Parallel and larger scale cross lamination, as well as small channel fills (Fig. 5.39 A) are displayed by the thicker (up to 50 cm) beds. Smaller scale current ripples associated with parallel lamination are frequent in thinner bedded sediments (Fig. 5.39 B and C).

No fair-weather wave or storm generated sedimentary structures have been observed in the sandy deposits from the Olteț River section. This suggests a possible deeper-water sediment accumulation.

Other features of the Maeotian Olteț River sequence are corroborating the deeper water indication suggested by the absence of the wave and storm ripples. Sediment mass flow processes are pointed out by the occurrences of breccias, consisting of resedimented clay and sand pebbles enclosed in a sandy matrix.

Two levels of breccias occur in the basal part of the Olteț River sequence. The Maeotian-Pontian sedimentary succession shows a large scale fining upward trend, a feature which is frequent to submarine fans.

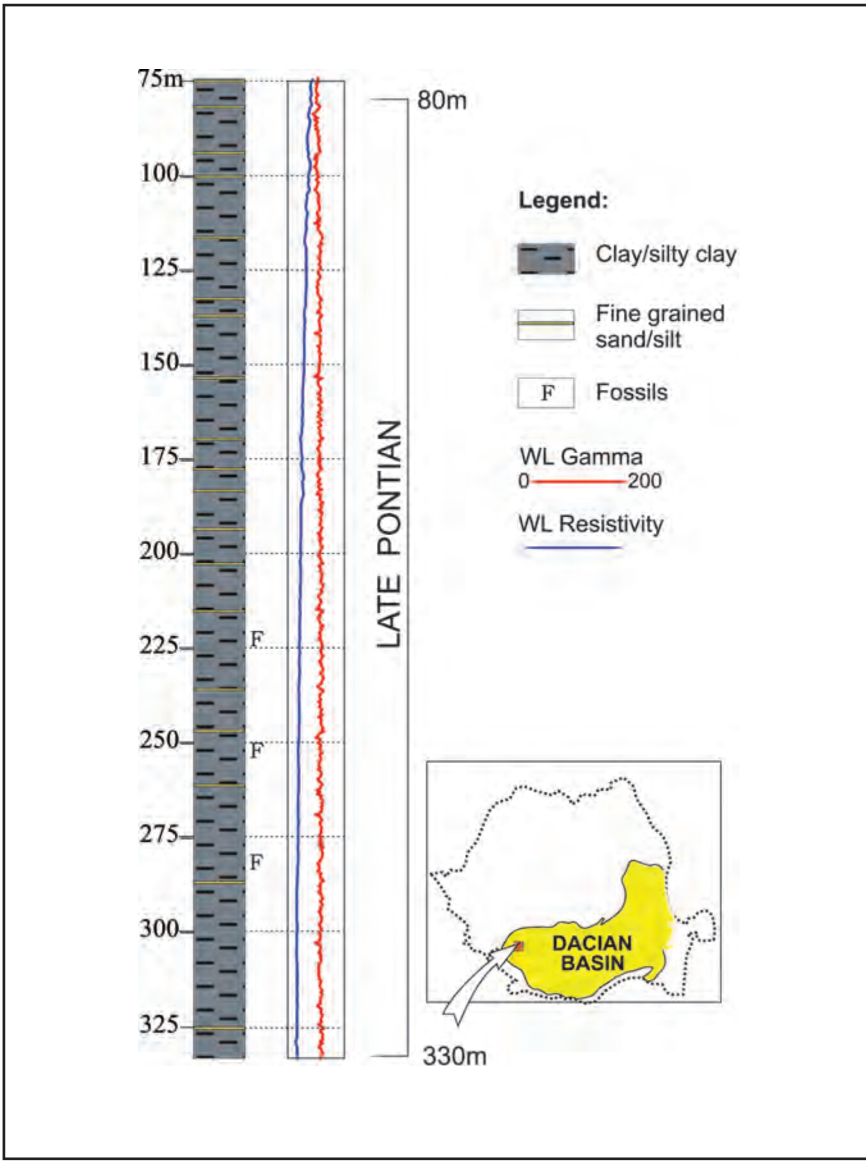


FIGURE 5.37. Example of the lithofacies from the western Dacian Basin. Well log of Baleni 1 well (data supplied by Rompetrol and Zeta Petroleum companies). See the index map for well location

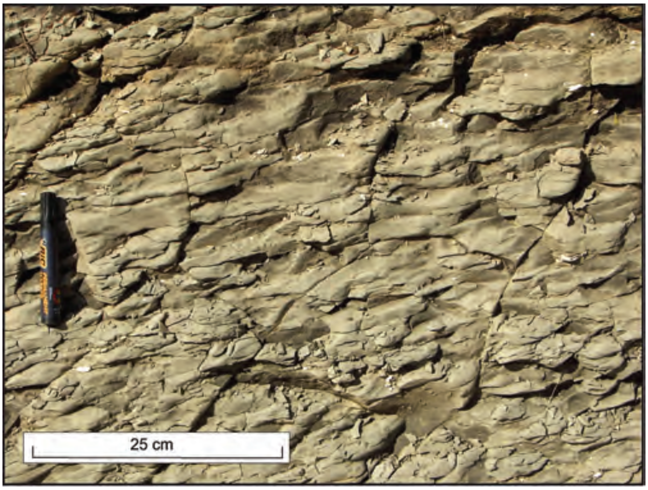


FIGURE 5.38. Early Dacian clay deposit in the littoral sequence cropping out on Bădislava River, Bălileşti (Argeş County). Note the apparent absence of bedding

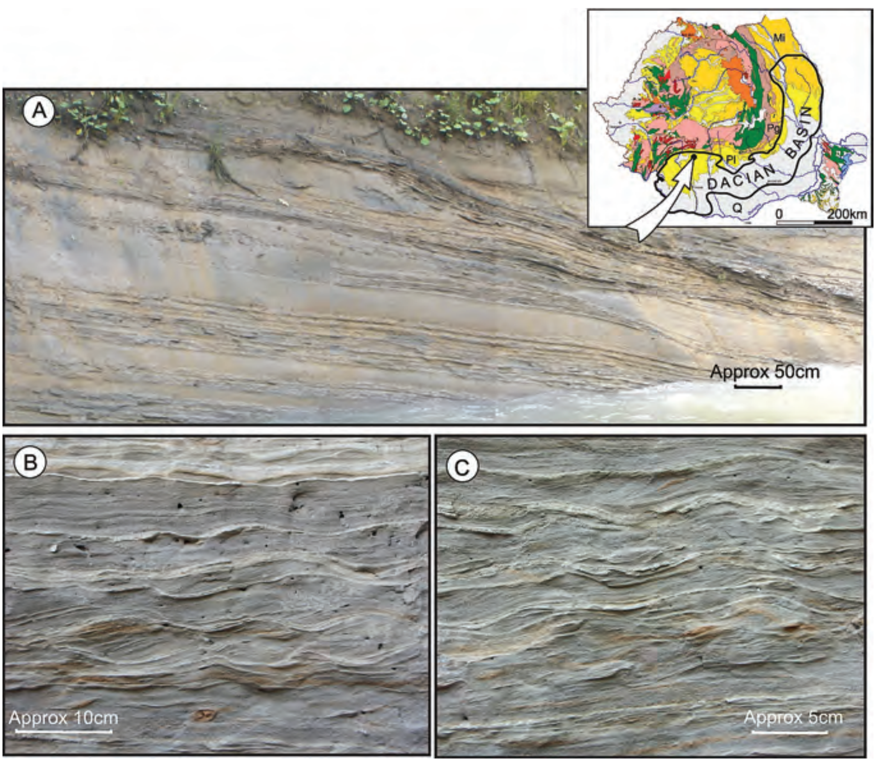


FIGURE 5.39. Current-transported Maeotian sediments interpreted as deeper-water accumulation, under the wave base. **A**. General aspect. Note the channel fill bodies with erosional relief. **B** and **C**. Small scale current structures. Upper right - index map, using the geological map of Romania (prepared by the Geological Institute of Romania). Olteţ River, Cireşu village (Vâlcea County)

Presently no specific sedimentation depth can be assigned to the sedimentary sequence cropping out along the Olteţ River. The only depth range which can be argued is the accumulation environment bellow the base of the fair-weather wave and storm action.

5.5.2. Littoral clay deposits: offshore or sediment-starved facies

Clay deposits are quantitatively dominant in the cropping out littoral sediment sequences from the central and western part of the Dacian Basin. Usually, these sediments have frequent intercalation of sand, mostly fine-grained. In the Bădislava River geological section, there are clay intervals, several tens of meters thick, practically devoid of any sandy or silty interbeds (Fig. 5.38).

The clayey intervals like those occurring on Bădislava River have been considered as offshore-type facies (Jipa *et al*., 1999). This interpretation is based on the lack of sand or silt intercalations, which suggests a calm sedimentation environment, outside the sand material influxes.

Presently, we believe that the calm environment aspect is better explained as a result of the lack of sand particles supply, because the clay deposits occur in the proximal, sub-Carpathian margin of the basin. Consequently, the littoral clay deposits could serve as markers of the sediment-starved time intervals.

5.6. CONCLUSIONS

The Dacian Basin sediment accumulation displaying features generated by wave and storm action have been attributed to the shoreline environment.

A separation was made between lower energy and higher energy wave-dominated shoreline environment, according to the thickness of the sandy units intercalated in the clayey sequence and to the presence of the coarsening upward trend. The sequences attributed to the lower or higher energy shoreface might also represent sediment accumulation in the lower or middle shoreface area. The rate of sediment influx could also control the character of the two types of shoreline sequences.

Parallel laminated shoreface sediments accumulated in a very high energy shoreline environment. The trough cross lamination and/or wave ripples at the upper part of sequence indicate that the environment was getting more tranquil at the end of the high energy event.

Shell beds in the Dacian Basin shoreline environment are of detrital origin, resulting by current transport and sedimentation. The shell accumulation required a high energy transport agent, acting in the shoreline or near shore environment. The storm-generated currents represent the agent able to transport, concentrate and accumulate the shells.

The storm-generated, hummocky-type structures occur in sequences with coarsening upward trend (prograding shoreline), as well as in non-graded sequences (stable, aggrading shoreline). The alternation of hummocky cross lamination and smaller structures, probably wave ripple lamination, reflects the fluctuation of storm and fair weather conditions.

The Dacian Basin fluvial-dominated delta-front deposits are coarsening upward and do not show (but very seldom) sedimentary structures produced by basinal agents (waves and storms). A special type is the deltaic body with delta-front mass transported sediment. This character is indicated by the presence of small quartzitic pebbles randomly distributed in fine-grained sand.

The deltaic plain environment of the Dacian Basin is represented by sedimentary sequences with both fresh-water and brackish-marine features. The picture which emerges is that of a fluvial network (distributary channels and their flooding plain) which switched laterally by avulsion and allowed brackish-marine shoreline sediments to accumulate in the same area.

Chapter 6

UPPER NEOGENE FLUVIAL SEDIMENTATION IN THE DACIAN BASIN

Fluvial sedimentation played a major role in the Dacian Basin evolution. The fluvial sediments were widely spread during the terminal part of the Sarmatian (*s. l.*) and in the upper Maeotian, but especially, in the middle Dacian-Romanian time interval. This chapter presents these sediment successions and their sedimentogenesis.

The bulk of the Dacian Basin fluvial sediments, of Middle Dacian-Romanian age, is deposited after the brackish-marine basin filled out and closed (Fig. 6.1).

The fluvial accumulations younger than Middle Dacian time (4.5 Ma) are part of the brackish-marine system, occurring as proximal facies at the sub-Carpathian margin of the Dacian Basin. The most important sub-Carpathian fluvial activity was recorded during the Late Sarmatian (*s. l.*) and the Late Maeotian (Fig. 6.1). The fluvial deposits younger than Middle Dacian time which are part of a deltaic system have been presented in Chapter 5.

6.1. SEDIMENTARY CHARACTERISTICS OF THE FLUVIAL DEPOSITS IN THE DACIAN BASIN

6.1.1. Litho-facies aspects

One of the Dacian Basin features is the deficiency of very coarse grained (gravel-sized) sediments. This characteristic is mainly reflected in the lithology of the fluvial deposits. The conglomerate (partly with an important sandy character) is best represented in the lithology of the Late Sarmatian (*s. l.*) accumulations at the sub-mountainous, northern margin of the Dacian Basin (Fig. 6.2). The lower part of the Late Maeotian fluvial deposits is conglomeratic, but in the Bădislava River geological section the finer-grained sediments are dominant in the upper part (Fig. 6.3). The post-Maeotian fluvial sediment are almost devoid of gravels, including the very thick Middle Dacian-Romanian continental deposits (Fig. 6.4). The amount of gravel-sized sediments seems to decrease steadily from the formation of the Dacian Basin until its final stages at the end of the Romanian time.

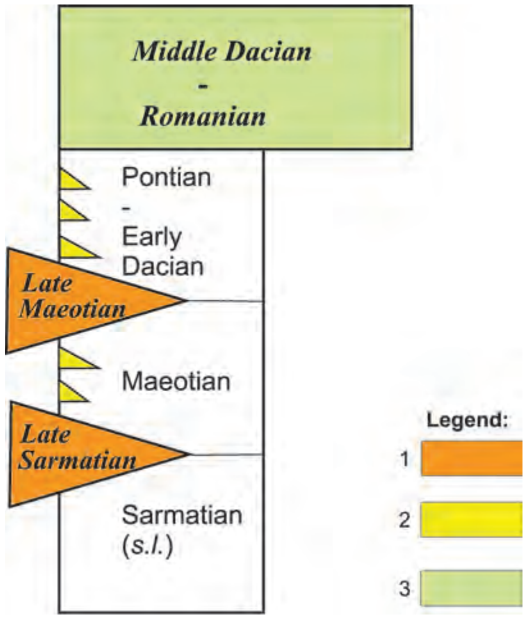


FIGURE 6.1. Schematic presentation of the fluvial accumulation in the geological history of the Dacian Basin. **1**. Fluvial deposits marking regressive events of the brackish-marine basin. **2**. Coastal, sub-mountainous fluvial deposits with local development in the proximal zone of the brackish-marine basin. **3**. Continental-fluvial sediments accumulated after the filling out (and closure) of the marine basin.

In the fluvial accumulations without significant gravel participation (that is, younger than the lower part of the Late Maeotian), the predominance of mud over sand sediments appears as a major lithologic characteristic. The Romanian fluvial succession cropping out on the Prahova River shows the largest quantitative prevalence of the clay (and clayey) component, in comparison with four other fluvial sequences (Table 6.1). Most of the compared sequences have the clay/sand ratio close to one. In some locations, the amount of sand is significant relative to the finer-grained sediments, as in the case of the Late Maeotian fluvial succession from the Bizdidel River (Table 6.1) (Fig. 6.5 E).

The bed thickness of the fluvial sand components varies. The thicker sand units are observed on the subsurface well log data, the 10 to 20 m thick deposits appearing frequently (Figs. 6.5 A and 6.6 A). The same trend was observed for the Romanian deposits from the Prahova River (Figs. 6.5 B and 6.6 B).

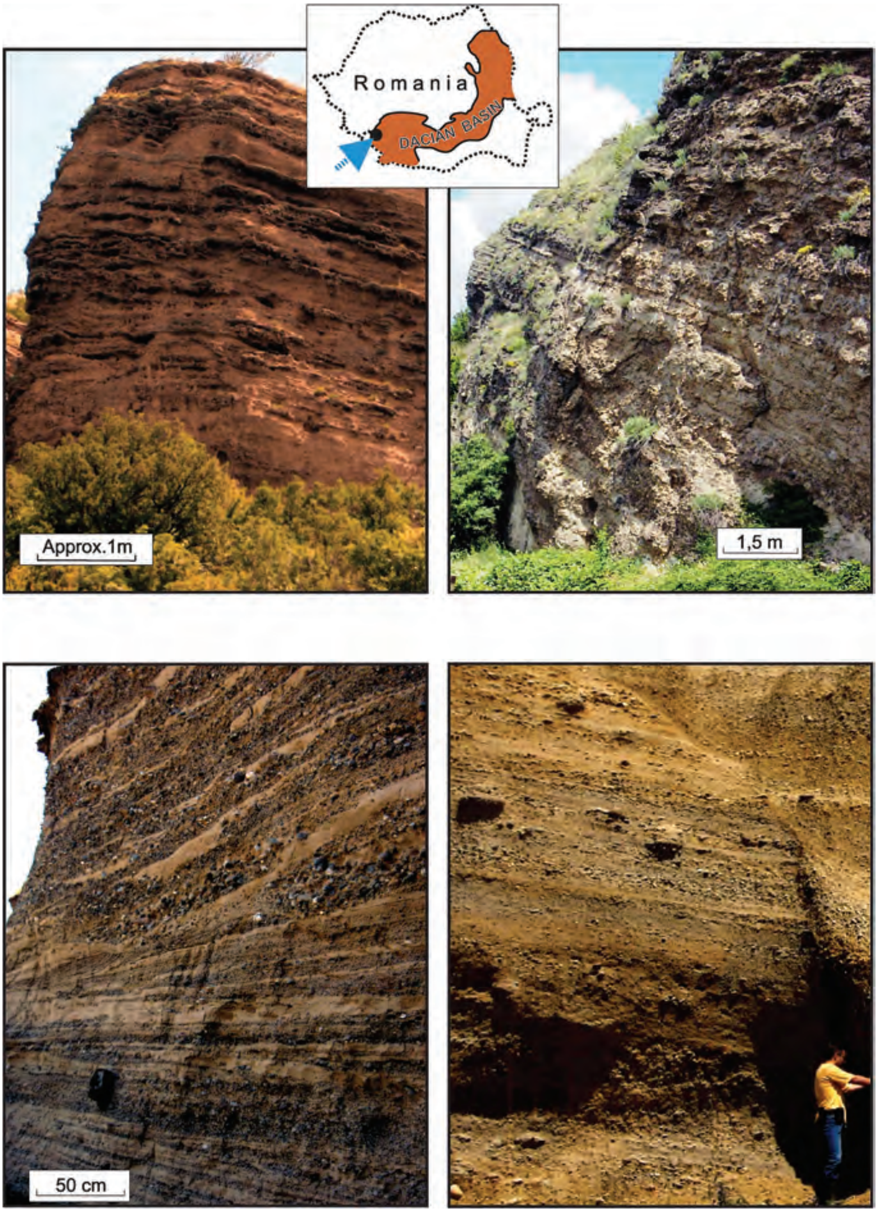


FIGURE 6.2. Late Sarmatian (*s. l.*) conglomerates. Orşova - Drobeta - Turnu Severin area. Index map - location of the study area in the Dacian Basin and in Romania

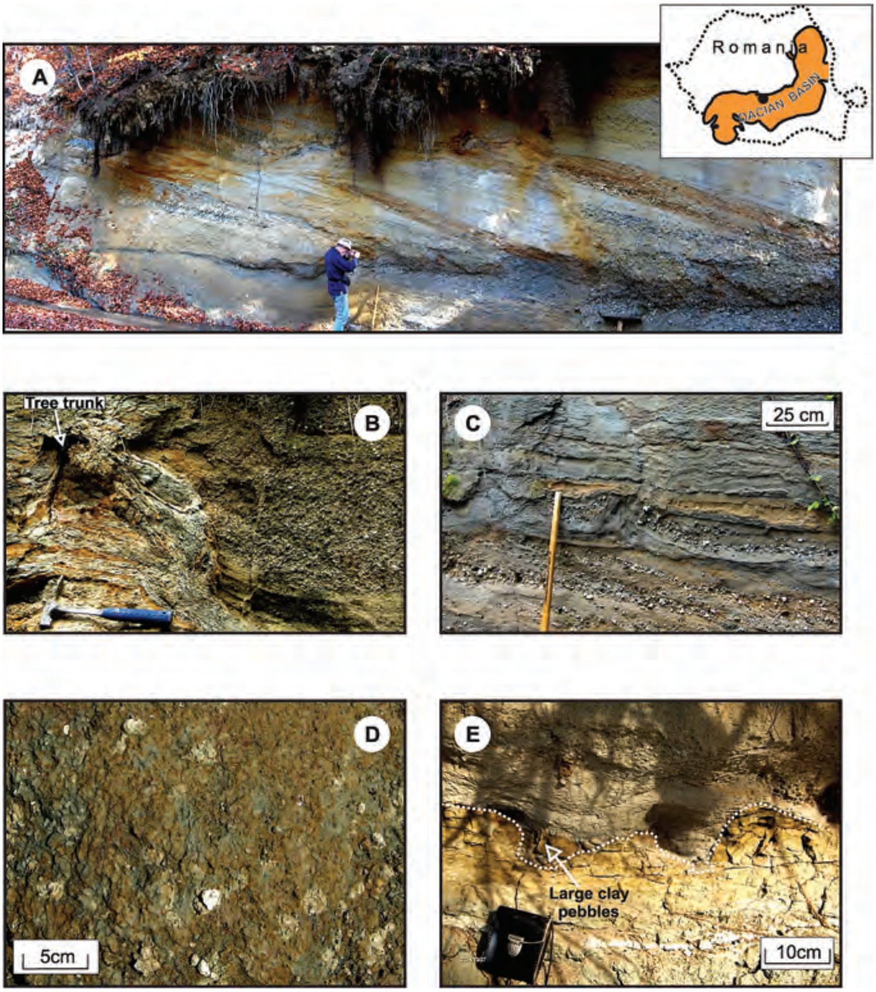


FIGURE 6.3. Maeotian fluvial sediments. **A** to **C** – coarse-grained (conglomeratic) deposits in the lower part of the Maeotian succession. **D** and **E** – fine grained (dominantly clayey deposits in the upper part of the Maeotian succession. Bădislava River (upstream from Vlădeşti village, Argeş County). **A** - Large scale current lamination. **B** - Erosion channel filled with conglomerates. Upper left - fossil tree trunk. **C** - Gravelly to sandy sequence, with water escape structure. **D** - homogeneous clay with calcareous concretions. **E** - Erosional base of a channel-fill coarse-grained sandstone, with large clay pebbles. *Index map* - location of the study area in the Dacian Basin and in Romania

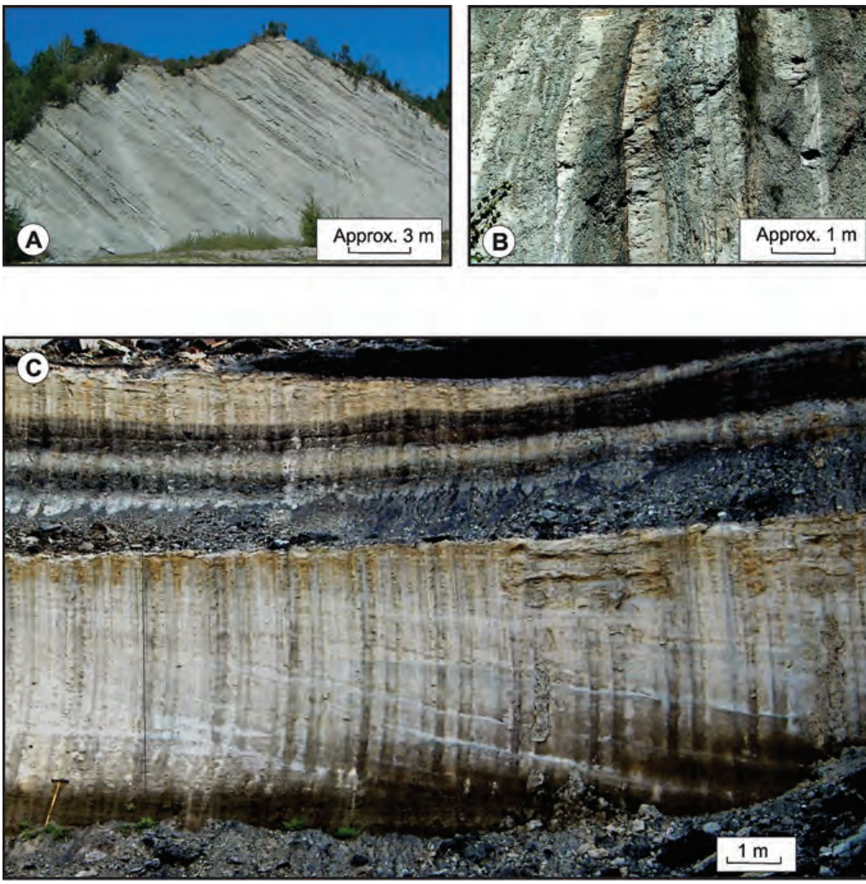


FIGURE 6.4. Fluvial deposits of Romanian age. **A** and **B** – Fluvial fine-gained sand and clay succession. Râmnicu Sărat River, Chiojdeni village (Vrancea County). Note the fining upward but also coarsening upward (?crevasse splay) in figure B. **C** - Thick sand bed with large scale current lamination (possibly a point bar). Coal bearing sequence, Pinoasa Quarry, Rovinari (Gorj County)

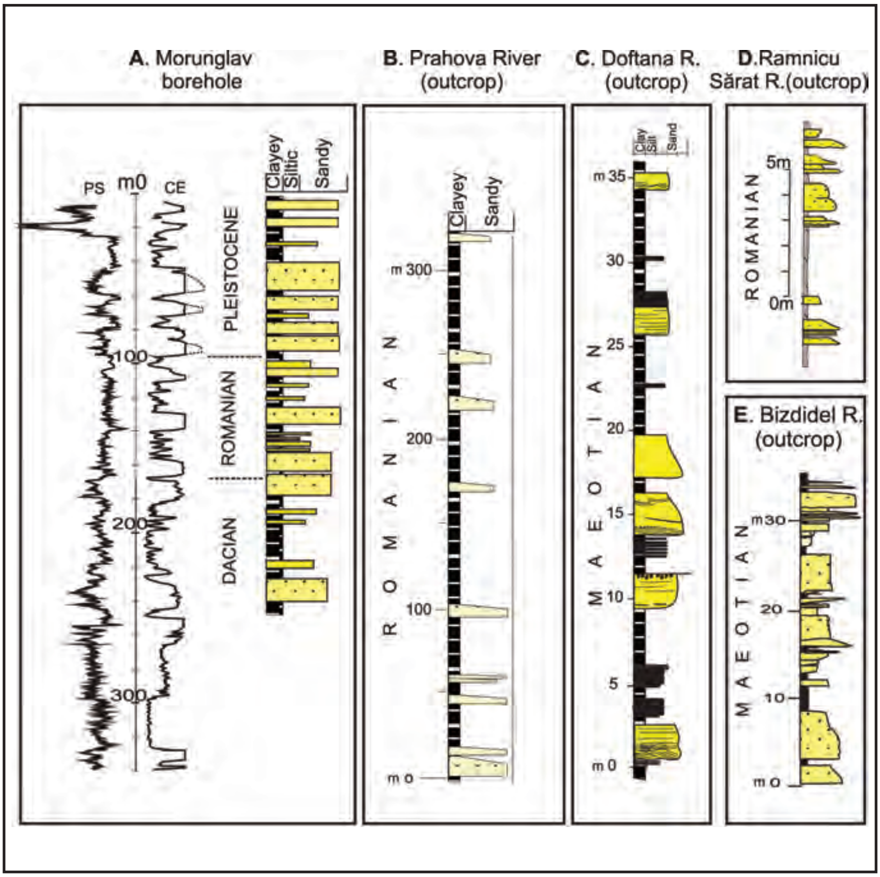


FIGURE 6.5. Fluvial lithologic sequences from the Late Neogene Dacian Basin deposits

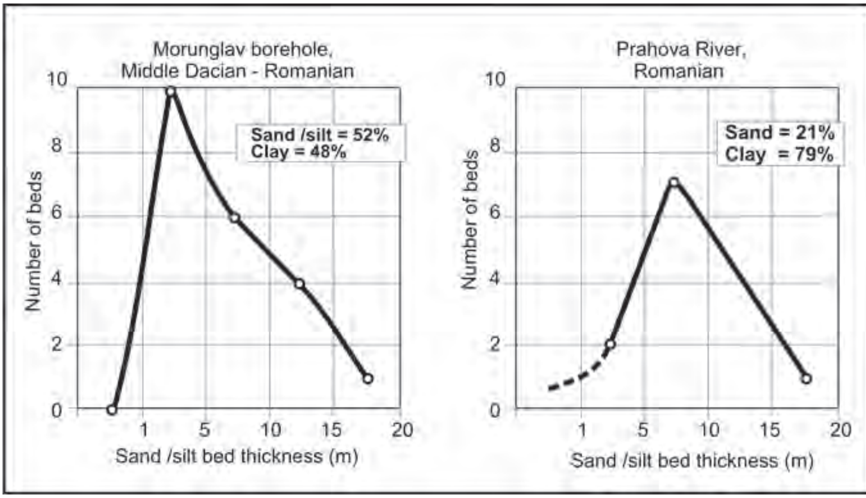


FIGURE 6.6. Distribution of bed thickness values for Romanian sand/silt fluvial deposits

TABLE 6.1. Sand to clay ratio of some fluvial deposits in the Dacian Basin. The figures are rough estimations resulted from comparison between sequences that are different in scale and detail of observation.

Geological section	**Sand** (and sandy) (%)	**Clay** (and clayey) (%)
Morunglav borehole *Middle Dacian - Romanian*	52	48
Prahova River *Romanian*	21	79
Doftana River *Late Maeotian*	36	64
Bizdidel River *Late Maeotian*	78	22
Râmnicu Sărat River *Romanian*	40	60

6.1.2. Graded bedding

The size variation of the clastic particles from the base to the upper part of a sedimentary unit represents an important character in the genetic interpretation of the fluvial Dacian Basin deposits.

The fining upward trend was interpreted in our study of the Dacian Basin as a characteristic of the fluvial sediment accumulation. The complete fining upward, from very coarse-grained sands to clay, was rarely noticed (Fig. 6.7). When the sediment sorting is advanced and the bottom grain-size is in the fine-grained sand range, the coarsening upward is visible only in the upper part of the bed (Fig. 6.8). The fining upward expressed by a decrease in grain-size from the bottom of the bed, is more frequent in case of some conglomeratic units (Fig. 6.9).

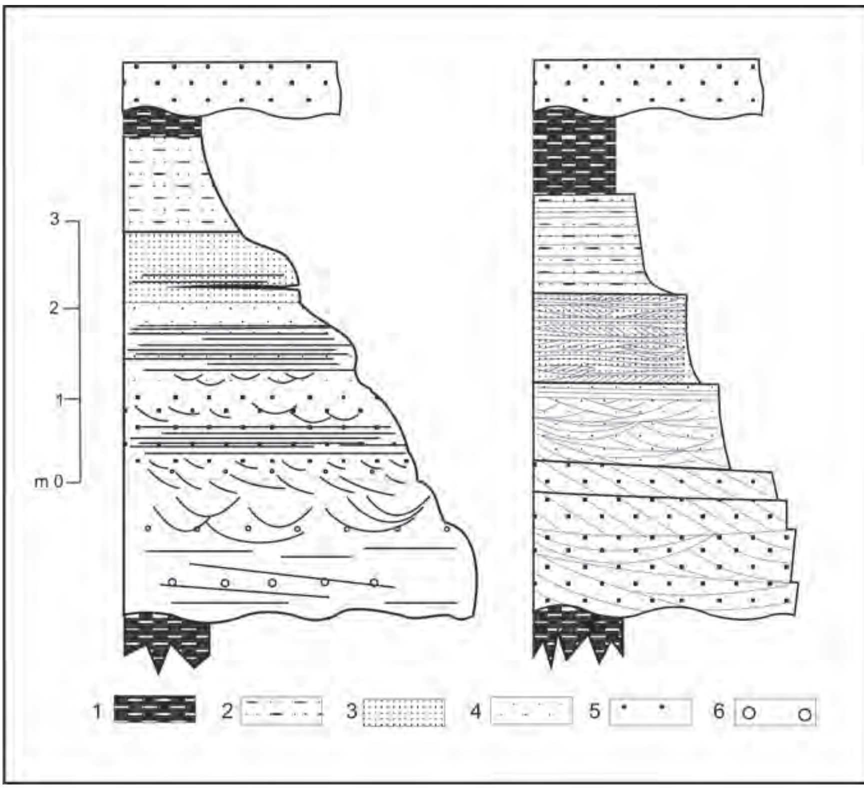


FIGURE 6.7. Composite images of the complete, fining upward sedimentary units, in the fluvial Middle Dacian - Romanian deposits from the Dacian Basin. **Legend**: **1**. Clay. **2**. Silt. **3**. Fine and very fine-grained sand. **4**. Medium and coarse-grained sand. **5**. Very coarse-grained sand and very fine-grained gravel. **6**. Fine and medium-grained gravel

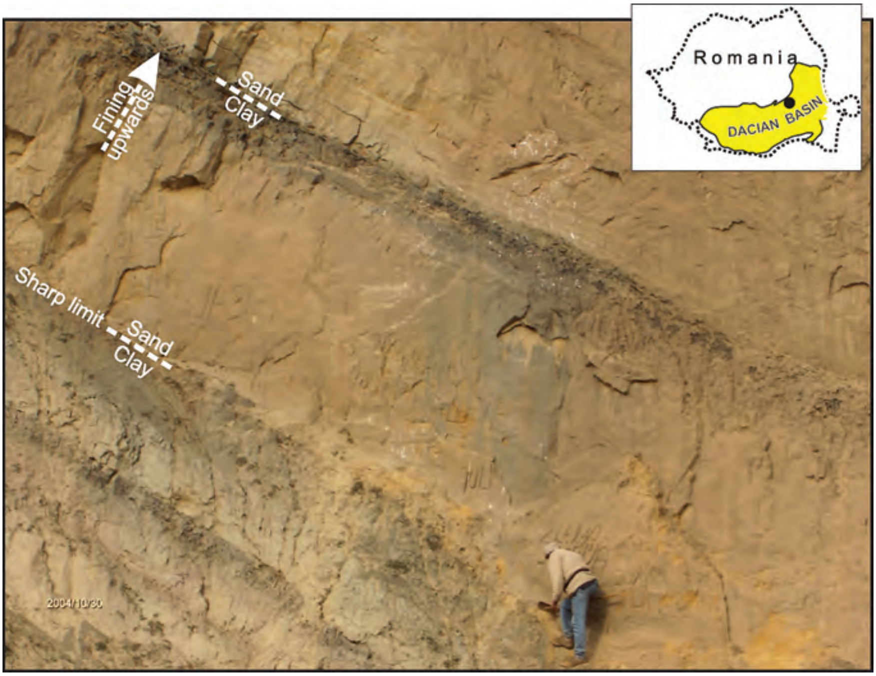


FIGURE 6.8. Thick fining upward sandy beds in the Romanian fluvial deposits. The fining upward is obvious at the upper part of the beds (the sand/clay limit). Buzău River, Berca (Buzău County). Index map - location of the study area in the Dacian Basin and in Romania

FIGURE 6.9. Conglomeratic bed with fining upward grading and erosional basal limit. Late Sarmatian (*s. l.*) . Valea Morilor Creek, Colibaşi village (east of Drobeta - Turnu Severin)

Coarsening upward grading also occurs in the fluvial environment. This grain size trend is related to processes of progradation that take place in the crevasse splay development.

The well logs offer the best way to examine the grain size grading. The Dobretu well logs point out four main grading types, each one with varieties (Fig. 6.10).

6.1.3. Sedimentary structures

The Dacian Basin fluvial deposits display the whole array of current lamination structures, in accordance with the general characteristic of the sediment accumulations generated by alluvial processes.

The current structures evolve within the fluvial graded sequences, following the fining upward trend and the corresponding level of sedimentary dynamics (Figs. 6.7; 6.11 and 6.12).

Frequently, the fluvial unit displays structures showing the effect of discharge pulses. The apparently unitary sequence in the figure 6.11A has three stages of clay pebbles accumulation, but the grain size of the consecutive pebble levels is fining upward. Closely successive sedimentary events can generate polygenetic units (Fig. 6.12 A) or separate units narrowly superposed (Fig. 6.12 C and D).

The characteristic erosional lower limit of the fluvial sequence has been observed in many cases in the fluvial sequences of the Dacian Basin (Figs 6.3C and 6.9), excepting the sedimentary units with fine-grained detrital material at the base (Fig. 6.8 C). Channels with basal erosional surface are sometimes present in the outcrops (Fig. 6.3 B), showing erosional irregularities at the decimetric scale. But the erosion within the Dacian-Romanian fluvial deposits can locally reach hundreds of meters, expressed by the absence of Late Dacian or Early Romanian deposits (Papaianopol, Marinescu, 2003).

The magnitude of the fluvial transport in the Dacian Basin is indicated by large scale current structures, occurring in coarse-grained deposits (Fig. 6.3 A) but also in sandy accumulations (Figs 6.4 C and 6.15).

6.1.4. Inclined bedded units

The lateral migration of the fluvial channels is the main process that generates large scale inclined stratification (Thomas *et al*., 1987), as the characteristic of the point bar facies. In the fluvial sediments of the Dacian Basin, a few point bar accumulations have been identified. One of the studied point bar unit has been observed in the terminal Dacian-aged deposits from Călugăreni village (Prahova County) (Fig. 6.13). Another point bar, cropping out in a coal quarry from Oltenia (west of Romania), is an outstanding feature which will be described in a separate chapter of this book (see Chapter 7).

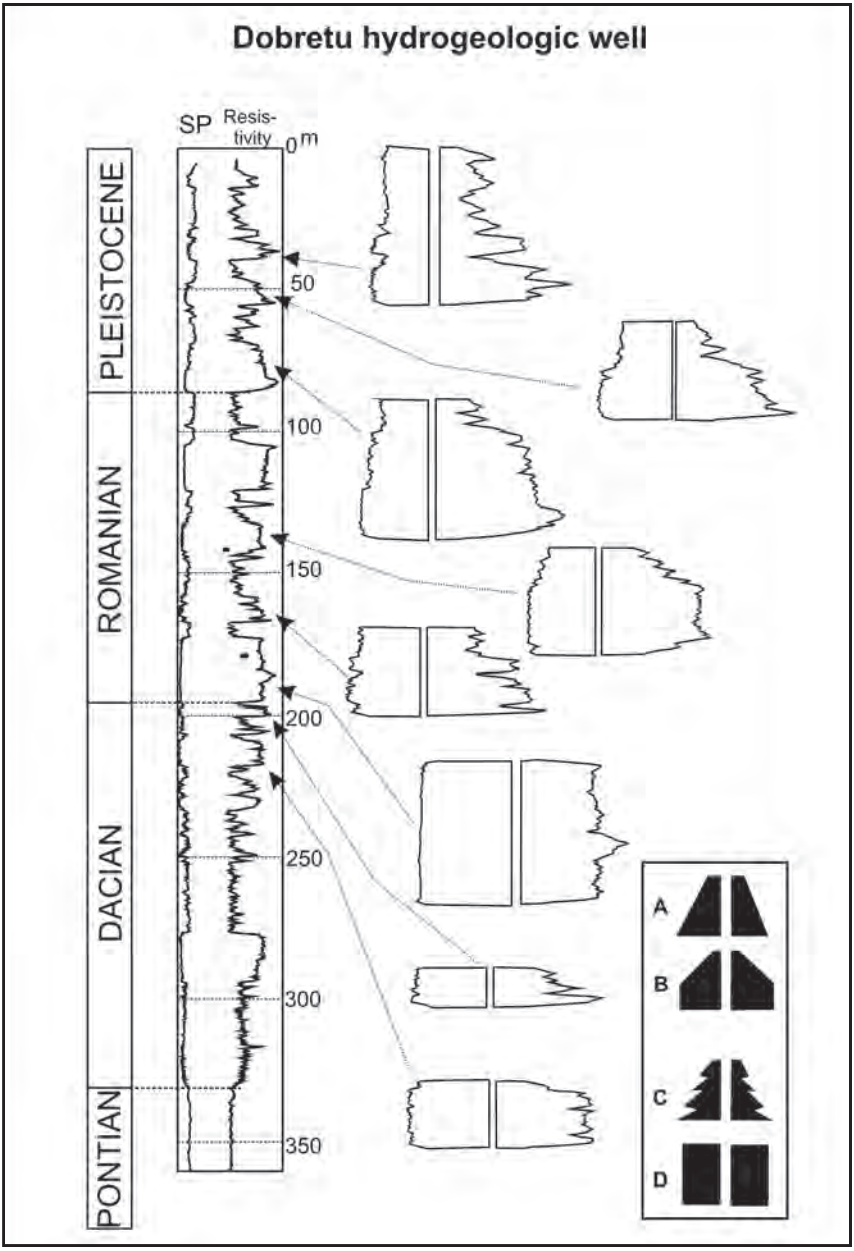


FIGURE 6.10. Types of fluvial grain size grading evidenced by the Dobretu well logs. Middle Dacian-Pleistocene deposits. **A** - Complete, continuous fining upward. **B** - Fining upward of the upper part of the bed. **C** - Multiple fining upward grading. **D** - No grading. From Jipa *et al*. (1999)

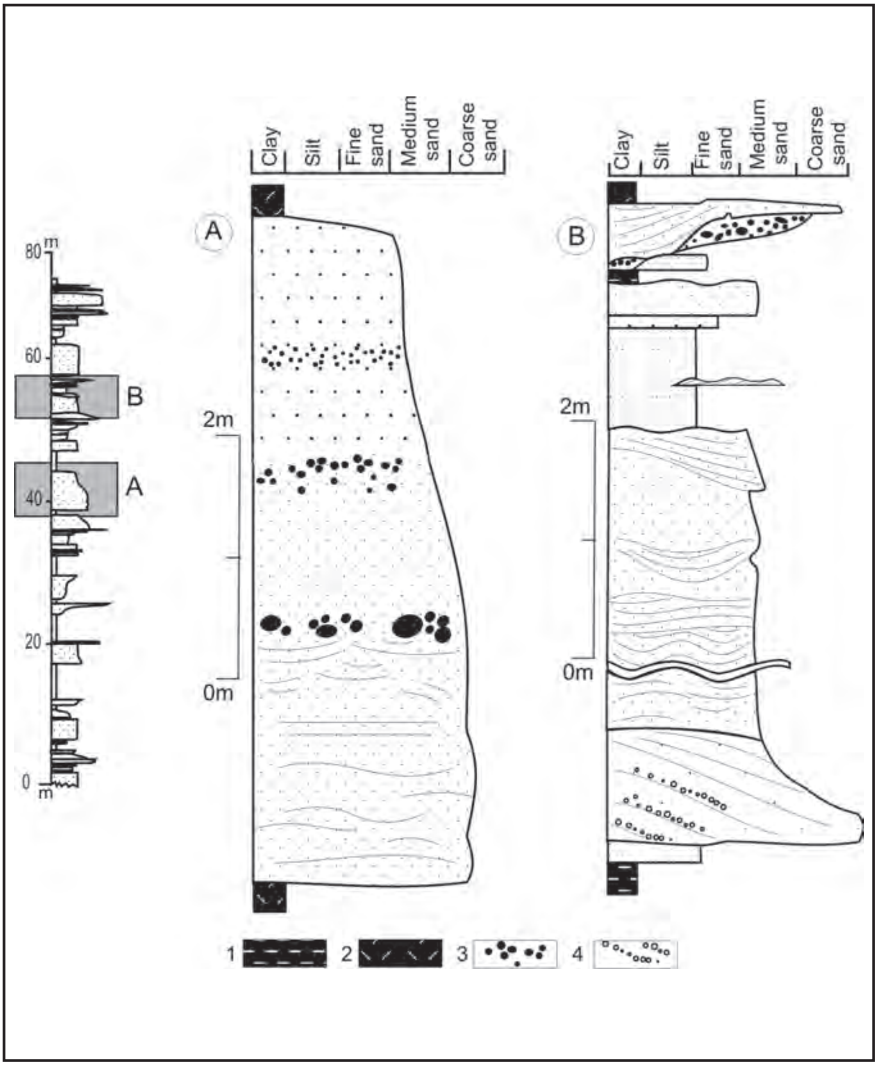


FIGURE 6.11. Coarsening upward grading and the distribution of the internal sedimentary structures. Upper part of the Late Maeotian deposits from Bizdidel River, Pucioasa (Dâmbovița County). Left side: location on the litho-stratigraphic log. **Legend**: **1**. Bedded clay. **2**. Homogeneous clay. **3**. Clay pebbles. **4**. Quartzitic pebbles

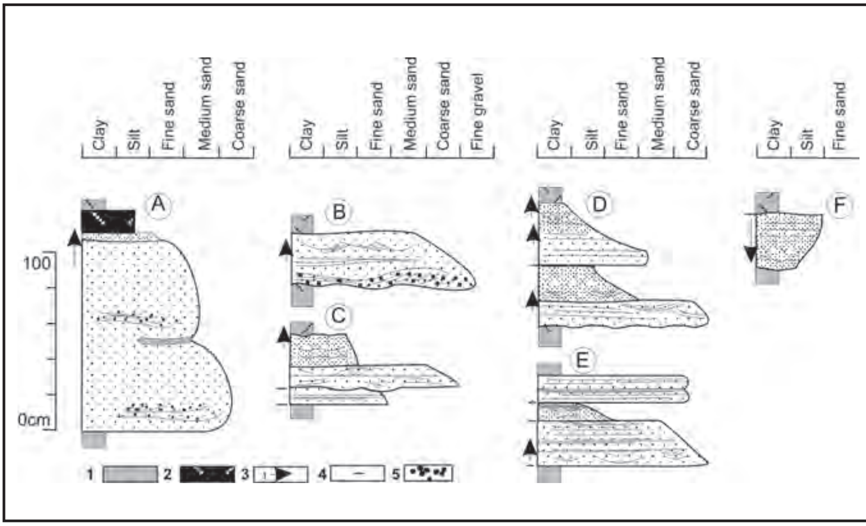


FIGURE 6.12. Graded bedding and sedimentary structures in the Romanian fluvial deposits from Râmnicu Sărat River, Dumitreşti (Vrancea County). **Legend**: **1**. Homogeneous clay. **2**. Paleosoil. **3**. Sense of grain size grading. **4**. Sharp limit. **5**. Clay pebbles

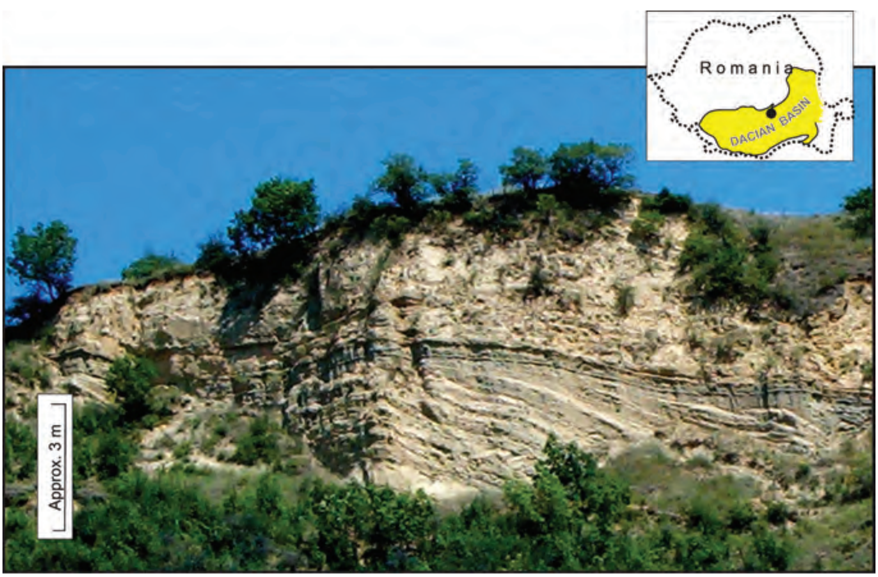


FIGURE 6.13. Point bar unit in Late Dacian deposits from Călugareni (Prahova County). The inclined bedded section is fining upward, from medium-sized sand to silty clay. Index map - location of the study area in the Dacian Basin and in Romania

6.1.5. The northern Dacian Basin fluvial sedimentation

The most dynamic fluvial sedimentation processes have taken place in the northern part of the Dacian Basin. This area was under the direct influence of large sediment influx and high subsidence.

Very thick sand beds are representative for the fluvial transport and accumulation in the northern Dacian Basin (Fig. 6.14). The internal and external structures of these sedimentary units illustrate a transition from the north to the south, from high energy to low energy detrital accumulations. In the northern part (Putna River, Milcov River) (Fig. 6.14 A and B), the thick fluvial beds show erosional basal limit, fining upward grading and large scale internal current structures. The sandy sediments at the base of the beds are coarse-grained, with small pebbles. The oblique laminated sets are from several centimeters to more than one meter thick (Fig. 6.15).

Southward, in the geological sections along the Râmnicu Sărat and Slănic de Buzău rivers, the fluvial sequences are still quite thick (2-3 meters and occasionally more) (Fig. 6.14 C and D). Excepting the Late Sarmatian (*s. l.*) sequences, these deposits rarely display large cross lamination, usually the current lamination sets occurring at centimeter size. In most of the cases, there is no visible fining upward, but the sandy beds appear homogeneous (Fig. 6.14 C and D).

6.2. DACIAN BASIN FLUVIAL SEDIMENTATION ENVIRONMENTS

The primary internal structures observed in the fluvial deposits of the Dacian Basin, are generated by unidirectional currents. The fluvial character of these paleocurrents is indicated by the following sedimentary features, representative for the investigated Late Neogene Dacian Basin deposits:

- grain size fining upward of the sedimentary units;
- size diminishing of the current lamination structures, according to the grain size variation of the fining upward strata, from larger cross lamination units in the base to micro-cross lamination units in the upper part of the graded bed;
- erosional character of the bottom surface of the sequence;
- existence of sedimentary accumulations with point bar characters.

6.2.1. Paleo-river type in the Dacian Basin

The fluvial sequences of the Dacian Basin contain alternating sand and clay beds. The clay component that is well represented quantitatively, even dominant. This suggests the fluvial deposits belong to the meandered-river type (Walker, 1979).

The existence of the inclined bedding, as a primary character, which marks the presence of the point bar facies, constitute a decisive argument that underlines the meandered nature of the rivers that produced the sedimentary accumulation in the Dacian Basin.

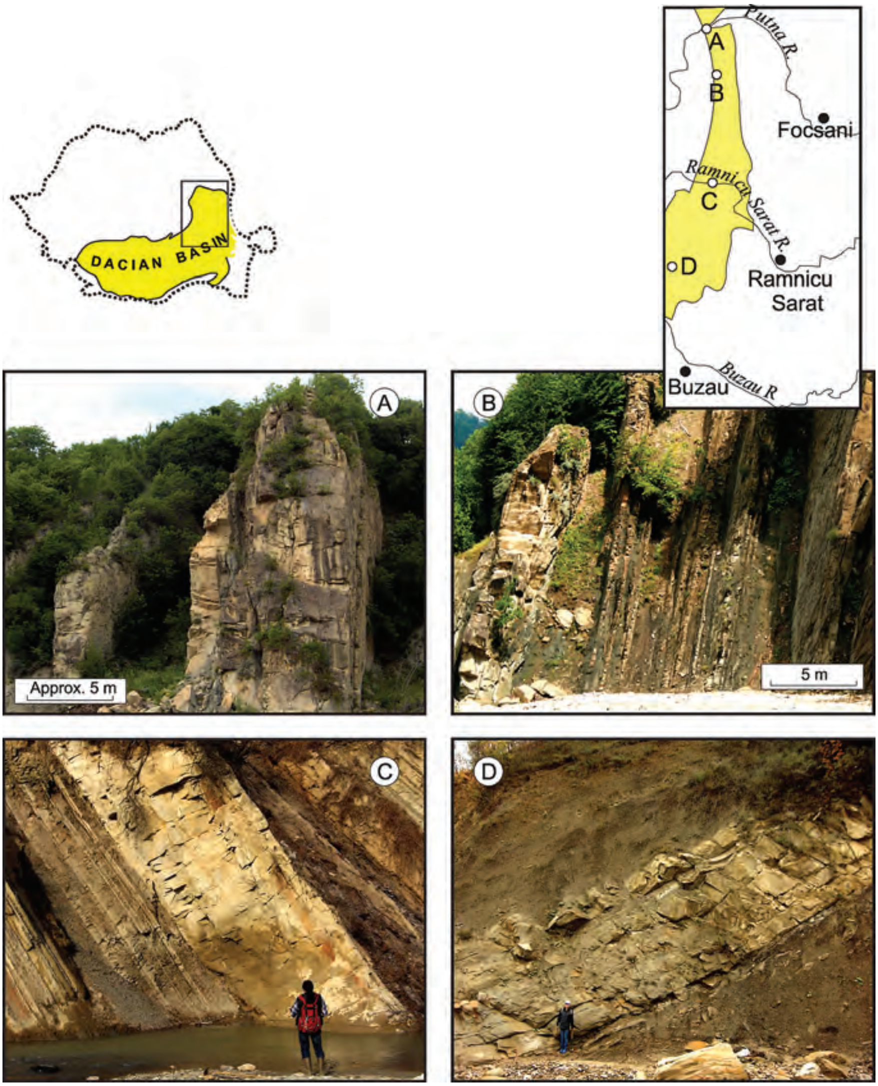


FIGURE 6.14. Thick sandstone beds representing fluvial accumulation processes at different sites in the northern Dacian Basin. **A** - Putna River. **B** - Milcov River. **C** - Râmnicu Sărat River. **D** - Slănic de Buzău River. *Upper-right*: location of the points **A** to **D**.
Upper-left: study area in the northern Dacian Basin

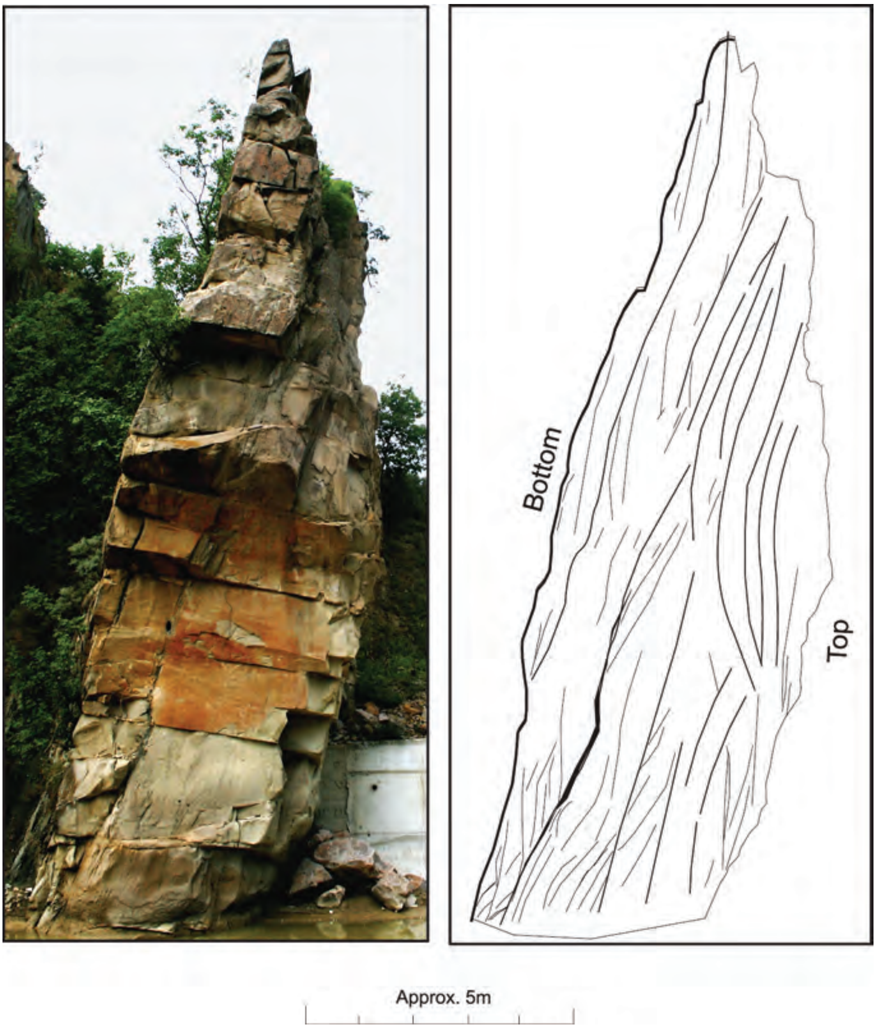


FIGURE 6.15. Large scale internal current structure. Late Sarmatian (*s. l.*). Milcov River, Reghiu village (Vrancea County)

6.2.2. Fluvial environments in the Dacian Basin

One of the best known classifications of the fluvial sedimentary facies considers the following genetic categories (Galloway and Hobday, 1983):

- fluvial channel facies and
- out-of-channel facies.

The out-of-channel environment includes:

- » sediments accumulated near the fluvial channel (levees and crevasse splays);
- » sediments accumulated away from the channel (fluvial floodplain).

The Dacian Basin fining upward units described in this chapter constitute the *facies of the sediment accumulated in the fluvial channel*. Certain sedimentation processes (disturbance of the fluvial channels, erosion immediately after sedimentation, advanced sorting of sand sediments etc.) restrict or modify the fining upward trend of the channel-fill deposits, which leads to the apparition of distinct types of grain size grading in the deposits of the fluvial channel.

Well log analysis shows that Middle Dacian – Romanian channel fill deposits are thick (10 - 20 m) and numerous. Many channels are discrete, separate bodies (Fig. 6.16 A) with fining upward trend. The non-graded channel fills (cylindrical pattern on the well log) are infrequent (Fig. 6.16 B). Some channel fill units are superimposed (Fig. 6.16 C), but this is not a dominant feature. Clayey, flood plain deposits separate the channel fill, sandy deposits. The well logs reveal the existence of coarsening upward alluvial cycles (Fig. 6.17 E) in the Middle Dacian. However, this trend is not common in the fluvial Pliocene sequence.

Images based on log data from a detailed hydrogeological wells network, supplied information on the geometry of fluvial channels in the Pliocene to Quaternary time (Jipa *et al*., 1999) (Fig. 6.17). The reconstructed channels are large features, up to several kilometers wide (between 300 m and over 4 km, especially between 1.5 and 2 km). The smallest channel sections are several hundreds of meters in width. The density of the channel system is remarkable. The individual fluvial channels have 5 to 25 m thick. No constant lateral switching trend emerges from the channel network reconstruction.

Due to the spectacular exposures created by the mining activities in the coal quarries from Oltenia, the facies of the *sediments accumulated on the edge of the channel (levees)* was occasionally recognized. We attributed to this category the fine and very fine sands that are bounding deposits interpreted as channel-fill sediments. The channel levee deposits interpretation is supported by the position on the edge of the channel, and by the presence of fossil wood (tree trunks in growing position) found in these deposits (Fig. 6.18).

The crevasse splay environment was identified in the fluvial deposits investigated from the Dacian Basin. The sediments of this fluvial environment occur as coarsening upward, fine-grained (silt to fine sand) sequences, with reduced thickness (decimeter to less than one meter).

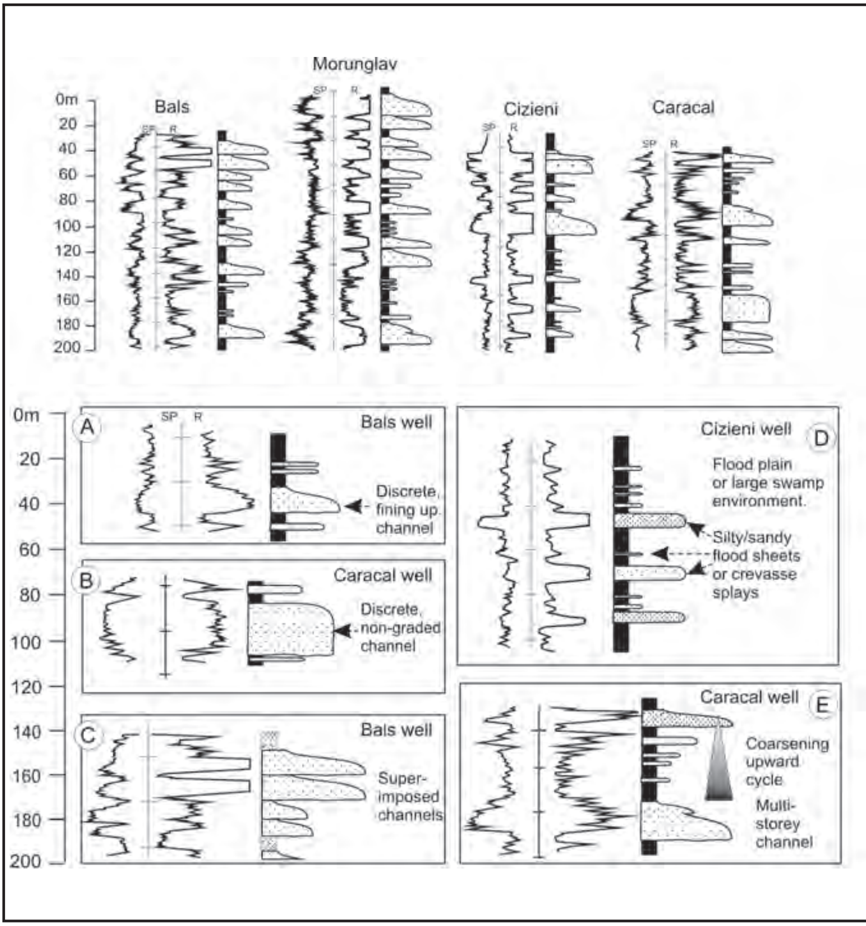


FIGURE 6.16. Main types of fluvial sediment accumulations revealed by well logs. Middle Dacian - Romanian sediment. Wells located in the Craiova - Slatina area (Olt County)

Crevasse splay units were found in the Late Maeotian deposits from Bizdidel River (Fig. 6.19) and in the Romanian deposits from the northern part of the Dacian Basin (Fig. 6.12 F).

The affiliation of the fluvial clay sediments to the *floodplain fluvial facies* results from their association – in the sedimentary sequence – with sediments accumulated inside or on the edge of the fluvial channel. The following types of fluvial clay deposits were identified:

- stratified clay, often with silt laminae, which show they were deposited by a current loaded dominantly with clay material;

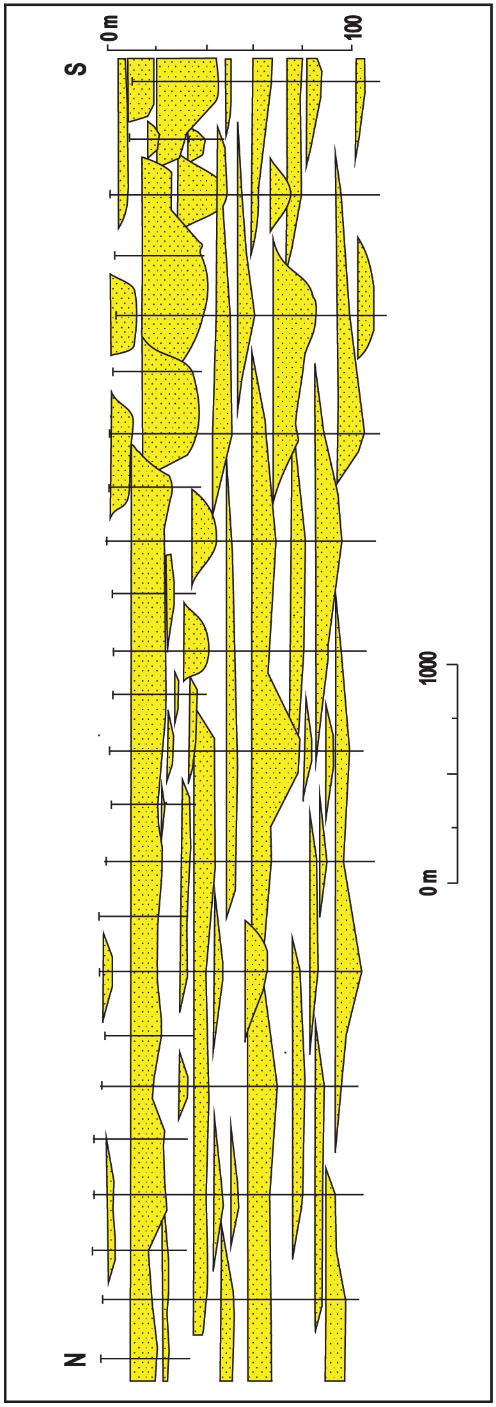


FIGURE 6.17. System of alluvial channels in Pleistocene sediments. Reconstructed with subsurface data (lithology and well logs). Slatina (Olt County). Modified, from Jipa *et al.* (1999)

FIGURE 6.18. Fossil tree stems in upright position. Early Romanian. Coal quarries from Oltenia (left -Jilţ Quarry; right - Roşiuţa Quarry)

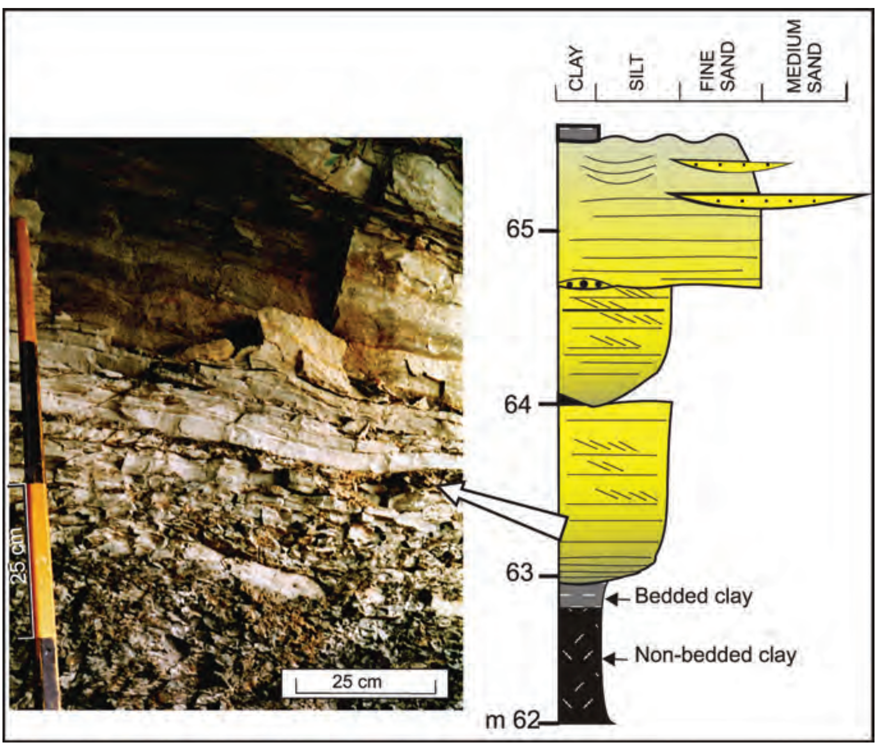


FIGURE 6.19. Crevasse splay sequence in Late Maeotian sediments from Bizdidel River, Pucioasa (Dâmboviţa County)

- homogeneous silty clay, often present under the coal beds, attributed to the swamp environment or to other environments with restrained water circulation. Sometimes, the massive clay includes calcareous concretions (Fig. 6.3 D). The dark colored clay, with a high content of organic material, are interpreted as indications of the incipient stage of paleo-soil formation.

The silty sediments intercalated in the floodplain clay, appearing as tabular bodies (Fig. 6.20) have been considered as silt flood sheet units (Fisher *et al.*, 2007). Thin and finer-grained sand/silty sedimentary units observed on well logs are also interpreted as flood sheet bodies.

The sections with dominating clay lithology visible on the well logs (Fig. 6.17 D) could also represent extensive swamp deposits and/or shallow lakes, in the framework of the flood plain environment.

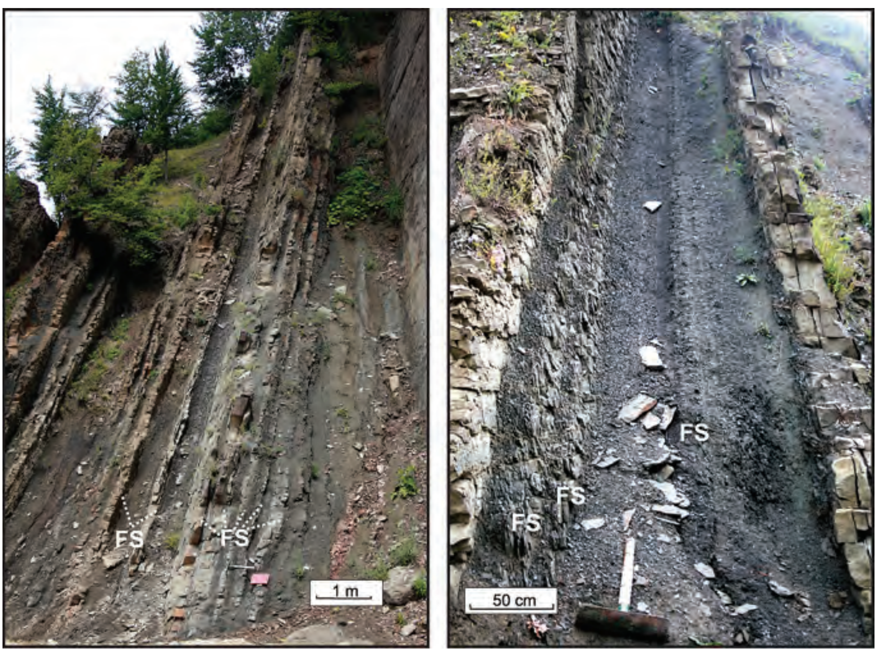


FIGURE 6.20. Flood sheet episodes (**FS**) in the clayey fluvial deposits from Reghiu, Milcov River (Vrancea County)

In the Romanian-dated fluvial deposits, like those cropping out in the Filipeştii de Pădure Quarry, the sand beds are very fine-grained. Their internal structure consists of parallel and small-scale cross lamination, as well as centimeter-thick silty-clayey horizontal bands. No coarsening or fining upward trend is evident. The base boundary of the sand units shows no erosional relief. The sand beds, with several meter thickness, are tabular and have large lateral extent (at least several hundred meters in the Filipeştii de Pădure coal Quarry). These sedimentary characters are not in accord with the model of the sediment accumulation in fluvial channels. The metric thickness of the main sandy units does not support the idea of their accumulation out of the fluvial channels (flood plain). The deposits like those from the Filipeştii de Pădure coal Quarry could be attributed to sediment accumulation in an alluvial fan environment.

6.2.3. The fluvial environment during the Dacian Basin evolution

Fluvial sedimentation occurred many times during the development of the Dacian Basin (Fig. 6.1). The transition to the fluvial sedimentation environment (occurring at the basin sub-Carpathian margin) represents the final regression of the geological transgression-regression type cycles.

The most significant period for the fluvial sedimentation in the Dacian Basin history starts in the upper part of the Early Dacian time (upper part of the Getian stage) and continues in the Romanian. The Late Getian is the initial time of the transition from the brackish-marine sedimentation of the Dacian Basin, to the continental-fluvial sedimentation that marks the sediment filling out of the basin. Unlike the previous fluvial occurrences, the Dacian-Romanian fluvial environment occurs throughout the Dacian Basin area.

Chapter 7

THE POINT BAR FACIES IN THE JILȚ QUARRY (ROMANIAN DEPOSITS): A MODEL OF LATERAL FLUVIAL SEDIMENTATION

The large and continuous rock exposures on an approximately 1000 m distance in the Jilț South Quarry revealed a sand body with lateral accretion sedimentation surfaces (as defined by Thomas *et al*, 1987) representing a point bar unit.

The Jilț South Quarry is located in the village Mătăsari, circa 10 km ESE of Motru town, in western Oltenia (Fig. 7.1). The Jilț River, a tributary of the Jiu River, gives the name of the quarry.

Since 1989, the study of the point bar in the Jilț Quarry exerted an attraction for sedimentologists from the Geological Institute of Romania. Thomas Ryer, who visited the Jilț Quarry in 1991 and pointed out the special development of the point bar deposits, revitalized this interest. As a consequence, most of the mining front where the point bar deposit cropped out was completely cleaned on 800 – 900 m length and around 15 m height (Fig. 7.2). In this way an extensive photographic documentation was made possible, together with a detailed mapping of the mining front. As this was advancing, additional observations were made several years after the main mapping stage.

The sedimentological description of the Jilț point bar was first presented by Jipa *et al*. (1992). The subject was approached by Jipa (1994) and recently by Jipa *et al*. (2006).

7.1. THE GEOLOGY OF THE JILȚ QUARRY AREA

The Jilț Quarry is located in the area of Late Neogene deposits of the Dacian Basin, on the eastern part of a large anticline. In the Jilț mining area, the Late Neogene deposits are dipping to the south a few degrees.

According to Stănescu *et al*. (1983; manuscript)[1] the sedimentary sequence in the Jilț Quarry area (Fig. 7.3) starts with a sandy horizon of 90-150 m thickness attributed to the Getian. The coal strata III and IV are included in this sequence. The

[1] Stănescu, T., Vlădescu Ang., Vlădescu, A., Slăvoacă, I., Arion, P. (1983) - Sinteza datelor obținute prin lucrările de prospecțiuni si explorări geologice efectuate pentru cărbuni în depresiunea getică, perimetrul Jilț-sud, Jud. Gorj. I.P.G.G., unpublished geological report (in Romanian), Fondul geologic, Bucureşti.

overlying Dacian deposits consist of clay and sand intercalated with the lignite beds V, VI and VII.

The 70 - 90 m thick Romanian Jilț sequence consists of clayey and sandy deposits with fresh-water fauna. The lignite beds VIII – XII are intercalated in these deposits. The overlying Early Pleistocene clay hosts the lignite beds XII and XIV. According to Stănescu *et al*. (1983; manuscript)[1], the Dacian/Romanian limit is located in between the VII and VIII lignite strata. Pană *et al*. (1981) consider that the Early Romanian (Siensian) starts above bed V and the sandy interval VII – VIII is in the middle of the Siensian interval.

The Jilț sand body that displays a coarser and thicker (up to 35 m) western part, overlaid by large scale inclined stratification sand (Fig. 7.4), was investigated for its point bar facies.

The point bar deposits are cropping out in the vertical walls of two mining fronts (Fig. 7.5), in the southern part of the Jilț mining area. The upper part of the investigated sand body appears in the coal extraction front E13 and the basal part of the studied deposits crop out in the immediately lower mining horizon (E 12).

The Jilţ point bar deposits are overlying a silty-clay level, which covers directly the lignite bed VII. An association of fresh-water mollusks was collected from this clay horizon. The basal clay horizon shows significant thickness variations (between 1.5 and 5 m) in the western part of the extraction front, generated by differential erosion due to the fluvial currents that deposited the Jilț sand.

FIGURE 7.1. Geographic location of Jilț Quarry

1 Op. cit., p 140

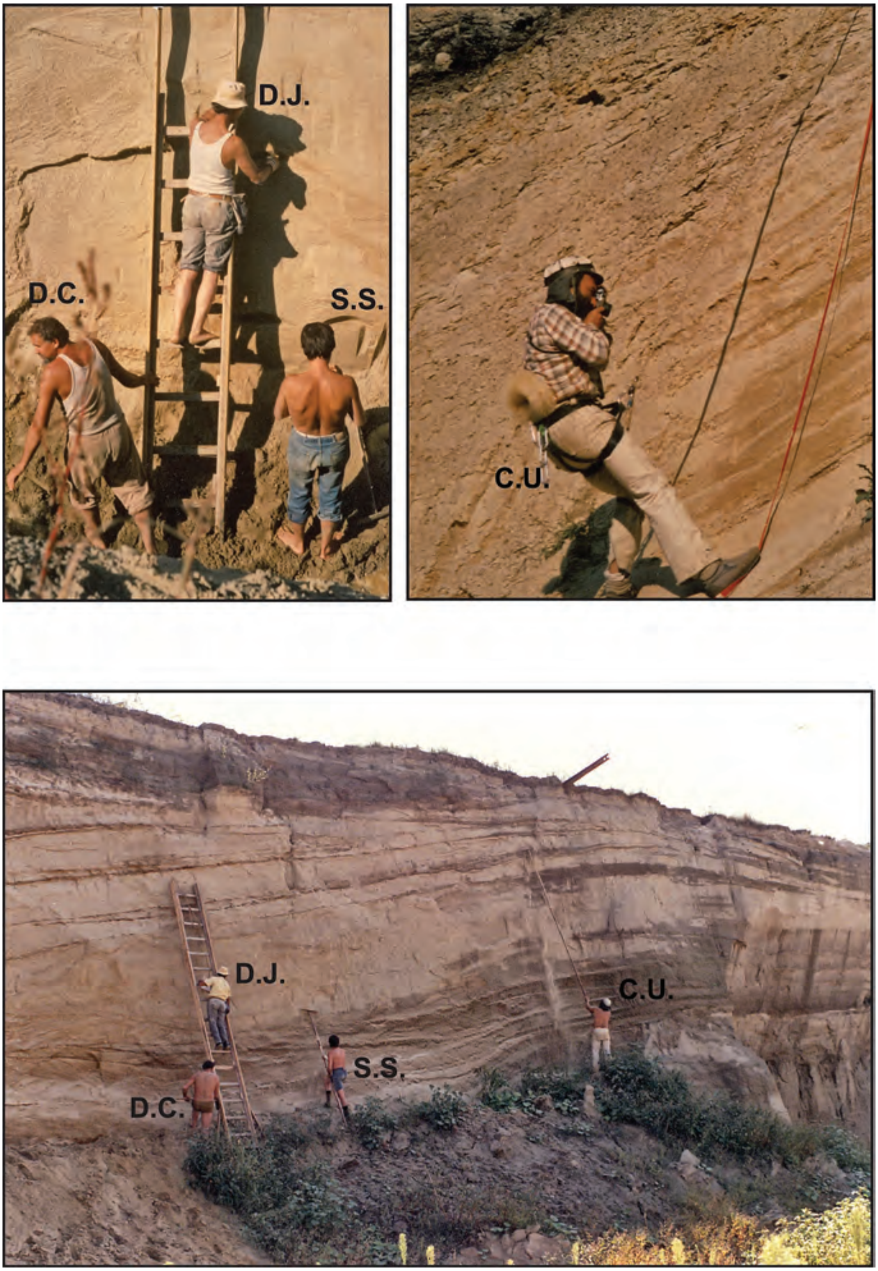


FIGURE 7.2. Outcrop preparation for the Jilț point bar investigation, in the summer of 1991. The geological team, with Costin Ungureanu (C.U.), Ştefaņ Szobotka (S.S.), Dan Constantinescu (D.C.) and Dan Jipa (D.J.), used climbing techniques, ladders and an array of scraping and brushing devices

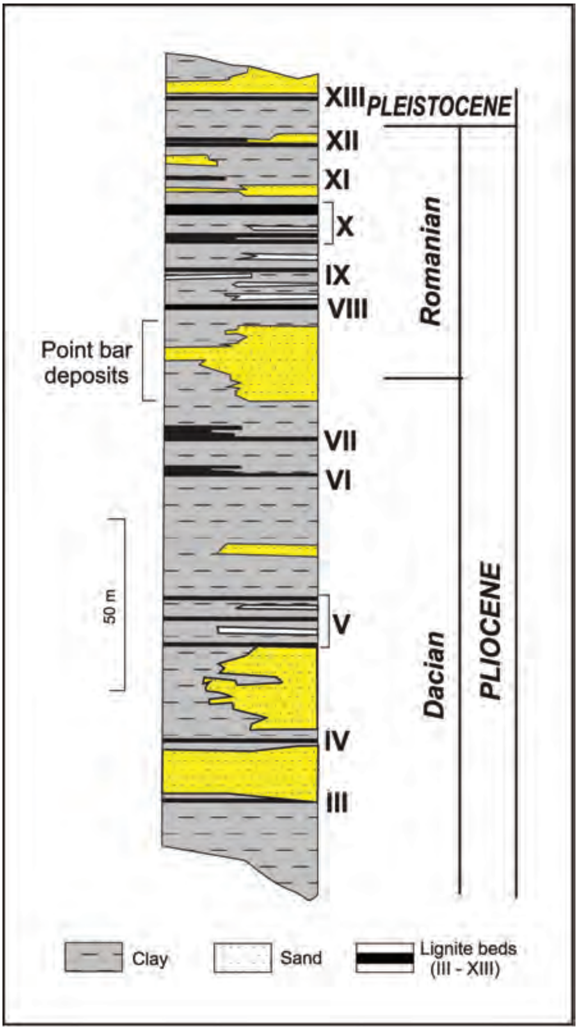


FIGURE 7.3. Lithostratigraphic succession of the deposits in the Jilț Quarry area. Based on data from Stănescu *et al*. (1983; manuscript)[1]

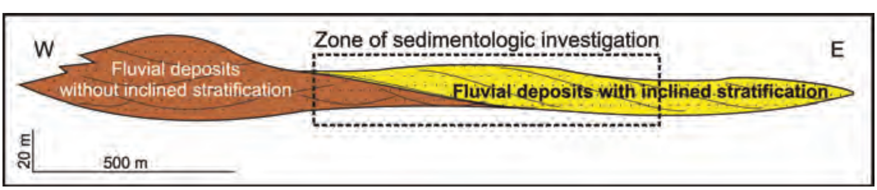


FIGURE 7.4. Longitudinal synthetic section through the inclined bedded sand body, in the mining area of the Jilț Quarry. The sand body is approximately 3 km long and up to 35 m thick

1 Op. cit., p 140

FIGURE 7.5. Jilț South Quarry during the summer of 1991. **A** - The two mining fronts where the point bar deposits crop out. **B** - The mining front A13. **C** - Drainage ditch at the E13 level, exposing the lower part of the fine-grained sand facies

7.2. THE SEDIMENTOLOGICAL DESCRIPTION OF THE JILȚ POINT BAR DEPOSITS

The dominantly sand deposits between the lignite beds VII and VIII are sub-divided by three thin gravel beds (Fig. 7.16). The inclined stratification deposits are delineated at their base by the third gravel bed. The upper limit of the point bar deposits is marked by a thin lignite layer (25-30 cm), which represents a minor coal episode preceding the main coal bed VIII.

Three facies have been distinguished in the Jilț point bar deposits: silty-clay, fine and very fine grained sand and medium and coarse grained sand facies. The three facies are partly superposed and partly transitional. Distinctive sedimentary structures are characteristic for each facies.

7.2.1. The upper, silty-clay facies

The silty-clay facies (Fig. 7.6) makes up the upper part of the inclined stratification unit in the Jilț Quarry. Immediately under the thin lignite/humic clay bed (Fig. 7.6 A), purely clay deposits occur (Fig. 7.6 B). This is a 0.5 to 1 m thick horizon, with lateral extent over the point bar deposits. Rootlets coming from the thin coal bed can be observed in the clay deposit. The dominant character of the clay is the lack of internal stratification. This unit will be called the *upper homogenous clay subfacies*.

Under the upper homogenous clay, there is a silty-sand to clayey-silt interval. The sand content is higher in the lower part of the interval, which becomes clayey-silt towards the upper part. This is the *silty-clay subfacies*. The internal sedimentary structures of these deposits are represented by parallel laminations and bioturbation with low intensity.

Large-scale inclined bedding is visible in the lower part of the silty-clay facies (Fig. 7.6). The large scale structure occurs as mud drapes which extend into the fine and medium-grained sand from the lower levels. There is also a set of silty inclined beds (or large scale current bedding) which develops at the upper part of the point bar, in the upper silty clay facies (Figs. 7.21; 7.23).

Homogeneous fine sand lens-like small bodies are occasionally observed in the clayey sediments under the coal bed (Fig. 7.7 A). This sandy material was injected from the lower part of the point bar through clastic dikes (Figs. 7.7 B; 7.18 C).

7.2.2. The fine and very fine-grained sand facies

The middle part of the point bar sequence consists of a sand accumulation of fine and very fine grain size, occurring under the silty-clay deposits. This is an important subdivision of the Jilț point bar deposit, because it displays most of the inclined stratification features. A very fine-grained sand facies with small scale current lamination (Fig. 7.8) develops at the upper part of this accumulation.

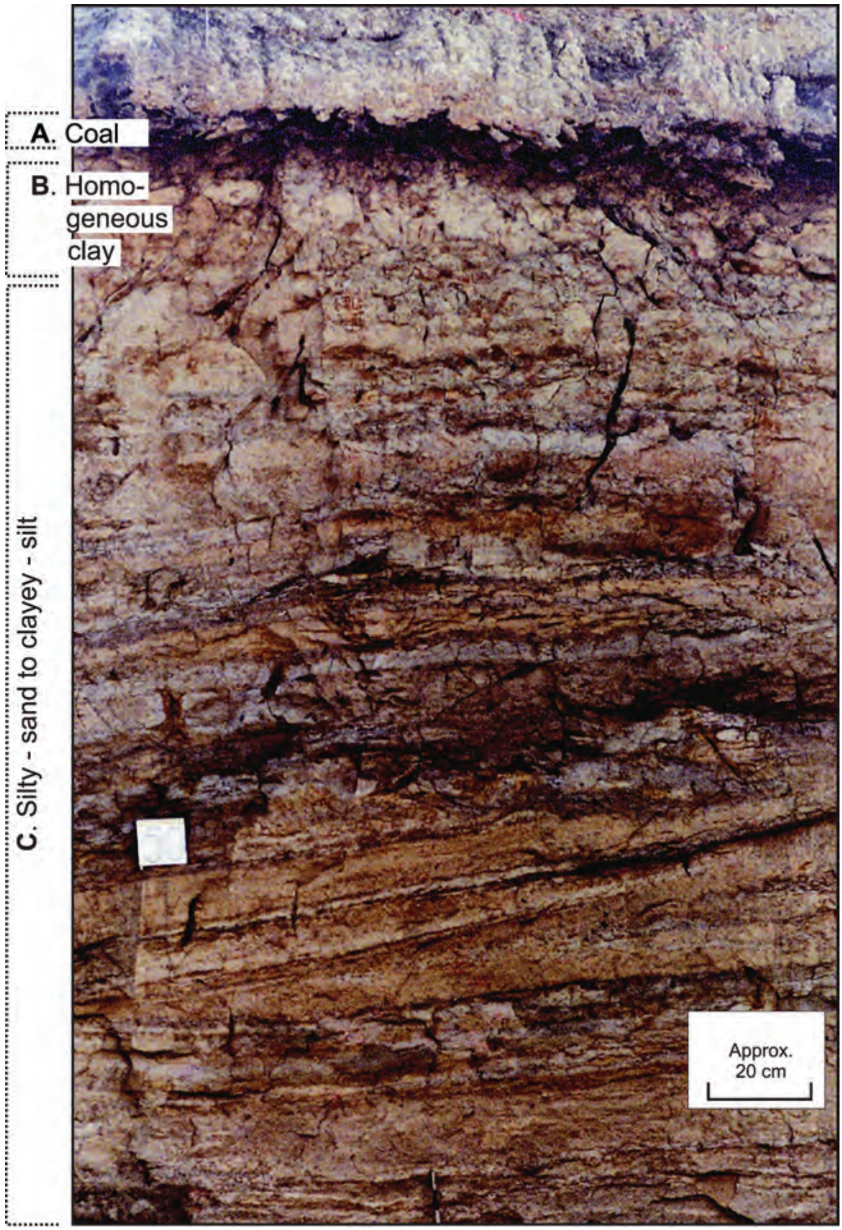


FIGURE 7.6. The upper, clayey-silt facies of the Jilț point bar deposits

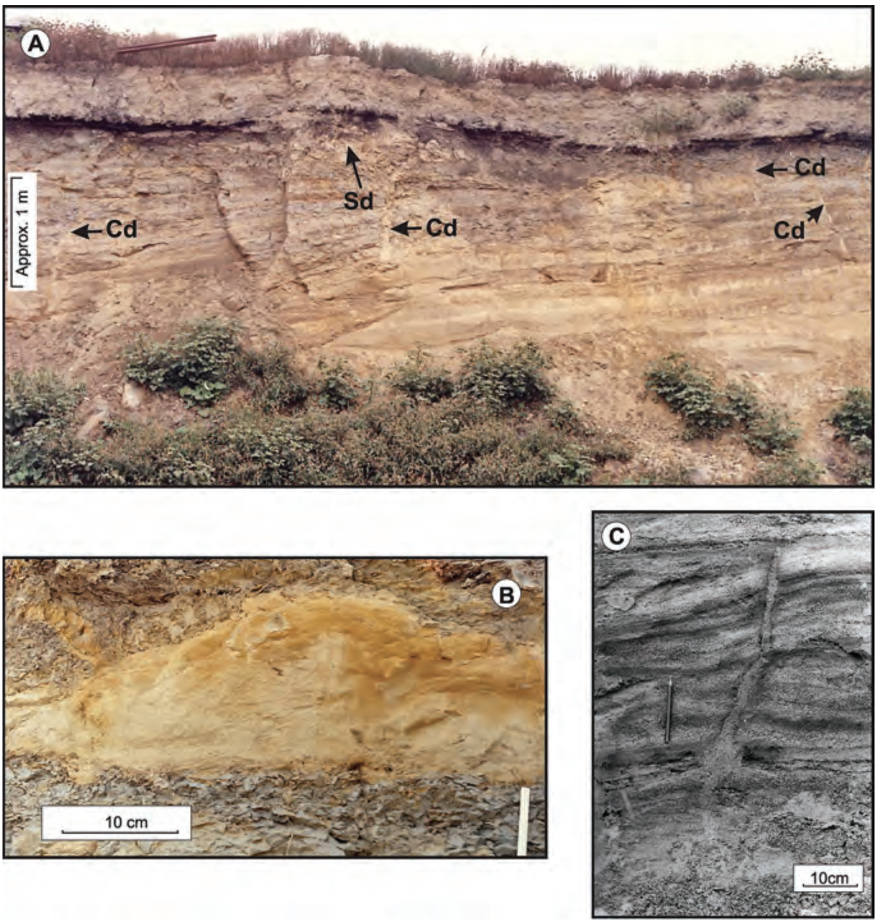


FIGURE 7.7. A - Long clastic dykes (**Cd**) in the upper part of the point bar sequence; Sand injected under the coal bed (**Sd**). **B** - Detail picture of a homogeneous sand body transported by post-sedimentary water expulsion along the clastic dykes in the clayey top part of the point bar sequence. **C** - Example of clastic dyke observed in the sandy section of the point bar. Jilț South Quarry, A13 mining front, eastern part

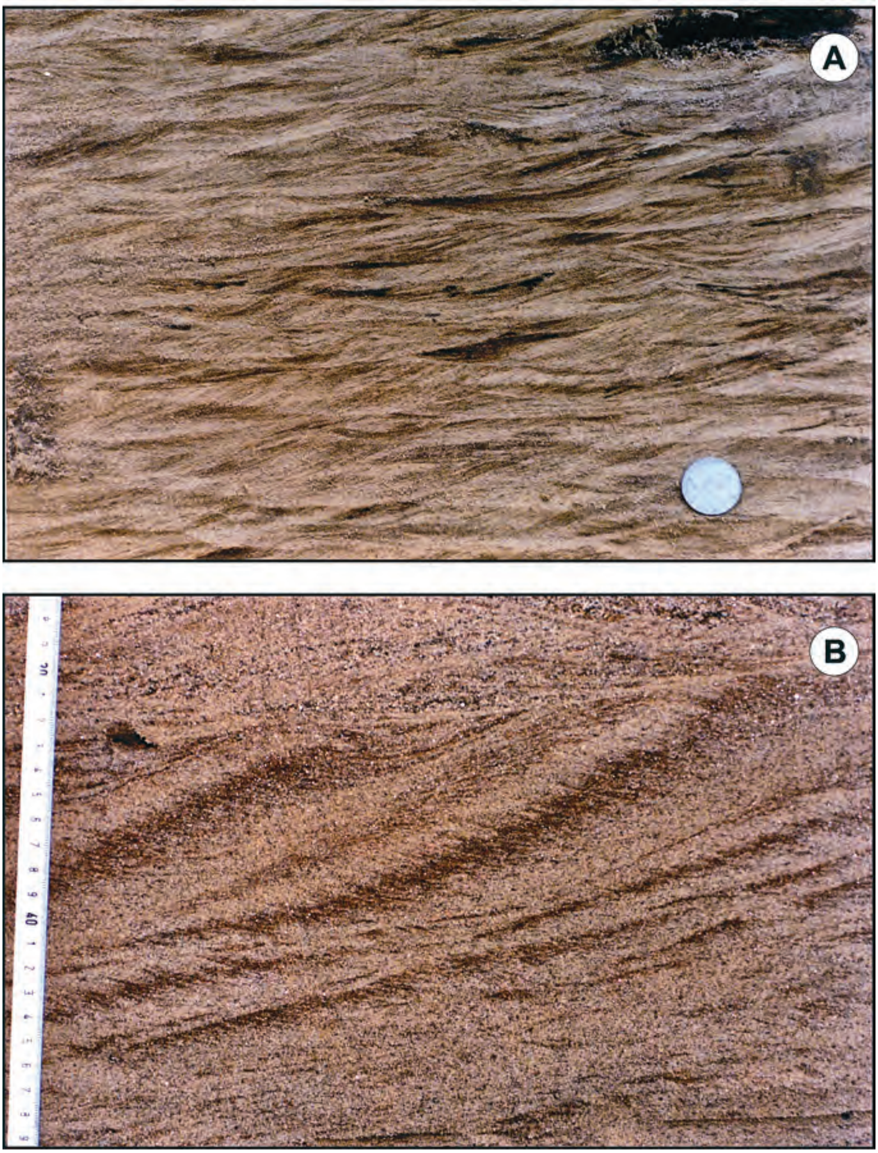


FIGURE 7.8. Micro-cross lamination in the fine/very fine-grained sand facies. A. Trough cross aspect of the micro-ripples. B. Climbing micro-cross lamination. Early Romanian, Jilţ Quarry, Mătăsari (Gorj County)

The sediments are coarser-grained (fine sand) and their sedimentary structures occur as larger units (medium scale cross-lamination) at the lower part of the fine and very fine-grained sand facies (Fig. 7.9).

Thin clayey intercalations (3 - 7 cm thick) appear within the fine and very fine sands. The inclined mud intercalations occur from the base of the upper, silty-clay facies and develop down-slope towards the base of the fine-grained sand sub-facies. The oblique pattern of the clay intercalations within the Jilț sand makes obvious the point bar character with large scale inclined stratification (*sensu* Thomas *et al*., 1987).

In the eastern part of the point bar deposits, the coarse-grained facies is missing and the vertical sequence begins with the fine-grained sand facies. At the base of the eastern part of the point bar, the fine sand facies shows very large cross-lamination structures (Fig. 7.10), as well as frequent pebble clay accumulations.

7.2.3. The medium and coarse-grained sand facies

The facies of the medium and coarse sand sediments represent the lower part of the point bar sequence in the Jilţ Quarry. In addition to coarse grain size, the occurrence of large scale current structures is a defining character of the lower point bar facies. The current structures are trough-cross strata (Fig. 7.11 A, E, F), extending along the trough axis for several meters (Fig. 7.11 B). Sometime, the foreset units are centimetres thick, occurring as thin (1 - 4 cm) inclined sand layers separated by silt laminae (Fig. 7.11 C). On one occasion current ripples have been observed on the top of the large scale cross-laminated structures (Fig. 7.11 C).

Thin clayey interbeds (mud drapes) extend into the upper part of the lower Jilt point bar facies, but are not visible in the lower part of the coarse sand facies.

A thin bed (10 - 50 cm) of fine gravel (Fig. 7.11 F) marks the basal limit of the point bar sequence.

FIGURE 7.9. Medium scale cross-lamination at the lower part of the fine and very fine grained facies. Jilț South Quarry, E13 mining front

FIGURE 7.10. Large-scale current structures in fine-grained sand at the base of the point bar unit. Jilț South Quarry, E13 mining front

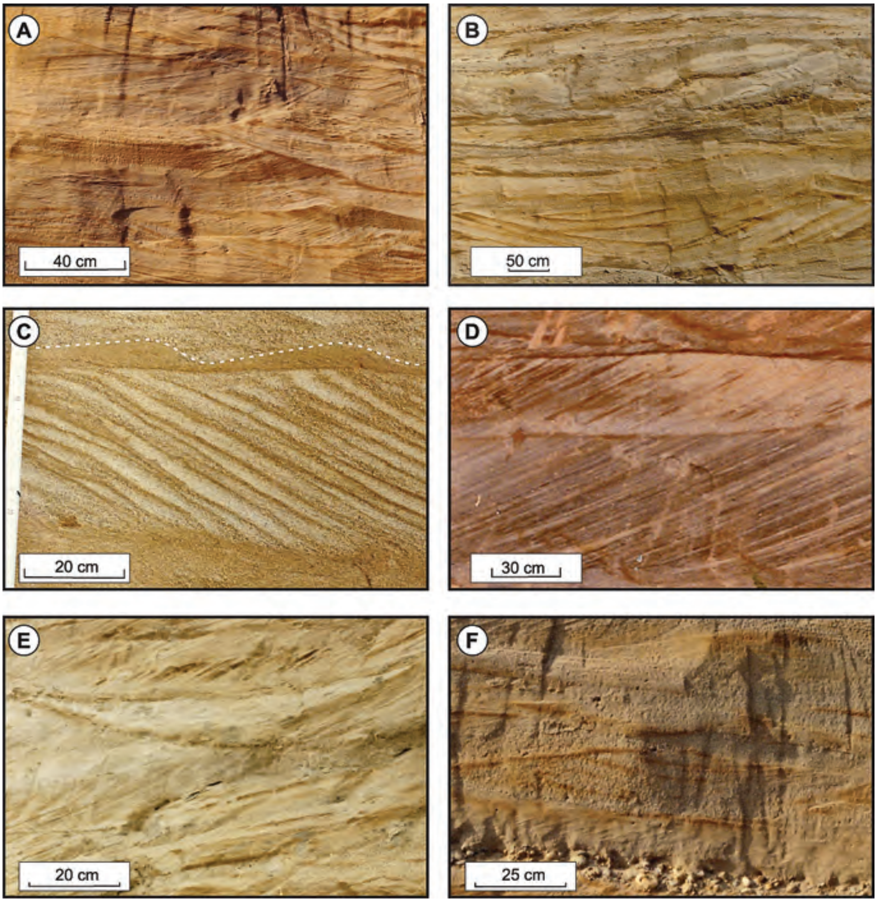


FIGURE 7.11. Large-scale cross-lamination in the lower, middle and coarse-grained sand facies of the Jilț point bar. Jilț South Quarry, E13 mining front. See text for comments

7.2.4. Jilț point bar sedimentary sequence

The inclined bedded sand body cropping out in the Jilț South Quarry is characterized by a vertical sequence with fining upward trend. In the western part of the studied point bar section, the grain size sequence starts with the coarse sand facies and continues with fine sand and very fine sand followed by silty clay deposits (Figs. 7.12; 13, 14). The clastic sequence ends with the homogeneous clay situated under the thin lignite bed.

The fining upward sequence with inclined stratification is highlighted also by the size distribution of the cross lamination structures. The units with large and medium scale cross lamination are present in the lower part of the sequence, and gradually decrease in size towards the upper part of the sequence (Fig. 7.14).

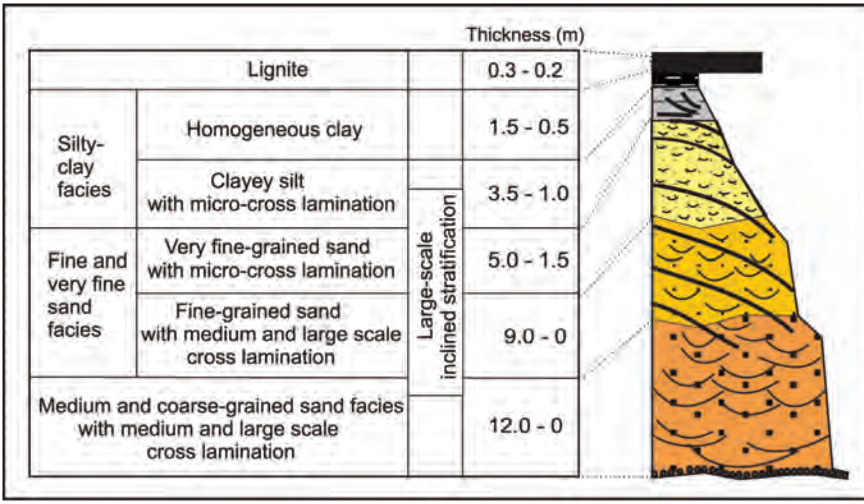


FIGURE 7.12. Main features of the vertical sedimentary sequence of the Jilț point bar deposits. This succession of facies applies to the western part of the point bar, as the lower coarse grained facies is pinching out eastward

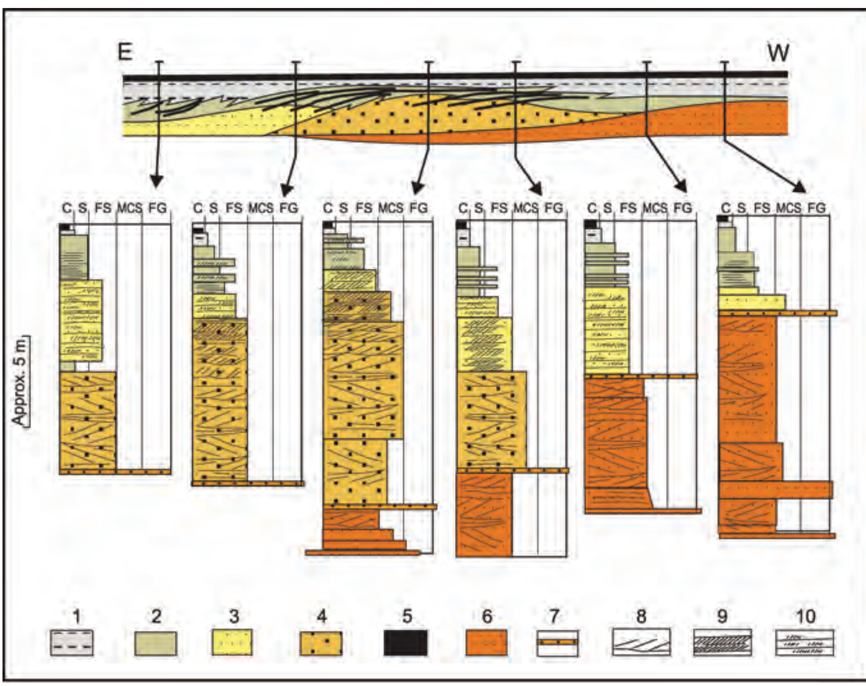


FIGURE 7.13. Litho-facial columns of the Jilț point bar body. **Legend**: **1**. Homogeneous clay. **2**. Clayey silt. **3**. Fine and very fine-grained sand. **4**. Medium and coarse-grained sand. **5**. Coal. **6**. Coarse sand showing no inclined bedding. **7**. Point bar basal lag (fine gravel). **8**. Large scale cross-lamination. **9**. Medium scale cross-lamination. **10**. Micro-cross lamination. **C**. Clay. **S**. Silt. **FS**. Fine and very fine-grained sand. **MCS**. Medium and coarse-grained sand. **FG**. Fine-grained gravel

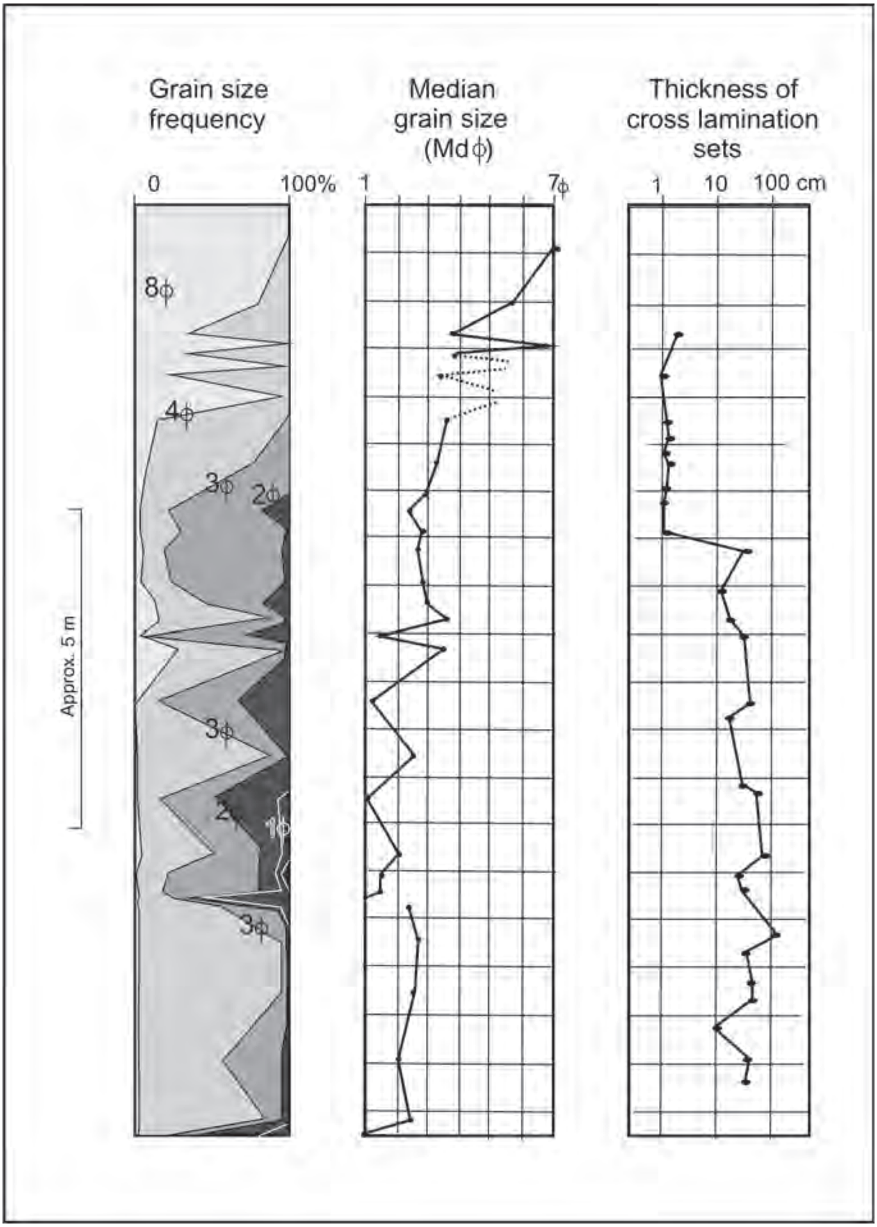


FIGURE 7.14. The fining upward of the Jilţ point bar sequence, expressed by the diminishing sediment grain size and by the decreasing thickness of the cross lamination units

The sequence with large scale cross stratification develops above an erosional basal limit, marked by a thin sheet of fine gravel, the basal lag (Fig. 7.10 F). A flood plain silty - sandy interval occurs under the point bar unit, separating the point bar from the underlying lignite bed VII (Fig. 7.15).

The upper limit of the Jilţ South sequence is normal, depositional, marked by the base of a minor coal episode. Another flood plain clayey deposit occurs above the point bar (Fig. 7.15), between the thin lignite bed and the lignite bed VIII.

7.2.5. Geometry of the facies units

The sandy deposits cropping out in the Jilţ Quarry belong to two types of fluvial accumulation. In the western part of the studied area, the point bar deposits overlie coarse and very coarse-grained sand (Fig. 7.16 A), with large cross lamination structures (Fig. 7.16). These deposits do not show mud drapes intercalations. Occasional inclined clay pebble units (Fig. 7.10) point out the sedimentation of the coarse and very coarse-grained sand facies into an environment of lateral accretion, probably close to the channel talweg.

Three thin sheets of fine-grained gravel divide the sandy accumulations into three units (Fig. 7.16). The first two units are in the coarse sandy sediments without inclined stratification. The entire sand succession is bounded by flood plain sediments (Figs. 7.15; 7.16A).

In the transversal cross section resulted from the mining work in the Jilţ South Quarry, the facies characteristics and geometric relationships are dominated by the existence of a large lens-shaped accumulation of coarse sand (up to 12 m thick) in the central part of the cross section (Fig. 7.16 B).

Pinching out of the coarse sand facies is compensated by the increasing thickness of the fine and very fine sand facies. Consequently, the general shape of the inclined stratification Jilţ body is approximately tabular in the eastern part of the section.

Westward from the central coarse sand lens, the very fine grained sand subfacies and the silty-clayey upper facies are getting thicker (Fig. 7.16 B). In the westernmost part, the very fine grained sand sub-facies gradually pinch out above an inclined surface (probably, the channel margin) made up by the coarse-grained sediments without inclined stratification.

7.2.6. Pattern of the inclined stratification

The thin clayey interbeds (mud drapes) indicate the internal inclined sedimentary surfaces within the Jilţ sand body (Figs. 7.18; 7.19; 7.20). The clayey intercalations (lateral accretion surfaces) have a common eastward dip direction, but their variable dipping value and extension differentiate several sets of inclined stratification sediments (Fig. 7.21).

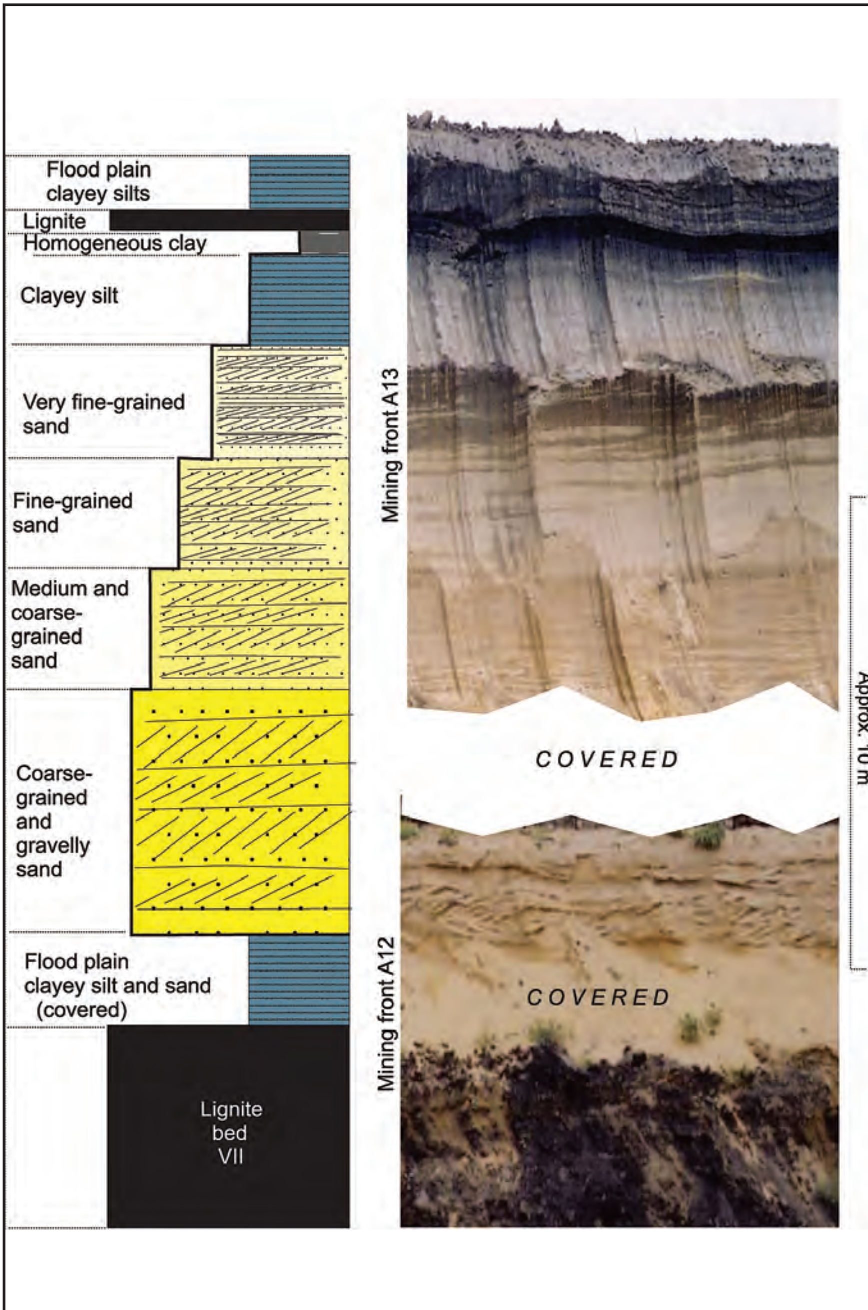


FIGURE 7.15. Synthetic litho-facial column of the deposits cropping out on the walls of the mining fronts E12 and E13. Jilț South Quarry

The westernmost set of mud drapes (set S1 in figure 7.21) shows the lowest dipping values and a large east to west extension. Eastward, the clay drape sets are getting less extensive and the mud drapes dip increases.

The shape of the mud drapes in vertical section is also variable. The western group (set S1) occurs as long, straight mud drapes, indicating that the fluvial channel was wide and the sedimentation on the accreting bank quite active. The mud drapes of the next group (set S2) are convex-up shaped, which possibly indicate the active lateral shifting of the channel. The rest of the clay beds (sets S3 to S6 in figure 7.21) are less extended, concave-up shaped and steeper (10 – 20°).

Between the sets of inclined mud drapes there are discontinuity relationships, but they are hard to observe directly in the outcrop. The obvious relationship in outcrop is between the sets S5 and S6 (Fig. 7.22). The discordance surface is evident, and the erosion surface is emphasized by an accumulation of mud pebbles.

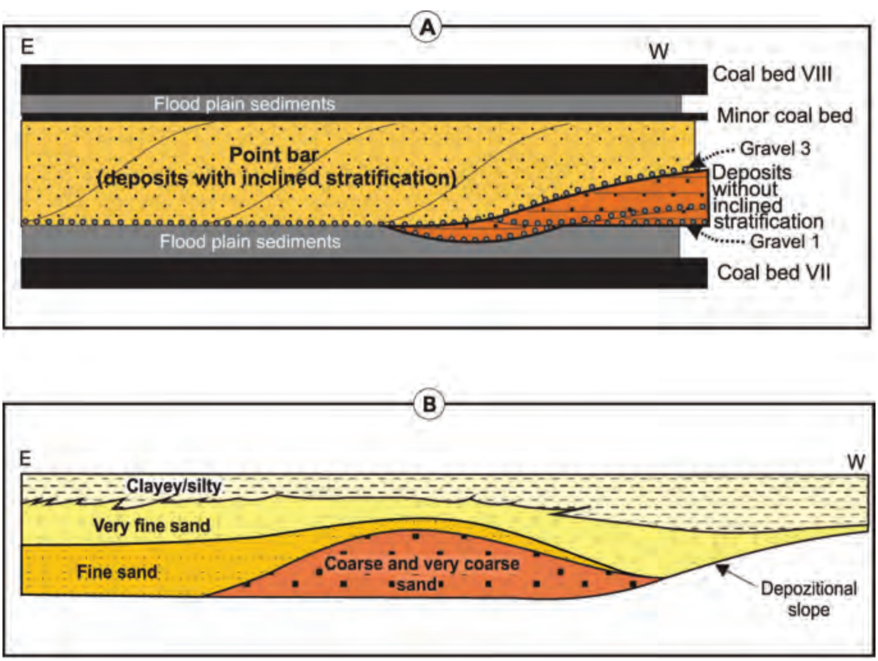


FIGURE 7.16. The sedimentary architecture of the Jilț Quarry sedimentary succession. **A**. General setting of the point bar unit. **B**. Geometry of the point bar facies. Not to scale

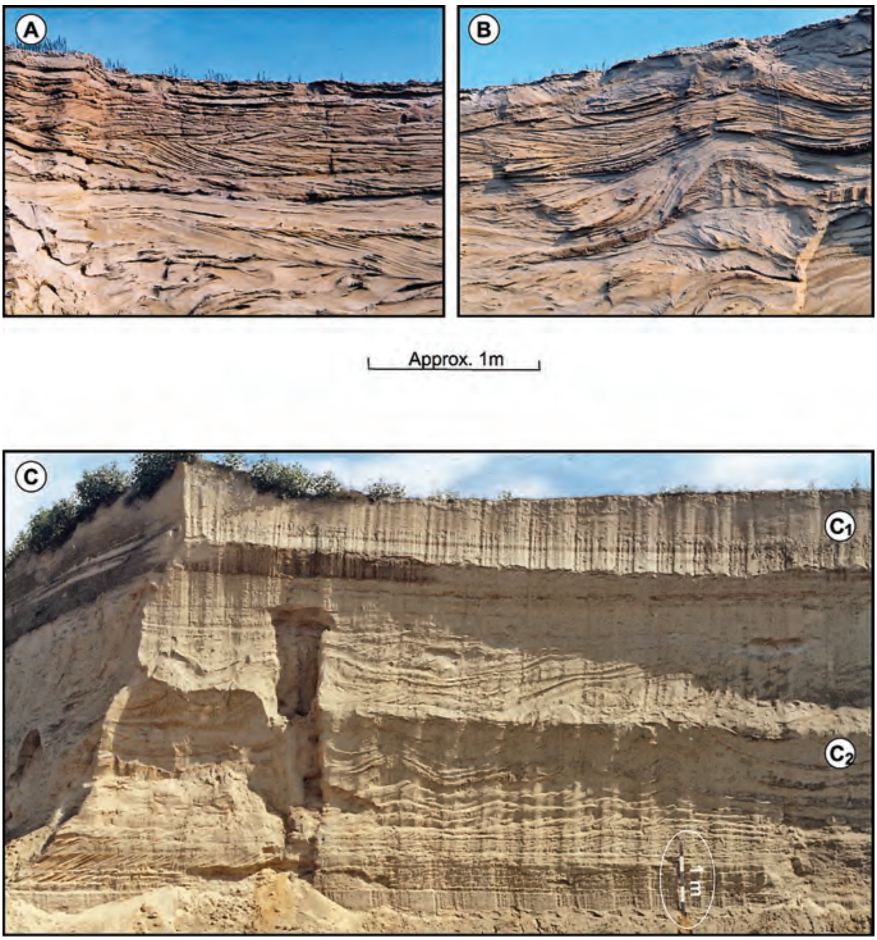


FIGURE 7.17. The coarse-grained sand fluvial deposits without inclined bedding, underlying the western part of the Jilț point bar deposit. **A** and **B**. Large trough cross-lamination units. The thickness of the trough cross-laminated units is between 15 and 30 cm. **C**. Upper facies of the Jilț point bar (**C1**) overlying the coarse-grained fluvial sand (**C2**), heavily disturbed by water expulsion

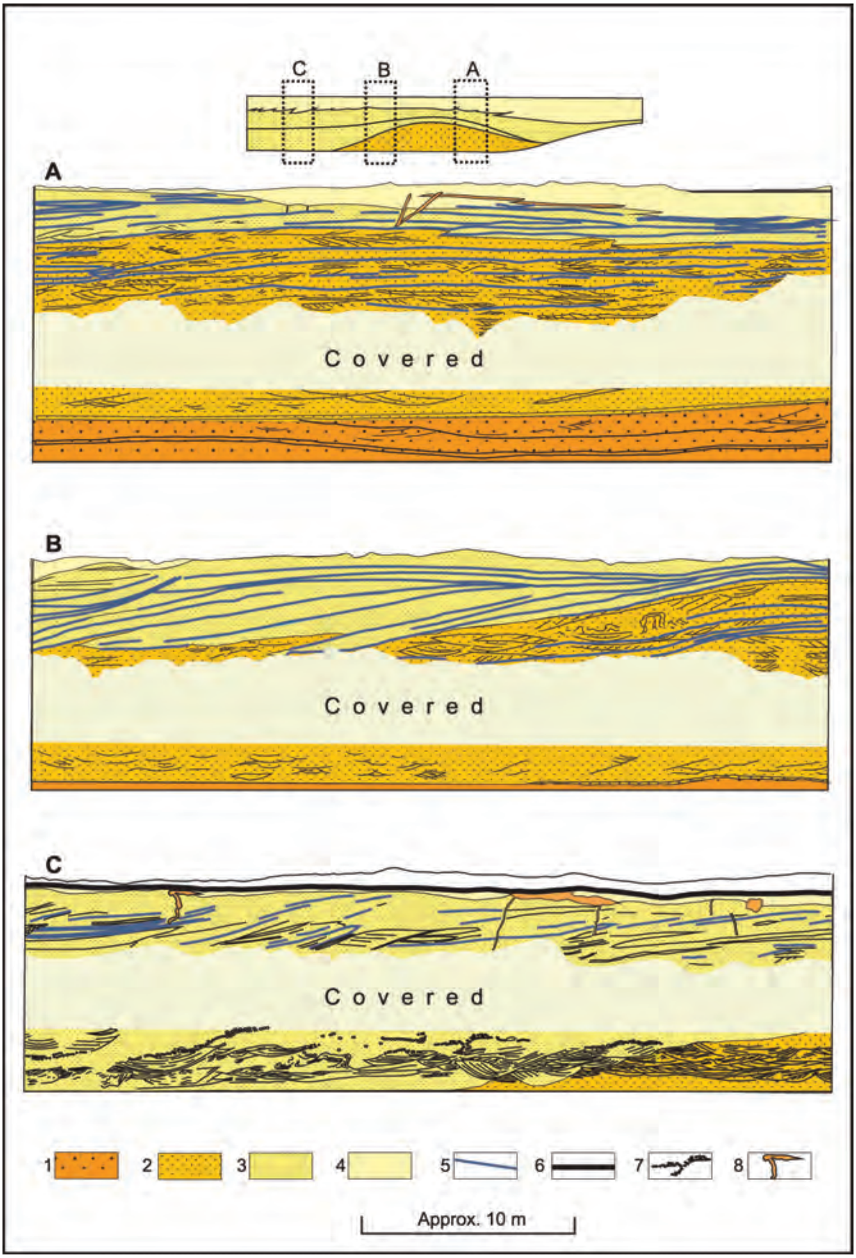
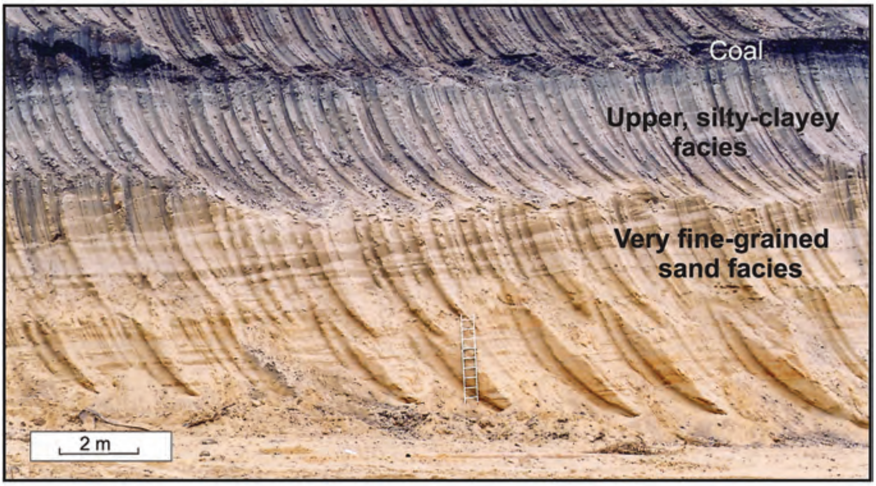


FIGURE 7.18. Inclined bedding and sedimentary structures in geological sections located along the Jilț point bar deposits (see index sketch in the upper-center). **Legend**: **1**. Fluvial channel, coarse-grained deposits without inclined bedding. **2**. Lower, middle and coarse grained point bar facies. **3**. Middle, fine and very fine grained point bar facies. **4**. Upper, silty-clayey point bar facies. **5**. Mud drapes **6**. Coal bed. **7**. Clay-pebble breccia. **8**. Clastic dykes

FIGURE 7.19. Point bar deposits cropping out on the wall of the E13 mining front. Jilț South Quarry. Gorj County. **A** - Minor coal bed, preceding the thicker coal bed VIII. **B** - clayey silt upper point bar facies. **C** - Clayey silt floodplain sediment accumulation



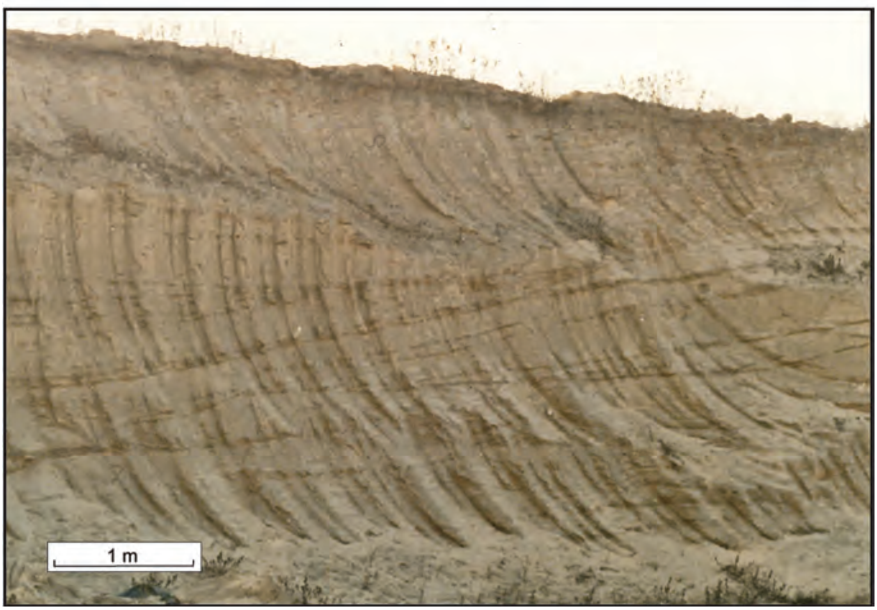


FIGURE 7.20. Upper part of the point bar sequence. Jilț Quarry, E13 mining front.

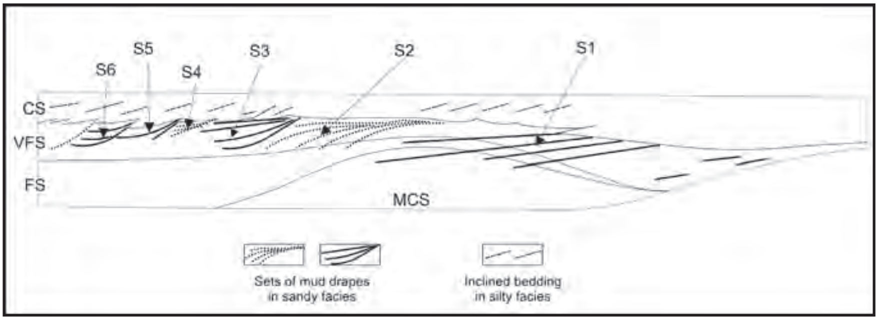


FIGURE 7.21. Groups of mud drapes (S1 to S6) with common prevailing inclined trend. Broken line - inclined stratification in the upper silty-clayey facies. Jilţ Quarry point bar deposit. **CS** - Clayey-silt facies. **VFS** - very fine-grained sand facies. **FS** - Fine-grained sand facies. **MCS** - Medium and coarse-grained sand facies

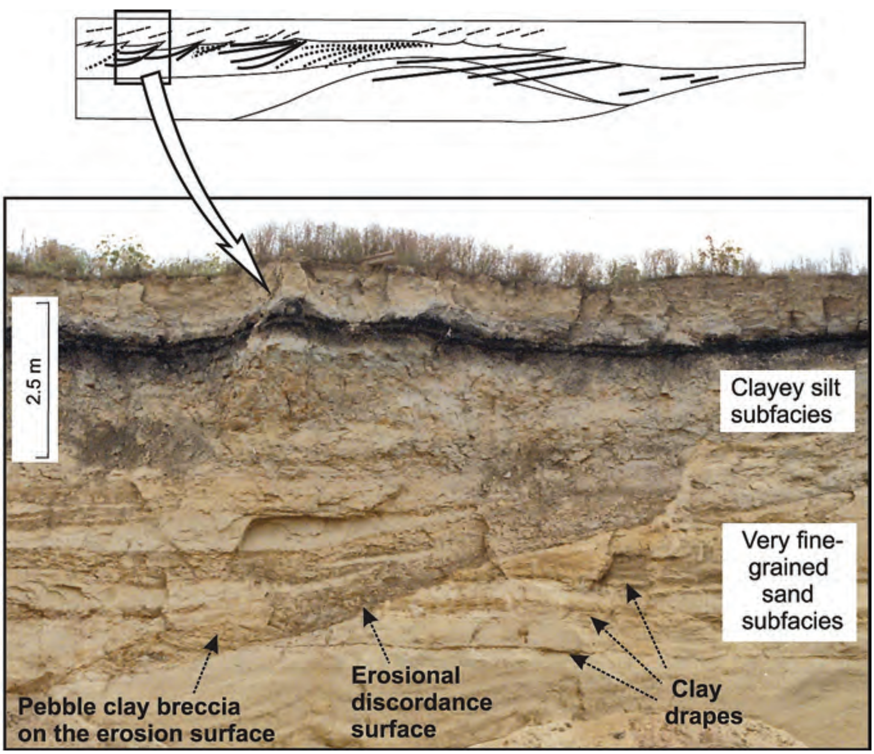


FIGURE 7.22. Discordance surface between the mud drapes groups 5 and 6. Eastern part of the mining front E13, Jilţ Quarry

A second inclined stratification system exists within the Jilţ point bar sedimentary architecture. The second system appears as a large scale cross stratification structure, several meters thick and tens of meters long. This large stratification structure is located toward the top of the Jilt sand body, within the upper, silty – clayey facies (sometimes representing the whole facies interval) (Fig. 7.23). The structure is tabular and develops on only one storey. A large stratified body occurs in the western part of the point bar deposit, and a second one was observed eastwards above the set S3 of mud drapes. The two structures are at the same level, probably forming a single depositional unit. The eastern structure is of a polygenetic nature, with three distinct sedimentary bodies succeeding laterally.

7.2.7. Paleocurrent directions

The estimation of paleocurrent directions in the Jilţ point bar deposits relied on cross lamination structures. A section parallel to the general bedding was dug into the weakly cemented sandstone with cross lamination. In this way, it was possible to correctly evaluate the foreset orientation of the current structures and find the paleocurrent direction.

The performed measurements indicate that the dominant direction of the paleocurrents was from SSE to NNW (Fig. 7.24). This direction is practically the same in all point bar facies and subfacies.

The dominant flow direction of the paleo-river appears to be at right angle to the trend of the paleo-river lateral shifting (dip direction of the large accretion surfaces), as it should be in a point bar environment.

7.3. MUD DRAPES CHARACTERS AND DISTRIBUTION

7.3.1. General aspect of the mud drapes

On the upper part of the sand unit with inclined stratification studied in the Jilt quarry, there are frequent clay intercalations (Figs. 7.19; 7.20). The most numerous clayey beds (mud drapes) appear as thin beds of 3-10 cm thickness, mostly 4-7 cm. The mud drapes length in the outcrop is large, up to 100 m. Constant thickness and uniform lithology characterize the mud drapes. The thick clay intercalations (30-60 cm) are rare.

The frequency of the mud drapes varies. Clayey intercalations occur at 1-2 m interval, when they are located in sand deposits. The siltstone beds between the clay strata are thinner close to the upper limit of the silty clay facies.

Considering the lithology and the internal sedimentary structure, three main types of mud drapes have been distinguished:

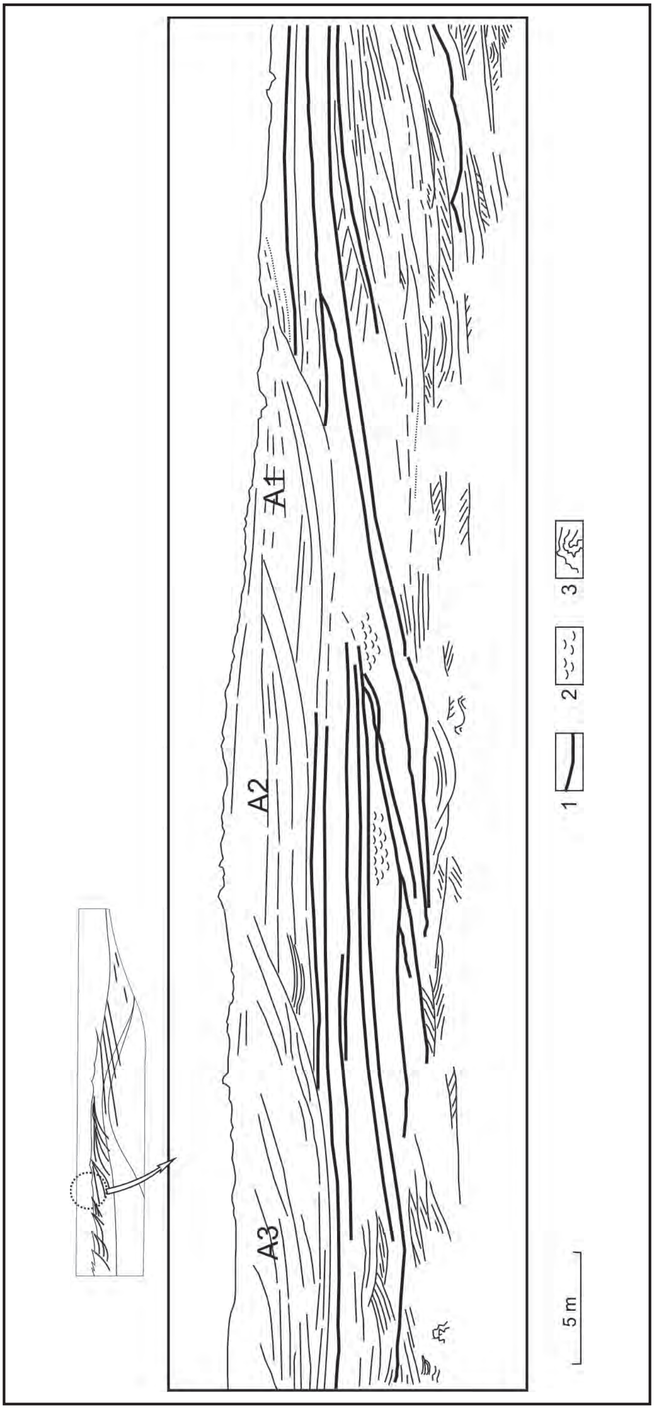


FIGURE 7.23. Large-scale current structures (**A1**, **A2**, **A3**) in the upper silty-clayey facies of the Jilț point bar. The three current generated units are part of a second lateral sedimentation system of the point bar. Mining front A13 (middle to eastern part), Jilț Quarry. **Legend**: **1**. Mud drapes. **2**. Small scale current lamination. **3**. Disturbed sedimentary structure

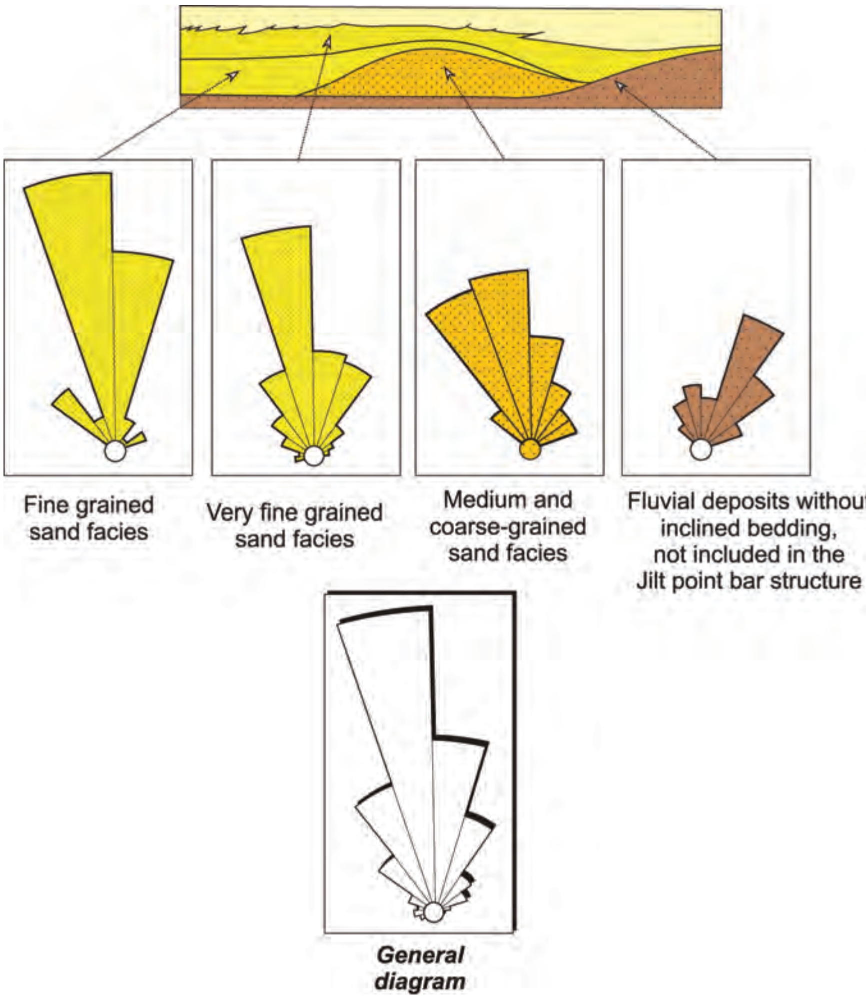


FIGURE 7.24. Paleocurrent directions measured in the point bar deposits from the Jilț Quarry. Measurements based on cross-lamination orientation, mostly small and medium size

- the least frequently observed are the homogeneous clay beds, without sandy or silty lamination;
- the most frequent is the clay drape type with relatively minor silt and sand laminae (Fig. 7.25 A);
- the third type of mud drape includes a significant amount of silt and sand, which occurs as small lens-like bodies or as interfingering thin beds (Fig. 7.19 B, C and D)

Usually, the mud drapes display parallel, sharp and smooth boundaries. The lower boundary is more rugged than the upper one. Irregular top surfaces of the thin clay beds have also been observed (Fig. 7.25 E and F). The internal lamination of the clayey beds is cut, indicating the erosional character of the upper surface.

7.3.2. The internal structure of the mud drapes

Even though the clay intercalations studied are thin, their internal structure is variable and revealing. Characteristically, the internal structure elements show up in the lower half of the mud beds (Fig. 7.25 A). The upper (and middle) part of the strata represents the interval of parallel and rarely cross silty-clay lamination. Sometimes, sandy beds occur in the middle of the mud intercalation (Fig. 7.25 B), or (occasionally) they are distributed on the entire vertical column of the mud bed intercalations.

Some mud beds have a lower interval with sand laminae and an upper interval with silty clay laminae (Fig. 7.25 A). The transition is gradual between the two lamination intervals, and the clay bed appears as fining upward.

The mud drapes are closely connected with cross strata (current structures). Within the mud drapes unit, there are cross-bedded sand thin units, with clay material between the oblique sets of sand laminae (Fig. 7.25 D). Clayey material is sometime draping large troughs of cross strata (Fig. 7.10). It is common for the mud drapes to occur between current laminated structures (Fig. 7.25 E and F).

7.3.3. Mud drapes down-dip endings

Types of clay drape ends. Beside the internal sedimentary structures, the nature of the mud drapes terminations represents an important feature.

Some mud drapes end with a sharp, irregular outline. This is an erosional down-dip termination of the mud drapes. The erosional characteristic is also revealed by the cut cross-laminae at the mud beds end (Fig. 7.26 A).

Another type of mud drapes termination is the sharp, irregular, erosional end continued with a row of clay pebbles (Fig. 7.27 A).

Other mud drapes terminate by pinching out of the clay bed. Some thinning mud drapes show features suggesting that the bed thickness reduction might be of erosional nature.

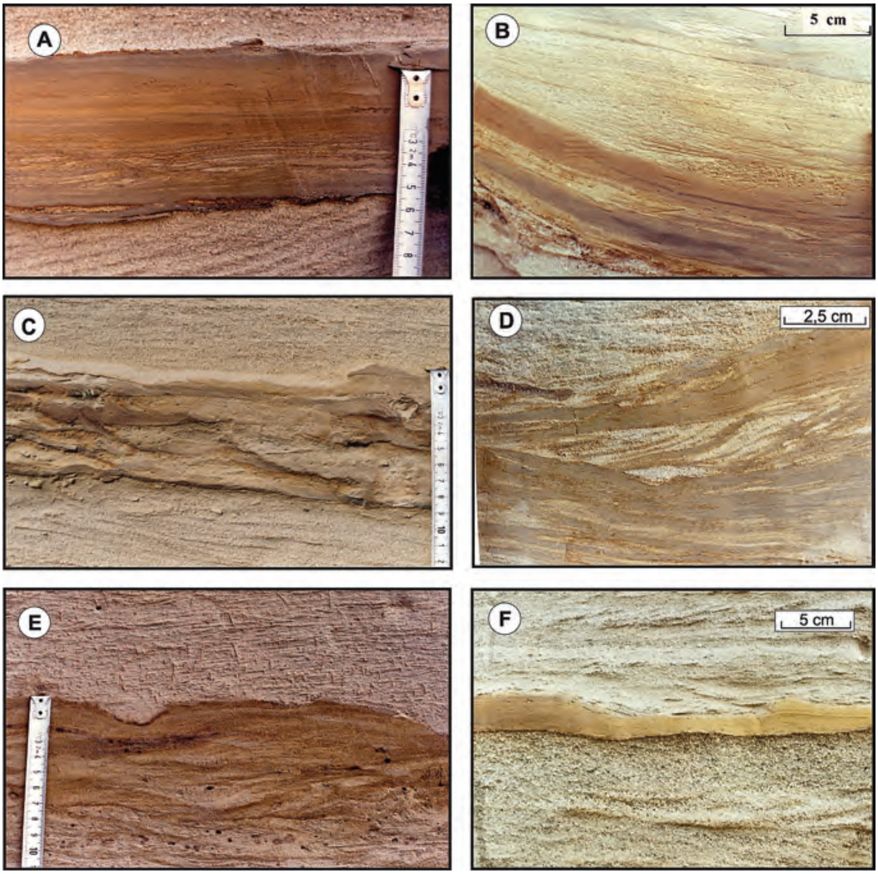


FIGURE 7.25. Sedimentary features of the mud drapes. Jilț Quary, E13 mining front. **A**. Clay drape with sandy laminae in the lower part of the bed. Rugged boundaries. **B**. Clay drape unit with a pinching out sandy interval in the middle. **C** and **D**. Clay drapes including many small sand bodies (current structure is evident in picture D). **E**. Fining upward clay drape unit. Erosional upper boundary. **F**. Mud drape with flat lower bed boundaries and irregular, erosional upper limit

Down-dip extent of the mud drapes. Mapping the point bar deposits that crop out in the Jilț South Quarry, it was established that the mud drapes never extend down-dip into the base part of the point bar (Fig. 7.21). In figure 7.28 the mud drapes lower extent is limited to a certain point bar basal level. This level of maximal down-dip extent appears to be the same, no matter if the point bar basal part is coarser-grained or finer-grained.

Practically, all the down-dip terminations of the mud drapes are of erosional nature. It appears that the high sedimentary dynamics characteristic for the base of the point bar sedimentary sequence (corresponding to the fluvial channel) is the main factor that limited the extent of the mud drapes.

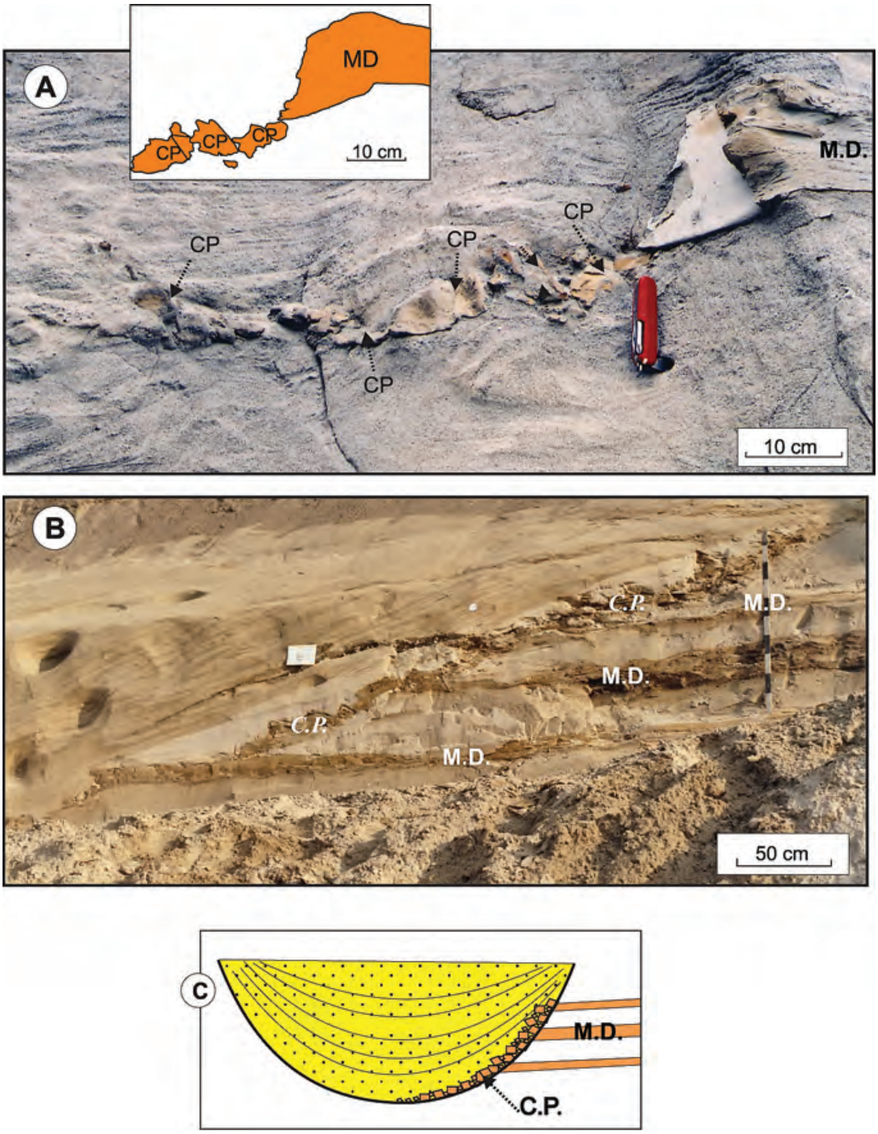


FIGURE 7.26. Mud drapes erosional terminations. **A** and **B**. Mud drapes (**M.D.**) erosionaly cut and clay pebbles (**C.P.**) accumulated on the erosion surface. **C**. Graphic presentation of the pebbles accumulation at the eroded end of the clay drapes (as in picture **B**)

FIGURE 7.27. Accumulation of clay pebbles resulting from the erosion of the down-slope mud drapes endings. **A**. Row of clay pebbles on the bedding plane, in the median part of the Jilț point bar deposit. **B**. Clay pebbles breccia. **C**. Clay pebbles accumulated as a discrete breccia unit or dispersed in the sand mass. **D**. Trough cross bedding with clay pebbles. Jilț South Quarry, Mining front A13

Clay pebble accumulation. During the evolution of the Jilţ point bar, the mud drapes have been partly eroded in different circumstances.

In the lower part of the fine-grained sand facies, well above the basal higher energy section of the Jilţ point bar, mud drapes appear occasionally eroded at the contact with small channels. The energy of the channel was probably insufficient to completely remove the clay pebbles produced during erosion. Consequently, a clay pebbles breccia accumulated inside the small channel, sometime in the vicinity of the eroded mud drape (Fig. 7.27).

When the mud drapes have been eroded in the basal, fluvial channel section of the point bar, the resulting clay pebbles have been transported and redeposited. In this way clay pebble breccia units have been generated within the basal sediments with large scale trough-cross lamination (Fig. 7.28 B, C and D). Occasionally, the dipping clay pebble breccia units show the presence of inclined stratification in the basal part of the point bar (Figs. 7.10; 7.18 C).

7.4. GENETIC SIGNIFICANCE OF THE SAND BODY WITH MUD DRAPES FROM THE JILŢ QUARRY

7.4.1. The sedimentation environment

The sediments exposed by the coal mining activity in the mining fronts A12 and A13 have been accumulated in a fresh-water environment, as attested by the fauna (Pană *et al*.,1981, Stănescu *et al*., 1983; manuscript[1]). The cross and parallel lamination are common internal structures of the studied sand accumulation. These two main sedimentary structures indicate that Jilţ deposits were formed in a fluvial environment, by unidirectional currents. The fining upward, scoured base with lag deposits and the large participation of clay deposits in the general sedimentary succession are characteristic to the fluvial environment of the meandering rivers (Walker, 1979; Miall, 1996).

The main sedimentary architecture element for the identification of the sedimentation environment of the sand body with thin clay intercalations cropping out in Jilţ Quarry is the large scale inclined stratification. This geometry of the beds shows that the Jilţ South deposits accumulated by lateral sedimentation.

The relatively orthogonal relationships between the dip direction of the large scale inclined stratification of the Jilţ sand bodies and the dominant paleocurrent directions (Fig. 7.24) confirm that the lateral sedimentation is of lateral accretion type, eliminating the possibility of forward progradation. The fact that the two directions are approximately rectangular indicates that the sediments were carried to the north through fluvial channels, while the channels were migrating eastward.

[1] Op. cit., p. 140

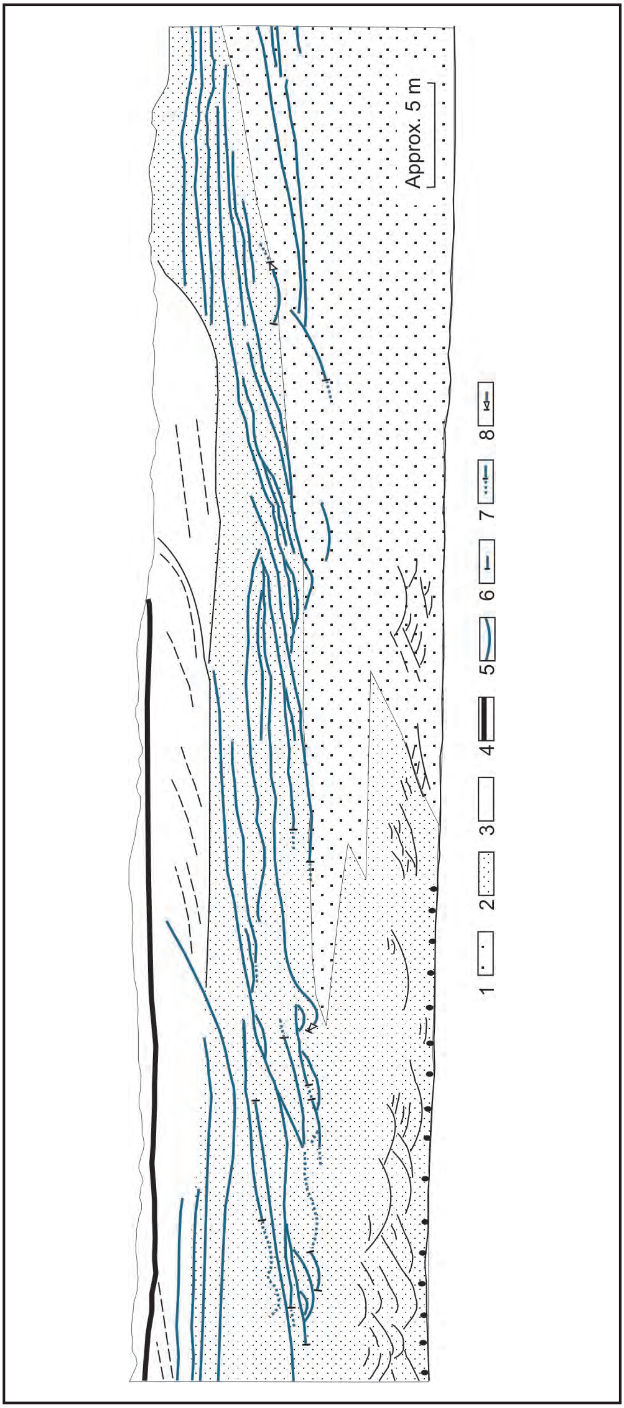


FIGURE 7.28. Mud drapes endings in a Jilț point bar segment. To be noted the limited down-dip extent of the mud drapes, irrespective of the facies dominant grain size. Not to scale. **1**. Medium and coarse-grained sand. **2**. Fine and very fine-grained sand. **3**. Clayey-sitty deposits. **4**. Coal. **5**. Mud drapes. **6**. Erosional ending. **7**. Erosional ending with a row of day pebbles. **8**. Pinching out ending.

Into an environment of fresh-water mollusk fauna such as the Jilţ South sand (Stănescu *et al*., 1983, manuscript[1]), the environment of the lateral accretion process may be identified as the point bar environment (Stewart, 1983; Thomas *et al*., 1987).

7.4.2. Genetic significance of the facies

All the facies of the Jilţ sand - except for the homogeneous upper clay - are associated through the common inclined stratification. The genetic relationship results from the fact that the thin clay intercalations start from the silty-clay facies and extend down-slope to the upper part of the medium and large grain size sand, crossing the fine and very fine sand deposits. Therefore, the Jilţ South point-bar sequence does not express a simple geometric superposition, but also a lateral-oblique continuity of the facies. The continuity relationship along the inclined stratification reveals the distribution of the deposits on the inner, convex bank of the fluvial channel that accreted laterally and generated the point-bar. During the lateral accretion the sedimentation unit consisted of (1) clayey-siltic sediments (upper Jilţ sand facies) of the marsh behind the channel, (2) fine and very fine-grained sand on the slope, and (3) coarse (later fine) grained sand in the trough of the fluvial channel.

The basal facies of the Jilţ sand is characterized by large cross lamination units and the coarsest-grained sediments of the point bar deposit. This basal point bar facies hosts rudaceous elements, consisting of quartzitic pebbles, most of them concentrated at the basal erosional limit. There are also clay pebbles assembled as breccia intercalations, or dispersed in the sand matrix. These features indicate that the basal Jilț sand facies reflects the highest energy of the Jilț deposits; that is the axial zone of the alluvial channel.

The middle facies of the point-bar sequence consists of very fine and fine sand. In this facies the inclined mud drapes are fully developed. Consequently, there are arguments to consider that the sediments of the middle facies accumulated on the depositional slope, which is the convex, accretional fluvial bank (the front of the point bar). Its reduced grain size and smaller cross-lamination units reflect the lower depositional energy of these deposits, as compared with the environment of the basal point bar facies.

The silty-clay subfacies is the place wherefrom the system of mud drapes starts. This indicates that the silty-clay subfacies is part of the large scale, inclined structure of the Jilţ sand. Therefore, we may consider that this subfacies includes sediments accumulated on the upper slope of the point bar, at the edge of the river, in the area with the shallowest water.

1 Op. cit., p. 140

The homogeneous clay subfacies represents the swamp area, located behind the accreting bank of the meandering river. This interpretation is based on the clayey lithology of the subfacies, the lack of internal structure, and the presence of rootlets.

7.4.3. The evolution of the Jilț fossil point bar

The lateral accretion deposits of Jilt Quarry interpreted as a fluvial point bar were preceded by a rather different fluvial environment. The coarse and very coarse sand that crop out in the western part of the A13 quarry front, under the point bar deposits (Fig. 7.21), is sediment accumulated by a fluvial agent with high energy. These deposits are not fining upwards and do not show any large scale inclined stratification.

The point bar sedimentation took place after the episode of the coarse and very coarse-grained sand. According to the major structure, marked by the clay drape geometry, two stages can be distinguished during the evolution of the lateral accretion process of the Jilț point bar.

The initial stage was a period of continuous and intense sediment accumulation. The sediments of the youngest mud drapes group (set S1 in the figure 7.21) accumulated during the initial development stage. The large areal extension of this set (the S1 mud drapes are 400 m long) indicates a relatively long and continuous period of lateral accretion. During this period, the transport energy of the meandered river reached its highest values. This is suggested by the important volume of the medium and coarse-grained sands.

The sets S2 and S3 mark the transition from the first to the second point bar stages. With the mud drapes set S2, the first break in sedimentation occurred. The S2 set has shorter mud drapes and S3 includes even shorter ones. The mud drapes seem to be steeper and their shape is different. These changes suggest that the sediment accumulation area was getting smaller and the periods of accumulation became shorter.

The second stage of the Jilț South fossil point bar is more evident in the sets S4, S5 and S6 (Fig. 7.21), when the process of sediment accumulation is interrupted by frequent erosion periods. The changes manifested in the development of S2 and S3 sets continued and accelerated during the second stage. The drastic grain size decrease in the basal point bar sediments indicates the decline of the sediment transport capacity. The river stability degraded and the breaks in sedimentation became more frequent.

Chapter 8

THE PALEOENVIRONMENTAL SIGNIFICANCE OF CLAY IN THE DACIAN BASIN

Clay is one of the most frequent rocks in sedimentary sequences. Due to its very fine grain size, no internal sedimentary structures may be identified in clay. Consequently, the data on the reconstruction of sedimentary conditions of the clay facies are much reduced. This makes the paleoenvironmental analysis incomplete or impossible to perform in the dominant clay or clayish only sedimentary series.

The sedimentological studies performed on the Dacian Basin deposits lead to the establishment of some criteria that reveal several types of clay of various sedimentary and facies properties. This fact may offer new possibilities for the paleoenvironmental analysis.

8.1. TYPES OF CLAY FACIES

The differentiation of clay facies using outcrop data can be made in terms of the properties of the clay sediments, as well as based on the features imprinted by other types of sediment occurring in the clay.

For the Late Neogene sediments studied in the Dacian Basin area, the clay may be differentiated based on the following sedimentary characteristics:

- the bedding of clay sequence, disregarding the stratification evidenced by other sedimentary intercalations;
- the homogeneity of clay sediment, implying the lack of visible bedding, in sequences that are not affected by the bioturbation;
- the presence of calcareous concretions or of the levels with paleosoil properties.

The sedimentary characters listed above are identified in two facies types of clay:

(1) **stratified clay**, sometimes with parallel laminae (silt or very fine sand) (Fig. 8.1);

(2) **homogeneous clay**, with no stratification or parallel lamination (Fig 8.2).

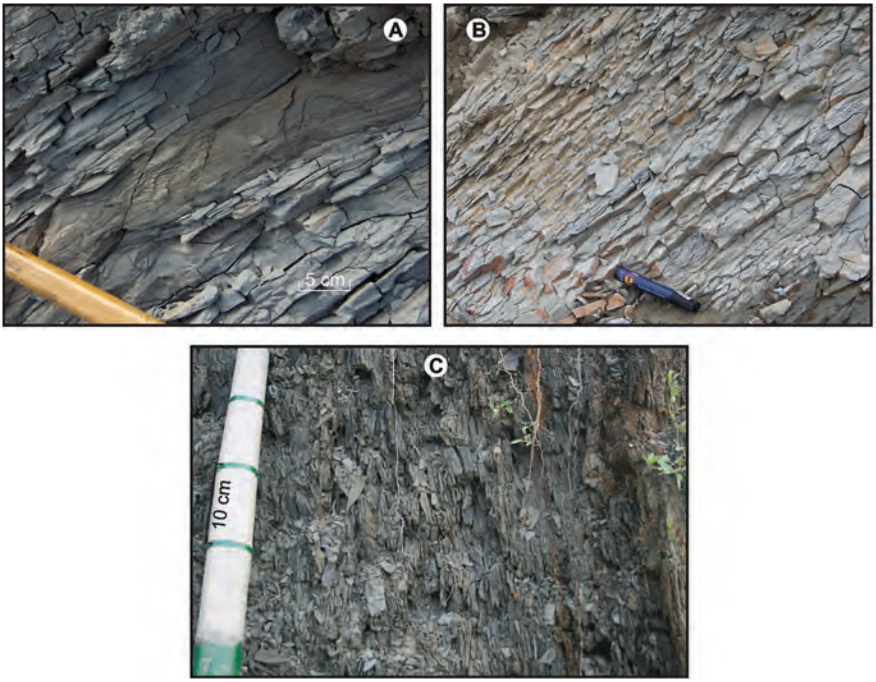


FIGURE 8.1. Clay deposits with evident internal bedding. **A** and **B** - Early Dacian. Sărăţel River, Plopeasa village (Buzău County). **C** - Sarmatian (*s. l.*). Milcov River, Reghiu (Vrancea County)

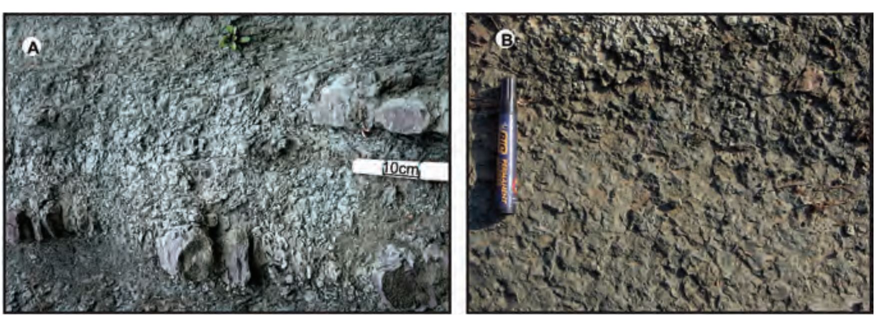


FIGURE 8.2. Homogeneous, non-stratified clay in fluvial deposits. **A** - Sarmatian (*s. l.*). Milcov River, Reghiu (Vrancea County). **B** - Late Maeotian, Vlădeşti (Argeş County)

8.2. CLAY FACIES AND SEDIMENTARY SEQUENCES

For the identification of the paleoenvironmental significance of the two types of clay, it is important to examine the sandy units and/or the sedimentary sequences associated with the clay facies.

In the Maeotian and Early Dacian-dated littoral deposits from the Dacian Basin, the stratified clay often show up as a basal term of the coarsening upward sequences. The littoral Late Maeotian stratified clay from Bizdidel River (Pucioasa) alternate with coarsening upward sand and has thin sandy interbeds with wave ripples (Fig. 8.3 A).

The homogeneous type of clay sediments were frequently found together with the sand sediments accumulated in the fluvial environment. This clay facies is the upper term, the finest-grained one, of the fining upward fluvial sequences (Fig. 8.3 B). The limit with the sand sediments of the next fining upward sequence which is overlying the homogeneous clay, is sharp, non-transitional.

In the upper fluvial part of the Late Maeotian deposits investigated in the Bizdidel River section, the stratified clay facies appears in crevasse splay sequences (Fig. 8.4) as a basal term of the sequence. In this case, the coarsening upward sequences show up in a thick fluvial succession with dominant homogeneous clay. The clay facies changes, becomes stratified, at the base of the coarsening upward unit.

8.3. SEDIMENT ACCUMULATION PALEOENVIRONMENT AND THE CLAY FACIES

The Late Maeotian – Early Pontian sediment cropping out on the Bizdidel River display a succesion of littoral to fluvial paleoenvironments. The study of these sediment (Jipa, Olteanu, 2003) had as one of its targets the environments of the clay (stratified and non-stratified) deposits.

In the Late Maeotian deposits from the Bizdidel River geological section the *stratified clay* appear associated with sands accumulated in the following sedimentation environments:

- shoreline environment (fair-weather or storm dominated); this environment is indicated by the coarsening upward sedimentary units with wave ripples and hummocky cross lamination; the stratified clay represents fair-weather moments sometimes preceding the storm weather;
- fluvial dominated deltaic environment, represented by coarsening upward units with current structures (but without wave or storm-generated lamination) intercalated in littoral deposits; in this case the clay can be attributed to the prodelta microenvironment;

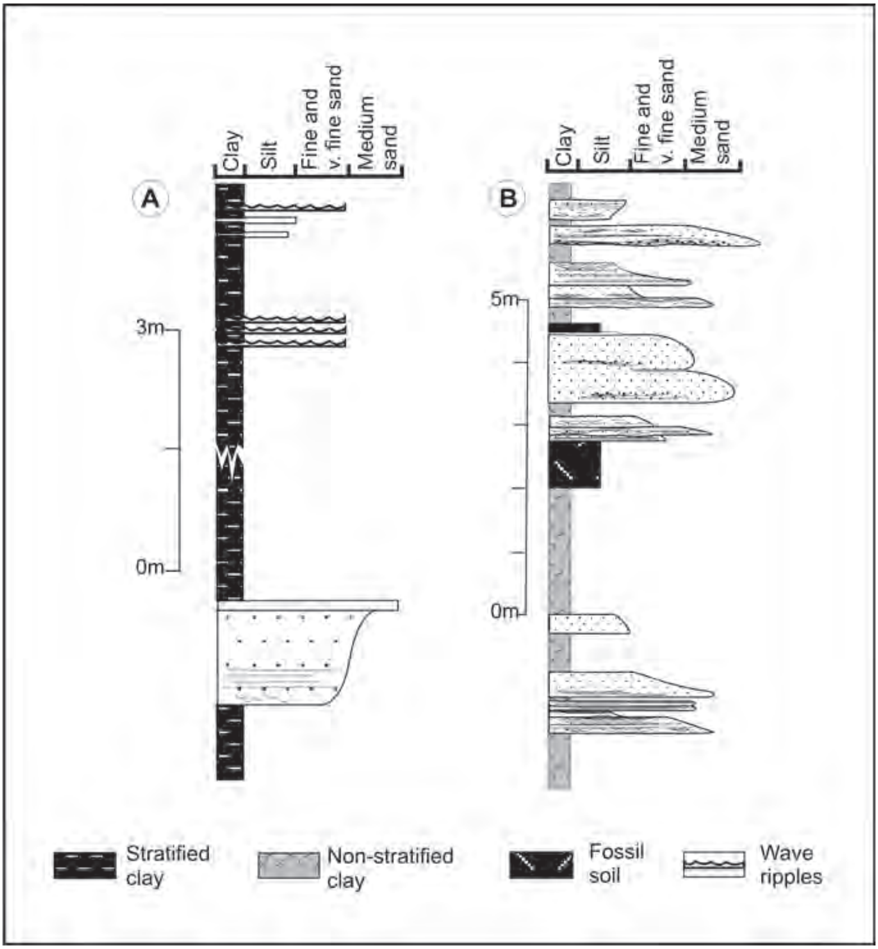


FIGURE 8.3. Types of clay and the associated sandy sedimentary units. **A** - Stratified clay in a littoral sequence with a coarsening upward bed and thin silty and sandy intercalations with wave ripples. Late Neogene, Bizdidel River, Pucioasa (Dâmbovița County). **B** - Non-stratified clay in a fluvial sequence with fining upwards sandy units. Romanian, Dumitreşti (Vrancea County)

- fluvial crevasse splay environment; this is the interpretation applied to the coarsening upward sedimentary units intercalated in fluvial deposits (characteristically with fining upward trend).

The *homogeneous clay* is associated with fluvial sequences. Taking into consideration that the homogeneous clay belongs to the fining upward sequence, we may conclude that some of this type of clay accumulate in the fluvial channel environments. Since this is an extremely fine sediment accumulation and without current structures, the homogeneous clay could represent the moment when fluvial channels were abandoned by avulsion and the clogging of the abandoned channels was in progress. The marsh is also a site where the homogeneous clay accumulated.

Another feature underlining the fluvial affiliation of the non-bedded clay is represented by the presence of soil fossil aspects. Some homogeneous clay display calcareous concretions (Fig. 8.5), either randomly distributed or aligned to evidence the bedding surface. Dark colored intervals, believed to be rich in organic matter, occur in some fluvial, flood plain sediments (Fig. 8.5 E).

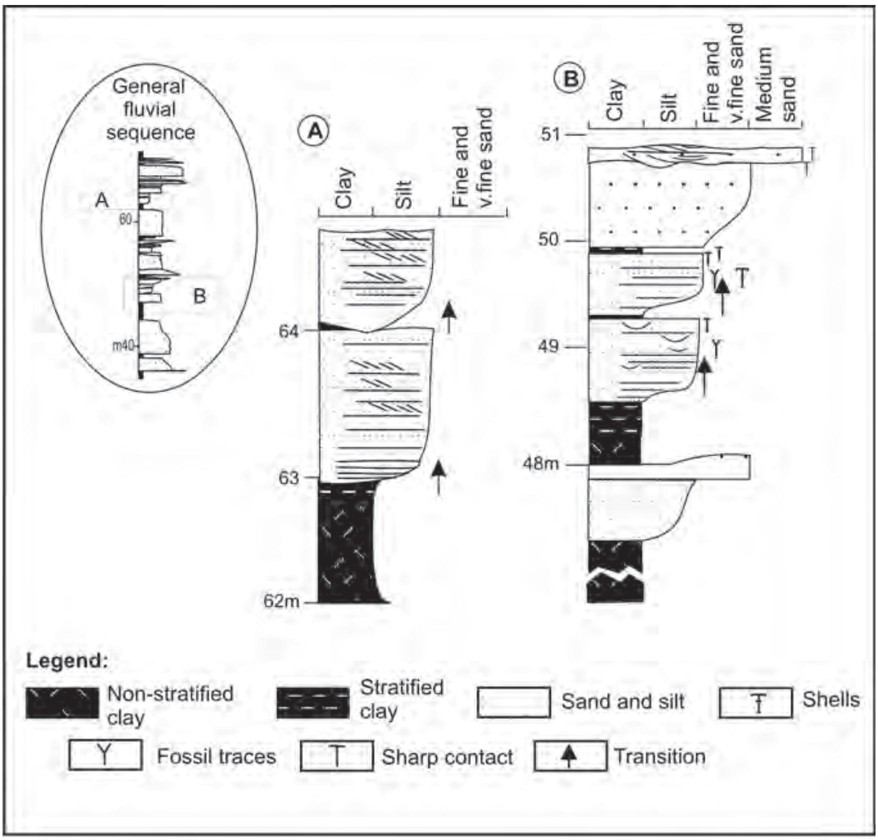


FIGURE 8.4. Stratified clay in a fluvial sequence. The bedded clay deposits are part of the crevasse splay units. See also Figure 6.19. Bizdidel River, Pucioasa (Dâmbovița County)

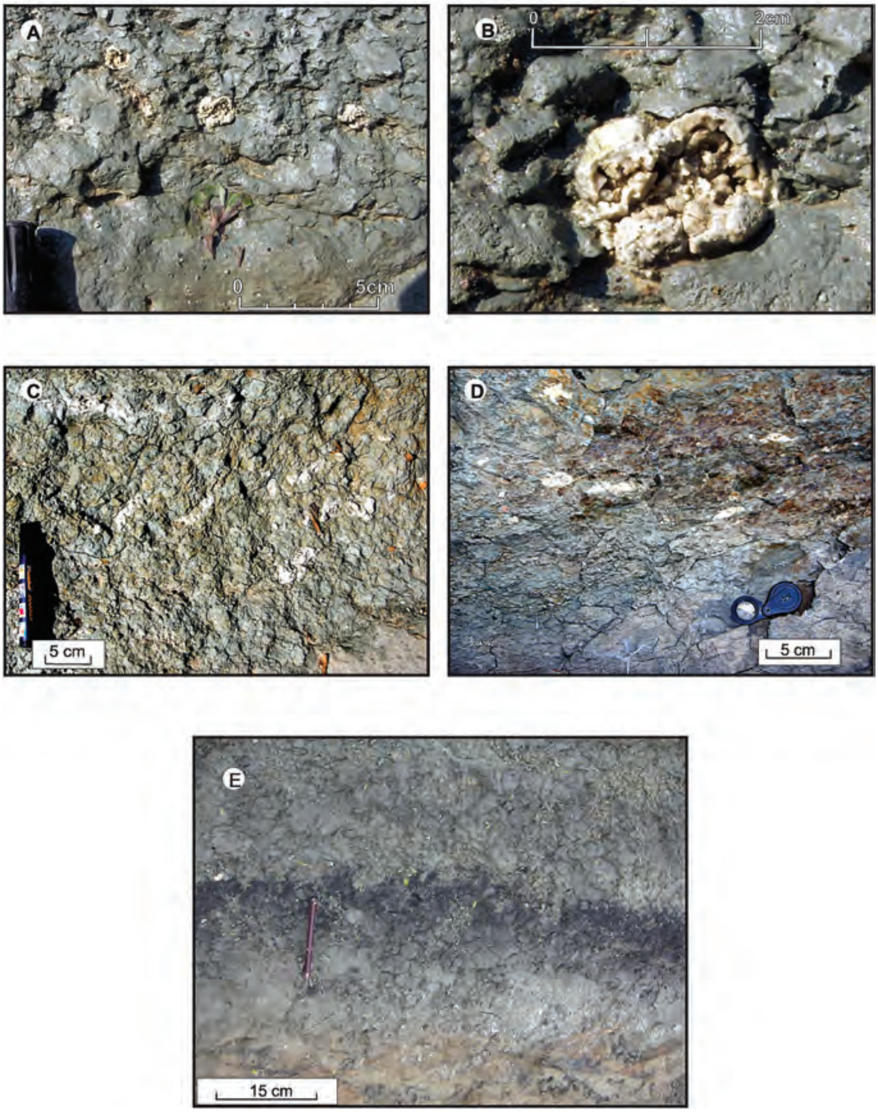


FIGURE 8.5. Homogeneous clay with palaeosoil aspects. **A** to **D** - Massive clay with calcareous concretions. Late Maeotian, Bădislava River. Vlădeşti village (Argeş County). **B** - Close up to a calcareous concretion. **E** - Organic matter-rich clay intercalated in gray homogeneous clay. Slănicu de Buzău River, Dumitreşti (Vrancea County)

8.4. THE PALEOBIOLOGIC ENVIRONMENT AND THE CLAY FACIES

The investigation of the Late Maeotian - Early Pontian sediments occurring on the Bizdidel River was approached from two sides, in order to reveal the sedimentogenetic features and their paleobiologic significance. The study of the biotopes, carried out by Radu Olteanu (in Jipa, Olteanu, 2005), relied on the analysis of the ostracod fauna.

The study of the ostracod fauna differentiated four succeeding Late Maeotian–Early Pontian ecological sequences (Fig. 8.6):

- ecological sequence **A** (Upper Maeotian), with mixed fresh-water and brackish ostracod fauna, interpreted as representing a coastal plain periodically invaded by brackish water;

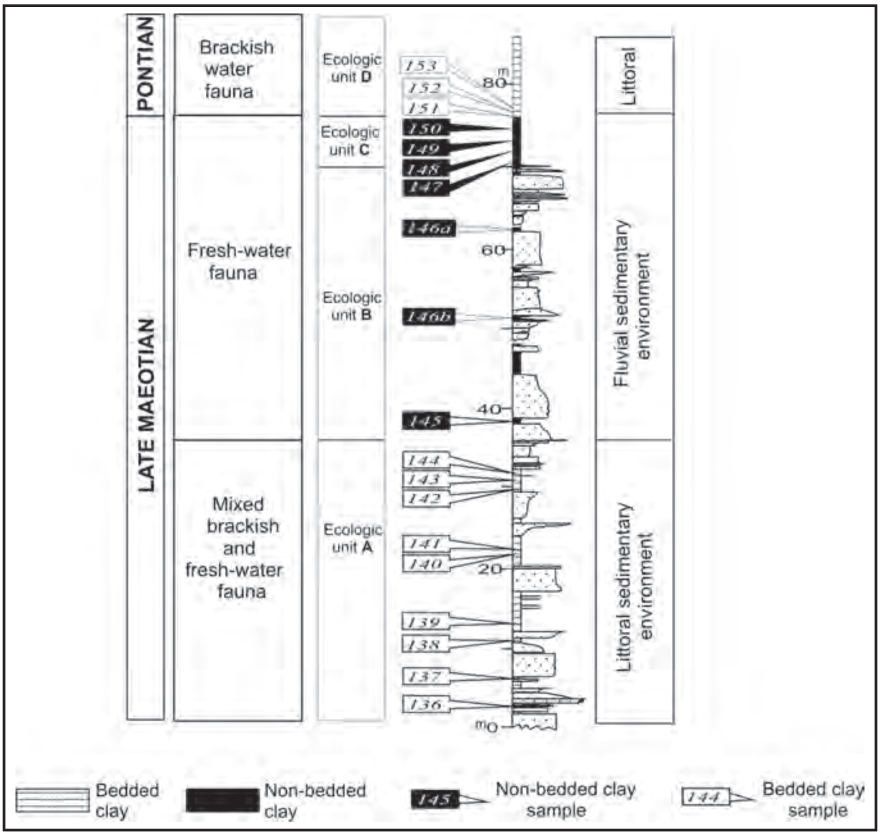


FIGURE 8.6. Paleobiologic environment of the bedded and non-bedded clay, based on ostracod fauna analysed by Radu Olteanu. Note the uppermost, apparently stratified Late Maeotian clay deposit (samples 147 to 150) which belongs to the fluvial, fresh-water environment. Late Maeotian-Early Pontian, Bizdidel River, Pucioasa (Dâmbovița County). Modified from Jipa, Olteanu (2005)

- ecological sequences **B** and **C** (Upper Maeotian), dominantly, with fresh-water fauna, believed to represent a fresh-water environment in the proximity of a brackish sea;
- ecological sequence **D**, exclusively brackish, belonging to a new Pontian community.

All the bedded clay sediments from the sequence considered to belong to the littoral paleoenvironment from the sedimentogenetic viewpoint have ostracods which indicated a biotope located into a coastal plain periodically invaded by brackish-water.

The non-bedded clay sampled from the upper part of the Late Maeotian deposits belongs to an environment considered fluvial by sedimentologic investigation, and fresh-water (at times in the proximity of a brackish-water basin) by the paleontologic analysis.

A departure from the results of the two study methods appeared in connection with the exclusively clayey sequence at the limit between Maeotian and Pontian. The faunal content of the clay considered to belong to an offshore-type environment indicated fresh-water fauna in the basal part, and brackish, for the rest of the succession. It should be underlined that this is the case of a clay sequence without sandy intercalations, consequently, devoid of specific data on the environment of sediment accumulation.

8.5. CONFIDENCE OF THE PALEO-ENVIRONMENTAL SIGNIFICANCE OF THE BEDDED/NON-BEDDED CLAY DEPOSITS

In most of the situations encountered during the investigation of the Dacian Basin clay deposits, there are arguments attesting the bedded clay are brackish-marine and the non-bedded clay are fluvial. However there are exceptions to this finding. For example the Early Pontian (Odessian) cropping out at Ilovăţ (Mehedinţi County) on the Coşuştea River, with brackish-marine fossil remains, are definitely non-bedded.

The bedded or non-bedded aspect of a clay deposit is primarily due to a sedimentary dynamic context which is frequently (not exclusively) present in a paleobiologic environment. Consequently, the use of the clay paleo-environmental significance based on the presence or absence of the internal bedding, is to be always checked with other features, especially the paleontologic content.

8.6. CONCLUSIONS

In the Late Neogene deposits of the Dacian Basin, the clay aspect in the outcrop provides paleoenvironmental information mostly by the presence or absence of stratification. In this context, we refer to the bedding which appears in the clay series where there are no silt or sand sediment intercalations or laminae.

The observations made by comparison with the environmental data offered by the sandy sediments with sedimentary structures lead to the idea that the clay stratification is due to the accumulation in an environment affected by currents activity. On the same line, the homogeneous clay indicates the absence of water currents during the accumulation of clay particles.

The Late Neogene homogeneous clay (lacking internal stratification) is closely associated with fluvial sequences. These clay deposits appear in the upper part of the fluvial fining upward sequences. In this case, the clay reveals the fluvial channel abandonment stage.

The homogeneous clay deposits are often found cropping out under the coal beds. This clay may indicate a swamp accumulation environment with no significant water circulation.

Even in the fluvial environment, the clay deposits are stratified when they associate with some environments where current activity is involved. This is the case of the sediments accumulated in the crevasse splay environment.

The study of ostracods confirmed most of the clay environment interpretation based on sedimentologic analysis. However, some of the sedimentological assumptions have been proven wrong by the results of the paleontologic investigation.

Chapter 9

SOURCE-AREAS IN THE GEOLOGICAL HISTORY OF THE DACIAN BASIN

The evolution and architecture of a sedimentary basin fill are controlled to a large extent, by the availability and the magnitude of the clastic material input, and the properties of the basin.

9.1. INVESTIGATION METHOD

The identification of the major sedimentary factors such as the source-area and the accumulation areas requires an overall image of the studied basin. The isopachs included in the lithofacies and paleogeographical maps of the Dacian Basin (Saulea *et al*., 1969) offer the entire picture of the distribution of sediment thickness in the Dacian Basin area. Consequently the contour maps represented the main source of information for the identification of the Dacian Basin source-areas and depocenters areas.

Other ways of approach used for the detection of the source-areas system are lithology distribution and paleocurrent directions. The sediment thickness distribution offers an estimation of the general location of the source-areas. The lithology and paleocurrent maps indicate sectors where detrital material was introduced in the basin (sediment input points).

Two sets of lithologic sketches were used to locate the sediment input points. The distribution of the coarsest-grained accumulated sediments was the criterion to locate the areas of detrital material input, and, implicitly, to estimate the source-areas of the supplied material.

Paleocurrent directions were acquired through the measurement of the current structures orientation. The sole marks, but mostly cross lamination were used to measure the paleocurrent directions of the sedimentary structures.

9.2. MAJOR FEATURES OF THE DACIAN BASIN ISOPACH MAPS USED AS SOURCE-AREA INDICATORS

As discussed in a previous chapter, the isopach maps emphasize two important features of the sediment thickness distribution in the development of the Dacian Basin.

One of the characteristics of the Dacian Basin sediment distribution is the location of the thicker sediments in the sub-Carpathian area. The sediment accumulation is thinning away from the Carpathians, toward the southern and eastern basin borderline. This distribution of the sediment thickness is obvious for the Maeotian and younger development stages of the Dacian Basin (Fig 9.1 B, C and D). The thickest Middle-Late Sarmatian (*s.l.*) sediments occur in the axial zone of the Dacian Basin trench, and are thinning southwards and eastwards (Fig. 9.1 A).

The fact that the thickness of the sediments is largest in the proximity of the Carpathian zone, and thins (until it thins out) away from the Carpathians, strongly indicates the northern, Carpathian provenance of the Dacian Basin clastic material (Jipa, 1997).

The second important characteristic of the Dacian Basin sediment fill is the bimodal character of the isopach pattern. Two areas with closed and roughly concentric contour lines are distinguished within the Dacian Basin. This isopachs con-

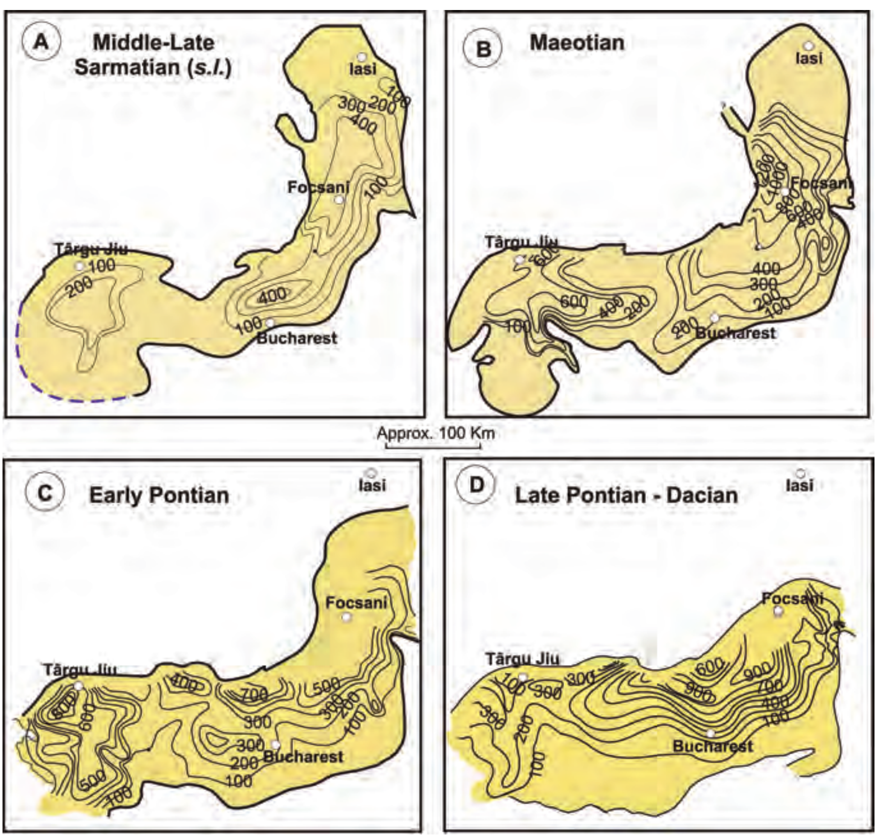


FIGURE 9.1. Sediment thickness distribution in the Dacian Basin. Isopach maps from Saulea *et al.* (1969). Contour interval is 100 m. **A**, **B**, **C**, **D** - see text

figuration is well illustrated by the isopach maps of the Middle-Late Sarmatian (*s.l.*) and Maeotian sediments (Fig 9.1 A and B). The two areas are less evident but still visible on the isopach maps of the Pontian sediments (Fig. 9.1 C and D) and barely recognizable on the Romanian sediments isopach map.

The two separated thick-sediment areas of the Dacian Basin represent large depocenters, at the scale of the entire basin. Within each depocenter the sediment thickness distribution pattern indicates that the Carpathians represent the source-area of clastic material, and there are two Carpathian sediment source-areas which supplied clastic material to the Dacian Basin.

9.3. CARPATHIAN SOURCE-AREAS

The Carpathian eastern source-area. As displayed by the isopach pattern, the most important depocenter of the Dacian Basin was located toward the eastern part of the basin (Fig. 9.1). The thickest sediment are located to the north of the depocenter, toward the northern end of the Dacian Basin (Focşani area) (Fig. 9.1). This indicates the source-area of this depocenter was in the vicinity of the northern Dacian Basin, in the south part of the present-day Eastern Carpathians, and close to the Carpathian bend zone (Fig. 9.2).

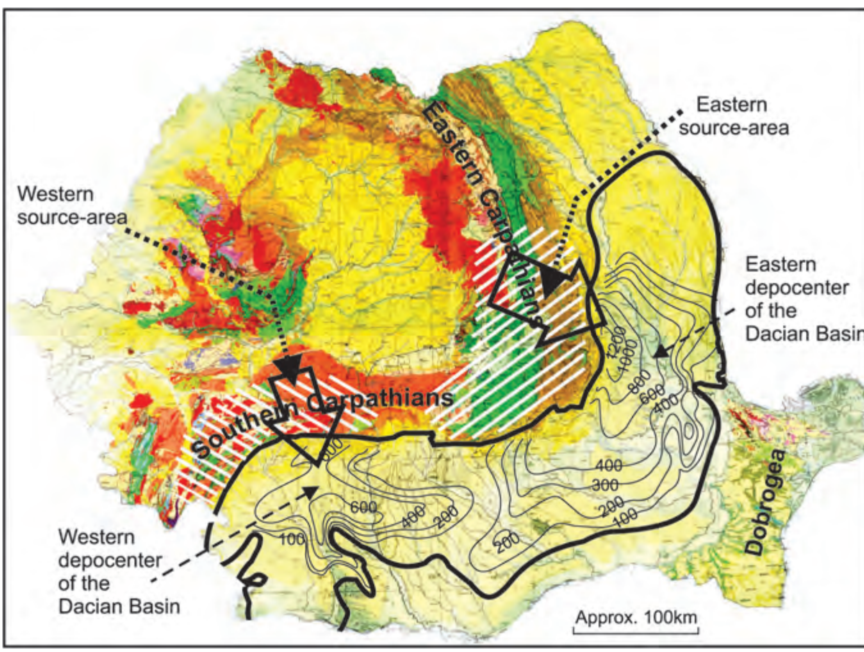


FIGURE 9.2. Carpathian sediment source-areas of the Dacian Basin. The Maeotian isopach map as example. In the background, the Geological map of Romania scale 1:1,000,000 (reduced and modified) prepared by the Geological Institute of Romania. Isopach map from Saulea *et al*. (1969). The assumed extent of the source-areas is hatched

The eastern depocenter area is getting wider and longer with time, from the Middle-Late Sarmatian (*s. l.*) to the Dacian time.

The isopach maps of the Middle-Late Sarmatian (*s. l.*) and Maeotian sediments have a simple shaped sediment accumulation of the eastern Dacian Basin depocenter (Fig 9.3 A and B). The Maeotian sediment thickness distribution illustrates a large body with only one core of high sediment thickness (Fig. 9.3 B). From this core the sediments thin out to the west, east and north, away from the Carpathians. Such a feature indicates the existence of a single input area for the sediments coming from the eastern Carpathian source-area during this time.

The Early Pontian and Late Pontian-Dacian isopach maps prepared by Saulea *et al*. (1969) present a more complex situation. The important northern sediment thickness core located in the Focşani area still existed at that time. At least two more minor sediment thickness cores emerged to the west of the main center, belonging to the large eastern Dacian Basin depocenter. This new geometry suggests that the clastic material supplied by the Carpathian eastern source-area has more input points distributed on the border of the Dacian Basin. The complex clastic supply system is also revealed by the existence of small thickness centers which appeared during the Early Pontian (Fig. 9.3 C) in the distal part of the eastern Dacian Basin.

During the Romanian time, the sedimentary material supplied from the eastern source formed a well developed, homogeneous body of a larger extent (Fig. 3.6).

According to the isopachs of the Quaternary deposits (Ghenea *et al*., 1971), the sedimentary accumulation generated by the eastern source-area during the Quaternary shows special properties. The surface covered by deposits of a thickness larger than 300 m is reduced compared to the Romanian deposits. However, the maximum thickness of the sediments is larger, reaching 2000 m. This large sediment accumulation is due to the Pleistocene uplift of the Carpathians orogen (Necea *et al*., 2005) which affected the eastern Carpathian source-area.

The Carpathian western source-area. The position and sediment thickness distribution of the western Dacian Basin indicate the location of the second Carpathian source of clastic material, situated in the area of the Southern Carpathians (Fig. 9.2).

During the Middle and Late Sarmatian (*s.l.*), the western Carpathian depocenter is defined by closed concentric sediment thickness contour lines in the internal part of the basin, suggesting the detrital accumulation into a sedimentary depression (Fig. 9.3 A). The amount of sediment supplied by the western Carpathian source-area was rather small.

Compared to the previous period, during the Maeotian the western source area supplied a larger quantity of clastic material (Fig. 9.3 B) and the sediment supply activity continued to increase. During the Early Pontian, the Carpathian western source-area generated sediment accumulation up to 800 m thick with a significant

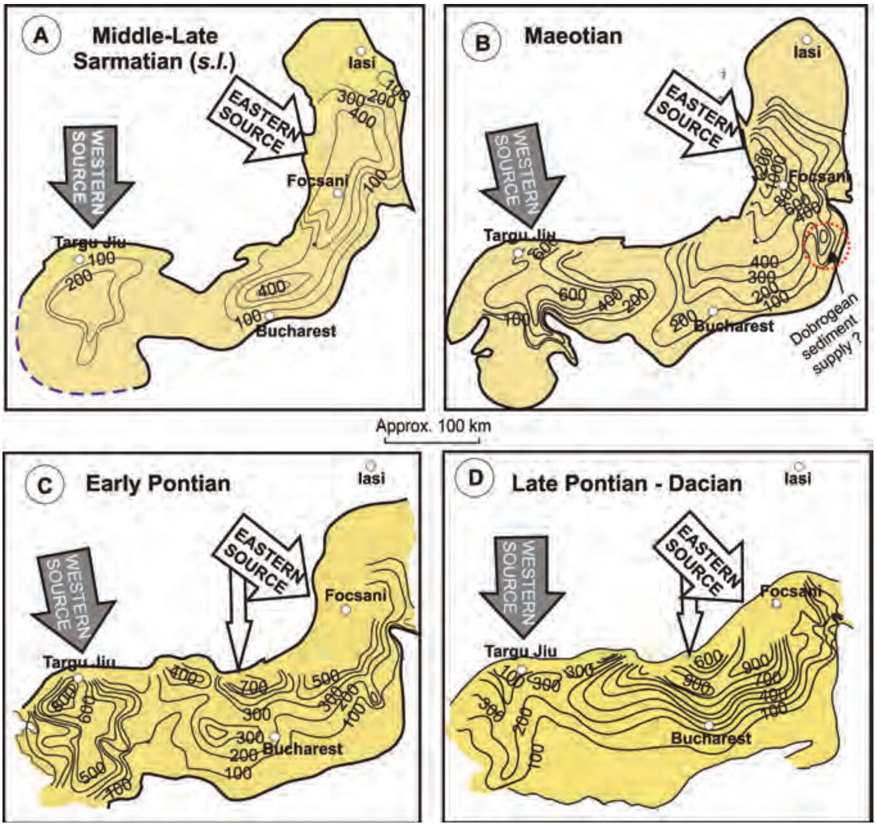


FIGURE 9.3. Carpathian source-areas of the Dacian Basin. Interpretation based on the sediment thickness distribution. Isopach maps from Saulea *et al.* (1969). Contour interval = 100 m. The small arrow represents the diversification of the eastern source sediment supply (more sediment input points). **A**, **B**, **C**, **D** - see text

areal extent (Fig. 9.3 C). The southward extent of the western depocenter also suggests the increased sediment supply (Fig. 9.3 B and C).

The sediment supply of the western source-area dropped significantly in the Late Pontian-Dacian time. The sediment accumulation in the western Dacian Basin depocenter reaches a maximum thickness of 300m. The extent of the western depocenter is also reduced during Late Pontian-Dacian (Fig. 9.3 D).

The contribution of the western source is not obvious on the Romanian isopachs map configuration (Fig. 3.6). A small western Dacian Basin depocenter is still apparent on the Romanian contour map.

The map of the Quaternary sediment thickness distribution in the western part of the Dacian Basin (Ghenea *et al.*, 1971) suggests a decrease in the sediment supply from the western source. This conclusion results from the fact the sediment is thin and no distinct depocenter is visible in the western part of the Dacian Basin (Fig. 9.4 B).

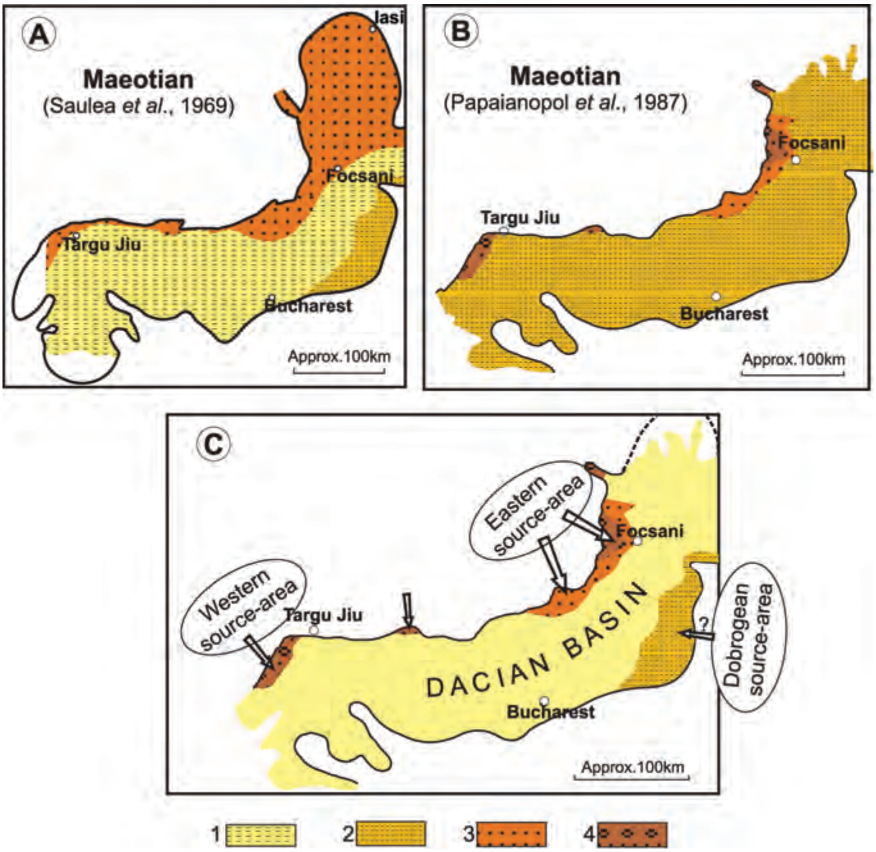


FIGURE 9.4. Sources of detrital material during the Maeotian, according to the Dacian Basin lithology distribution. Lithologic sketches of the Dacian Basin after Saulea *et al.* (1969) (**A**); Papaianopol *et al.* (1987) and Papaianopol, Marinescu (1989) (**B**). **Legend**: **1**. Clay dominated. **2**. Silt dominated. **3**. Sand dominated. **4**. Gravelly sand

9.4. SOUTHERN, BALKANIAN AND DOBROGEAN SOURCE-AREAS

The Dacian Basin isopach maps do not indicate important source-areas other than the Carpathians. On the Pontian isopach maps (Figs 9.3 C and D), the sediments of the southern part of the western Dacian Basin depocenter extend down to the southern limit of the basin, but a contribution from the southern source is not detectable. In Dobrogea, the thickness of the Pontian, Dacian and Romanian deposits cropping out on the right bank of the Danube River, does not exceed 30 m (Andreescu and Pană, in Avram *et al.*, 1996).

Lithology distribution maps have been used to indicate sediment accumulation attributed to the southern Dacian Basin source-areas. These data allow to distinguish reduced source-area supply based on grain size trend (usually, a coarser-grained detrital material indicate the source-area).

The first indication of a source-area other than the Carpathian comes from the Dacian Basin Maeotian litholgy and paleogeography map (Saulea *et al*., 1969) (Fig. 9.4 A). On the map, silty-sandy deposits, coarser-grained than the deposits in the central area of the basin, are marked in front of the Dobrogea highland area. However, the indication is not confirmed by the Maeotian lithology map of Papaianopol *et al*. (1987) (Fig. 9.4 B).

The Dacian Basin Early Pontian lithologic map of Saulea *et al*. (1969) (Fig. 9.5 A) does not show coarser-grained sediment accumulations, except in the northern part of the basin. There is an indication regarding the activity of the Dobrogean source-area on the Papaianopol *et al*. (1987) and Marinescu, Papaianopol (1989) map (Fig. 9.5 B). The confidence of this indication is low, because it is not confirmed by the Saulea *et al*. (1969) lithology map (Fig. 9.5 A) and the sediment in front of the Dobrogean High is rather fine-grained.

The provenance of the Dacian Basin Middle Pontian (Portaferrian) detrital material is well documented by multiple occurrences of coarser-grained sediment (Papaianopol *et al*., 1987; Marinescu, Papaianopol, 1989) (Fig. 9.6). Four sediments source-areas were active during this time: two northern Carpathian sources and two southern sources (southwestern Balkanian, and southeastern Dobrogean). Silt dominated sediments occur in intermediary position between the mentioned source-areas, offering little information about their provenance.

In contrast to the Portaferrian deposits, the provenance of the Late Pontian (Bosphorian) sediment is poorly supported by direct observation. Only one of the lithologic maps was made for the Bosphorian time (Fig. 9.7 B). On this map the coarser-grained sediments are not restricted to the border of the basin, consequently, the indications offered in connection with provenance areas are not clear. Besides, the second lithologic map (Fig. 9.7 A) was` prepared for a larger time-span, and offers information based mainly on fine-grained sediments.

9.5. PALEOCURRENT DIRECTIONS AND SEDIMENT SOURCE-AREAS

Measurements of current sedimentary structures in the sub-Carpathian part of the Dacian Basin deposits evidenced two major paleocurrent trends. The dominant paleocurrent directions are transversal to the axis of the Dacian Basin trough. Numerous current directions indicate north to south flows, longitudinal to the basin axis. The data suggest initial transversal currents turning longitudinal along a sedimentary trough with a slight westward slope (Fig. 9.8).

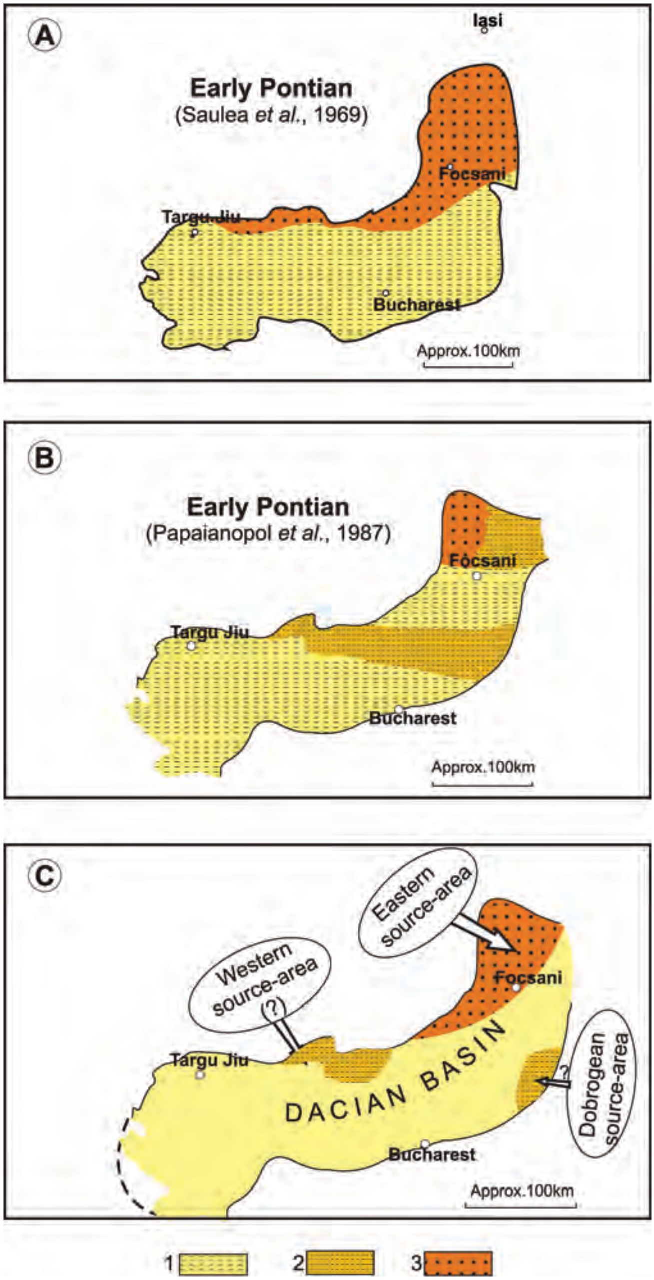


FIGURE 9.5. Sources of detrital material during the Early Pontian (Odessian), according to the Dacian Basin lithology distribution. Lithologic sketches of the Dacian Basin after Saulea *et al*. (1969) (**A**); Papaianopol *et al*. (1987) and Papaianopol, Marinescu (1989) (**B**). **Legend**: **1.** Clay dominated. **2**. Silt dominated. **3**. Sand dominated

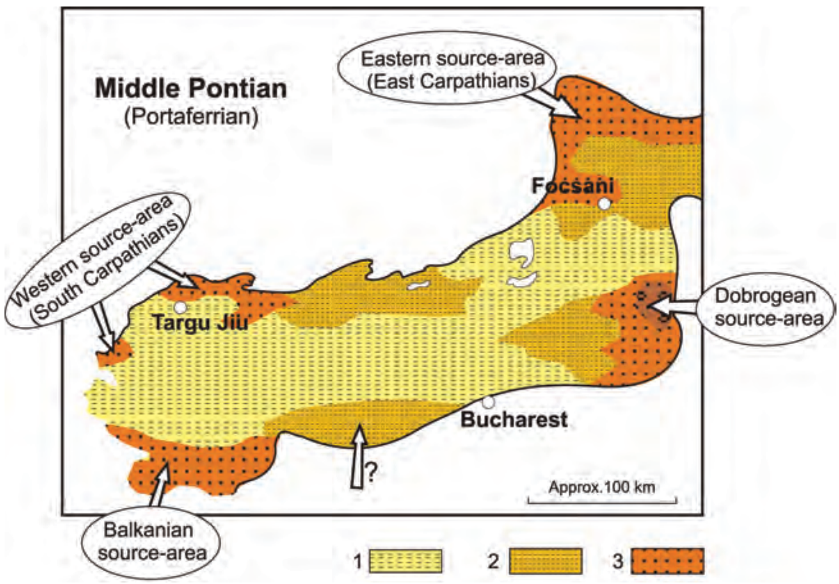


FIGURE 9.6. Dacian Basin sources of detrital material during the Middle Pontian (Portaferrian), according to the Dacian Basin lithology distribution. The identification of the main areas of detrital material input is based on the distribution of the coarsest-grained sediments. The Dacian Basin lithologic sketch after Papaianopol *et al*. (1987) and Papaianopol, Marinescu (1989). **Legend**: **1**. Clay dominated. **2**. Silt dominated. **3**. Sand dominated

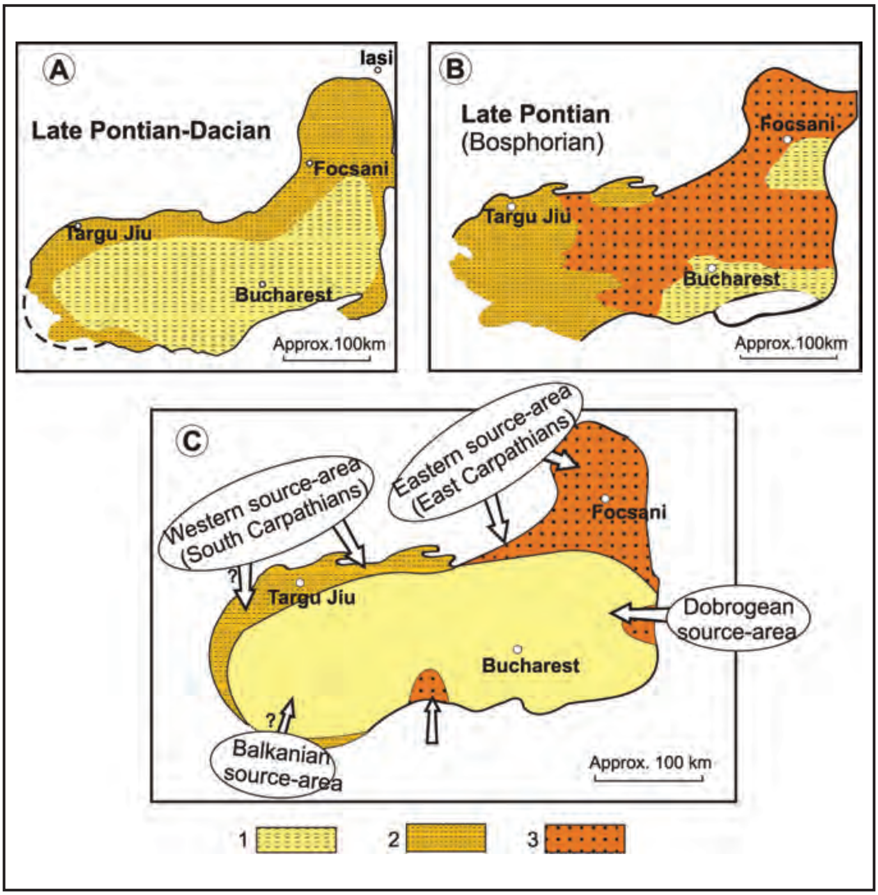


FIGURE 9.7. Sources of detrital material during the Late Pontian (Bosphorian), according to the Dacian Basin lithology distribution. The identification of the main areas of detrital material input is based on the distribution of the coarsest-grained sediments. Lithologic sketches of the Dacian Basin after Saulea *et al*. (1969) (A) and Papaianopol *et al*. (1987) and Papaianopol, Marinescu (1989) (B). **Legend**: **1**. Clay dominated. **2**. Silt dominated. **3**. Sand dominated

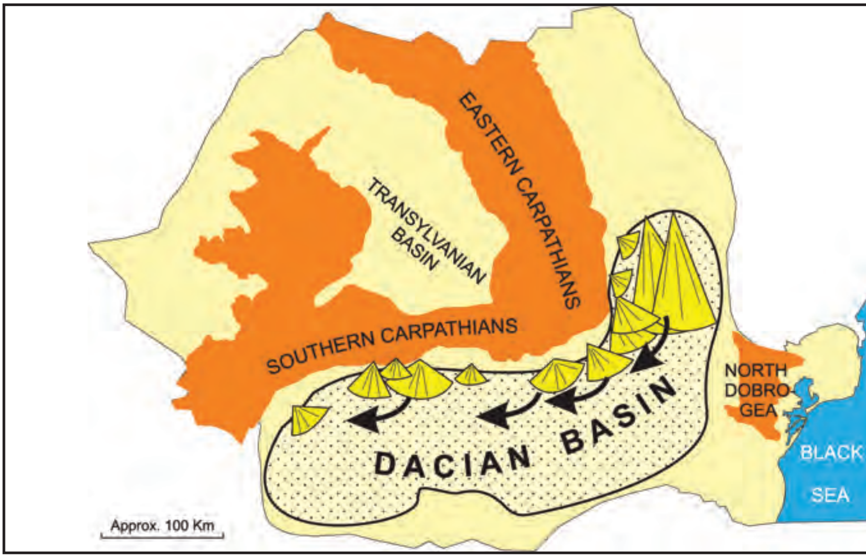


FIGURE 9.8. Main interpreted trends of the Middle - Late Sarmatian (*s. l.*) to Dacian palaeocurrent systems, in the sub-Carpathian side of the Dacian Basin

The paleocurrent measurements show that all sediments accumulated on the sub-Carpathian side of the Dacian Basin are derived from the Carpathian area. This is a direct evidence confirming the significant part played by the Carpathians as a source-area of the Dacian Basin. The paleocurrent data cannot differentiate the two major depocenters of the Dacian Basin.

9.6. SEDIMENT SOURCE-AREAS DURING THE DACIAN BASIN EVOLUTION

The source-area system. The provenance analysis of the Dacian Basin detrital material revealed the existence of four source-areas (Fig. 9.9). The Carpathians represented the most important source. The Carpathian clastic material was supplied independently from two areas: the southern part of the Eastern Carpathians and the western part of the Southern Carpathians. The bulk of the Dacian Basin material is of Carpathian origin.

Two source-areas supplied clastic particles from the southern side of the Dacian Basin: the Balkanian and the Dobrogean source-areas. As the Balkans were relatively far from the Dacian Basin, only a small volume of detrital material from Balkanians entered the Dacian Basin. Dobrogea was a highland area with a reduced surface and, probably not very high relief. The amount of clastic material supplied to the Dacian Basin from the Dobrogean source-area was small. Due to the low amount of the southern clastic supply the isopach maps, with contour line interval of 100 m, do not show separate southern depocenters of the Balkanian and Dobrogean source-areas.

Middle-Late Sarmatian (s. l.) source-areas. Only Saulea *et al*. (1969) made a Dacian Basin litho-paleogeographic map for the Middle-Late Sarmatian (*s. l.*) time interval. The lithology (Fig. 2.5) and the isopachs (Fig. 9.3 A) shown on this map suggest that the Eastern Carpathians were the only important acting source-area. The western South Carpathians area represents, probably, the sediment source for the western Dacian Basin depocenter.

Maeotian source-areas. The isopach map (Fig. 9.3 B) offers unambiguous evidence for the large sediment supply which came from the eastern and western Carpathian source-areas.

The isopach and lithologic map pattern does not indicate the Balkanian as a source-area during the Maeotian time.

Dobrogean sediment supply is suggested by some lithologic data (Fig. 9.4 A). On the isopach map (Fig. 9.3 B) the contours indicate a small sediment accumulation in front of the Dobrogean dry-land, which is backing the lithologic indication.

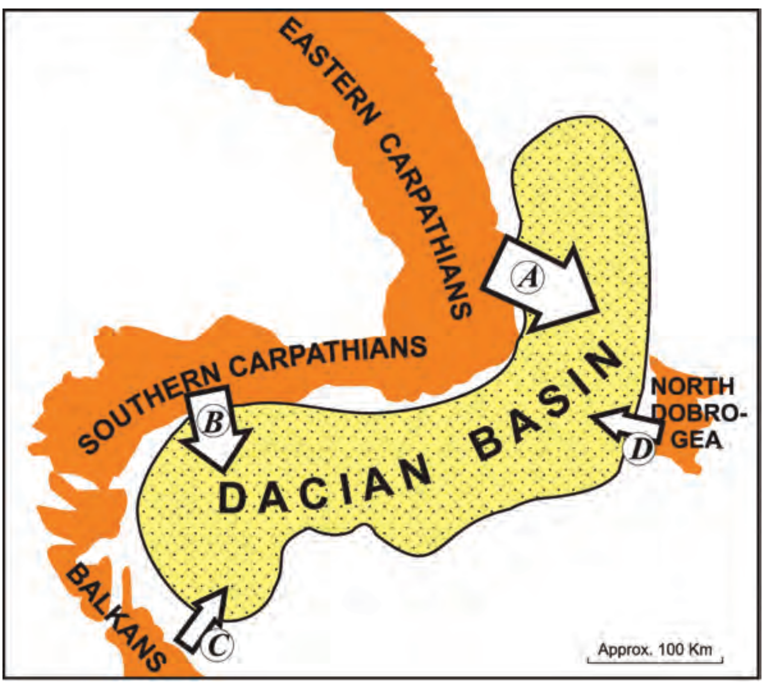


FIGURE 9.9. The sediment source-areas system of the Dacian Basin. The size of the arrows suggests the importance of the volume of sediment supplied by the source areas. **A**. Eastern Carpathians source-area. **B**. Southern Carpathians source-area. **C**. Balkanian source-area. **D**. Dobrogean source-area

Early Pontian (Odessian) source-areas. The two Carpathian source-areas continued to supply significant volume of detrital material into the Dacian Basin. Both depocenters extended significantly (Fig. 9.3 C), especially the western Dacian Basin depocenter. The lithology map indicates coarser-grained, sandy sediment accumulation on the northern, sub-Carpathian, margin of the Dacian Basin, that is on the proximal part of the depocenters. The more distal clastic material is probably relatively fine-grained (silt, fine-grained sand).

During the Early Pontian the western Dacian Basin depocenter extended southward to the boundary of the basin. There is no indication the detrital material accumulated at the southern limit of the Dacian Basin is of Balkanian origin, nor that it was transported all the way from the northern, sub-Carpathian margin.

The Dobrogean detrital contribution to the Dacian Basin sediment accumulation is suggested by some lithologic and isopach map features, similar to the Maeotian maps features.

Middle Pontian (Portaferrian) source-areas. Portaferrian is the time when all Dacian Basin source-areas were active. Coarser-grained, sandy and gravelly sediments, marked on the lithologic map in all the four "corners" of the basin, present reliable information about the contributions of the source areas. The sediment supply from the Dobrogea area appears surprisingly large (Fig. 9.6), especially when compared with the outcrops where the Pontian (Middle or Late) deposits are only several meters thick (Andreescu and Pană, in Avram *et al.*, 1996).

The presence of the coarser-grained sediments during Portaferrian suggests increased energy (water discharge) and strong erosional processes in the exposed relief around the Dacian Basin.

Late Pontian (Bosphorian) source-areas. Little data are available regarding the Dacian Basin source-areas during the Bosphorian time. The Bosphorian lithologic map (Fig. 9.7 B) suggests both Carpathian source-areas were supplying detrital material, with fewer indications concerning the western area. Coarser-grained material exists in front of the Dobrogean source-area. There is no data about the activity of the Balkanian source-area during the Bosphorian time.

Late Pontian-Dacian source-areas. Eastern Carpathian source-area appears to have been very active during the Late Pontian-Dacian time, according to the isopach map thickness (Fig. 9.3D). In contrast, the volume of detrital material supplied by the source-area of the Southern Carpathians decreased.

The sedimentary contribution of the southern Dacian Basin source-areas is not marked on the isopach map, and is not evident on Saulea *et al*. (1969) lithologic map (Fig. 9.7 A). The Late Dacian deposits from the western side of Dobrogea dry-land are dominantly sandy (Andreescu and Pană, in Avram *et al.*, 1996), indicating the activity of the Dobrogean source-area.

Romanian source-areas. The Dacian Basin suffered thorough changes after the Middle Dacian time, when the brackish sea closed and the area became continental (fluvial). The Carpathians continued to provide abundant detrital material to the former Dacian Basin area. Presently, we have no knowledge if the sediment supply continued to come from two separate Carpathian source-areas.

When the Danube River came into existence, the clastic material derived from the Balkans and Dobrogea did not accumulate in the Dacian Basin area (except for some sediment stored on the Paleo-Danube River course), but was transported toward the Black Sea Basin.

9.7. CONCLUSIONS

Four source-areas supplied the Dacian Basin with sediments. The Carpathians was the most important provider of detrital material. The Carpathian supply was made independently from two areas: the Eastern Carpathians (southern part) and the Southern Carpathians. The bulk of the Dacian Basin material (roughly about 90%) is of Carpathian origin.

During the entire evolution of the Dacian Basin, the Carpathian eastern source-area constantly provided a high amount of sedimentary material over a large surface.

The detrital contribution of the Carpathian western source-area to the Dacian Basin sediment accumulation was less important compared with the eastern source-area. The volume of clastic material supplied by the western source dropped significantly after the Late Pontian-Dacian time.

Two source-areas supplied clastic sediment from the southern side of the Dacian Basin: the Balkanian source-area and the Dobrogean source area. The amount of detrital material furnished to the Dacian Basin from the Balkanian and the Dobrogean source-areas was small compared with the amount of sediment derived from the Carpathian sources.

Chapter 10

HISTORY OF THE DACIAN BASIN SEDIMENT ACCUMULATION

10.1. SEDIMENT ACCUMULATION AREAS IN THE DACIAN BASIN

The areal distribution of the sediment thickness reveals the contour and the morphology of the Dacian Basin depositional surface. The areal distribution of the sediment thickness during the development of the Dacian Basin in the Late Neogene indicates the existence of two separate areas of sedimentary accumulation (depocenters).

The depocenters are delineated by roughly concentric isopachs, with one or more areas of maximum thickness values. This way, an eastern accumulation area and a western accumulation area are identified and delineated.

In the Middle Sarmatian (*s.l.*) – Romanian interval, the two sediment accumulation areas were separated. The sediment thickness variations produced in this interval refer to the contour of the areas and the distribution model of the sediment thickness for each area.

The eastern sediment accumulation area. This unit extends from the north-eastern extremity to the western area of the Dacian Basin (Fig. 10.1). In the time period from the Middle-Late Sarmatian (*s.l.*) to the Romanian, the eastern area extended continuously toward the west and the south. During the Maeotian, the eastern depocenter of the Dacian Basin widened (Fig. 10.1 B), suggesting an enlargement of the basin trough in comparison to the Middle-Late Sarmatian (*s.l.*). During the Pontian, the eastern Dacian Basin depocenter extended westward along the main axis of the sedimentary trough (Figs. 10.1 C and D). This indicates that the rate of the detrital material input in the eastern area was maintained or even increased during the development of the Dacian Basin (Jipa, 1997).

The western sedimentary area is the second, smaller depocenter of the Dacian Basin, representing approximately one third of the eastern accumulation area (Fig. 10.2).

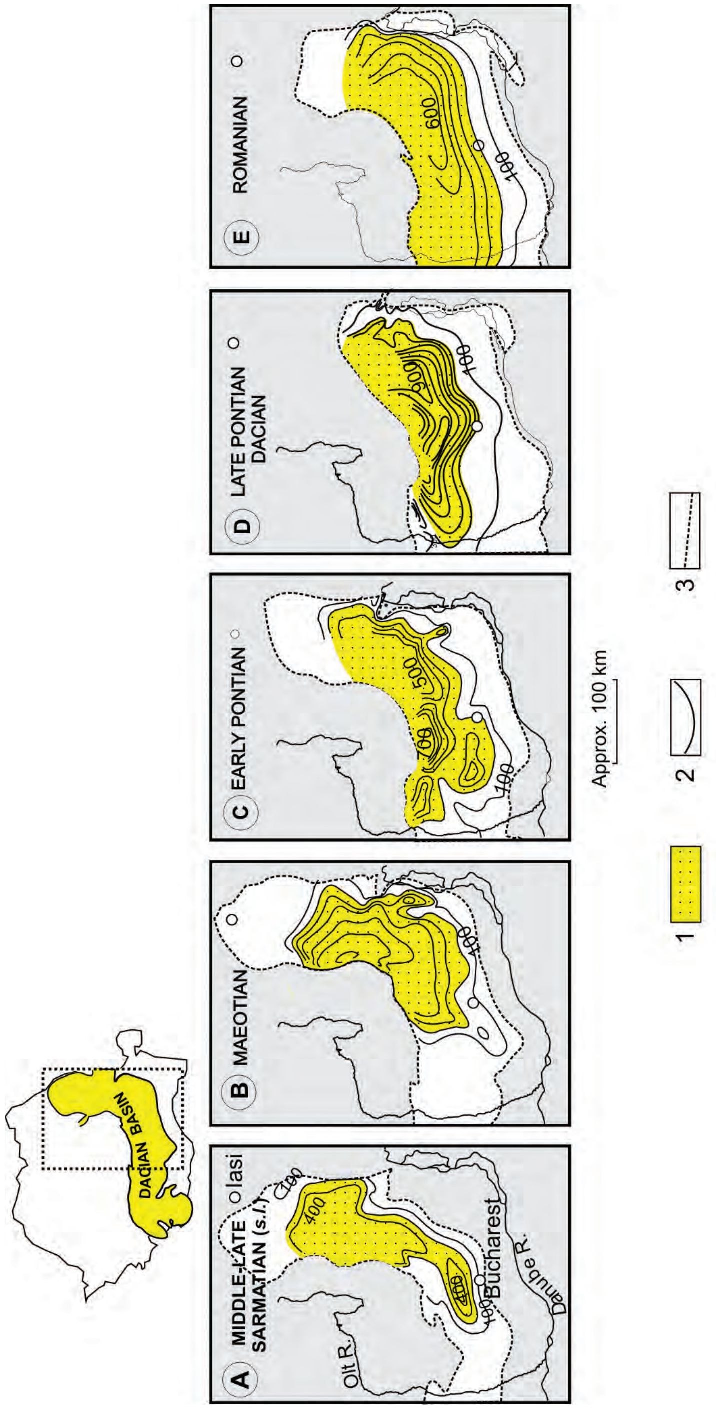


FIGURE 10.1. Dacian Basin eastern sediment accumulation area. Isopach maps from Saulea *et al.* (1969). Thickness in meters. **Legend**: **1**. Eastern sediment accumulation area (sediments thicker than 200 m). **2**. Isopach lines. **3**. Dacian Basin extent. *Upper left*: index map of the studied area

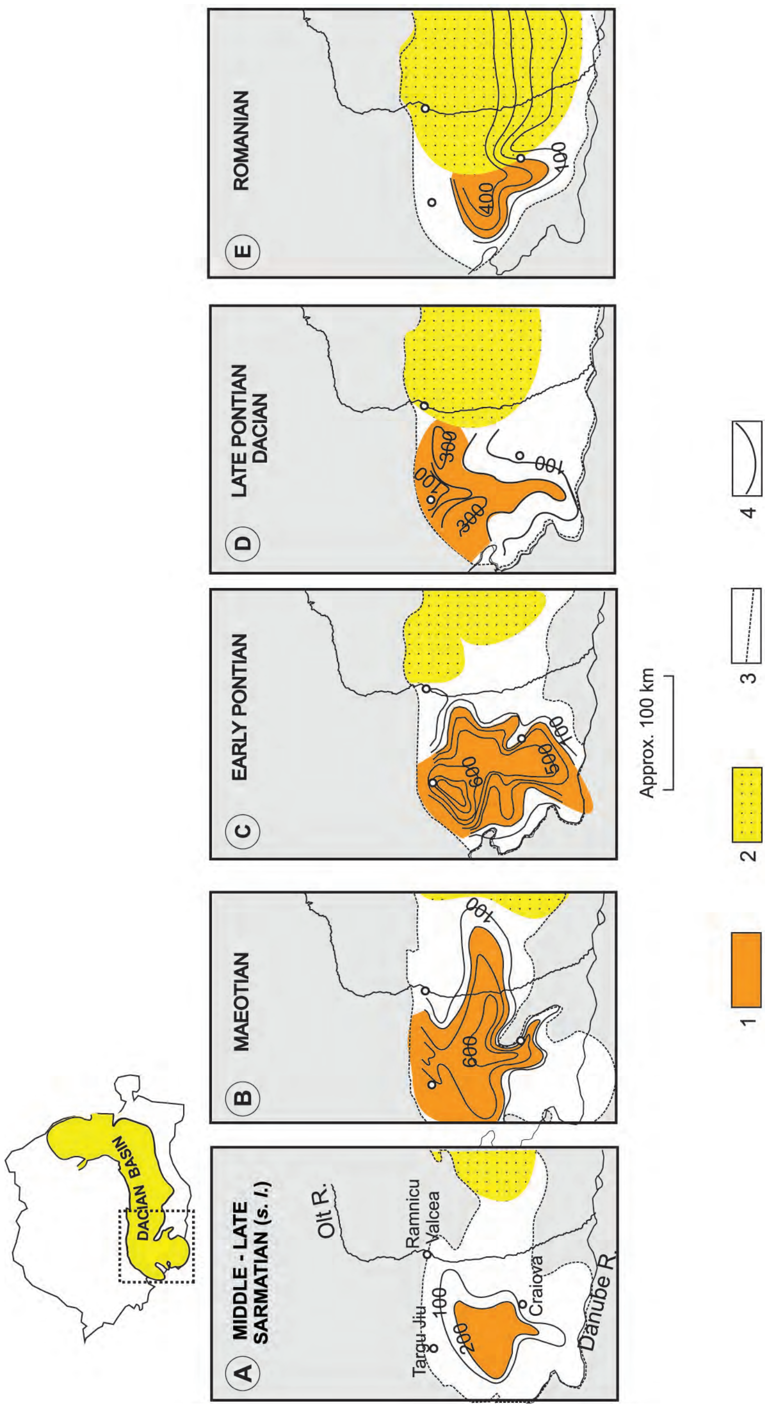


FIGURE 10.2. Dacian Basin western sediment accumulation area. Isopach maps from Saulea *et al.* (1969). Thickness in meters. **Legend**: **1**. Western sediment accumulation area (sediments thicker than 200 m). **2**. Eastern sediment accumulation area. **3**. Dacian Basin extent. **4**. Isopach lines (thickness in meters). *Upper left*: index map of the studied area

The western sedimentary area is well defined in the Middle Sarmatian (*s.l.*)-Early Pontian time interval. From a small enclosed area during the Middle-Late Sarmatian (*s.l.*) (Fig. 10.2), the western depocenter extended greatly during the Maeotian and Early Pontian.

The amount of accumulated sediment increased from about 200 m maximal thickness during Middle-Late Sarmatian (*s.l.*), to more than 800 m in the Early Pontian (Fig. 10.2 B and C). The shape of the sediment accumulation extent to the western depocenter reflects the irregular relief of the Dacian Basin western part. The western depocenter grew mostly to the south. The main southern expansion was during the Early Pontian (Fig. 10.2 C). Since the Late Pontian-Dacian, the western depocenter area decreased and accumulated smaller quantities of sediment (Fig. 10.2 D and E).

Because of the western extent of the eastern depocenter, after the Late Pontian, the eastern and western Dacian Basin depocenters merged and formed one integrated sediment accumulation. During the Quaternary, the western accumulation area lost its identity; it appears as a continuation of the eastern area (according to the isopachs from Ghenea *et al*., 1971).

The western sedimentary area of the Dacian Basin is characterized by concentric isopachs with the largest thickness in the middle (Saulea *et al*., 1969). The circular, "bull's eye", pattern suggests a rounded shape of the depression that formed the western accumulation area. This geometry is best observed in the Middle Sarmatian (*s.l.*) to Early Pontian stages of the Dacian Basin development.

10.2. DACIAN BASIN PALEOCURRENT PATTERN

Mapping the paleocurrent directions was the main method to identify the sediment transport pattern in the Dacian Basin. Cross-lamination and sole marks were the directional structures available for the identification of the paleotransport directions. The sole marks are uncommon in the studied deposits. Most paleocurrent measurements used cross-lamination structures, observed in sections parallel to the general bedding (Fig. 10.3). The right conditions to record the accurate orientation of the cross-lamination were not frequently met.

10.2.1. Paleocurrent directions

The first data on the paleotransport directions were presented by Lorin Constatinescu (in Macarovici *et al.*, 1967), from the northern part of the Dacian Basin. The authors concluded all measured directional sedimentary structures indicate currents that flowed from north to south, longitudinal to the axis of the sedimentation basin.

FIGURE 10.3. Small-scale cross-lamination structure observed in section parallel to the general bedding. Current flow direction to the north-west (arrow). Late Pontian. Badislava River, Vlădeşti village (Argeş County)

Paleocurrents in the northern Dacian Basin. Paleocurrent directions were recorded in Maeotian to Romanian sediments from the northern part of the Dacian Basin, in the area between Suşiţa River and Buzău River. The rose diagram of the measurement data (Fig. 10.4 A) shows a large variability (from SW to E) of the paleocurrents direction, but most occurrences indicate south flow directions. These data confirm the results of Macarovici *et al*. (1967) on the sediment paleotransport.

In addition to the north-south dominant directions, in the Suşiţa-Buzău Rivers area there are also paleocurrents with other flow directions. Three groups are important, showing secondary current directions toward the east, the west-south-west and south-east. A small number of measurements reveal flow directions toward the west-north-west and to the north.

Middle Pontian paleocurrents measured at Şerbeşti geological section (Slănic de Buzău River) (Fig. 10.4 B) show the same directions as in the northernmost part of the Dacian Basin. However, due to the bending of the basin axis in this location, the paleocurrents appear not any more longitudinal but transversal to the trough of the basin.

Paleocurrents in the central Dacian Basin. The rose diagram of the paleocurrents data from the area between Ialomița and Dâmbovița Rivers (Fig. 10.4 C) indicates a flow direction toward the south-west. The angular dispersion is important, but the dominant direction clearly shows oblique currents compared to the orientation of the basin axis.

Paleocurrents in the western Dacian Basin. Measurements of the current structure orientation in the central-western part of the Dacian Basin produced rose diagrams with large dispersion around the north-south direction. The modal angular sectors indicate current directions toward the south-west, the south and the south-east (Fig. 10.4 D). The data from the area between Otăsău and Olteț Rivers (Fig. 10.4 E) indicate paleoflows toward the south.

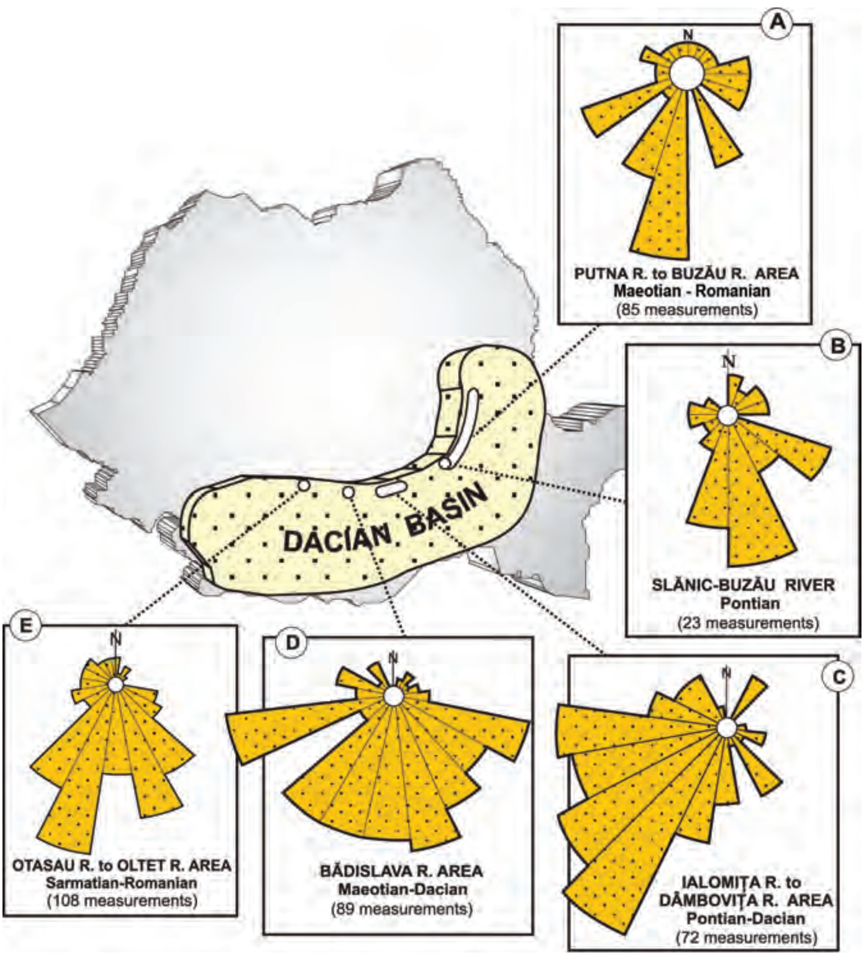


FIGURE 10.4. Paleocurrent directions measured in the Dacian Basin deposits

In the westernmost part of the Dacian Basin little paleocurrent data are available. The azimuth of the paleocurrents measurements performed in the Sarmatian (*s.1.*) deposits from the Morilor River (west of Drobeta-Turnu Severin) varies between 120º and 130º, that is, toward south-west.

10.2.2. Paleocurrent directions in the stratigraphic succession

The pattern of the paleocurrent flow directions was remarkably constant during the Dacian Basin evolution. Paleocurrent measurements carried out in the same area, but in sediments of different geological ages, display comparable current flow trends.

A series of paleocurrent diagrams representing sediments of different ages from the Otăsău River – Olteţ River area (Fig. 10.5 A) show variability due to the large variation of the measurement numbers. However, the main current flow direction toward the south is prevailing.

The examination of the paleocurrent map from the Tigveni area (Fig. 10.6) may suggest differences between flow directions of the Maeotian, Pontian and Dacian deposits. The rose diagrams show the paleocurrent orientation, and the sediment dispersal systems. They had similar orientation during the three time stages of the Dacian Basin.

10.2.3. Paleocurrent directions *vs*. grain size and bed thickness

In order to investigate possible directional differences between paleocurrents with diverse types of sediment loads, the flow directions measured in sediments with different grain size and bed thickness have been compared.

The analysis of the paleocurrent data from the northern part of the Dacian Basin (Fig. 10.7) indicates that the flow directions of the currents with medium grain size sandy loads are more dispersed compared with currents which transported coarse-grained sand. The same observation applies to directions obtained from sand beds with moderate thickness (10 to 100 cm) *versus* very thick sand beds (over 100 cm). Due to insufficient number of measurements, no conclusion can be made regarding paleocurrents in very fine-grained sand or very thin beds.

A similar comparative evaluation was made between the paleocurrent directions recorded in Tigveni area (Argeş County), and the grain size of the measured sediments (Fig. 10.8). The paleocurrent diagrams show a wide orientation, probably generated by the large number of measurements, but the same current flow trends emerged from every diagram, irrespective of the sediment grain size.

The current directions measured in sediments with different grain size from the Otăsău River – Olteţ River area (Fig 10.5 B) show the same current flow trends as the general currents diagram (Fig. 10.5 C).

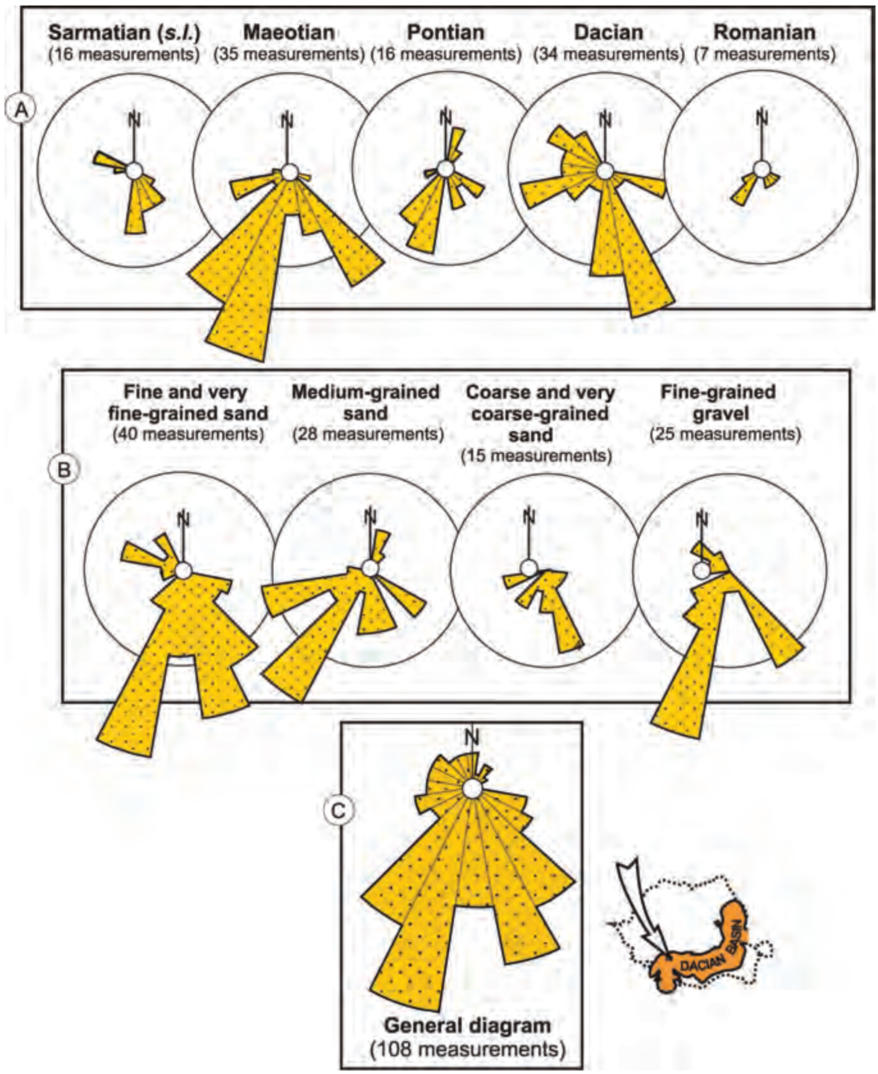


FIGURE 10.5. Dacian Basin paleocurrent directions in the area between Otăsău River and Olteț River (location in the down-right index map). **A**. Current measurements carried out on Dacian Basin sediments of different geological ages. **B**. Direction of paleocurrents in deposits with various grain sizes. **C**. General paleocurrents diagram

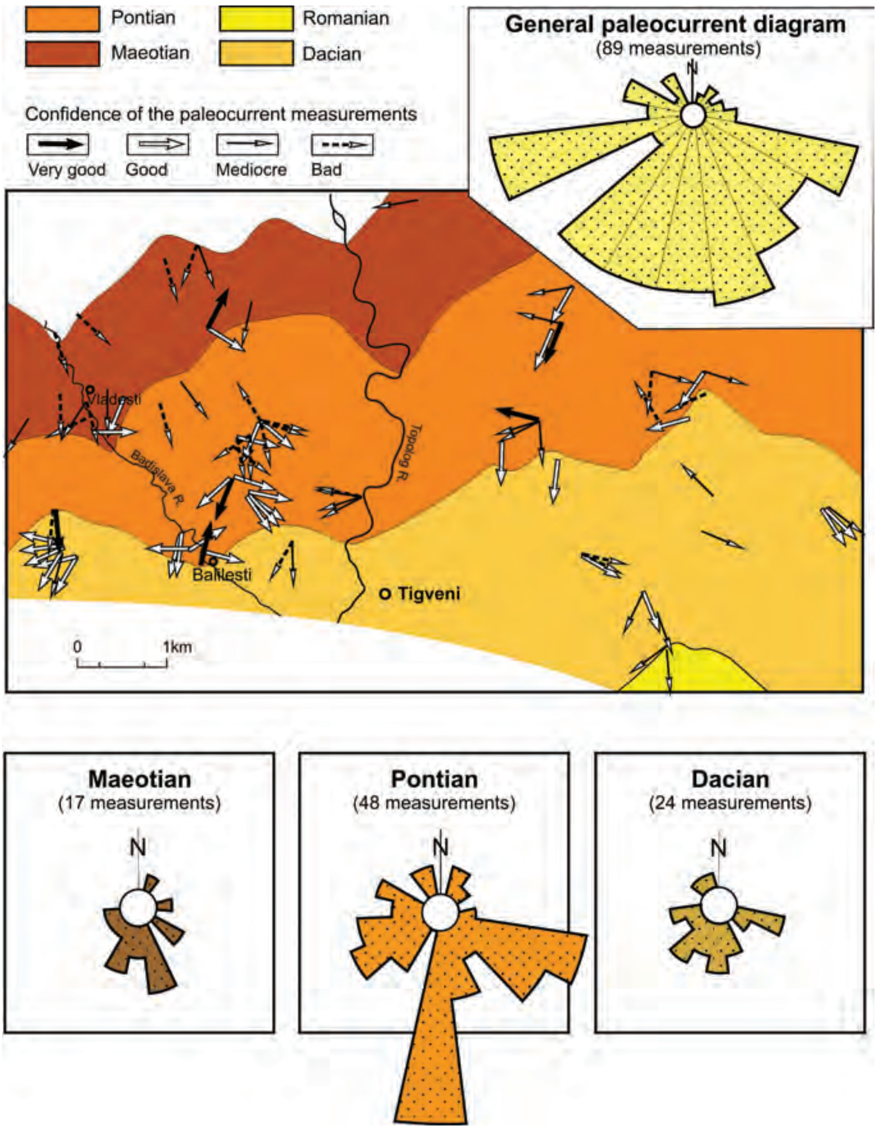


FIGURE 10.6. Paleocurrent map and paleocurrent circular diagrams of the Maeotian - Dacian deposits from Tigveni area (Argeş County). The paleocurrent diagrams for deposits of different ages indicate similar paleocurrent systems functioned during the time evolution of this Dacian Basin area

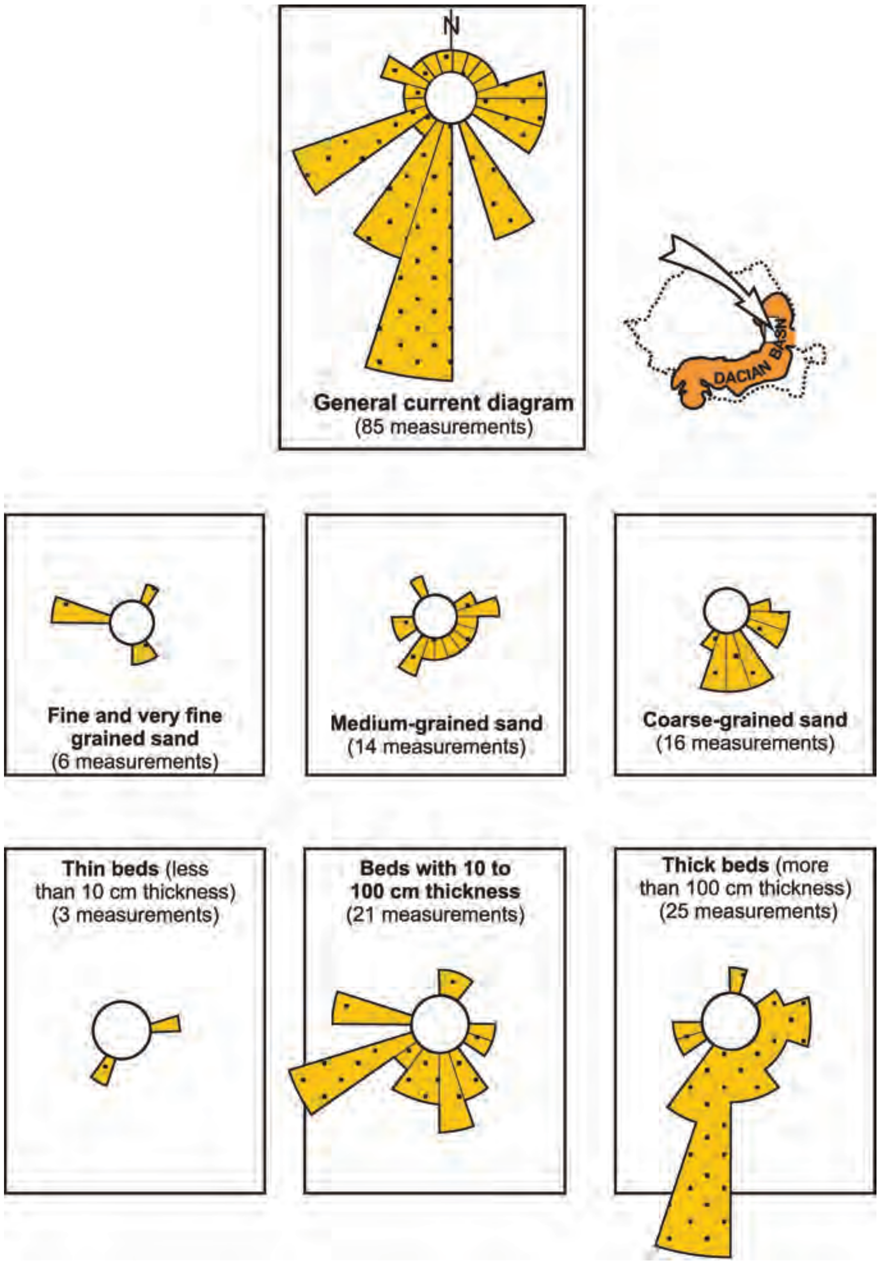


FIGURE 10.7. Comparison between the paleocurrent flow directions and the grain size and bed thickness of the measured sediments. Sarmatian (*s. l.*) - Dacian. Northern part of the Dacian Basin (Putna River to Buzău River)

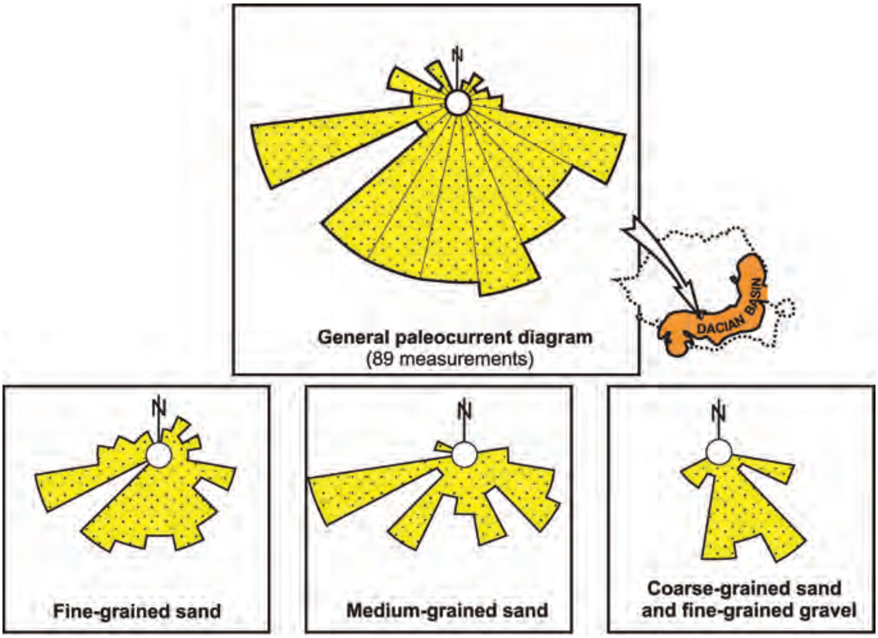


FIGURE 10.8. Comparison between the current flow directions and the sediment grain size for Maeotian to Dacian deposits. Bădislava-Tigveni area (Argeş County)

10.2.4. Sediment transport in the Dacian Basin

Information on the Dacian Basin sediment transport system is restricted to the outcrop locations in the sub-Carpathian area. These paleocurrent flow directions represent the direct knowledge on the sediment transportation pattern. The meaning of the paleocurrent data is limited to the narrow littoral area of the sub-Carpathian basin margin.

Supplementary information on the sediment transport pattern in the central part of the Dacian Basin resulted from the interpretation of some subsurface data.

Seismic profiles in the western part of the Dacian Basin revealed the existence of large-scale progradation structures (Tărăpoancă, 2004; Leveer, 2007) (Fig. 4.6). These data are important, not only for the sedimentary architecture of the basin fill, because it is firsthand information regarding the sediment transport in the central, deeper area of the Dacian Basin.

Features inferred through the interpretation of the physiography of the Dacian Basin have been used in building the sediment transport pattern. The sediment transport concept relies on the concept that the Dacian Basin was an elongated sedimentary trough, very shallow in the northern end area and becoming deeper and deeper toward its western end (see Chapter 3 for a discussion on this subject).

The marginal, shallow-water sediment transport pattern is an important and better-known aspect of the detrital material transfer within Dacian Basin. The paleocurrent flow directions in the sub-Carpathian marginal area (Fig. 10.4) reveal the following main characters:

- longitudinal paleocurrents, flowing southward along the basin axis, prevailed in the northern part of the Dacian Basin, coexisting with transversal currents (Fig. 10.4 A and B);
- in the littoral area from the central and western Dacian Basin, the current directions are largely dispersed, but they show a dominant component describing a south-west current flow trend (Fig. 10.4 C, D and E).

These data indicate that the littoral paleocurrents have a tendency to turn and flow toward the western end of the Dacian Basin (Fig. 10.9). The general, westward dip of the trough axis was probably the factor that controlled the reversal of the paleocurrents flow direction.

The flow direction along the trough axis is better observed in the northern part of the Dacian Basin. This is evidenced by the dominant paleocurrent direction, but also by the large scale transition observed in the area between Putna and Buzău Rivers, shown by the grain size and current structures of the thick sand beds (see Chapter 6.1).

The gradual deepening of the Dacian Basin axial zone is supported by the long term westward extension of the eastern depocenter (Fig. 10.1). The subsidence cannot be invoked as a factor to explain the westward extension of the sediment accumulation area. The extension took place from the high subsidence area in the north (Focşani-Buzău zone; Bertotti *et al*., 2003) toward a less subsident zone in the west (Fig. 4.8).

If we accept that the westward deepening of the Dacian Basin influenced the paleocurrents orientation in the littoral zone, it means that in the axial part of the basin the paleocurrents are longitudinal, flowing toward the western end of the Dacian Basin trough (Fig. 10.9). The dominantly longitudinal Dacian Basin sediment transport result also from the successive Maeotian-Dacian patterns of the sediment thickness (Fig. 9.1).

In the deepest part of the Dacian Basin, near its western end, the dominant sediment transport is made by prograding sedimentary bodies with large scale inclined surfaces (Figs 4.6 and 10.9). These structures probably appeared as a reaction to the deepening in the western area of the Dacian Basin, combined with a large sediment supply.

In conclusion, the sediment transport pattern of the brackish-marine Dacian Basin includes three segments: (1) the transversal, turning longitudinal sub-Carpathian littoral current system, (2) the longitudinal sediment transport in the axial zone of the deepening trough and (3) the prograding system in the deepest western end of the basin. The segments (1) and (3) of the sediment transport are based on recorded data, but the segment (2) is entirely interpretative.

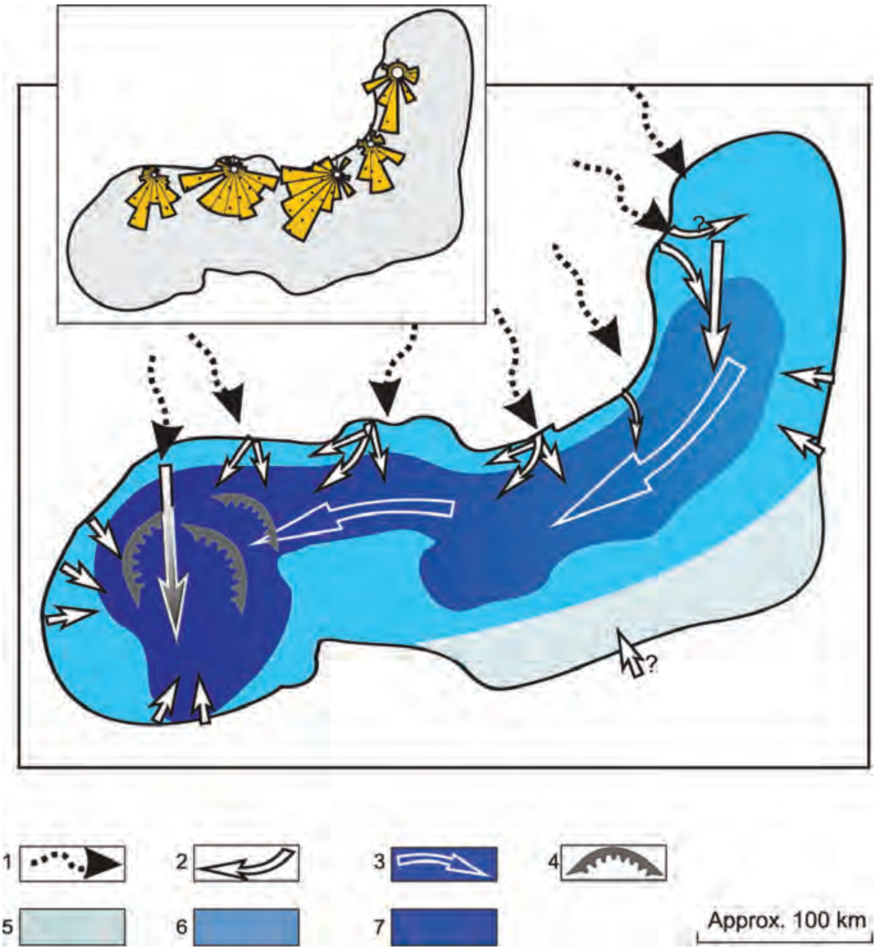


FIGURE 10.9. Tentative representation of the Dacian Basin sediment transport system. **1**. Carpathian fluvial network (conceptual image). **2**. Paleocurrents in the littoral/sublittoral zone. **3**. Paleocurrents in the Dacian Basin trough. **4**. Area with large scale Maeotian-Pontian progradation structures. **5**. Southeastern Dacian Basin shelf. **6**. Zone with intermediary water depth between shelf and trough (including the sub-Carpathian littoral zone). **7**. Axial zone of the Dacian Basin trough. *Upper-left*: paleocurrent measurement data

10.3. STAGES OF THE DACIAN BASIN SEDIMENT FILLING

The evolution of the two depocenters offers the best information on the Dacian Basin sediment filling process. Three stages have been distinguished in the evolution of the sediment filling process.

Stage 1. Brackish sediment accumulation restricted to two separated depocenters. This stage extends through the Middle-Late Sarmatian (*s. l.*) – Maeotian time interval.

The main distinctive character of the stage 1 is the sediment accumulation within two distinct Dacian Basin depocenters (Fig. 10.10 A and B). The areas of the individual depocenters enlarged considerably during the Maeotian, as compared to the Middle-Late Sarmatian (*s. l.*) extent.

During the Maeotian time interval the eastern depocenter extended mostly toward the south-west with a fan-like geometry (Fig. 10.10 B).

The western depocenter enlarged eastward and southward, and the maximal sediment thickness increased from 200 m during Middle-Late Sarmatian (*s. l.*) to 600 m in the Maeotian time (Fig. 10.10 B).

In the space between the two depocenters a reduced amount of sediments accumulated, with around 100 m thickness.

Stage 2. Brackish sediment filling, mainly through the extension of the eastern depocenter. This stage covers the time span from the Early Pontian to the Early Dacian.

The characteristic of the sediment filling process during the stage 2 is the westward advance of the sediment accumulation along the sedimentary trench (Fig. 10.10 C and D). The main effect of this process was the filling of the accommodation space of the former sediment deficient area between the two depocenters.

In the western depocenter, the southward extension of the sediment accumulation area continued, reaching its maximum during the Early Pontian (Fig. 10.10 C). The Late Pontian-Dacian isopach map (Saulea *et al*., 1969) shows the end of this process and the decrease of the sediment accumulation in the western depocenter of the Dacian Basin (Fig. 10.10 D).

The two depocenters coalesced into a single depocenter sometimes between Late Pontian and Early Dacian. The stage 2 ends with the filling out and closure of the brackish-marine Dacian Basin.

Stage 3. Fluvial sediment accumulation subsequent to the filling out of the Dacian Basin. Starting from the Middle Dacian time, the sedimentation in the area of the Dacian Basin is fluvial. The isopach map indicates a single area, with an east–west elongated sediment accumulation front (Fig. 10.10 E). The large scale geometry of the sediment accumulation, belonging to the piedmont type, indicates an exclusively Carpathian sediment supply. In contrast with the preceding sediment filling stage, the sediment accumulation tends to extend southward.

10.4. CONTROL FACTORS OF THE SEDIMENT FILLING PROCESS

The history of the sediment filling in the Dacian Basin was strongly influenced by the tectonic factor. Being a foreland unit, the Dacian Basin physiography have been shaped mainly by the tectonic forces. The Dacian Basin elongation (a typical fore-

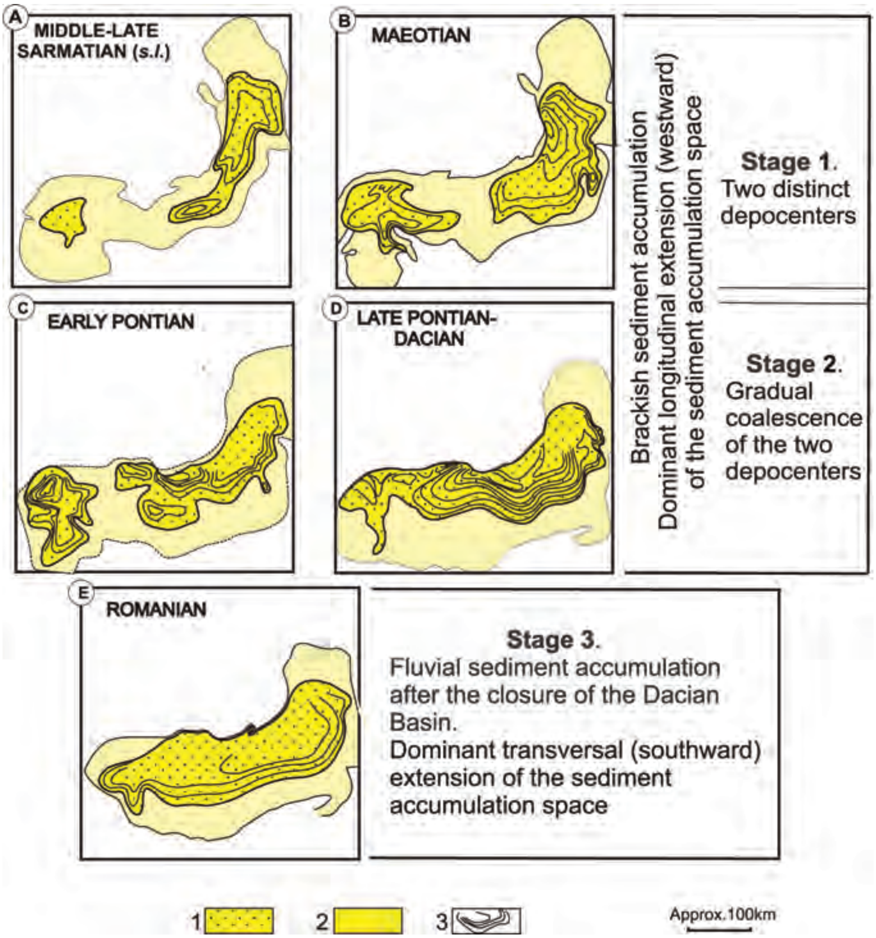


FIGURE 10.10. Stages of Dacian Basin sediment filling. **Legend**: **1**.Sediment accumulation area (sediments thicker than 200 m). **2**. Dacian Basin extent. **3**. Isopachs (from Saulea *et al*., 1969). Isopach values in Figure 9.1

land basin character) imposed a dominantly longitudinal sediment transport (another common feature of the foreland basins).

The characteristic of the Dacian Basin sediment filling evolution is marked by the initial existence of two synchronous and separated depocenters. This feature was also imposed by tectonics, and is due to the existence of two separated subsidence and source-areas generated by differential Late Neogene uplift in the Southern Carpathians and Eastern Carpathians.

After the development of the two depocenters, the control of the sediment filling process was dominated by the westward tilting of the Dacian Basin axial zone. The two depocenters were located at both ends of the inclined sedimentary trench. Being positioned at the base of the general sedimentary slope of the basin, the western depocenter was not exposed to important morphologic changes (except for the southward extinction). Its main role was to accumulate the detrital material supplied by the low relief western source-area of the Carpathians to the limit of its accommodation space.

The eastern Dacian Basin depocenter had a complex evolution. Being affected by high subsidence, the eastern depocenter acted as a huge sediment trap, being able to store Late Neogene sediments with a total thickness of several kilometers.

The other role played by the eastern depocenter was controlled by the progressive westward deepening of the sedimentary trench which created a sedimentary slope. Being positioned upslope the eastern Dacian Basin depocenter acted as a sediment conveyor. The detrital material, which exceeded the storing capacity of the eastern depocenter, was progressively transferred down slope toward the sediment deficient area between the eastern and western depocenters. Being initially out of the reach of the sediments supplied by the two Carpathian source-areas, the area in between the depocenters, developed an excessive accommodation space during the initial sediment filling stage. The isopach maps (Saulea *et al*., 1969) (Figs. 10.1; 10.2; 10.10) show the evolution of the process, which led to the filling of this inter-depocenter area, and the implicit sediment fill of the brackish-marine Dacian Basin.

During the existence of the Dacian Basin trench the Carpathians-derived sediment had to be transported longitudinally along the trench elongation and parallel to the orientation of the mountain range. After the sedimentary trench of the Dacian Basin was completely filled, the sediments supplied by the Carpathians continued to accumulate at the base of the mountain. The new post-fill stage allowed the direct southern transfer of the sediments transversally from the Carpathians.

10.5 CONCLUSIONS

The sediment thickness pattern during the development of the Dacian Basin in the Late Neogene shows two separate areas of sedimentary accumulation: the eastern depocenter and the western depocenter.

The initial appearance of two synchronous and separated depocenters represent the characteristic of the Dacian Basin sediment fill evolution. This feature was imposed by the existence of two separated Carpathian source-areas located in the Southern Carpathians and in the southern part of the Eastern Carpathians.

The western sedimentary area was a smaller depocenter of the Dacian Basin, representing approximately one third of the eastern accumulation area.

The eastern Dacian Basin depocenter was the most active sediment accumulation area of the Dacian Basin. Due to high subsidence this depocenter served as a huge sediment trap storing Late Neogene sediments with total thickness of several kilometers.

The detrital material which exceeded the storing capacity of the eastern depocenter was progressively transferred down slope toward the sediment deficient area between the eastern and western depocenters.

The sediment transport pattern of the brackish-marine Dacian Basin includes three segments: (1) the transversal, turning longitudinal sub-Carpathian littoral current system, (2) the longitudinal sediment transport in the axial zone of the deepening trough and (3) the large scale prograding system, in the deepest western end of the basin.

During the existence of the Dacian Basin trench the bulk of Carpathians-derived sediments were transported longitudinally along the trench elongation and parallel to the orientation of the mountain range. After the sedimentary trench of the Dacian Basin was completely filled (by the end of the Dacian time), the sediments supplied by the Carpathians continued to accumulate at the base of the mountain. The new paleogeography existed after the filling of the brackish-marine trench allowing the direct southern transfer of the sediments, transversally from the Carpathians.

Chapter 11

FROM BRACKISH-MARINE TO CONTINENTAL-FLUVIAL DEPOSITIONAL ENVIRONMENT IN THE DACIAN BASIN

11.1. LATE PONTIAN-ROMANIAN REGRESSIVE UNIT

11.1.1. Sedimentary succession at the Pontian/Dacian limit

Outcrop investigations carried out in the sub-Carpathian zone of the Dacian Basin evidenced a sedimentary succession which develops from Pontian brackish-marine clay to Romanian fluvial deposits. A coarsening upward sandy interval formed between the marine and the fluvial deposits.

The main characteristics of the uppermost Late Neogene sedimentary succession are easily recognized on the electric well logs from the Dacian Basin area (Jipa *et al*., 1999). The log interval with funnel-shaped profile (Figs. 11.1 and 11.4) have been remarked previously, being used for correlation between wells. The well logs of the sedimentary succession underlying the funnel shaped interval display a linear electric log profile with constant SP high values, typical for dominantly clayey sediments. Overlying the funnel interval, the well logs show a very thick succession of bell or blocky-shaped electrical logs units, alternating with clayey intervals.

Brackish-water Upper Pontian (Bosphorian) fauna were collected from the lower, clayey succession (Marinescu 1978 and others). The upper, fluvial unit shows fresh-water fauna and have been dated as Late Dacian-Romanian. Consequently, the Late Pontian-Romanian succession has a regressive character, indicating the transition from the marine to the continental environment (Fig. 11.2). The coarsening upward interval from the terminal part of the marine sedimentary succession represents the transitional deposits from marine to non-marine fill of the Dacian Basin.

The interval with coarsening upward trend shows a gradual transition from the lower clayey Pontian to the Dacian fine-grained sand/silt deposits. The limit at the top of the coarsening upward unit is sharp, non-transitional. These characters are best observed in well logs (Fig. 11.4).

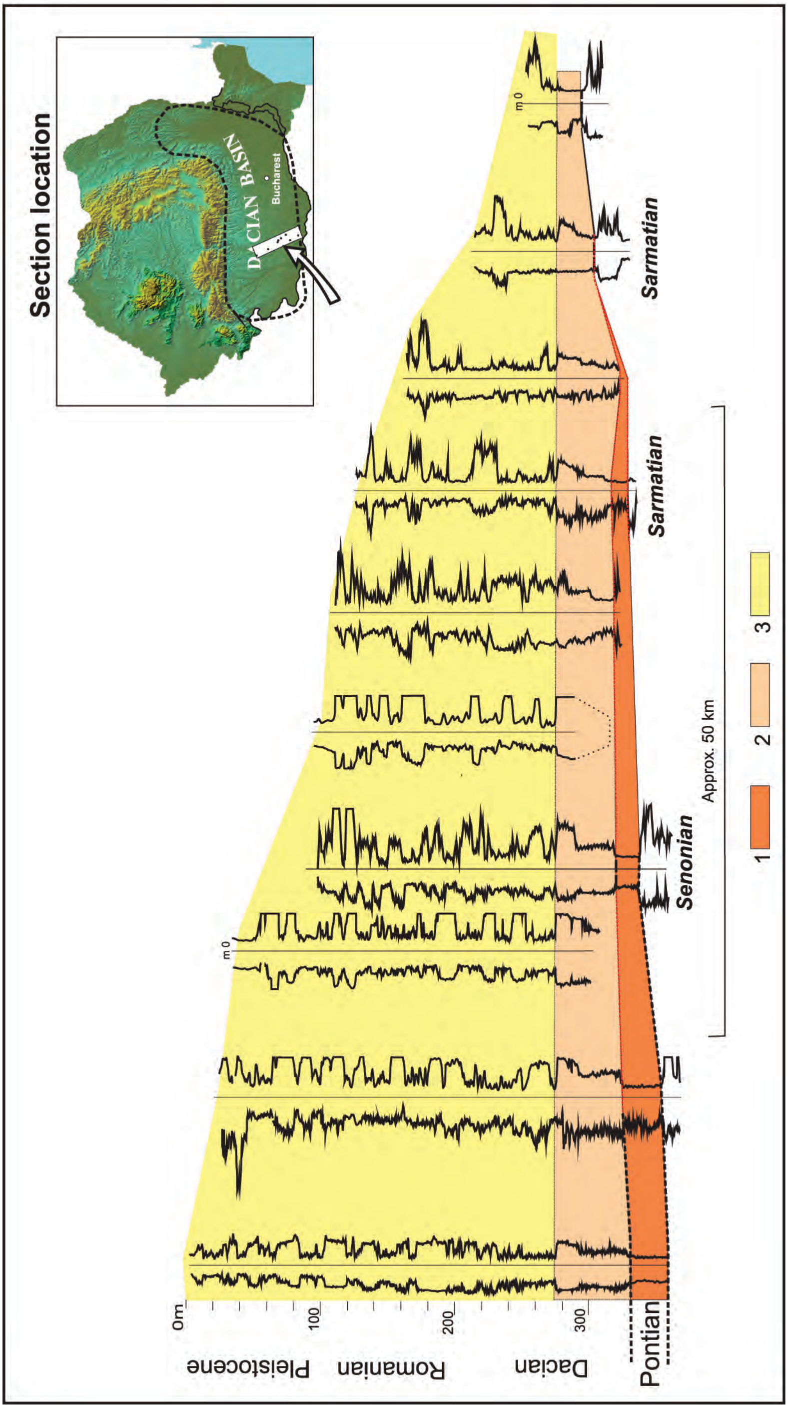
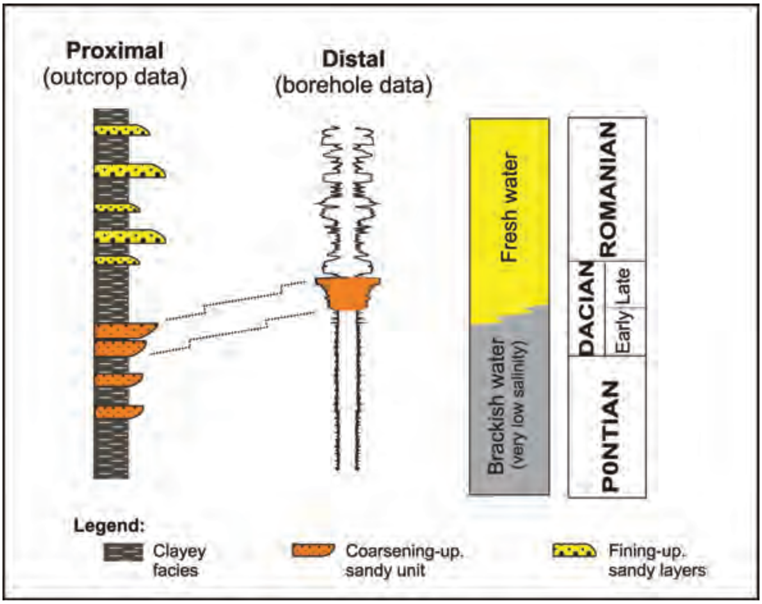
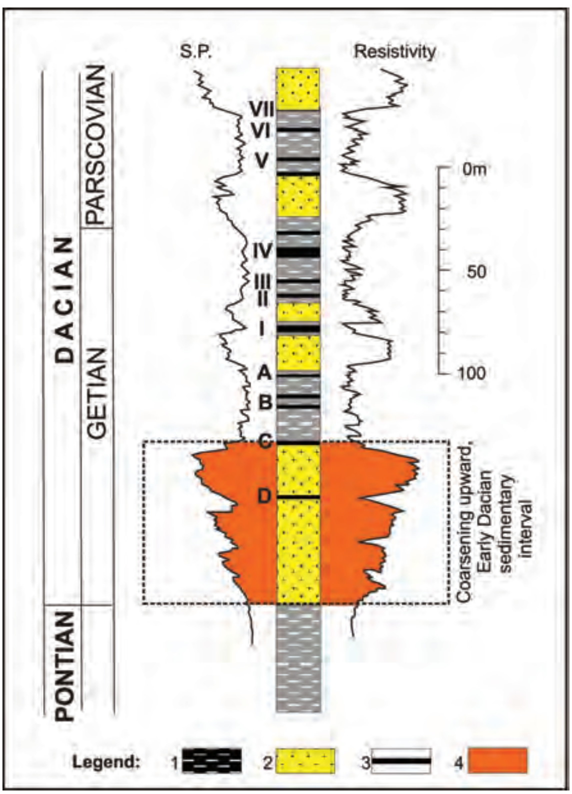


FIGURE 11.1. The Pontian - Romanian regressive sequence in a well section in Drăgăşani-Slatina area (west of the Olt River). Note the gradual passage from the clayey Pontian to the coarsening upward fine-grained sand. **Legend**: **1**. Brackish water clayey Pontian deposits. **2**. Brackish, shallow water coarsening upward Early Dacian deposits. **3**. Romanian fluvial deposits



▲**FIGURE 11.2.** Sedimentary environment evolution of the Dacian Basin. This pattern shows the situation in the western and central parts of the basin. Not to scale. Modified after Jipa *et al.* (1999)



◀**FIGURE 11.3.** Stratigraphic position of the coarsening upward sandy interval in the coal bearing Oltenia area (western Dacian Basin) (from Marinescu, 2004). The lignite beds are used as stratigraphic markers. **A** to **D** are thin, discontinuous coal beds, preceding the **I** to **XIII**, thicker, industrial coal beds. Note that, with one exception, the coal beds are younger than the coarsening upward interval. **Legend**: **1**. Clayey deposits. **2**. Sand. **3**. Coal beds. **4**. Coarsening upward interval

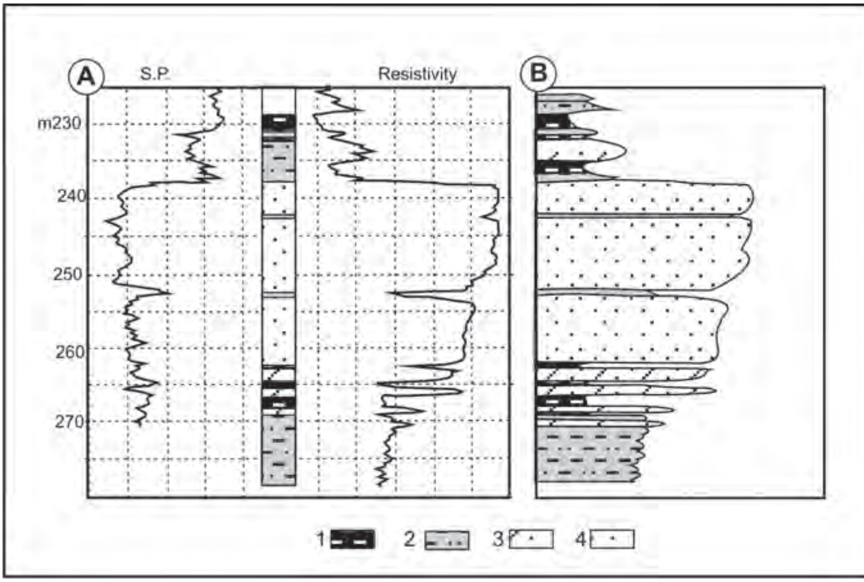


FIGURE 11.4. The well log signature of the coarsening upward Early Dacian interval. Note the transitional lower limit and the sharp upper limit of the coarsening upward unit. **A** - Well logs. **B** - Sedimentary interpretation of the funnel-shaped logs. From Jipa *et al.*, 1999. **Legend**: **1**. Clayey sediments. **2**. Siltic sediments. **3**. Silty-sandy sediments. **4**. Sandy sediments

11.1.2. Stratigraphic position of the coarsening upward unit

The macro-fauna of the coarsening upward unit, from the northern part of the Dacian Basin, show sediments accumulated during the lower part of the Late Dacian (Getian) time. Papaianopol *et al*. (1995) described the coarsening upward unit from Bengesti village as the stratotype of the Getian sediments. The same Early Dacian age was assigned to the sandy level overlying the Pontian clayey deposits from the Piatra valley (Dâmboviţa County, between Târgovişte and Pucioasa).

Based on the paleontological and stratigraphical data of the coal-bearing unit from the western Dacian Basin, Marinescu (2004) assigns the coarsening upward unit to the lower part of the Getian (Early Dacian) time interval (Fig. 11.3). The coarsening upward sands extend from the top of the Pontian deposits to the lignite layer **C**.

All the stratigraphic data presented above refer to deposits from the sub-Carpathian side of the Dacian Basin.

11.1.3. Sedimentary characteristics of the Dacian coarsening upward unit

Sedimentary facies in the outcrop. The coarsening upward unit crops out in the proximity of the Southern Carpathians, on the northward margin of the Dacian Basin. The best exposures of this coarsening upward unit were found in Bobolia village (Prahova county and Valea Rea point - south of Câmpina, the right bank of Prahova River).

Lithologically, the coarsening upward unit is characterized by the predominance of fine to very fine sand and silt over clay. Fine grained gravel can occur in small quantities.

The sedimentary structures observed in the Dacian coarsening upward unit are represented by different types of cross laminations and are interpreted as shallow water coastal deposits. The most frequent sedimentary structures are the small-scale asymmetrical, current ripples. Large-scale cross lamination also has been observed (Fig.5.28). At the Bobolia outcrop a 1.5 m thick cross laminated unit occurs in the upper part of a unit which is part of the Early Dacian interval.

In the outcrop from Bobolia (Prahova County) the Early Dacian coarsening upward unit consists of six to ten (or more) parasequences. Each of these parasequences shows a coarsening upward trend, with mud at the base and sand at the upper part. Often at the upper part of the coarsening upward units, the sandy sediments become coarser (medium or coarse grained sand), even include small pebbles (Fig. 5.26 B). The upper limit of the units between the sand and the mud of the overlying unit is commonly sharp (Fig. 5.26).

In some cases the sandy sediments of the coarsening upward units are apparently homogenous, without visible sedimentary structures. The lack of structures results from the fact that many parasequences are made of well sorted, very fine sands. Sometimes it is obvious that the coarsening upward units were highly bioturbated and the sedimentary structures have been obliterated partially or totally (Fig. 5.27).

The coarsening upward unit on the well logs. The coarsening upward Dacian unit on the well logs has an easily distinguishable character due to the funnel pattern reflecting the coarsening upward grain size trend (Jipa *et al*., 1999) (Fig. 11.4).

Some well logs indicate the complex structure with multiple coarsening upward parasequences of the Early Dacian interval discussed. The coarsening upward littoral units observed in the outcrop and the similar units noticed in well logs show similar and complementary sedimentological features.

Characteristics of the Dacian coarsening upward unit. The coarsening upward unit is singled out by its sedimentary characteristics, as well as by its position within the Pliocene sedimentary succession (Figs. 11.1 and 11.5).

From the sedimentological point of view, the Early Dacian sedimentary interval is identified by the following features:

- coarsening upward trend, from clay at the base to sand at the top;
- dominant fine-grained sand lithofacies;
- sedimentary structure indicating littoral depositional environment;
- alternating brackish-marine and fresh-water fauna.

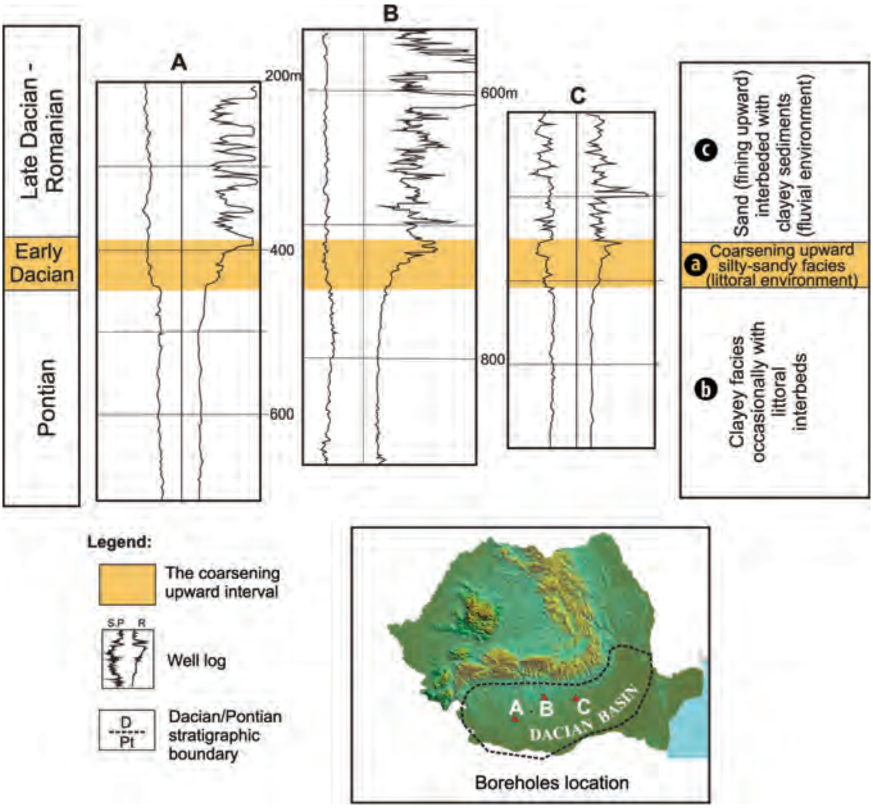


FIGURE 11.5. The Early Dacian unit (**a**) is visible in the sedimentary column being placed between a dominantly clayey Pontian succession (**b**) and an alternating sand-clay fluvial sequence (**c**)

The Dacian-aged coarsening upward sedimentary interval overlies muddy, low salinity upper Pontian deposits and is followed by a very thick upper Dacian-Romanian fluvial unit (sandy beds intercalated within the muddy deposits). The distinct facies of the three stratigraphic entities is the factor that singles out the lower Dacian unit investigated in this paper. In the sub-Carpathian area of the Dacian Basin coarsening upward units occur in the Early Dacian but also in the Late Pontian stratigraphic interval, due to the proximal character of the area. Only the Early Dacian coarsening upward bodies extend in the distal area of the basin (Fig. 11.2).

11.1.4. The thickness of the Early Dacian coarsening upward unit

During this study, Dacian coarsening upward units were recognized in many wells drilled in the Dacian Basin area. The thickness of this unit was measured only on

73 well logs, where it was possible to indicate confidently the boundaries of the coarsening upward interval.

The thickness values of the coarsening upward unit are in the range of 50-80 m, but the thicknesses between 60-70 m are the most frequent (Fig. 11.6). The lowest thickness measured on the well logs is 23 m. The maximum determined thickness is 85 m.

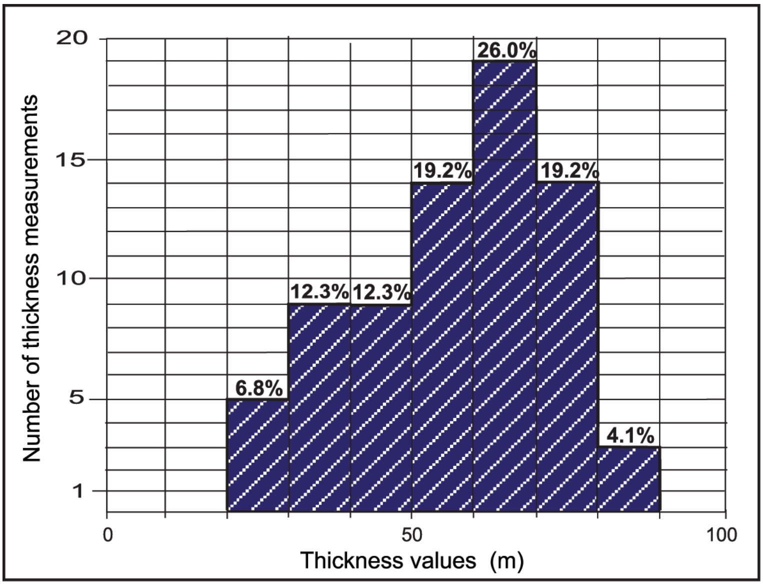


FIGURE 11.6. Thickness values of the Early Dacian coarsening upward sedimentary sequence. The graph of the frequency distribution is based on 73 borehole thickness measurements

11.1.5. Areal extent of the Dacian coarsening upward unit

About one hundred Dacian Basin well logs were used to map the extent area of the Early Dacian coarsening upward units. The presence of the coarsening upward unit was noticed in almost the whole area covered by the Dacian Basin (Fig. 11.8). The north-eastern part of the basin is the region where the coarsening upward unit was not identified (Fig. 11.8 d).

The coarsening upward unit was distinguished in the northern, outcrop belt, in the central region and in the southern part of the Dacian Basin. On the Jiu-Olt transect (Fig. 11.7), the coarsening upward unit appears from the northern part of the Dacian Basin to its southern edge.

Even within the area where the Dacian-dated coarsening upward unit was mapped, this sedimentary unit may be locally absent. However, the well logs with-

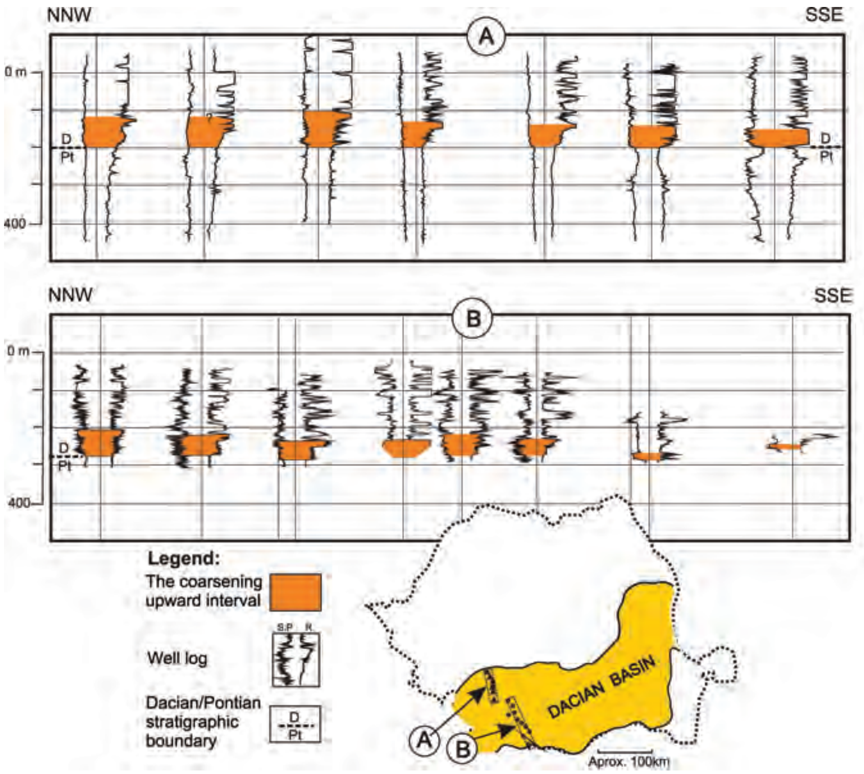


FIGURE 11.7. The north to south areal distribution of the Early Dacian coarsening upward interval. The sedimentary sequence of this interval occurs from the northern, proximal part to the south, distal limit of the Dacian Basin

out coarsening upward unit were few; they represent less than 5% from all the analyzed localities.

11.1.6. The diachronism of the coarsening upward Dacian-aged unit

The coarsening upward trend of the deposits indicates these sedimentary units have prograding characteristics. The coarsening upward Dacian unit extends over most of the Dacian Basin area (Fig. 11.8). Consequently, the migration of the coarsening upward Dacian-age deposits represented a significant event produced throughout the Dacian Basin.

The Dacian coarsening upward deposits migrated southward from the vicinity of the Carpathian Mountains (the clastic material source-area). In the south-western part of the Dacian Basin, the progradation of the coarsening upward sediments advanced up to the southern limit of the Dacian Basin.

FIGURE 11.8. Occurrence extent of the Early Dacian coarsening upward interval (**a**). The coarsening upward sequences occur all over the Dacian Basin area, except for the northernmost area (**d**). **Legend**: **a** - the coarsening upward interval marked by funnel-type logs; **b** - geophysical logs; **c** - Dacian/Pontian stratigraphic boundary; **d** - the northern Dacian Basin area

Taking into account the time required for the shoreline sediments to prograde from the Carpathian Mountains to the southern limit of the basin, it can be considered that the sub-Carpathian coarsening upward deposits are older than the similar deposits in southern locations.

The diachronous character is obvious when the extent of the coarsening upward stratigraphic level is superposed on the Dacian-time paleogeographic maps of the Dacian Basin (Marinescu and Papaianopol, 1995) (Fig. 11.9). Consequently, the occurrences of the coarsening upward bodies from the central and north-western part of the basin are of Early Dacian age. Some of the southern locations (close to the present-day Danube River course), where the coarsening upward unit was identified, occur into the area of the Late Dacian deposits.

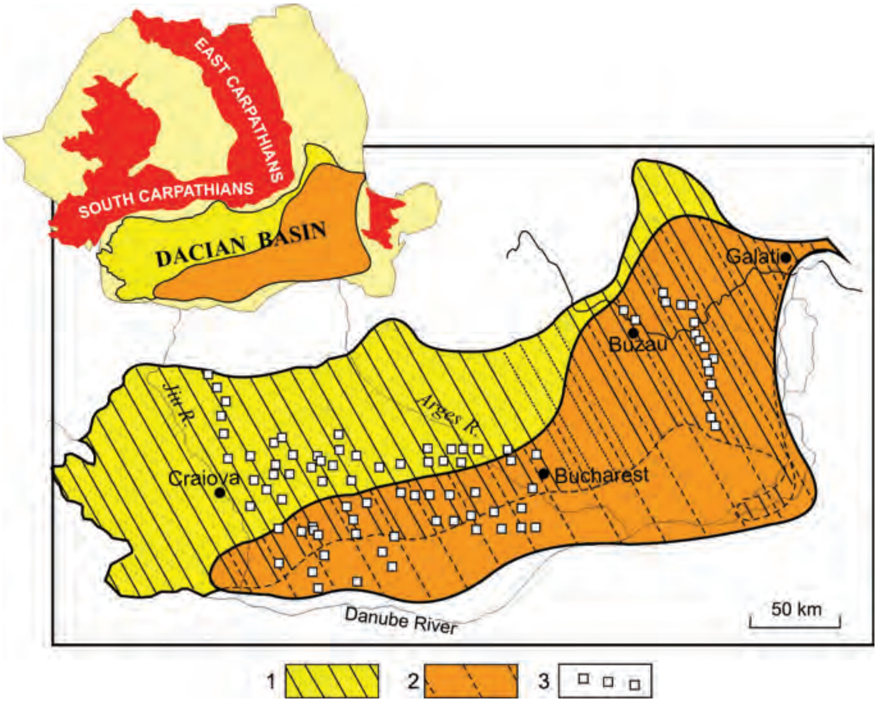


FIGURE 11.9. The distribution of the coarsening upward unit on the Dacian-age paleogeographic map (Marinescu, Papaianopol, 1995). The unit has a diachronous character, as the coarsening upward interval occurs in both the Early Dacian (northern part of the basin) and in Late Dacian deposits (southern part of the basin, in the present-day Danube River area). **Legend**: **1**. Early Dacian (Getian). **2**. Late Dacian (Parscovian). **3**. Well locations where the coarsening upward unit was identified

11.1.7. The coarsening upward sequence – a marker unit in the Dacian Basin

The existent data emphasize the presence of the Dacian coarsening upward unit in outcrops and in well logs on most parts of the Dacian Basin extent. This unit has not been identified in the northern part of the basin which corresponds to the Focşani depression. Consequently, the Dacian coarsening upward unit is a marker level with basinal extent.

The coarsening upward unit was informally used as a stratigraphic marker of the Dacian/Pontian limit. The existing data indicate that although the coarsening upward unit may be continuous over a wide area of the Dacian Basin, its geological age varies from the Early Dacian to the Late Dacian.

The Dacian coarsening upward marker unit is part of the Pontian-Romanian transgressive-regressive cycle. The marker unit represents the last event with brackish-marine characteristics. After the deposition of this unit, the brackish-marine Dacian Basin filled and the sedimentation became fluvial.

11.1.8. Genetic significance of the coarsening upward Dacian unit

The Dacian marker unit was studied from different perspectives: in outcrops at sub-metric scale and from well logs at tens of meters scale. Observations made in the outcrops (Jipa *et al*., 2007) indicate the shallow water, deltaic character of the sedimentary environment of the Early Dacian unit. The littoral Dacian Basin environment was dominated by either basinal (waves, storm) or by fluvial factors. The magnitude and grain size of the sediment supply were also significant factors that influenced sedimentation.

The Dacian coarsening upward unit appears as a deltaic accumulation, developed during moments of high fluvial discharge (Jipa *et al*., 2007). Because of the high fluvial sediment supply the waves and littoral currents were unable to rework the sediments in front of the delta. The coarsening upward of this alluvially controlled accumulation underlines its prograding trend.

The deltaic character and the highly variable shoreline explains the presence of the brackish fauna alternating with fresh-water fauna in the sedimentary column of the coarsening upward unit.

A specific character of the deltaic type Dacian-age unit is its basin-wide extension. The presence of this unit in the entire basin suggests the migration of the shoreline, from the proximal zone in the north, to the distal and marginal zone in the south.

The shoreline progradation through individual deltaic bodies explains the failure to identify the Dacian coarsening upward unit in some boreholes. These deltas could overlap, but sometimes could be apart, between the existing shoreface deposits with different sedimentary structures.

11.2. THE DACIAN BASIN TRANSITION FROM BRACKISH-MARINE TO CONTINENTAL AND ENVIRONMENTAL CONDITIONS DURING THE SEDIMENT FILLING OUT PROCESS

The time span when the Dacian Basin was being filled out with sediments was marked by several major processes, each of them capable of influencing the basin evolution and sedimentation.

Subsidence was one of the important forces active during the entire Dacian Basin evolution, including the Dacian time. The strongest subsidence was active in the Focşani – Buzău area (Bertotti *et al*., 2003; Necea *et al*., 2005) (Fig. 4.8). Uplift and erosion in the eastern, Carpathian source-area were coupled with the northern Dacian Basin subsidence (Bertotti *et al*., 2003). The joint action of the two processes resulted in a major storage of sediments in the center of the northern part of the Dacian Basin. The sediment supply exceeded the sediment storage rate and a volume of detrital material was transported southward and later westward. As discussed in this book (Chapter 4.4), the high supply probably balanced the subsidence. There is no clear evidence a depression-like relief was created in the northern Dacian Basin as a consequence of the subsidence process. However, it is not known if the subsidence overcame the sediment accumulation for any limited period of time during the basin evolution.

An important environmental circumstance which marked the development of the Dacian Basin was its permanent communication with the Euxinian Basin (that is, the Black Sea Depression and shelf area). The existence of water interchanges between the Dacian Basin and the Euxinian Basin during the Pontian time is demonstrated by the faunal communities between the two basins (Saulea *et al.*, 1969 and others). In contrast, it is difficult to attest the Dacian Basin connection with the Euxinian Basin during the Dacian time. Marinescu and Papaianopol (1995) concluded that one should admit the existence of short-time communication periods between the Dacian and Euxinian basins, during the Dacian time.

At the beginning of the Dacian time, the sedimentation depth decreased and/or the sediment influx intensified and coarsening upward, deltaic sediments accumulated. The shoreline migrated toward the internal part of the basin. The large extent of the coarsening upward unit shows the significant (tens and hundreds of kilometers) migration distance. As indicated by the south-western extent of this unit, the prograding shoreline reached the southern extremity of the Dacian Basin and probably its eastern limit. The Dacian-time paleogeographic map (Marinescu and Papaianopol, 1995) (Fig. 11.9) illustrates the magnitude and duration of the migration.

11.2.1. Dacian-time transition from brackish to fresh-water fauna

Paleontological information shows that during the Dacian time, the fresh-water fauna appeared earlier (middle part of the Dacian time) in the western area of the Dacian Basin (south of the Southern Carpathians). In the east (the Buzău-Râmnic area of the Carpathians) and in the north (Focşani depression) marine-brackish fauna continued to subsist till the end of the Dacian time.

As mentioned by Marinescu and Papaianopol (1995), beginning from the upper part of the Early Dacian time in the western zone of the Dacian Basin (west from the Prahova River) a marsh facies developed.

11.2.2. The closure of the brackish-marine Dacian Basin. Proposed scenario

The scenario of the process of transition to a continental environment, which means the closure of the brackish-marine Dacian Basin, is an interpretation based on several sources of information about important developments which took place in the basin. The main data of the proposed scenario is relying on are the following:

- the Dacian Basin became a fresh-water area earlier (upper Early Dacian) in the western part; while the brackish-water environment persisted in the eastern part of the basin until the end of the Late Dacian time;
- a basin-scale shoreline migration started in the Early Dacian time and continued during the Late Dacian.

The pattern of the time and space occurrence of the fluvial, fresh-water facies in the Dacian Basin area suggests the shoreline migration was directed toward the south and to the east. The areal distribution of the locations where the coarsening upward unit was identified and the paleogeographic areal changes during the Dacian time (Fig. 11.9) confirm these shoreline migration trends.

Due to the shoreline migration the area of the marine-brackish body decreased progressively and was replaced by a continental area with fluvial sediment accumulation (including extensive marshes). At the upper part of the Early Dacian (Getian) time, the shoreline position described an oblique line, eastward in the sub-Carpathian zone and westward at the Danube area (Fig. 11.10 B). This shoreline pattern is pointed out by the marsh area, crossed by fluvial channels, which developed in the western Dacian Basin (Oltenia area) (Marinescu and Papaianopol, 1995).

At the beginning of the Late Dacian time (Fig. 11.10 C), the shoreline location corresponds to the western limit of the basin. According to the direction of migration and to the Dacian-time paleogeographic map (Marinescu and Papaianopol, 1995), the western limit marks the base of the Late Dacian sediment accumulation.

The last evolutionary process of the Dacian Basin closure is the final transgression that covered the area with brackish water during the terminal part of the Late Dacian (Parscovian) time (Fig. 11.10 D).

11.2.3. Timing of the Dacian Basin sediment fill out

The complete sediment filling of the Dacian Basin started at the beginning of the Dacian time and was concluded at the end of the Dacian time. According to Vasiliev *et al*. (2005) the Dacian stage time span extended from 4.8/4.7 Ma to 4.1/3.9 Ma (Figs 1.4; 11.11). Consequently, the Dacian Basin transition from brackish-marine to continental was completed during a period of about 700.000 years.

11.2.4. Normal or forced regression

Recent studies carried out in the northwestern part of the Black Sea produced data indicating during the Dacian time the Black Sea depression experienced an important sea level fall (Konerding *et al*., 2009). Because of this event the northwestern shelf of the Black Sea Depression was sub-aerially exposed and was being crossed by major fluvial incised channels. Ţambrea (2007) and Konerding *et al*. (*in press*) showed data on Kimmerian (equivalent Dacian) incised channels a few kilometers

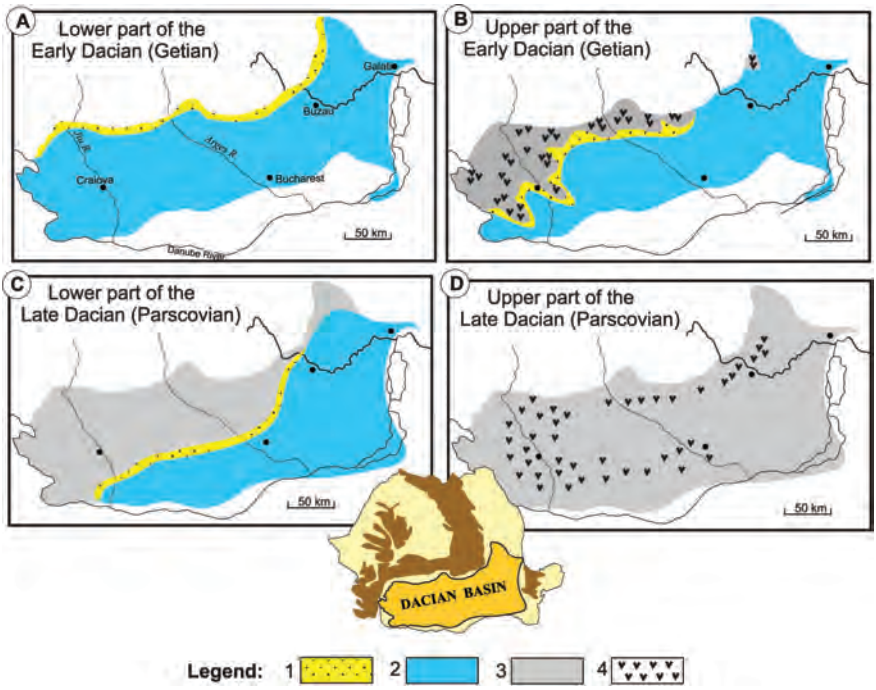


FIGURE 11.10. Stages of the shoreline migration during the Dacian time. The shoreline position is based on the interpretation of Marinescu and Papaianopol (1995) paleogeographic concept. **A** - shoreline as the sub-Carpathian limit of the Early Dacian paleogeographic space; **B** - shoreline position traced in front (on the eastern part) of the coal-generating marsh (upper part of the Early Dacian); **C** - shoreline corresponding to the western limit of the Late Dacian paleogeographic space; **D** - situation at the end of the Late Dacian - beginning of Romanian time. **Legend**: **1**. Shore face facies. **2**. Brackish-water sediments. **3**. Fresh water sediments. **4**. Coal generating swamps

wide and 100 - 200 m deep (Fig. 11.12), in the Black Sea shelf area in front of the present-day Danube Delta.

The sea level drop associated with possible fluvial incision of the north-western shelf of the Black Sea Depression suggests an event that can explain the base level fall of the Dacian Basin. In this model the draining process was a forced regression mechanism, the shoreline being compelled to migrate by the falling base level.

The use of the forced regression concept as the major factor of the brackish-marine Dacian Basin drying out, explains very well the west to east direction of the shoreline migration. The 700.000 year duration of the sea level fall might be rather long, but still possible.

The coarsening upward Dacian-aged unit, which represents the migrating shoreline sediments, shows a gradual transition from the underlying clayey Pontian to the Dacian sand (Figs. 5.25; 11.4). This feature does not fit well into the picture of the Dacian Basin drying out as a result of a forced regression. Ainsworth and

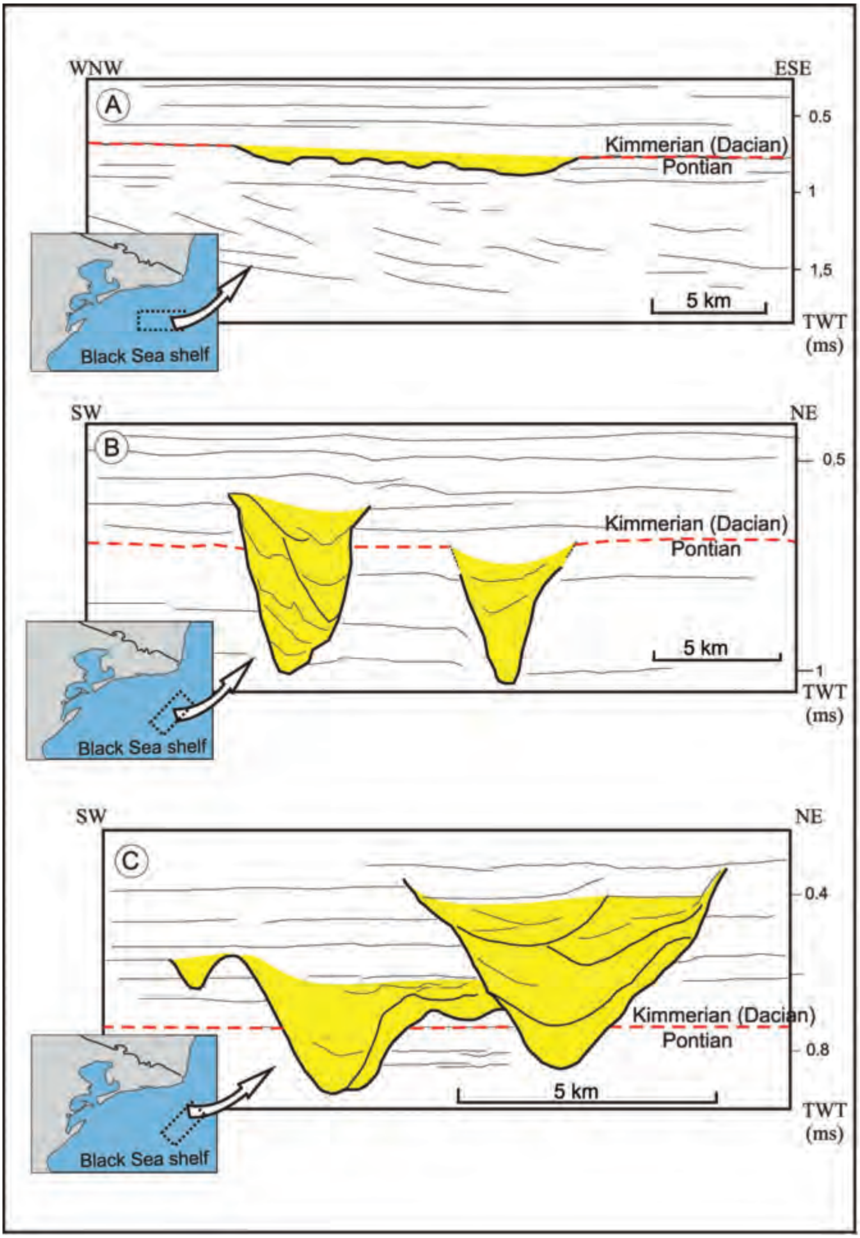


FIGURE 11.11. Kimmerian (Dacian equivalent) incised channels on the north-western Black Sea shelf. **A** - From Tambrea (2007). **B** - From Konerding *et al*. (*in press*). **C** - From Popescu (2002)

Crowley (1994) argued that the lower shoreface of a littoral unit forced to prograde because of a sea-level fall, should show a sharp, not a transitional basal limit.

Another explanation of the Dacian Basin fill resorts to the sediment filling out process. Indeed, the Dacian Basin could have been almost full with accumulated sediments by the time the Early Dacian shoreline began to migrate. The 700.000 year time lap might be enough for the sediment accumulation to fill out the eastern part of the basin.

The concept of the transition to continental environment due to the filling out of the Dacian Basin during the Dacian time does not provide an explanation to the possible west to east gradual filling out of the basin. Why should the western part of the basin fill out first, when the bulk of sediment accumulation is in the eastern part of the basin? Was the eastern part of the Dacian Basin a separated depressional area as a result of the subsidence process?

The role of the subsidence in any scenario of the Dacian Basin fill might be very important. The high subsidence was restricted to the Focşani-Buzău area, conferring individuality to the north-eastern part of the Dacian Basin. Subsidence may explain why the northern part of the basin was the last to be drained out by forced regression. Also, subsidence could provide the explanation of the eastern part of the basin which continued to accumulate sediment, while the western Dacian Basin was filled out.

The complete explanation of the Dacian Basin closure and the identification of the forcing factors which controlled the process require more data.

Chapter 12

DACIAN BASIN IN THE PARATETHYS DOMAIN

During the post-Badenian time, four sedimentary basins made up the Paratethys domain (Fig. 12.1). In order to understand the Dacian Basin evolution among the other Paratethys basins, sedimentary comparisons are unavoidable. This type of evaluation is necessary but difficult because there are more differences than similarities, concerning the evolution of the basins, as well as their physical and sedimentary characteristics and our scientific level of knowledge.

12.1. GENERAL OBSERVATIONS ON THE AREAL VARIATION OF THE DACIAN BASIN AND ITS NEIGHBORING BASINS

The palaeogeographic maps of the Dacian Basin and of the adjoining Pannonian and Euxinian basins (Fig. 12.2) indicate several large scale changes which took place during the time span of the Dacian Basin existence.

The Pannonian Basin suffered the greatest changes. The size reduction of this brackish basin during the time period from 11 Ma to 3.5 Ma is very important.

The Euxinian Basin area also decreased, however, the size reduction of the Euxinian Basin appears moderate compared to the total area of the basin. The surface of the deep sea area (the Black Sea Depression) recorded a small expansion, as indicated by the paleogeographic maps (Popov *et al*., 2004). The most significant surface reduction was shown by the northern shelf area of the Euxinian Basin.

In contrast to the adjacent basins the Dacian Basin did not suffer a total size reduction. The length reduction of the basin was compensated by its widening.

Both Pannonian and Dacian basins have been completely infilled with sediment and disappeared as brackish-water basins. At present, the Euxinian Basin is still a low salinity sea. The rate of the changes suffered by the Late Neogene Paratethys basins probably depended on the balance between the rate of the source area supplied sediment and the volume to be filled out with sediment. The Dacian Basin and especially the Pannonian Basin received large volumes of sediment from important nearby sediment source-areas. At the same time, they represent sediment sinks definitely smaller than the Euxinian Basin.

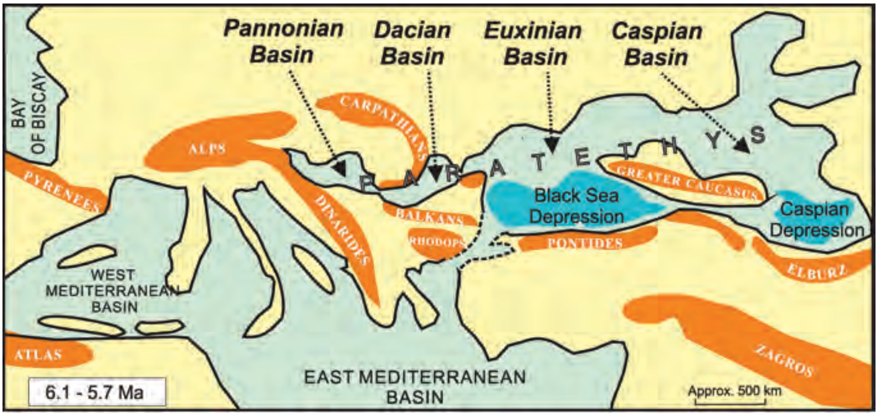


FIGURE 12.1. Paratethys component sedimentary basins during the Dacian Basin existence. Simplified and modified after Khondkarian *et al.* (in Popov *et al.*, 2004)

12.2. SEDIMENTARY RELATIONSHIPS BETWEEN THE DACIAN BASIN AND THE EUXINIAN BASIN

12.2.1. Facies at the boundary between Dacian and Euxinian Basins

The Dacian Basin sedimentary history includes two distinct development periods. During the first one, the brackish-marine stage, which extends from the appearance of the Dacian Basin (Middle-Upper Sarmatian *s.l.*; approximately 11 Ma) until it dried out (starting with Middle Dacian time; approximately 4.5 Ma).

A comparison of the facies features of the Dacian Basin and the adjoining Black Sea shelf is important for the knowledge of the sedimentary relationships between the Dacian and the Euxinian basins (Jipa, 2008). The investigation focused on the critical area of the limits between the Dacian and Euxinian basins. This area, situated northward of the Dobrogean High and the contact between the north-eastern part of the Dacian Basin trough and the western Black Sea Depression shelf, is known as the Galați seaway (Saulea *et al.*, 1969).

During the Late Miocene (approximately 11 to 4.5 Ma) both Dacian and Euxinian basins represented brackish-marine water bodies, with common fauna, suggesting faunal interchanges. At their contact area the two basins were morphologically very different. The Dacian Basin appeared as a shallow but subsiding sedimentary trough, which received a high amount of Carpathian-derived sediment, and accumulated it with a high sedimentation rate. At the contact with the Dacian Basin, the Euxinian western shelf was characterized by reduced detrital accumulation, with its dominance of shell fragments and very fine-grained clastics. The lithofacies and sedimentation rate differentiation between the Dacian and the western Euxinian areas persisted during the Late Miocene time.

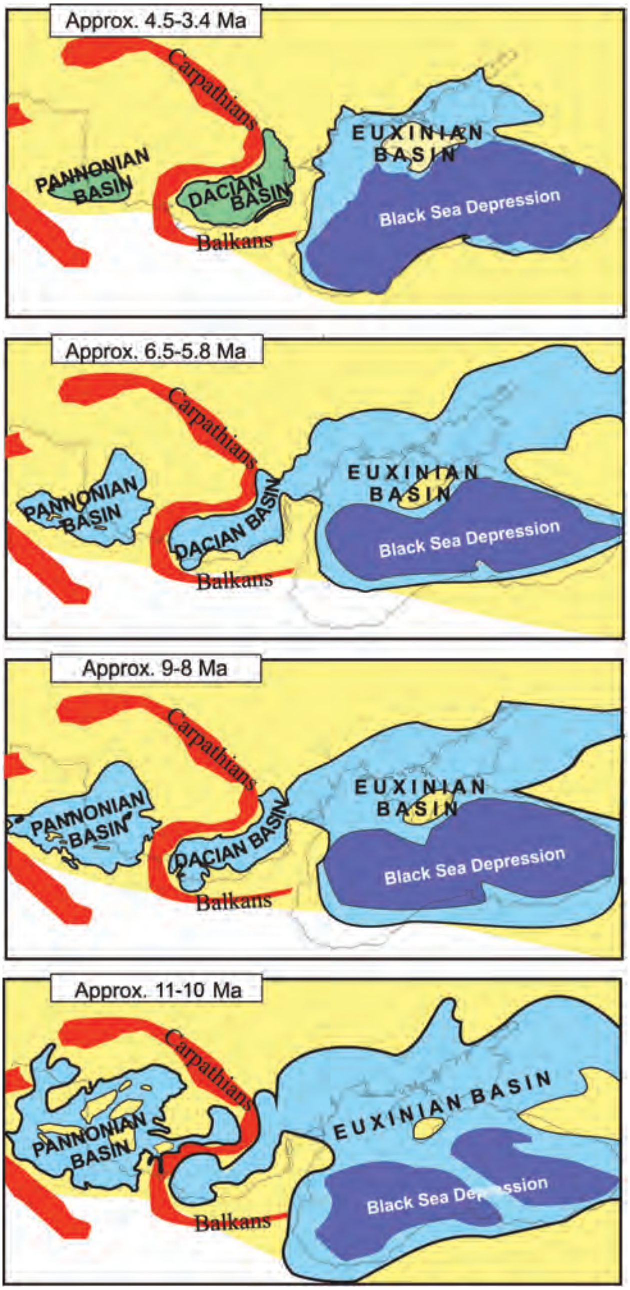


FIGURE 12.2. Paleogeographic sketches showing the comparative areal evolution of the Dacian Basin and the neighbouring Paratethys basins. Compiled from Saulea *et al.* (1969), Papaianopol *et al.* (1987), Hammor *et al.* (1988), Magyar *et al.* (1999) and Popov *et al.* (2004). The Carpathians and the Balkans are shown in the present-day setting as markers of the areal evolution

During the second development period (Middle Dacian to Romanian), the Dacian Basin functioned as a continental area, with fluvial sedimentation. The continental-fluvial development period of the Dacian Basin established a sharp environmental distinction between the fluvial Dacian area and the brackish Euxinian area. During the Dacian-Romanian fluvial stage the Danube paleo-river came into existence in the Dacian Basin (not earlier than 4.5 Ma time) (Fig. 12.3). With the Danubian sediment discharge on the western Euxinian shelf, direct and intensive relationships were established for the first time between the Dacian Basin and the Euxinian Basin.

12.2.2. Brackish Euxinian influxes into the fluvial Dacian Basin area

Sediments with brackish fauna are sometimes interbedded with fluvial Late Pliocene (Romanian, approx. 4 - 1.6 Ma) deposits of the Dacian Basin (Liteanu *et al*., 1968; Andreescu, 1972). The current interpretation of this evidence is that intermittently the eastern area of the fluvial Dacian Basin was transgressed with marine water, from the Euxinian Basin (Fig. 12.3). During these Euxinian transgressions brackish fauna and normal marine flora were brought into the Dacian Basin territory.

Presently there is no data confirming the sediment supply connected with the Euxinian brackish transgressions that took place in the Dacian Basin area during the Romanian time. The question is if large amounts of sediment have been introduced into the Dacian Basin area. If so, the sediment influx should have generated a large deltaic structure. It is probably more realistic to believe that the influx consisted mostly of brackish water, without a significant supply of sediment.

12.2.3. The Dacian Basin between the Carpathians and the Black Sea shelf

The Carpathian Mountains acted as a source of clastic sediment which promoted the development of the Dacian Basin. But how much of the Carpathian-derived clastics reached the Black Sea Depression? The problem of the detrital material exchange between the Dacian Basin and the Euxinian Basin, during the Middle Sarmatian – Romanian time (approx. 11 – 1.6 Ma), was investigated on the bases of the information offered by published paleogeographic - lithofacies maps and the data resulting from the sedimentogenetic study of the Dacian Basin.

The Dacian Basin was one of the brackish–marine units of the Paratethys epicontinental sea (Fig. 12.1). This small basin was in the western neighbor of the large Euxinian Basin, which included the Black Sea Depression and its shelf area. Dacian and Euxinian basins were always in direct communication, as the faunal assemblages indicate. But the important facies differences show that during its brackish-marine existence the Dacian Basin was a different sedimentary province and had no sediment exchanges with the Euxinian Basin.

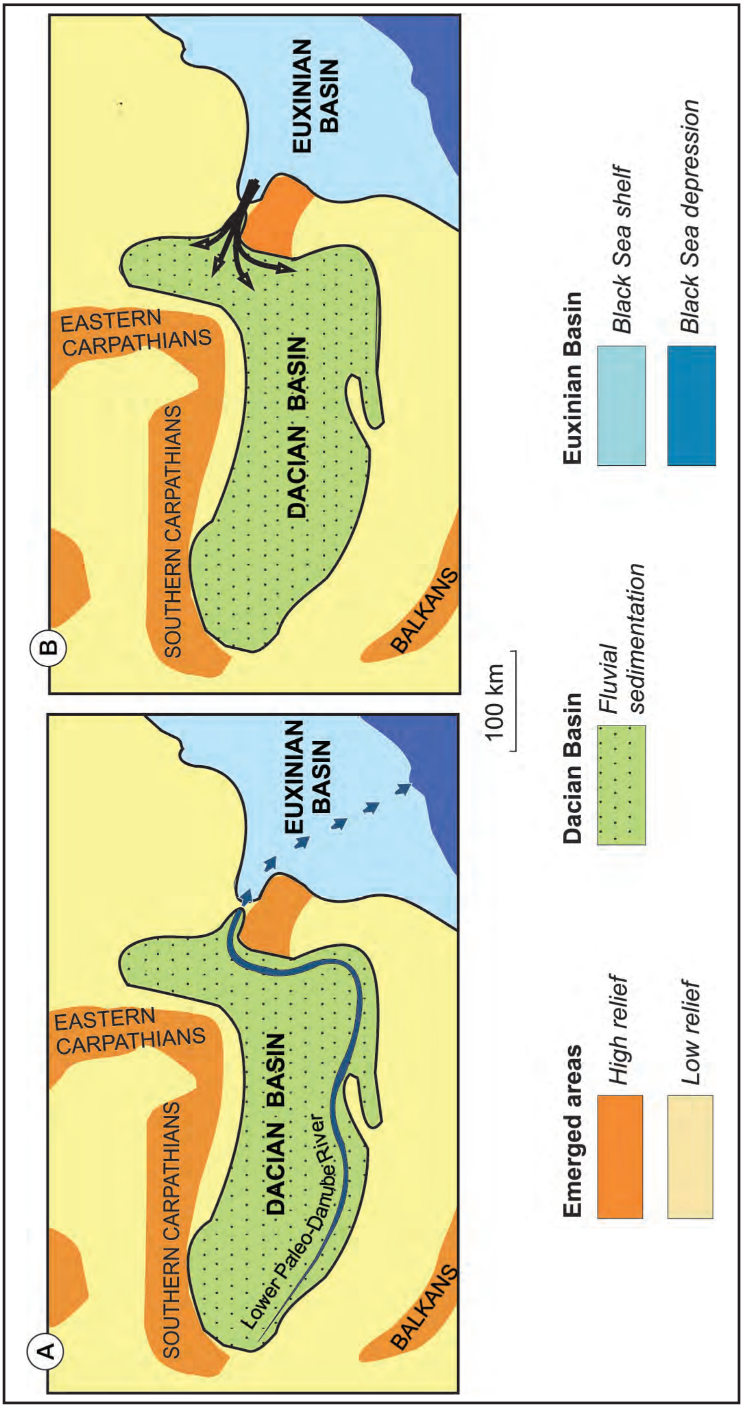


FIGURE 12.3. Sedimentary fluxes between the Dacian and Euxinian basins during the Romanian/Kujalnician time (approx. 4 to 2 Ma). Paleogeographic sketches simplified and modified after Popov *et al.* (2004). **A**. The Carpathian detrital influx to the Black Sea Shelf, via the Paleo-Danube River. The paleo-Danube River tentatively located (no arguments presented) by Khondkarian *et al.* (in Popov *et al.*, 2004). **B**. The Euxinian episodic influx into the eastern part of the Dacian Basin. So far it has not been established if Euxinian sediments were also carried during this influx

Due to its location in the proximity of the Carpathian Mountains, the Dacian Basin became the primary sink of the Carpathian-derived clastic material. The bulk of the sediment supply entered into the northern part of the Dacian Basin (Fig. 12.4). A large part of the Carpathian sediment supply was stored in the subsidence area of the Focşani Depression. Other part of the supplied sediment was transported toward the western part of the basin, along the axis of the sedimentary trough.

During Late Neogene and Early Pliocene (approximately 11 - 4.5 Ma) the Carpathian-derived clastic material was withheld in the Dacian sedimentary trough and did not reach the Black Sea area. The Dacian Basin acted as sediment trap in between the Carpathian source-area and the Black Sea Depression

Subsequent to the discharge of the Pliocene Danube paleo-river on the Euxinian shelf, the Carpathian-derived sediment reached the Black Sea Depression, passing through the Dacian Basin and the western Euxinian shelf areas (Fig. 12.3). At this stage the Dacian Basin collected the Carpathian sediments and transported a large part of it toward the Black Sea Depression.

12.2.4. The source-area of the Pontian sediments from the north-western Black Sea

During the Pontian time a large amount of sediment accumulated in the north-western part of the Black Sea Depression (Konerding *et al.,* 2009, in press).

For the north-western Black Sea Pontian deposits the Carpathians appear as the closest mountain area capable of supplying large sediment volumes. However the sedimentary pattern indicates the Dacian Basin was in the way (Fig. 12.4), obstructing a direct Carpathian sediment supply.

According to the fission track study of Sanders *et al.* (1999), the Carpathian area with high erosion rate extends northward much more than the Dacian Basin source-area. It is realistic to consider that a Pontian river, with the setting of the present-day Prut River, could have supplied the north-western Black Sea area with Carpathian-derived clastic material (Fig. 12. 4).

12.3. COMPARATIVE SEDIMENTARY EVOLUTION OF THE DACIAN BASIN AND THE PANNONIAN BASIN

12.3.1. Dacian-Pannonian faunal exchanges recorded in the western sector of the Dacian Basin

The westernmost sector of the Dacian Basin is the best place to record the faunal connection with the Pannonian Basin and the most advanced faunal immigration coming from the Euxinian Basin.

It was suggested the Dacian Basin and the Sarmatian Basin evolved entirely independently after the middle part of the Sarmatian (*s. l.*). Marinescu (1978) showed the faunal connections were well marked. The congerids (especially the *C. rampho-phora*) are considered the best evidence of the water exchanges between the two basins.

Maeotian faunal affinities identified by Marinescu (1978) between the western sector of the Dacian Basin and the Pannonian Basin relate to the Pannonian zones C, D and E. The connections between the two basins are characterized by this author as temporary and restricted.

Scarcity of macro-fauna is characteristic of the western sector of the Dacian Basin during the terminal Maeotian time. The first forms which inhabited the area are immigrant species from the Pannonian Basin (Marinescu, 1978). A good example is *Paradachna abichi* which rapidly extended in the whole Dacian and Euxinian space with clayey sedimentation.

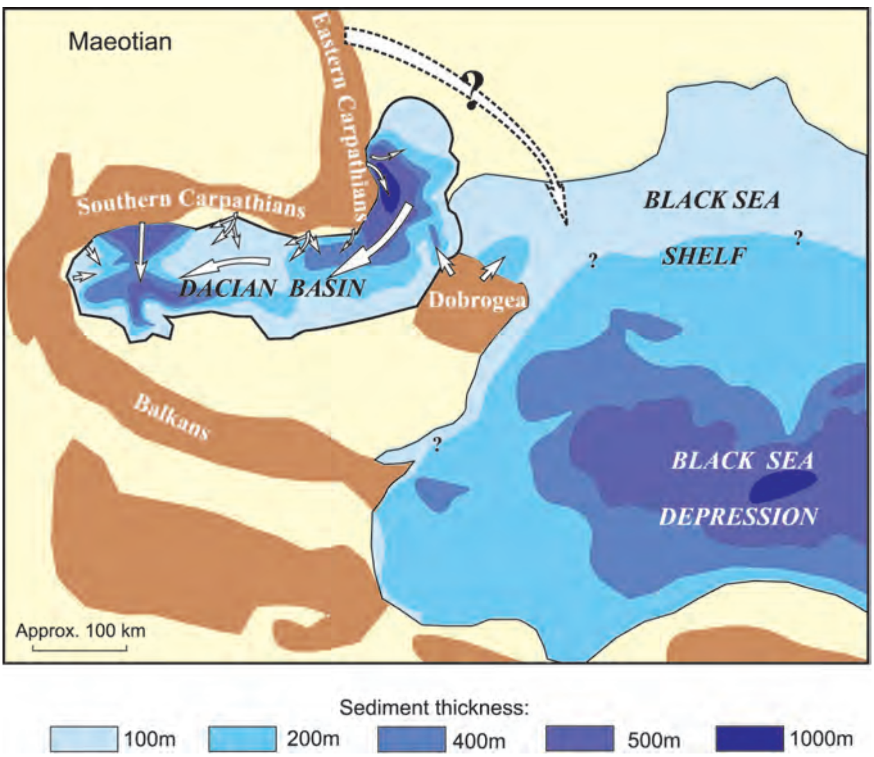


FIGURE 12.4. Sediment thickness distribution in the western Euxinian basin and in the Dacian Basin during the Maeotian time. Sediment thickness and the paleocurrent system indicate the Dacian Basin acted as a trap for the Carpathian-derived sedimentary material. A palaeoriver acting outside the Dacian Basin could have supplied the Black Sea shelf with Carpathian clastics. Provenance of sediment thickness data: Dacian Basin after Saulea *et al*. (1969); Black Sea, after Ilyina *et al*. (in Popov *et al*. (2004)

The western Dacian Basin area experienced a permanent and sometimes powerful faunal influence from the Pannonian area. The Early Pontian fauna consists especially of Pannonian immigrant species.

During the Early Pontian, out of the scarce Late Maeotian fauna only several specimens survived (*Congeria navicula*), and competed with Pannonian immigrant species trying to advance eastward. Marinescu (1978) believed that the lower salinity and the clayey dominant sedimentation of the western Dacian Basin prevented a more intense population with Pannonian specimens.

According to Marinescu (1978), the Dacian Basin functioned during the Late Neogene (especially during Pontian) as a passing zone for the Pannonian fauna migrating toward the Euxinian Basin. In the western Dacian Basin, the migration from the Euxinian space was subordinated.

12.3.2. Dacian Basin and Pannonian Basin coeval evolution

The Dacian and Pannonian basins came into existence at almost the same time. Separated at about 12 Ma time (Magyar *et al*., 1999), the Pannonian Basin appears to be not much older than its eastern neighbor, the Dacian Basin.

A long regression (12 Ma) led to the separation of the Pannonian Basin from the rest of Paratethys epicontinental sea (Magyar *et al*., 1999). After this initial moment the basin evolved during a gradual transgression phase (12 - 9.5 Ma) and continued with a long regression and sediment filling stage (9.5 – 4.5 Ma) (Fig. 12.5).

According to Magyar *et al*. (1999) the about 2.5 million year long transgression transformed the archipelago-looking Pannonian Basin into a large brackish-water body with several deep discrete depressions. The regression started abruptly after 9.5 Ma. The great terrigenous influx determined the progradation of the deltas and a continuous size reduction of the brackish-water body.

By the 4.5 Ma moment the small water body, which remained from the large basin surface, gradually became a fresh-water lake (Paludina lake), the last vestige of the Pannonian Basin (Magyar *et al*., 1999).

The Dacian Basin separated from the Carpathian foredeep during the Middle Sarmatian (*s. l.*) (Saulea *et al*., 1969). Until turning from a brackish-water type to a fresh-water body, the Dacian Basin suffered moderate but continuous changes. The most significant change was the enlargement of the basin, through the southward shift of its south-eastern boundary. Another change took place at the northern end of the Dacian Basin, determining the shortening of the basin (Fig. 12.5).

The Dacian Basin was a foreland trough, whose depth increased from the northern to the southern end of the basin. The deepest part, at the western end of the basin had a depth of several hundred meters.

The passage from brackish-water to fresh-water of the Dacian Basin did not result in a reduction of the basin size. The brackish basin became a large fluvial plain, with

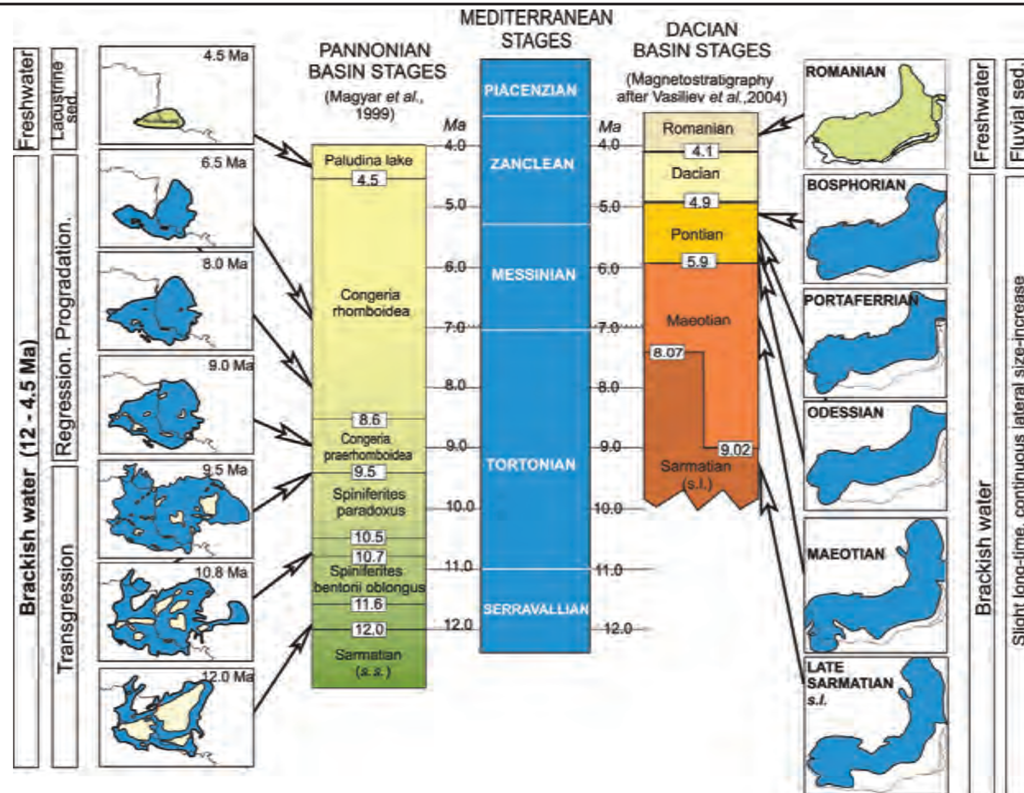


FIGURE 12.5. Comparative development of the Dacian Basin and the Pannonian Basin. Paleogeographic sketches compiled after Saulea *et al.* (1969) and Magyar *et al.* (1999). Pannonian Basin development features from Magyar *et al.* (1999)

extensive coal-generating marshes. This process took about 700.000 years, from the Early to the Late Dacian time (approximately from 4,8/4,7Ma to 4,1/3,9 Ma).

12.3.3. On the sedimentary pattern of the Dacian and Pannonian basins

The dominant sedimentary process which shaped the Pannonian Basin architecture was the delta progradation, generated and maintained by a strong fluvial supply of detrital material (Juhász *et al*., 2007). The size reduction of the Pannonian Basin resulted from the advancement of the frontal part of the fluvio-deltaic system, under pressure from the high rate of the sediment supply.

The Dacian Basin sediment filling evolved without significant changes of the basin size. The sediment entering the northern part of the basin was transferred along the trench axis. This action did not build large scale inclined bedded structure (clinoforms) as in the Pannonian Basin, which means that the sediment transfer was not made through deltaic-type frontal progradation in deep water, but by extended superposed sediment sheets.

A notable exception is the progradation structure from the deeper, western end of the Dacian Basin (Tărăpoancă, 2004; Leveer, 2007) (Fig. 4.6). This architectural feature was built at the end of the longitudinal route of the transported sediment, probably induced by the steeper bottom slope of the deeper western area.

Except for the large scale Maeotian-Pontian clinoform structure in the western end of the basin, no large-scale progradation was evidenced in the brackish Dacian Basin. This is in contrast to the dominant progradation aspect of the Pannonian Basin sediment filling.

In the Pannonian Basin the transition from the brackish to the fresh-water environment was gradual, and the sedimentation has become lacustrine. The Dacian Basin passed to the fresh-water environment rather abruptly, following the migration of the shoreline, which swept the entire basin (see Chapter 11.2). The fresh-water sedimentary environment appeared as a very extensive, multiple fluvial plain, which included large coal-generating marshes.

12.3.4. Similarity and difference in the sedimentary evolution of the Dacian and Pannonian basins

To conclude this short analysis of the comparative sedimentary evolution of the Dacian and Pannonian basins, let us underline the main similarities and differences between the two Paratethys units.

The similar aspects of the parallel Dacian – Pannonian basins evolution refer to the initial and final moments of their sedimentary history. The time of basin separation of the Pannonian and Dacian basins is relatively close. Even closer is the time of passing from brackish to fresh-water environment, that is about 4.5 Ma for the

Pannonian Basin (Magyar *et al*., 1999) and 4,8/4,7Ma to 4,1/3,9 Ma for the Dacian Basin.

The long time areal changes represent a striking difference between the Dacian and Pannonian basins. The Pannonian Basin decreased from a large brackish-water body to the small fresh-water Slovanian lake, a change that took about five million years (Magyar *et al*., 1999). In contrast, during the seven million year sedimentary evolution, the Dacian Basin size stayed roughly constant.

The difference in the changes affecting the basin size is a result of important sediment filling mechanism of the two basins. The Pannonian Basin was filled out mainly by lateral sedimentation. The only lateral sedimentation documented feature of the Dacian Basin is at its western end.

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