PALAEOGEOGRAPHY OF DOBROGEA BASED ON LITHOFACIES MAPS OF THE MOESIAN COVER

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Abstract. Based on the lithological and palaeontological record from outcrops and boreholes, several lithofacies map have been designed in order to illustrate the palaeogeographic evolution of Dobrogea area since the Palaeozoic. Geological evidence indicates that since the end of the Proterozoic, the areas of Central and South Dobrogea were repeatedly subject to periods of uplift and erosion, followed by deposition and subsidence. Sedimentation took place in normal marine environments from the Ordovician to the Early Devonian and during the Givetian-Visean, while paralic sedimentation prevailed in the Namurian-Westphalian. During Permian-Triassic the area was an emerged land, where tectonically controlled continental sedimentation took place upon restricted areas. The marine environment was re-established in the Middle Jurassic and shallow marine (carbonate platform to coastal) environments prevailed throughout the Late Jurassic until the Cretaceous, with sedimentation controlled by sea-level changes. Late Jurassic carbonate deposition was replaced by an Aptian-Albdetrital sedimentation. Following the Santonian-Maastrichtian period of uplift, a shallow sea rich in carbonates invaded South Dobrogea in the Paleogene (Ypresian). The Miocene Sea retreated in the Meotian, and the emerged land was covered by continental sediments especially in the western part.

Key words: lithofacies maps, palaeogeography, Palaeozoic, Mesozoic, Palaeogene, Miocene, Pliocene, Dobrogea

INTRODUCTION

The Moesian Platform (or Moesia) is a large structural unit of the Carpathian foreland west of the Black Sea, directly related to important segments of the Alpine belt and the Cimmerian orogenic belt of North Dobrogea. This location rises questions not only regarding the geological history of Moesia, but also concerning palaeocontinental reconstructions, geodynamics of the alpine belt of SE Europe and formation and evolution of the Black Sea. The present study tries to review the geological information of the eastern part of Moesia – the Dobrogean sector – in order to reconstruct the paleogeographic evolution of this area throughout the Phanerozoic.

GEOLOGICAL SETTING

The Moesian Platform is the flat area surrounded by the South Carpathians and the Balkans and confined by the PeriCarpathian and North preBalkan Faults. The North Dobrogea Orogen joins the NE platform margin along the Peceneaga-Camena Fault (PCF).

The Intra-Moesian Fault separates an eastern, dobrogean sector from a western, Wallachian sector, which occupies the Romanian Plain. The structure of the Dobrogean sector is controlled by a system of NW-SE trending crustal faults. In the area between the Black Sea and the Danube River, this sector consists of two major tectonic blocks: Central Dobrogea, elevated between the Peceneaga-Camena and Capidava-Ovidiu Faults, and South Dobrogea, lowered along the Capidava-Ovidiu Fault.

The platform basement is heterogeneous. The oldest rocks are orthogneisses ascribed to the Archaean, and a banded iron formation (BIF) of Early Proterozoic age (Giusca *et al.*, 1967, 1976), pierced by boreholes in South Dobrogea. The BIF includes magnetite bearing quartzites, amphibolites and micaschists showing LP/HT meta-morphism (Giusca, 1977). A volcano-sedimentary succession (Cocosu Group) lies on top of the BIF, considered Neoproterozoic (Vendian), coeval with the Histria Formation, although a Riphean age cannot be precluded in the absence of reliable geochronological evidence. K-Ar data indicate for the Cocosu Group the same Cadomian/Baikalian age of their very-low grade, subgreenschist facies metamorphism.

In Central Dobrogea the basement is exposed, consisting of probably Neoproterozoic metamorphic rocks (Altîn Tepe Group) and a thick Neoproterozoic-Early Cambrian (Vendian) turbiditic succession (Histria Formation, Seghedi, Oaie, 1995). The latter was deformed by open folds in very low-grade metamorphic conditions during the Baikalian/Cadomian events (Giusca *et al.*, 1967). In outcrops, the Cadomian basement is overlain by a Late Jurassic carbonate platform succession, continuous in the Casimcea syncline above local remnants of a pre-Bathonian paleo-weathering crust (Radan, 1994). Bore-holes west of the Danube have pierced the Palaeozoic cover of this unit. This suggests that the block of Central Dobrogea had been uplifted at the end of the Variscan events, and it has been subject to a long period of erosion throughout the Permian-Bajocian.

The basement of South Dobrogea is concealed by the Palaeozoic-Neozoic cover with a cumulated thickness of about 3500 m. Only Lower Cretaceous to Pliocene deposits of this cover are exposed in South Dobrogea.

According to the geological record, the undeformed sedimentary cover of the Dobrogean Moesian sector consists of Ordovician to Quaternary formations separated by gaps. They belong to several cycles: Cambrian-Westphalian, Permian-Triassic, Bathonian-Eocene and Miocene-Quaternary (Paraschiv, 1975; Ionesi, 1994).

LITHOSTRATIGRAPHY OF THE PLATFORM COVER

The Paleozoic sedimentary cover of the dobrogean sector is known in the subsurface of South Dobrogea and in several boreholes west of the Danube. A detailed zonation was based on faunal assemblages (graptolites, trilobites, tentaculites, brachiopods, bivalves, corals, crinoids, placoderms, conodonts) and plants (Iordan, 1981, 1984, 1990, 1992a, b, 1999; Iordan, Spassov, 1989; Murgeanu, Spassov, 1968), as well as on forams and palyno-protistological assemblages (Danet Ali-Mehmed, 1964; Nastaseanu, Paraschiv, 1973; Paraschiv *et al.*, 1973; Pana, 1997 and respectively Beju, 1972, 1981). The main lithostratigraphic units and a detailed description of the facies is found in Iordan (1988, 1990, 1992b).

The Cambrian, identified in borehole Mangalia, develops in the facies of shallow marine quartzitic sandstones. The Ordovician consists of orthoquartzitic sandstones with shale interbeds, overlain by glauconite bearing shales. They contain graptolites, palynomorphs, inarticulate and acrotretid brachiopods. The Llandovery corresponds to a stratigraphic gap. The Silurian shows the typical graptolite shale facies, classical in the lower part and mixed in the upper part (with predominant small bivalves, flattened orthoconic cephalopods, tiny brachiopods and crinoidal ossicles, as well as scarce graptolites). The Early Devonian develops in Rhenish facies. In borehole 5082 Mangalia, the Siegenian black argillites contain tentaculites, brachiopods, bivalves, crinoids, ostracods, corals and gastropods. The Emsian fauna is dominated by trilobites and bivalves, while brachiopods, gastropods, orthocerathids, corals, crinoids, bryozoans and ostracods are subordinate. The Eifelian shows a sandstone-dominated facies with psilophital plants, placoderm fishes and spore-pollen assemblages, suggesting the proximity of an emergent mainland. The Givetian marks the establishment of the carbonate facies in the platform area. Marls, black bituminous Givetian limestones contain anhydrite beds and a fauna of tentaculites and brachiopods. The Famennian (Viroaga Limestones) consists of brownish light grey limestones, in which Holothuryan sclerites, ophiuroids, Moravaminids and calcispheres occur along with brachiopods and conodonts.

The Early Carboniferous facies consists of limestones and dolomites devoid of evaporites; they are rich in macrofauna (brachiopods and gastropods), microfauna (forams, ostracods, conodonts, sponge spicules, radiolarians), as well as spores. In borehole Dobromiru, the mixed facies of the Middle-Late Visean includes seven levels of black limestones interbedded with black and grey argillites and siltstones and dark sandstones with plant debris (*Calamites*), representing a transitional facies to that of the Late Carboniferous. The facies is rich in large productides and foram assemblages (fusulinids, endothyrids and archaeodiscides). Local siliciclastic deposits and coal (Vlasin Formation) have yielded a fauna of small productids, orthoceratids, goniatites, bryozoans, corals and gastropods, as well as macroflora and spores. West of the Danube, at Smirna, basic and acid volcanic rocks are associated with continental sediments. The Permian is represented by the Dobromiru breccia, reworking Carboniferous limestone clasts.

The unconformable Triassic deposits cover restricted areas in South Dobrogea. They include Early Triassic red-beds (red-brown quartzitic sandstones and microconglomerates) overlain by Middle-Late Triassic calcareous successions (calcarenites, limestones and dolomitic limestones) (Paraschiv, 1983).

The Jurassic (up to 500 m thick) consists of mainly carbonate platform sediments. In Central Dobrogea, the Casimcea Formation accumulated during Late Bathonian-Early Kimmeridgian (Draganescu, 1976a). This includes: Late Bathonian-Early Lower Callovian calcarenites and calcirudites; Oxfordian bioconstructed and bioclastic spongalgal facies typical for external carbonate platform environment; late Lower Kimmeridgian subtidal-marine (algal-corpuscular) facies, topped by a skeletal, coralgal facies, formed in a high-energy, tidal flat environment (Draganescu, 1985; Draganescu *et al.*, 1979). In South Dobrogea, strongly dolomitized limestones and calca-renites prevail when compared to Central Dobrogea. The typical marine patch-reef facies is replaced northward by regressive deposits, with alternating marine limy and evaporitic-lagoonal facies, partly coeval with those of the Oxfordian-Tithonian and the Kimmeridgian-Tithonian, respectively (Avram *et al.*, 1997).

A succession of twelve distinct Cretaceous formations, separated by stratigraphic discontinuities, was established by detailed biostratigraphic studies on outcrops and boreholes in South Dobrogea (Neagu *et al.*, 1977; Neagu, Dragastan, 1984; Avram *et al.*, 1988, 1993; 1996; Pop *et al.*, 1991; Ion *et al.*, 1998; Iva *et al.*, 1990). The age of Cretaceous formations is supported by their content in palynomorphs, nannofossils, charophytes, algae, forams, ammonites, brachiopods and/or echinoids (for details see also Avram *et al.*, 1988, 1993; Avram *et al.*, 1997; Ion *et al.*, 1998).

The Valanginian (Zavoaia Member of the Amara Formation) is an evaporitic-detrital succession. In the southernmost part of South Dobrogea, the Berriasian?-Valanginian-Early Hauterivian (Dumbraveni Formation) is a limestone body with clayey interbeds. In the western part, east of the Danube, the Berriasian-Valanginian (Cernavoda Formation) includes 5 members: calcarenitic, dolomite-clayey, coarse siliciclastic, calcareous-detrital and calcareous-marly. The Late Barremian-Early Aptian (Ramadan Formation) consists of a detrital-clayey variegated facies, a calcarenite-calcirudite facies and a bioconstructed cryptalgal facies. The Middle-Late Aptian (Gherghina Formation) is a fluvio-lacustrine facies with red-beds and kaolinite. The Late Aptian-Albian (Cochirleni Formation) is an on-shore facies of cross-bedded gravels/conglomerates and sands, with sandstone and pebbly phosphatic interbeds (The Remus Opreanu member). The Upper Early and Late Albian (Băcăleşti Formation) is an offshore marly-silty facies. The Early Cenomanian (Pestera Formation) includes a basal quartzitic-phosphatic conglomerate, a somewhat cross-bedded sandstone, a transitional member to the glauconitic chalk and an upper, massive chalky sandstone. The local Late Cenomanian (Dobromiru Formation) is marl dominated. The patchy Turonian (Cuza Vodă Formation), is detrital, with a basal conglomerate lag followed by interbedded sands and gravels. The Santonian-lowermost Upper Campanian (Murfatlar Formation) consists of a basal conglomerate, a chalky-glauconitic-quartzitic sandstone with inocerams shell-debris, followed by the common, very thick chalk with chert. The Late Campanian (Satu Nou Formation) is a breccia with chalky limestones and chalky sand elements. The Lower Maastrichtian (Nazarcea Formation) is a lacustrine, variegated clayey and marly succession, 16-45 m thick. The Maastrichtian (in places only Upper Maastrichtian) (Nisipari Formation), consists of interbeded chalky marls and clays, chalky glauconitic sands/sand-stones and massive chalky limestones.

The Paleogene deposits are known mainly in the southern part of South Dobrogea (Mangalia-Dumbraveni area) (Bombita, 1964,1987). In the Eforie-Tuzla area there is continuity in sedimentation between various Eocene terms, but northward the upper members transgressively overlie the Cretaceous deposits (Chiriac, 1968). Siliciclastic, occasionally glauconitic sands, with scarce sandstone and clayey interbeds (Valeni Formation) represent the Early Ypresian. The local Late Ypresian (Lespezi Formation) consists of thick sandy biocalcarenites, rich in nummulites, echinoids and shells. The Late Ypresian (Cetate Formation) includes up to 30m thick chalky biocalcarenites, with a variable siliciclastic content. In the Poarta Alba-Navodari canal, at the contact between Central and South Dobrogea, quartzitic sands, spongoliths and chalky marls with *Nummulites* assemblages occur, typical for the uppermost Lower Paleogene; they resemble the Cetate Formation biocalcarenites, in highly variable successions, indicating deposition in tectonically controlled environment (Avram *et al.*, 1998).

The Neogene includes Miocene and Pliocene sediments, ingresively overlying a Cretaceous-Paleocene paleorelief. The Middle Miocene transgressively overlies the Mesozoic-Paleogene successions of South Dobrogea. The Miocene succession consists of normal marine Upper Badenian (Kossovian) and brackish Sarmatian, separated by a break in sedimentation (Popescu, 1995).

The Upper Badenian is exposed mainly in the western part of South Dobrogea, and it consists of sands or conglomerates, seldom limestones rich in molluscs (ostreids, pectinids, turritelids) and poorer in foraminifers. The fossil assemblage, especially the planktonic foraminifera (*Velapertina luczkowskae*) from Seimenii Mari, indicates the Upper Kossovian (probably an equivalent of Konkian) is present.

The Sarmatian, unconformably overlying the Kossovian or even older successions, is subdivided into the Volhynian, the Basarabian and the Chersonian based on mollusc fauna. The succession starts with sands or conglomerates (with numerous fossils reworked from the underlying sediments), overlain by an interbeded succession of organogenic limestones, calcarenites, oolitic limestones, sands and marls. The largest part of these limestone deposits belong to the Basarabian (Middle Sarmatian), as indicated by the molluscs or foraminifera assemblages. In the upper part of the calcareous Sarmatian succession, faunas typical for the Chersonian have been identified (in sections Sipote and Cotu Vaii).

The Volhynian consists of a shaly horizon with Mactra and Cardium faunas typical for the Volhynian, as well as species common both to the Volhynian and the Basarabian. Based on these assemblages, the successions were ascribed to Upper Volhynian (Ionesi, Ionesi, 1973; Tatarîm *et al.*, 1977).

The Lower Basarabian consists of clays, diatomitic clays and diatomites containing a macrofauna with *Cardium, Tapes* and *Mactra*, exposed in the Mustafa Hill, at Valeni (Ionesi, Ionesi, 1973). The Upper Basarabian is supposed to be represented by the upper calcareous horizon (Chiriac, 1960; Tatarîm *et al.*, 1977), with *Mactra* and *Tapes* faunas. The top of the Basarabian succession from Cochirleni consists of biocalcarenites with calcareous sandstone interbeds.

The Chersonian, known in the SE part of South Dobrogea, shows calcareous coquina lithofacies with various *Mactra* species, also containing ostracods (Tatarîm *et al.*, 1977).

Pliocene deposits are represented by 20-30 m of neritic terrigenous sediments, consisting of sands, conglomerates and silty-clays. They contain a mollusc fauna typical for the Upper Pontian, the Dacian and the Romanian.

The Lower Dacian, exposed in the southwestern part of South Dobrogea, consists of clays in the lower part and sands in the upper part of the succession dated on molluscs (Pana, Kruck, 1972; Tatarîm *et al.*, 1977; Papaianopol, 1997, 1998). The Upper Dacian (Parscovian) is represented by clays, overlain by cross-bedded sands with sandstone interbeds (Tatarîm *et al.*, 1977), with macrofaunas characterized by species of subgenus *Psilodon*.

The Upper Romanian (Pelendavian), considered the latest term in the Dacian succession, consists of bentonitic clays that fill the cavities from lacustrine limestones with Lymneids (Tatarîm *et al.*, 1977).

The Quaternary sediments cover almost the entire area of Dobrogea, showing variable thickness due to the erosion and pre-existing relief. The Lower Pleistocene consists of red clays; these are overlain by Middle-Upper Pleistocene loess deposits (fine-grained silts) and by Latest Pleistocene-Holocene loessoid deposits. The Upper Holocene includes alluvial sediments (sands and muddy-sandy sediments of the Danube Delta, Danube River and the mainland valleys (Ghenea *et al.*, 1984 a, b).

LITHOFACIES MAPS

A series of lithofacies maps have been constructed to illustrate the palaeogeographic evolution of the Dobrogean sector of the Moesian Platform since the Palaeozoic. The maps were drawn based on geological maps scale 1: 50,000 of the Geological Institute of Romania (GIR), the Lithofacies Atlas of

Romania, scale 1:2,000,000 (Patrulius *et al.*, 1970a, b, 1971), as well as on the following geological and biostratigraphic data: Iordan (1981, 1984, 1990, 1992a, b; Iordan, Spassov, 1989); Iordan *et al.*, (1967a, b); Paraschiv *et al.* (1983); Pană (1997) (for Palaeozoic); Paraschiv *et al.* (1983) (for Triassic); Barbulescu (1974), Barbulescu *et al.* (1979); Draganescu (1976a, 1985), Draganescu *et al.* (1979) (for Jurassic); Avram *et al.* (1988, 1993, 1996, 1999-2000); Iva *et al.* (1990); Ion (1995, 1996); Ion *et al.* (1998); Szasz, Ion (1988); Vinogradov (1983) (for Cretaceous); Paraschiv (1979); Cătuneanu, Maftei (1994); Georgescu (1997), as well as unpublished reports of GIR (for the Black Sea offshore); Costea *et al.* (1978); Patrut *et al.* (1983) (the Danube Delta); Bombita (1987) (for Palaeogene); Marunteanu (1994) and a set of unpublished maps; Papaianopol (1998); Popescu (1995) (for Miocene-Quaternary).

Boreholes used in the area of South Dobrogea are deep or shallow boreholes: 5082 and 5083 Mangalia, 5065 Negru Voda, 3 Viroaga, 5 Dobromiru, 10 Comana, Eforie, Tuzla, 5055 Biruinta, 5051 Cocosu, 5044 Tortoman, 5045 Dunarea, 5053 Castelu, Ghiolpunar. The area west of the Danube River includes boreholes 2881 Calarasi, 1052 Tandarei, Piua Pietrii, Gura Ialomitei, Amara, 2841 Smirna, Liscoteanca, 2581 Zavoaia, 2811 Bordei Verde, 2808 Ianca-Berlescu.

The lithofacies maps refer mainly to Central and South Dobrogea, parts of the Moesian Block. The areas of North Dobrogea and the Danube Delta were included in our interpretations only starting with the Cretaceous, as North Dobrogea became a stable area only at the end of the Jurassic. For the Cretaceous times the offshore areas were also included, considering that the facies distribution and type is significant for the opening of the Western Black Sea Basin.

PALAEOZOIC PALAEOGEOGRAPHY

In the western part of the MP, the Palaeozoic marine domain extended over the Cadomian/Baikalian basement since the Late Cambrian. A subsiding, shallow marine continental platform was established in the beginning of the Palaeozoic, accumulating fine-grained siliciclastic sediments throughout the Ordovician-Early Devonian. At a minimum, the western part of Central Dobrogea was probably covered by sea. However, in this case the Palaeozoic sediments were completely removed by erosion during post-Carboniferous uplift.

In the Upper Ordovician, a shallow, epicontinental marine basin was established in South Dobrogea, where a quiet, mainly terrigenous sedimentation was taking place. The occurrence of marine phyto-planktonic elements (acritachs, leiosphaerids), together with well-preserved chitinozoans (marine benthic organisms) suggests basin depths rarely exceeding 200 m, with weak currents and moderate temperature (10-15°C) (Fig. 1A).

During the Silurian the sea advanced toward NW, as Silurian deposits unconformably overlie both Ordovician sediments as well as the Neoproterozoic basement (Fig. 1B). The basin depocenter was located west of the Danube, around Tandarei (713 m). The graptolite shale facies indicates a sedimentary environment typical for restricted, euxinic basins, with reducing conditions, due to complete lack of bottom currents and large amounts of decomposing organic material. This suggests a large, open sea, with submarine barriers preventing water circulation. Still waters and low depths are indicated by the presence of chitinozoans (Danet *et al.*, 1965). A cold climate is suggested by the presence of glauconite.

The continental platform environment and euxinic facies continues up to the Early Devonian, with attenuation of the reducing conditions (Fig. 1C). The basin depocenter was located in the area of Calarasi, where accumulation of up to 700 m thick Early Devonian shales indicates continuous subsidence. The fauna and microfauna suggest prevalence of a marine environment, but marine eurypteride remnants, preserved at Calarasi, suggest subcontinental conditions probably generated by the Ardenic phase (Paraschiv, 1975).

The change from marine to continental conditions in the Early Devonian was probably connected to the Bretonic events. Sub-continental, freshwater environments prevailed in the Eifelian, as indicated by the fossil record (placoderm and ostracoderm fishes, psilophital plants) (Fig. 1D). Marine fauna (brachiopods, tentaculitids, crinoids, bivalves, gastropods, corals, ostracods and conodonts) forming local interbeds at Calarasi and Mangalia indicate short marine ingressions. The overall features of the deposits suggest that, during the Eifelian, the area was part of the Old Red Continent (Paraschiv, 1975), which was well established on the area of the East European Platform subsequent to the Early Lower Devonian collision of Baltica and Laurentia. The accumulation of coarse clastics indicates considerable input from the adjacent uplifted areas, with a low energy relief, well organized hydrographic network and a short distance of alluvial transport. Local evaporite layers and red colored rock sequence are indicative of a warm and arid climate.

A shallow marine carbonate platform was established in the Givetian in the entire area of the platform and continues up to the Late Visean (Fig. 2A, B). The sea covered the southern part of South Dobrogea and extended north of Calarasi. Up to the end of the Devonian, the area was located in warm, tropical climate, favoring chemical deposition of evaporitic beds and dolomites. The sedimentary basin was divided into several lagoons separated by deeper channels, where sedimentation took place in restricted, euxinic conditions, favoring hydrocarbon formation. The restricted conditions attenua-ted towards the end of the Devonian, when limestone deposition indicates establishment of open sea enviro-nments.This environment prevailed up to the middle Carboniferous.

At the end of the Namurian, as a consequence of the Sudetic phase, the depositional area was restricted and the largest part of the Moesian basin became a continental area, where the warm and humid climate stimulated the development of terrestrial flora. The presence of marine macrofauna and continental macroflora indicates that, throughout the Namurian-

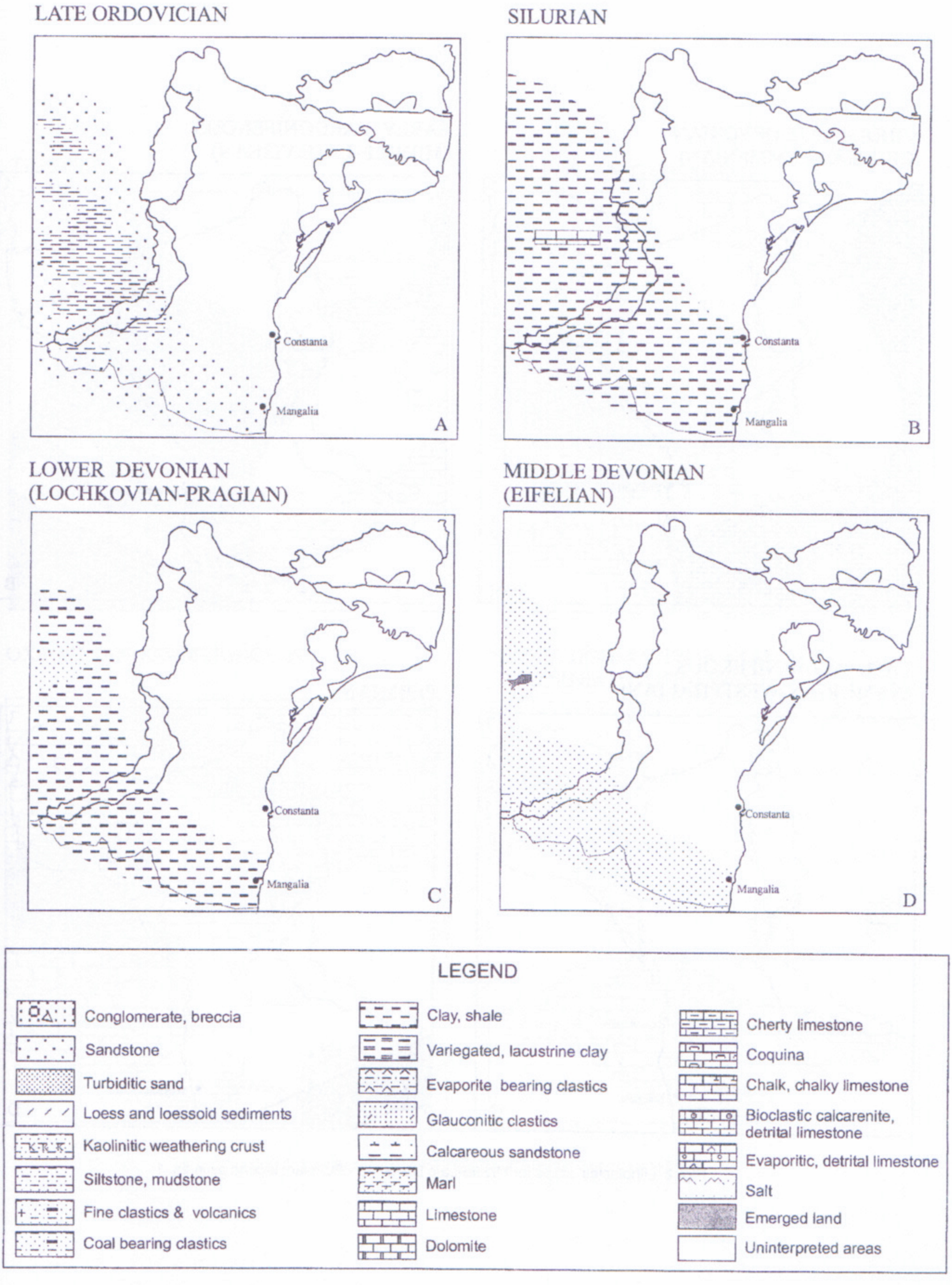

Fig.1 Lithofacies maps for Ordovician - Middle Devonian

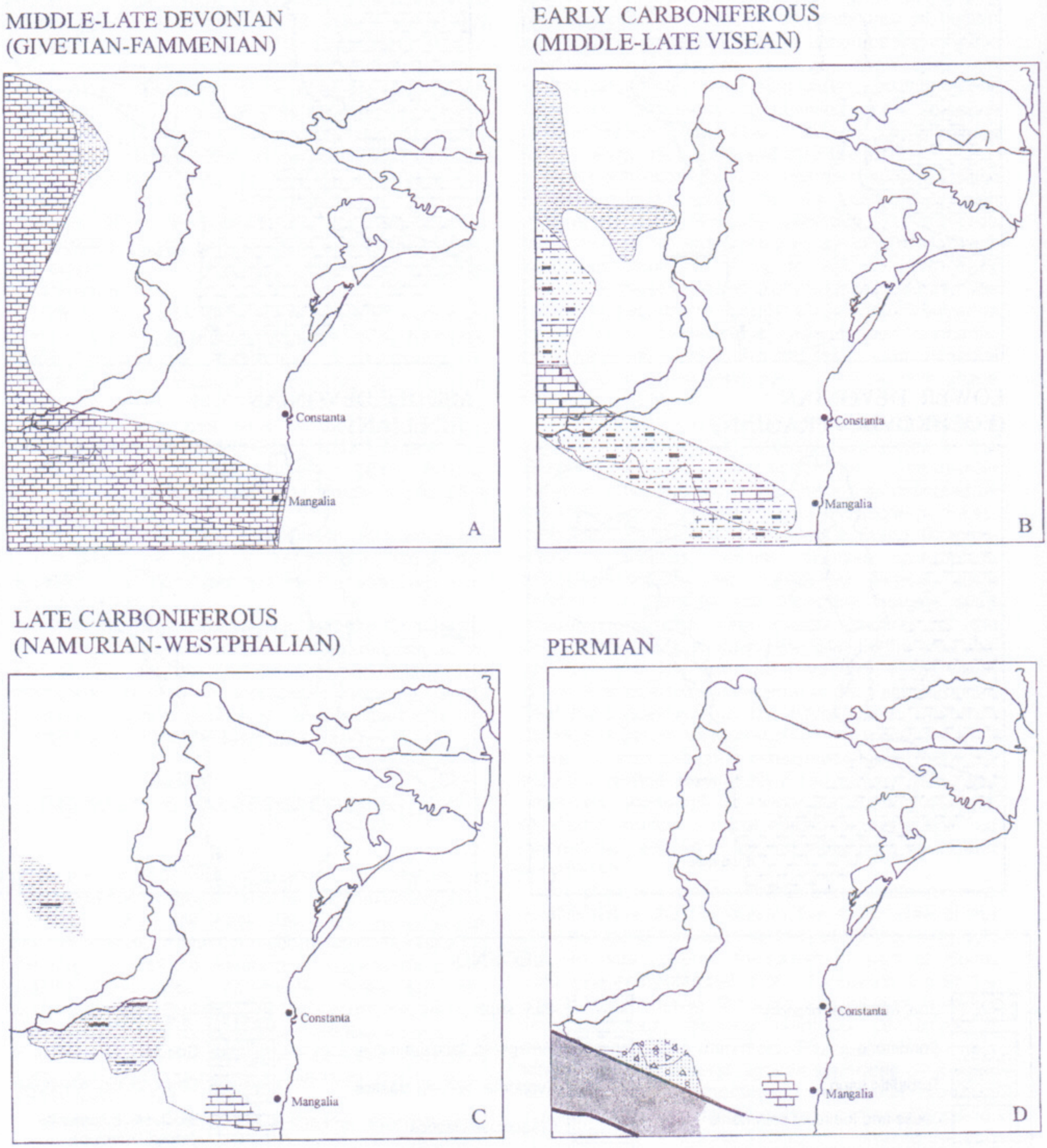

Fig. 2 Lithofacies maps for Middle-Late Devonian - Permian; legend as in fig. 1

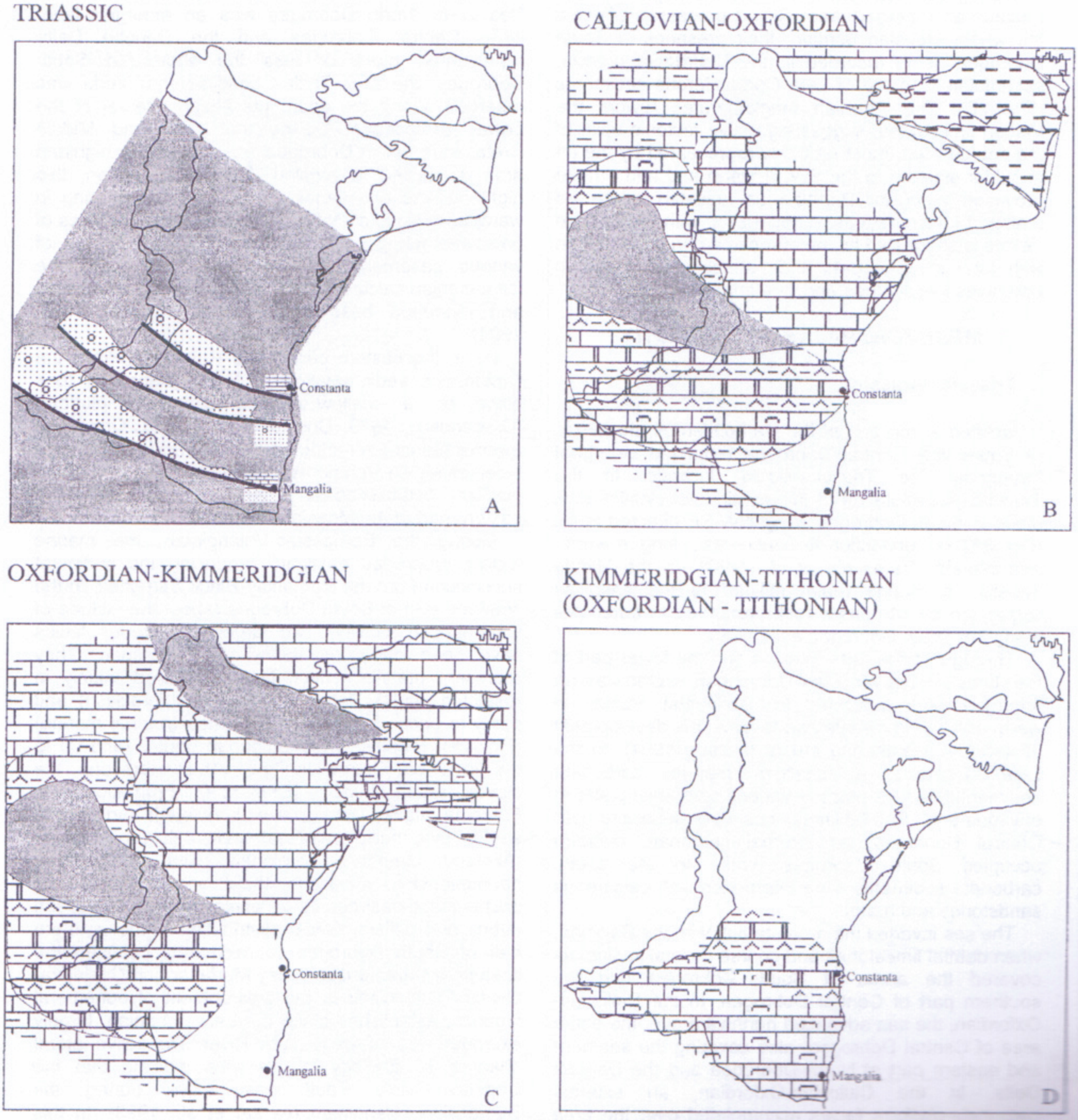

Fig.3 Lithofacies maps for Triassic -Tithonian; legend as in fig. 1.

Westphalian, sedimentation in South Dobrogea took place in a delta environment (Fig. 2C). The delta lied between a large land mass to the north and a narrow uplift to the south, while the shallow marine sedimentary basin was located south-eastward, as suggested by the carbonate facies preserved west of Mangalia (Pana, 1997).

During the Permian, the entire Dobrogean sector became an emerged land. Rifting processes affected the whole Moesian domain, their presence in South Dobrogea being recorded in the Dobromiru breccia, accumulated on top of Late Carboniferous sediments (Fig. 2D). The Permian fanglomerates rework the Visean limestones, suggesting active tectonic uplift of the source area, most probably represented by the rift shoulder situated to the SW. A warm and arid climate prevailed during the Permian, as indicated by the red matrix of fanglomerates. A connection with the Eastern Tethys is suggested by the marine carbonate formation with forams, conodonts and ostracods, identified in boreholes Negru Voda and Comana (Pana, 1997).

MESOZOIC PALAEOGEOGRAPHY

Triassic-Jurassic

Uplifted at the end of the Carboniferous, the areas of South and Central Dobrogea remained emergent throughout the Triassic-Middle Jurassic. In the Triassic, accumulation of thin continental clastics took place in South Dobrogea along NW-SE directed faults (Fig. 3A), in connection to continental rifting in warm, arid climate (Paraschiv *et al.*, 1983). In the Middle Triassic, a marine realm existed to the east, as suggested by carbonate rocks recorded in boreholes along the South Dobrogea east shore.

Throughout the Late Triassic and the lower part of the Jurassic, the Moesian Dobrogean sector was an emerged land, subjected to continental erosion in warm and humid climate and favoring the development of kaolinitic weathering crusts (Radan, 1994). In the Late Jurassic, a shallow marine carbonate sedimentation took place in various carbonate platform environments. Detrital limestones were deposited over Central Dobrogea; an internal carbonate platform occupied South Dobrogea, while to the south, carbonate sediments were interbeded with calcareous sandstones and marls.

The sea invaded the area starting with the Bajocian, when detrital limestones and coarse coastal sediments covered the areas of South Dobrogea and the southern part of Central Dobrogea. In the Callovian-Oxfordian, the sea advanced northward over the entire area of Central Dobrogea, also covering the southern and eastern part of North Dobrogea and the Danube Delta. In the Callovian-Oxfordian, an external carbonate-platform facies accumulated over the area of Central Dobrogea at depths of 10-20 m (Draganescu, 1976, 1985) (Fig. 3B). Basin shallowing in the late Lower Kimmeridgian is suggested by the sedimentation in the subtidal marine, followed by a tidal flat environment.

In the Tithonian the sea started to retreat to the south. Evaporites interbedded in limestones suggest restricted lagoonal conditions (brackish to hipersaline) in the northern part of South Dobrogea, while bioclastic limestones were laid down over its southern half (Fig. 3C,D).

Cretaceous

Generally speaking, the sedimentary environment of the pre-Albian Cretaceous overlaps the South Dobrogea, and from time to time, the Romanian Black Sea shelf. North Dobrogea was an emerged land, while Central Dobrogea and the Danube Delta represented more or less the shore. In South Dobrogea, the area Tuzla-Cobadin-Negru Voda was emerged during the entire pre-Albian interval of the Lower Cretaceous. During the Early and Middle Cretaceous, North Dobrogea was probably a highland area, subjected to erosion. During the Aptian, this highland was experiencing continental weathering in warm and humid climate, as proved by scarce relics of paleoweathering crust scattered in places on top of various basement rocks, or preserved below the Cenomanian calcarenites overlying strongly weathered and reddened basement gneisses (Radan, 1989, 1994).

As in the eastern part of the Romanian Plain, the Cretaceous sedimentation in South Dobrogea took place on a shallow marine carbonate platform (Draganescu, 1976; Costea et al., 1978). Open sea (normal marine) to restricted lagoonal (from brackish to hipersaline) environments prevailed in this carbonate platform, established since the Late Tithonian in the eastern part of the Moesian Platform.

During the Berriassian-Valanginian, the marine waters prograded eastward producing the sediment succession from the Romanian Black Sea shelf. In the southern part of South Dobrogea (about the latitude of Caramancea locality), two largely calcareous facies have been deposited during this time-span. They represent marine sediments accumulated mainly in restricted shallow lagoonal conditions (brackish) and partly in open shallow lagoonal ones (normal marine) (Fig. 4A). Parallel to the Bulgarian border (and up to the lineament Ostrov-Lipnita-Sipote-Dumbraveni), the clayey carbonate facies (Dumbraveni Formation) with Favreina, algae, Trocholina accumulated; north north-east of this, the foraminiferal shelly calcarenitic facies (Alimanu Member) developed, with foraminifera, nannoplankton, moluscan shells and dominated by pachiodontic-gastropodic levels, dasycla-dacean debris and pellets. Facies distribution in the northern half of South Dobrogea (aproximately between the lineament Caramancea valley-Murfatlar and Capidava-Ovidiu Fault) confines the environment of ephemeral lagoons, established since the Late Tithonian, largely extended west of the Danube River. The active lateral changes in lithology in this area indicate that the Capidava-Ovidiu Fault was active during the Berriassian-Valanginian (Avram et al., 1993). In this domain, the most widespread facies in space and time (Tithonian?-Berriassian-Valanginian) is the evaporitic facies with freshwater interbeds (Amara member sensu Avram et al., 1993), including characea, dasycladacea, nannofossils, microflora, sponge spicules. During the Lower Berriassian, in the marginal zone of this realm, the foraminiferal and shelly Alimanu member was variously replaced from east to west by several other facies (Avram et al., 1993, 1996; Ion et al., 1998): evaporitic, nearshore or tidal flat to inner

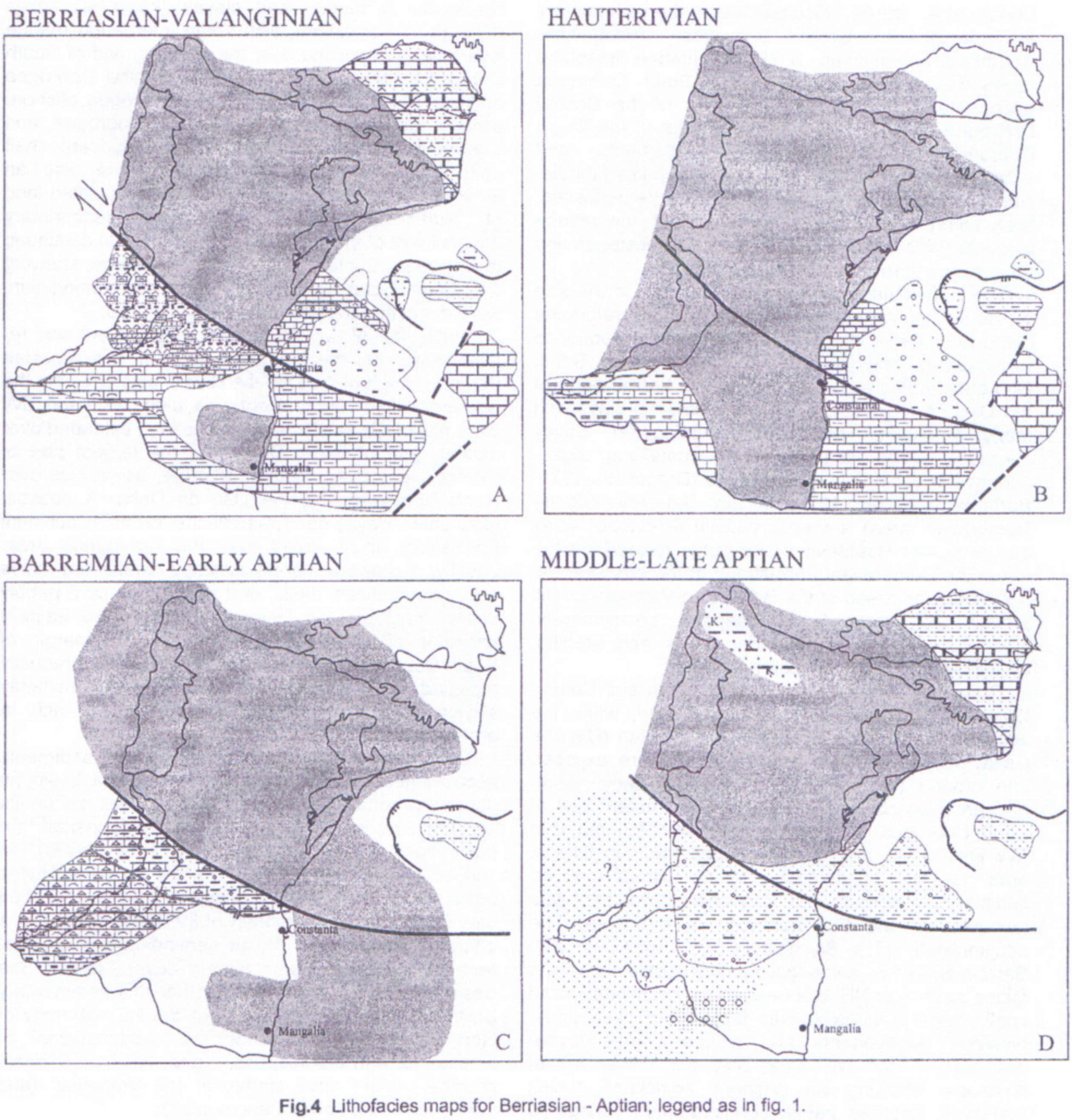

Fig.4 Lithofacies maps for Berriasian - Aptian; legend as in fig. 1.

shelf carbonate platform facies. In the Late Berriassian-Valanginian, the foraminiferal shelly calcarenitic Amara facies was deposited on this marginal area. It surrounds the central part of the lagoonal domain progressively occupied during the Late Berriassian-Valanginian by the evaporitic facies (as documented by nannoplankton, Melinte, in Avram et al., 1993). It is presumed that this facies has extended over the area of Central Dobrogea too (Avram et al., 1996). In connection to the sedimentary environment in South Dobrogea, during the Berriassian-Valanginian, a shallow marine limestone facies was deposited both on the South Dobrogea offshore and on the eastern margin of the Central Dobrogea offshore. Towards the interior of the South Dobrogea offshore, evaporitic sediments and subordinately oolitic limestones and dolomites (Middle-Upper Berriassian, Patrut et al., 1983) were deposited, followed/replaced eastward by coastal/shallow marine deposits (Valanginian-Hauterivian) with limestones and rudites, and then with arenite and rudites.

The Hauterivian marks a great reduction in the size of the sedimentary basin from the eastern carbonate platform: the Hauterivian overstep sequence accumulated only on the SW extremity of South Dobrogea, being a continuation of that known north of the Danube (Fig. 4B). They are yellow-red clays with marly limestone, micrite and variegated clayey interbeds (Vederoasa Member), containing algae, sponges, brachiopods, gasteropods (Dragastan, 1978; Barbulescu et al., 1979); locally (Adamclisi-Sipote-Dumbraveni area) a micritic-pelletal limestone facies occurs (Lower Hauterivian Ghiolpunar facies from the top of the Dumbraveni Formation). In the offshore, the sedimentation areas of the Beriassian-Valanginian still prevail, with slight facies changes: conglomeratic interbeds develop in the inner facies and arenitic-ruditic facies occupy the external part.

During Barremian-Lower Aptian, North and Central Dobrogea represented an emerged land, while the southern and central as well as the Scytian (Danube Delta) sectors of the Romanian shelf were exposed and eroded (Fig. 4C). The Barremian-Early Aptian transgression covered more than the western half of South Dobrogea. Progressive advance of the sea from SW toward NE and E overstepped the depositional area of the Hauterivian. Mainly littoral marine sediments were deposited. Lagoonal environment was favoured on the SW extremity of the area. The accumulation of a Barremian-Lower Aptian or only Barremian-Aptian cryptalgal bioconstructed limestone facies passes to NE to a near-shore foraminiferal and shelly calcarenitic-calciruditic facies with gastropods, bivalves, pachyodonts and scarce corals (Izvoru member). In the NE area, only the Lower Aptian develops, showing an onshore siliciclastic facies (sands, sandstones, pebble conglomerates, variegated clayey with subordinate calcarenitic interbeds), followed by the near shore reef shelly calcarenitic detrital facies, well developed in the SW part. The Barremian-Aptian (not divided) sediments accumulated on the North Dobrogea offshore area in shallow marine sand, with dark silty-clayey facies. The isolated presence (within the Histria basin) of the Barremian-Aptian shelf facies implies the possibility of its connection with the sedimentary environment of the incipient Black Sea. A continental-lagoon facies develops in the Danube Delta, with clays, sandstones and siltstones, with carbonate-iron and dolomite-gypsum cement.

During the Middle-Late Aptian, almost the entire area of the Moesian Platform from the Romanian territory was a land. Only on its eastern extremity, also covering the SW part of South Dobrogea, sediments of a marine depositional environment have been preserved (Fig. 4D). Continental, fluvial-lacustrine sediments in detrital and clayey (kaolinitic) facies (Gherghina Formation), with some interbeded marine layers were deposited over the northern half of South Dobrogea, the southern margin of Central Dobrogea and the western part of the South Dobrogea offshore areas. The northern part of South Dobrogea and Central Dobrogea, together with the adjacent shelf units from the Black Sea offshore were also an emerged land. Bordered westward by the uplifted land of North Dobrogea, the marine sedimentary environment of the incipient Black Sea Basin continued to the north. Continental-lagoonal sediments, showing the same facies as in the Berriassian-Valanginian, were deposited over the Danube Delta area.

During the Albian, the marine environment was re-established on the northern area of the Moesian Platform (north of the Danube River), also covering the western half of South Dobrogea along with the SW extremity of Central Dobrogea. The land extended over eastern part of South Dobrogea, the largest part of Central Dobrogea and their offshore, as well as over North Dobrogea and the Danube Delta. A coastal-glauconitic clayey-sandy/sandstone facies (Cochirleni Formation) accumulated over the Dobrogean area. Locally, it shows a marshy-swampy condensed facies with phosphatized shells, or it is replaced by a pebbly shelly conglomeratic facies that marks the eastern shoreline of the Albian Sea. On the SW margin of South Dobrogea, its uppermost Albian part is gradually replaced by an offshore marly, predominantly silty/sandy facies, poor in glauconite and rich in ammonites (Băcăleşti Fm).

On the North Dobrogea offshore, Albian sediments accumulated within a closed basin – Istria basin (in detrital-carbonate turbiditic facies) as well as on its western, northern and southern palaeoshelf (in polygenous carbonatic-terrigenous shelf facies). In connection with the Albian from the incipient Histria basin, pelitic and arenitic sediments were deposited also over the eastern margin of the Central Dobrogea offshore area. These Albian sediments are the first term of the euxinic sedimentary cover (Black Sea basin sediments). It is possible that this sedimentary basin has already extended over the NE extremity of North Dobrogea, so that the accumulation of limestones with brachiopods, algae, bivalves (Enisala member) might have started in the Vraconian (and continued in the Lower Cenomanian).

In the Lower Cenomanian, the Moesian sedimentation area has transgressed over the entire area of South Dobrogea (on its eastern half it is documented more or less doubtfully only in subsurface). A marine near shore quartzose-glauconitic detrital facies accumulated on the western part of South Dobrogea (with a basal conglomerate reworking the Albian phosphatized macro-fauna) that was progressively replaced northward by an offshore quartzose-glauconitic chalky facies (Fig. 5A). The

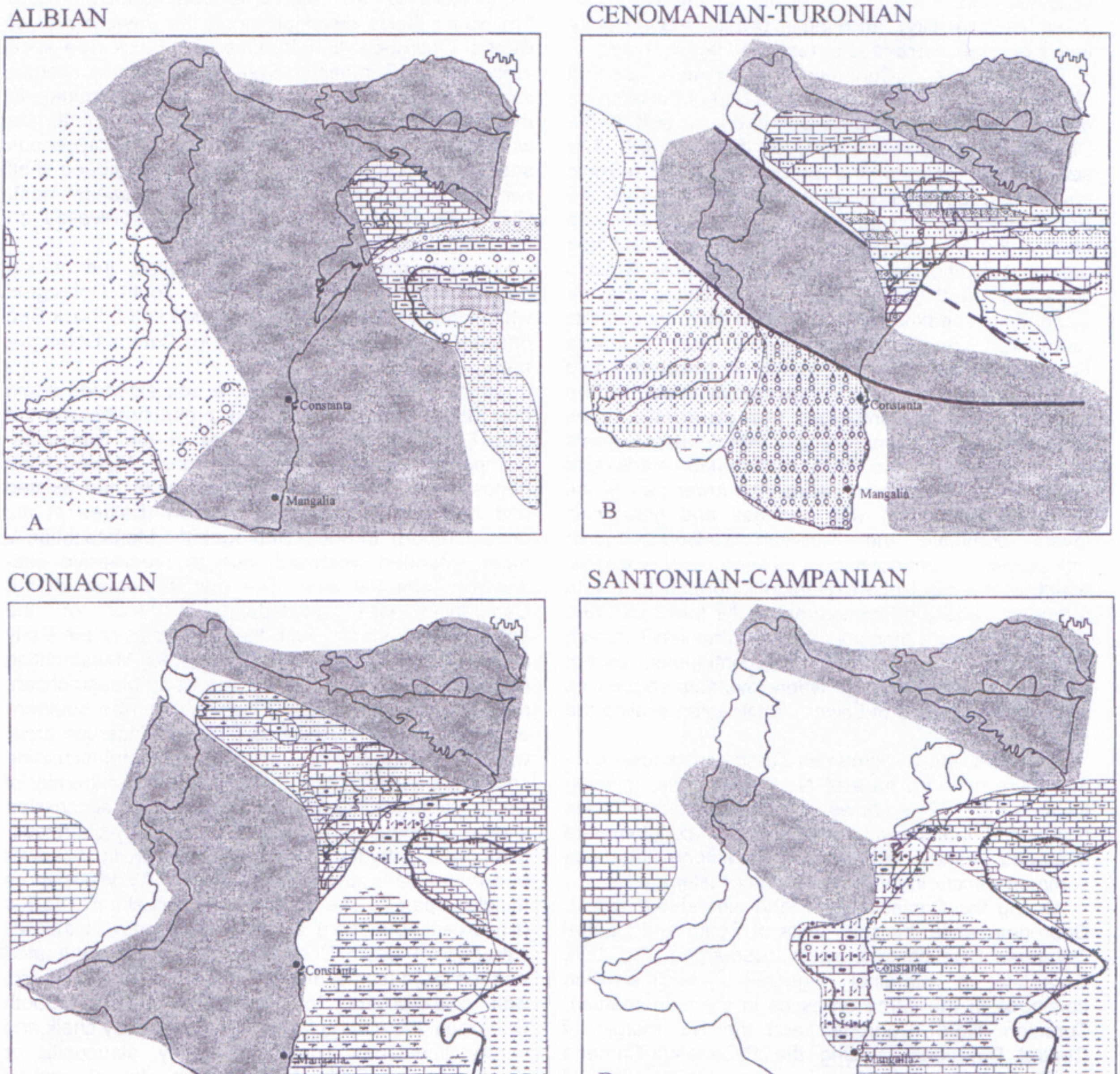

Fig. 5 Lithofacies maps for Albian - Campanian; legend as in fig. 1.

eastern part of South Dobrogea was occupied by a detrital glauconitic facies with carbonate cement. The Middle Cenomanian is not known. The Upper Cenomanian was documented in subsurface only in the southern extremity of South Dobrogea, in a marly-sandy facies (with foraminifera).

Although the Turonian was removed by erosion, its distribution in South Dobrogea probably followed the same areas as the Lower Cenomanian. Turonian sediments are known only locally (in the vicinity of Cuza Voda locality), showing a coastal marine gritty facies of lower shore-face or restricted lagoon type.

During the Cenomanian-Turonian, Central Dobrogea, together with the largest part of the offshore areas of Central and South Dobrogea, as well as the Danube Delta area were emerged land (Fig. 5B). The sedimentary realm of the Black Sea stage (euxinic cover) has transgresively extended westward over the North Dobrogea and beyond the Peceneaga-Camena Fault in the NE part of Central Dobrogea (Baia-Sinoe area), beginning the deposition of the post tectonic cover of North Dobrogea (the Babadag Basin). Cenomanian sediments (with Neohibolites, Inocerams, Ammonites, planktonic foraminifera, etc. – Iancila Formation) develop predominantly in calcareous and detrital facies, with scarce calcareous marls. At the basin margins, conglomeratic and glauconitic facies (with bivalves and brachiopods) with limestone clasts are common; to the NW, bioturbated marlstones predominate. Calcareous facies (the lower part of the Dolojman Formation) with sponges and glauconitic layers dominate the Turonian sediments (with inocerams, ammonites, fishes, bryozoans, melobesiaee, calcispheresplanktonic foraminifera) with a modest sandstone component in the lower part and towards the basin margins. The Cenomanian-Turonian (and Coniacian) succession is continuous, except towards the basin margins where overstep sequences are observed (some of Lower Cenomanian sealing the PCF).

Eastward, the Cenomanian-Turonian is known over the entire offshore area of North Dobrogea, thinning towards the PCF. It shows a detrital-carbonatic facies (clays and marls with sandstone and conglomerate interbeds; sandy and micritic limestone interbeds commonly occur in the Turonian succession).

During the Coniacian, the land extended to South Dobrogea, while the shelf units of South and Central Dobrogea type became again submerged (Fig. 5C). Excepting a marginal ingression, sedimentation continued in the same areas as in the Cenomanian-Turonian: North Dobrogea and the NE margin of Central Dobrogea (sealing the Peceneaga-Camena Fault). Here, the Coniacian succession consists of limestones and marly limestones, sometimes chalky and cherty, while detrital deposits occur on the marginal area.

At the beginning of the Santonian, the marine environment from North Dobrogea and the NE extremity of Central Dobrogea was retreating eastward (Fig. 5D). In the Late Santonian it probably occupied a more restricted area. The sea was fringing the eastern margin of South Dobrogea, with the exception of a small SE uplifted area, which was covered by sea waters only since the lower part of the late Campanian.

During upper Early Santonian-lower Late Campanian, the eastern part of South Dobrogea was progressively invaded by the sea from NE to SW (with periods better marked in the upper part of the Early Santonian and the lower part of the Late Campanian) (Fig. 5D). During this time interval, mainly offshore chalky (glauconitic and cherty) facies with some glauconitic and chalky clastic near-shore deposits in the lowermost part, and in some areas with limestone interbeds. This facies includes echinids, brachiopods, inoceramids, belemnites, benthic and planktonic foraminifera as well as calcareous nanno-plankton. The same facies develops along the eastern part of Central Dobrogea domain. Over the Black Sea shelf area, the Campanian-Santonian facies shows variations from north to south. Limestones dominate in the North Dobrogea shelf area (spongolithic to the west and associated to detrital sediments). Polygenous sediments accumulated on the Central Dobrogea shelf (with calcareous clays, marls, limestones, sandstones). Clayey-sandy to calcareous sediments prevailed on the South Dobrogea shelf zone.

Towards the end of the Campanian, the marine domain was again retreated from South Dobrogea, while marine sedimentation continued in the Black Sea offshore area. There are no data for Central Dobrogea area.

In the Early Maastrichtian the sea extended again over South Dobrogea (Fig. 6A), probably showing the same offshore development like in the Santonian-Campanian, with some exceptions: Maastrichtian deposits are not known, but they might had existed and had been removed by erosion (Baltres et al., unpubl. report). In South Dobrogea the Maastrichtian is more extended westward, due to progressive sea-invasion from the east. The marine domain of the Campanian was overlapped by that of the Maastrichtian, starting with the upper part of the Early Maastrichtian, but mainly with the Late Maastrichtian (Fig. 6B). In the lower part of the Early Maastrichtian, or during the entire Early Maastrichtian, the southern extremity of South Dobrogea (Nisipari-Nazarcea area) was an emerged land, where continental-lacustrine sediments accumulated. In the S and NE extremity of South Dobrogea, the marine Maastrichtian succession shows a nearshore, predominant chalky-quartzous-glauconitic gritty-sandy/sandstone facies in its lower and upper parts and an offshore, chalky facies in its middle part. The continental-lacustrine facies (Nazarcea Formation) accumulated locally in the NE extremity of South Dobrogea, consists of variegated and red clays (sometimes carbonaceous and kaolinitic) with charo-phytes. In the middle part of South Dobrogea, the marine facies is dominated by chalk and chalky limestones, sometimes sandy, glauconitic or cherty in the Early Maastrichtian. In all marine Maastrichtian deposits of South Dobrogea (Nisipari Fm), there are planktonic and benthic forams, calcareous nannoplankton, dinofla-gellates. Chalky facies Maastrichtian sediments (with planktonic and benthic foraminifera) accumulated in the Black Sea offshore areas.

CENOZOIC PALAEOGEOGRAPHY

Palaeogene

During the Eocene-Early Oligocene, the North and Central part of Dobrogea and the Danube Delta area

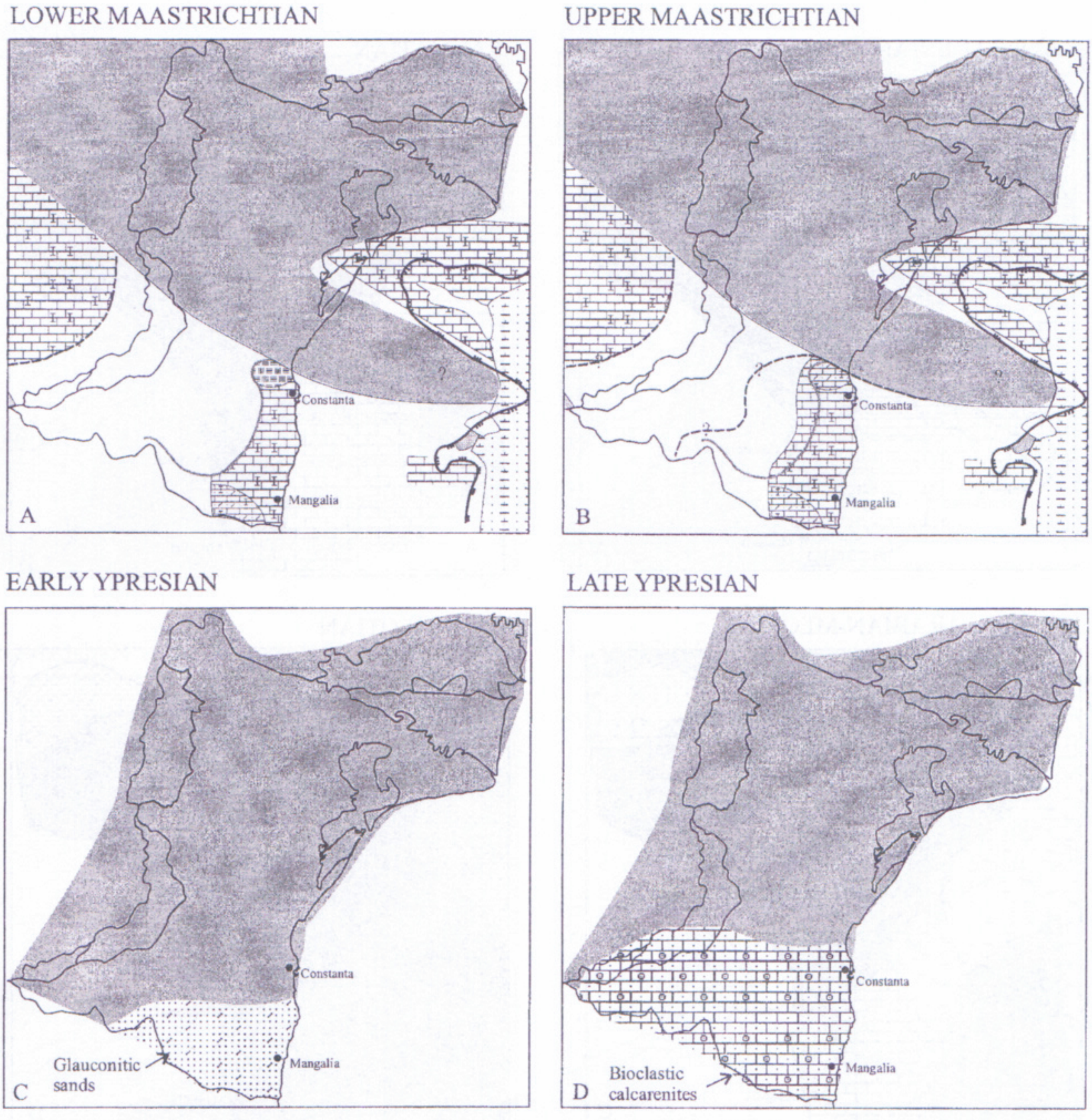

Fig. 6 Lithofacies maps for Lower Maastrichtian - Late Ypresian; legend as in fig. 1.

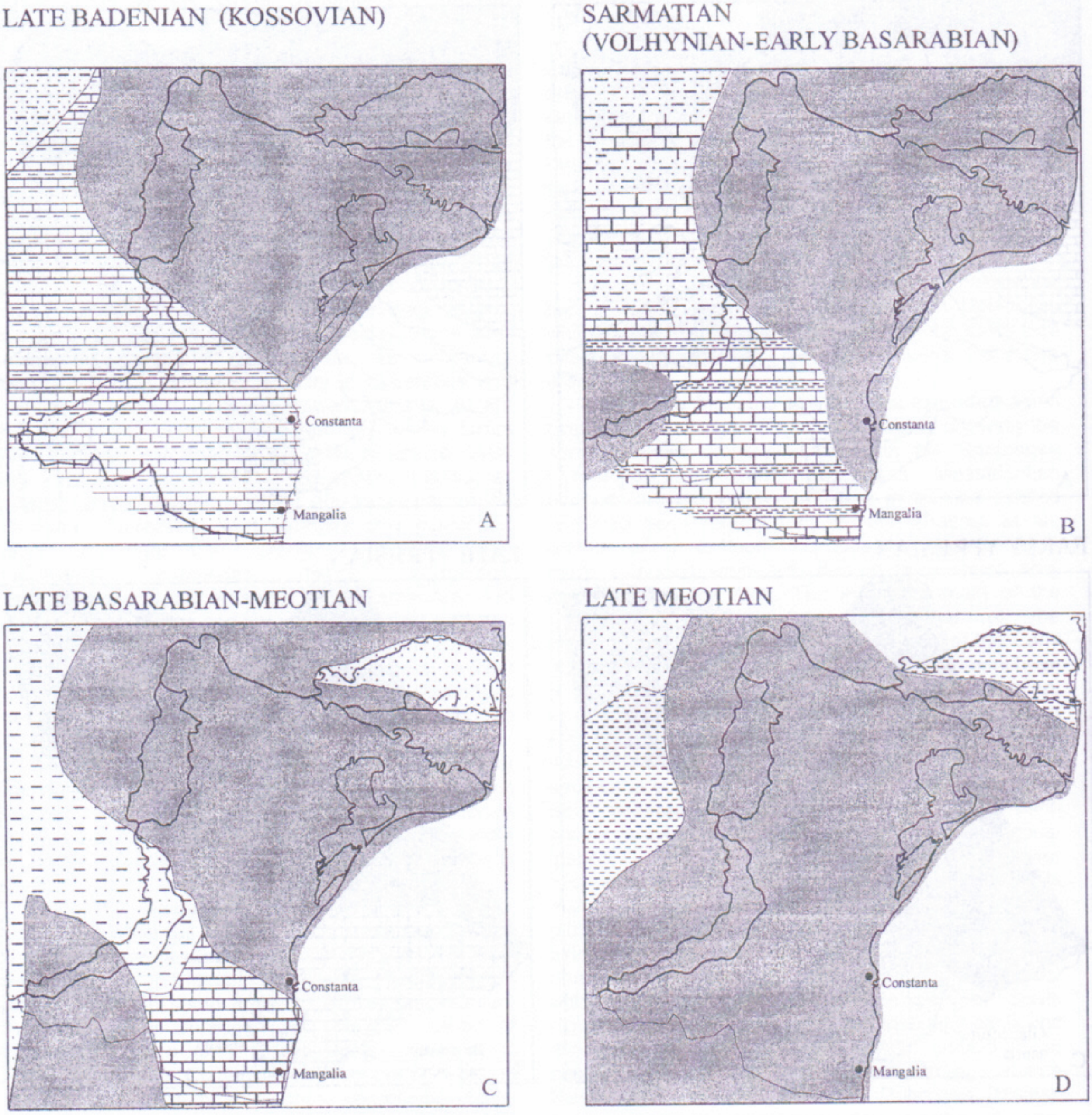

Fig.7 Lithofacies maps for Late Badenian - Late Meotian; legend as in fig. 1.

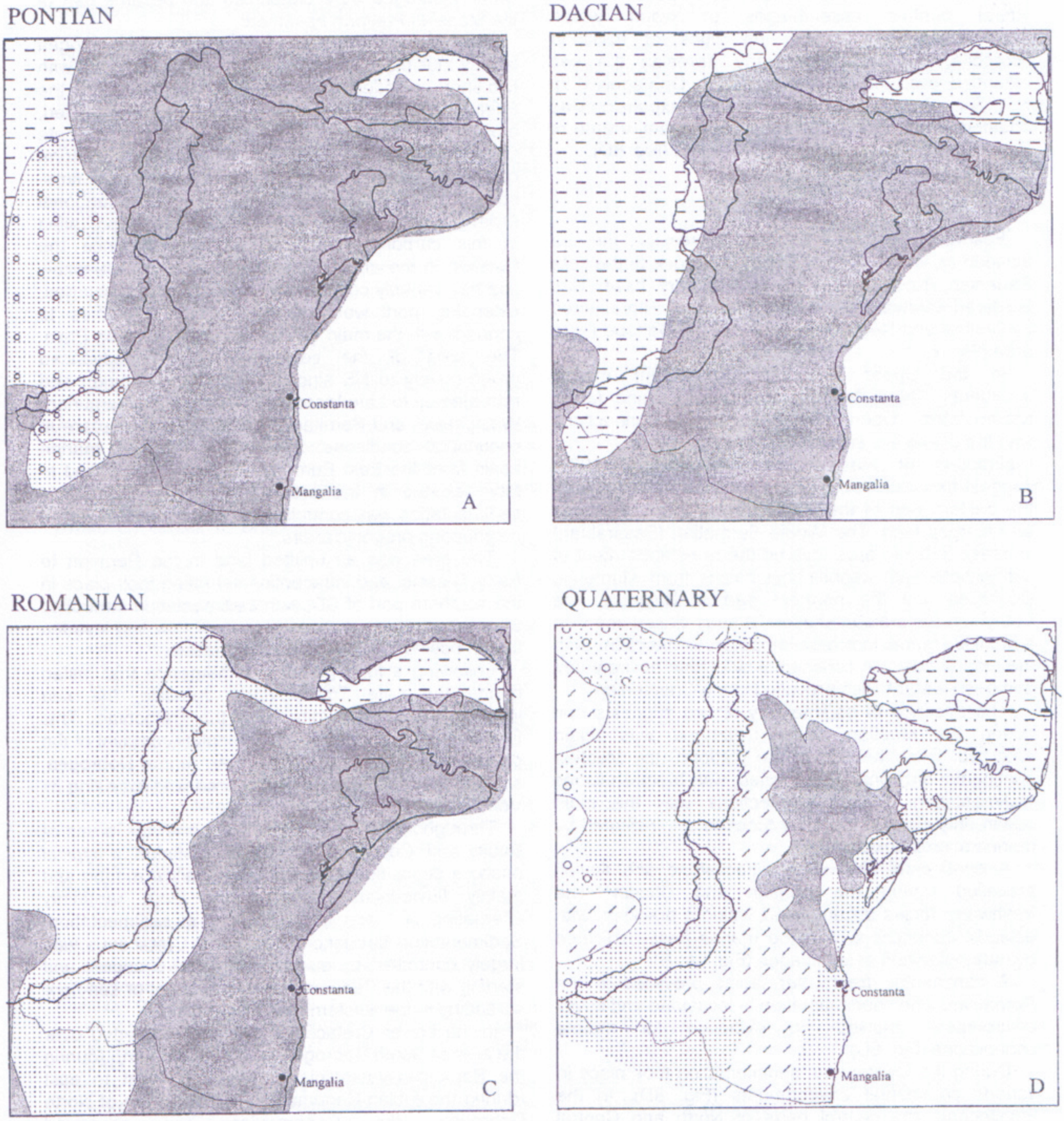

Fig. 8 Lithofacies maps for Pontian - Quaternary; legend as in fig. 1.

represented the land. The Dobrogean sector of Moesia was part of the Mesogean domain (southern territories with unstable paleogeography, corresponding to the Old Mediterranean). It was an epicontinental, neritic sea, extremely rich in carbonates and populated by organisms, especially macroforams, extending over the southern margin of the East European Platform, south of the Ukrainian Shield. The fauna includes littoral benthic assemblages of warm water, accumulated in situ with no signs of transport (Bombita, 1964). In the Early Ypresian the sea extended over the SE half of South Dobrogea (Fig. 6C). The maximum of Palaeogene sea expansion was attained in the Late Ypresian, when the entire area of South Dobrogea was covered by the sea (Fig. 6D).

Neogene

Following the Late Paleogene regression, the sea invaded again the area of South Dobrogea in the Late Badenian (Kossovian). The sedimentary basin was bordered eastward by an emergent land, represented by Central and North Dobrogea and the Danube Delta area (Fig. 7).

In the Upper Badenian (Kossovian) marine sediments, littoral-neritic, with normal marine facies accumulated. Open palaeogeographic connections with the ocean are indicated by faunal content.
Distribution of macrofaunas (Papaianopol, 1997) suggest that, during the Lower Sarmatian (Volhynian), the eastern part of the platform area (Muntenia) was an emerged land. The Middle Sarmatian (Basarabian) increase in basin area favored the re-establishment of connections with depositional basins from Muntenia, Dobrogea and the northern part of Bulgaria. The Volhynian-Basarabian shallow, a semi-closed sea with a brackish fauna, indicates temporary connections with the marine basin. A continental-lacustrine environment and fresh-water facies prevailed in the Chersonian.

The absence of sedimentary record suggests that during the Meotian South Dobrogea was again emerged. Over the rest of the platform, the Meotian continental environment prevailed, with brackish facies sedimentation. Scarce connections with the main ocean only during the Lower Meotian are indicated by marine microplankton.

A continental environment (lacustrine and fluvial) prevailed during the Pontian and Dacian. The freshwater facies accumulated, seldom brackish, with episodic connections with the marine basin indicated by nannoplankton assemblages (Fig. 8A, B).

A continental, freshwater facies prevailed in the Romanian, when sedimentation in lacustrine and fluvial environment showed no evidence for marine connections (Fig. 8C).

During the Quaternary, sedimentation took place in various continental environments (Fig. 8D). In the Pleistocene, the central parts of North and Central Dobrogea belonged to the mainland. Wind-blown silts accumulated, mantling the Pleistocene relief and filling up depressions. These were largely reworked in alluvial basins during the Late Pleistocene-Holocene. In the Holocene, fluvial sediments are dominant. Sands accumulated on the alluvial plane of the Danube River, while the pebbly facies was deposited along the main tributaries. Sand bars were deposited along the western shore of the Black Sea, while silty-muddy sediments prevail in the Danube Delta area and lakes of the Razelm-Sinoe complex.

CONCLUSIONS

Following the Cadomian deformation, at the beginning of the Paleozoic the areas of Central and South Dobrogea were cratonized and became part of the Moesian Platform basement.

The Palaeozoic sedimentation in South Dobrogea largely took place in various marine environments, with two short episodes of continental deposition during the Eifelian and the Westphalian-Stephanian. Restricted, euxinic environments prevailed throughout Late Ordovician-Silurian, while marine carbonate platform conditions characterized the Givetian-Visean time-span. Open sea (normal marine) to restricted lagoonal (from brackish to hipersaline) environments prevailed in this carbonate platform, established since the Givetian in the entire Moesian realm. The Palaeozoic sea has variably covered the area of South Dobrogea, extending north-west of the Danube Branches to connect with the main basin from the Romanian Plain. The area of the sedimentary basin advanced progressively to NE since Ordovician to Silurian and retreated up to Late Visean. Although in the Namurian-Westphalian and Permian sedimentation took place in continental conditions, a connection to the marine basin from the East European Craton is supposed to have existed in the area of Mangalia. Palaeozoic sedimentation was controlled by tectonic events in the neighboring orogenic areas.

The area was an uplifted land in the Permian to Early Triassic, and intracontinental rifting took place in the southern part of SD, with sedimentation controlled by extensional faults. The eastern shallow sea invaded the rift basins in the Middle-Late Triassic.

Following a long period of emergence that lasted during the Late Triassic-Early Jurassic, the sea invaded the area starting with the Bathonian. This time-span can account for the complete removal of the presumable Palaeozoic cover from Central Dobrogea, since in the Middle Jurassic this area was exposing its Vendian basement.

Throughout the Jurassic to Neogene, the areas of South and Central Dobrogea represented a typical onshore depositional area, where shallow marine and mainly fluvio-lacustrine conditions were randomly alternating and with frequent gaps in sedimentation. Sedimentation throughout the Lower Cretaceous was largely controlled by eustatic sea-level changes, and starting with the Cenomanian by the onset of sea-floor spreading in the western Black Sea Basin.

In the Lower Cretaceous, the sea prograded over the area of South Dobrogea from south to north (during the Berriasian-Valanginian), then from west to east (during the Albian-Cenomanian). In the area of North Dobrogea, the Cenomanian sea advanced progressively north-westward from the Albian to the Cenomanian, connected to the opening of the Western Black Sea Basin. This sea was progressively widening southward in the Coniacian and prograding westward in Santonian-Campanian. Following a short period of regression in the Late Campanian, the waters of the Western Black Sea Basin prograded again westward in the Maastrichtian. After the Late Cretaceous regression, the Lower Tertiary transgression marked two phases: the Cuisian and the Priabonian, the latest representing the maximum of the Palaeogene sea expansion, which prograded from south to north.

During the Neogene, the depositional area of the MP showed a non-uniform evolution. The Miocene expansion of the sea, which started in the Upper Badenian, was amplified in the Sarmatian, culminating in the Middle Sarmatian (Basarabian). The sedimentary basin area was wider in the Badenian and Sarmatian, retreating again in the Meotian. During the Miocene sedimentation evolved from normal marine (Upper Kossovian) to brackish (Sarmatian), accompanied by an important break in sedimentation. Throughout the Pliocene, the largest part of Dobrogea was emergent land and sediments accumulated largely in the SW part of South Dobrogea. Continental sedimentation in dominantly freshwater conditions prevailed in the Pliocene and the Quaternary, with only minor brackish sedimentary environ-ments.

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