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EARLY TO MIDDLE MIOCENE FACIES SUCCESSION IN LACUSTRINE AND MARINE ENVIRONMENTS ON THE SOUTHWESTERN MARGIN OF THE PANNONIAN BASIN SYSTEM (CROATIA)

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Abstract: A continuous succession of Ottnangian-Badenian sediments along the southern margin of the Pannonian Basin System indicates transition from lacustrine to marine depositional environments. The Ottnangian lake is characterized by the alternation of silts deposited from suspension and sands representing sedimentation from turbidity currents, debris flows or grain flows. These facies continue into the Karpatian, although the depositional environment becomes marine. At the transition into the Early Badenian, the environment shallows, and is represented by high energy siliciclastic shoreface and stacked Gilbert-type fan deltas. The succession is terminated with marls deposited in an offshore environment, with intercalated biocalcarenites from turbidity currents. The marine sediments are subdivided into two depositional sequences separated by a correlative conformity of a type 2 unconformity. The first sequence consists of a transgressive systems tract which is represented by the Karpatian offshore sediments, and a highstand systems tract, which is represented by offshore sediments deposited close to the nearshore, shoreface and stacked Gilbert-type fan deltas of the Karpatian and the Lower Badenian age, showing rapid progradation. The second sequence consists of a shelf margin systems tract composed of aggrading shoreface sediments, and a transgressive systems tract composed of Lower Badenian offshore sediments.

Key words: Croatia, Pannonian Basin System, Miocene, sequence stratigraphy, sedimentary environments.

Introduction

The study area (Fig. 1) is located along the southern margin of the Pannonian Basin System (a Middle Miocene back arc type extensional basin that opened behind the coeval Carpathian thrust belt, Horváth & Royden 1981; Horváth 1984, 1993, 1995; Royden et al. 1983; Royden 1988; Tari 1993; Tari et al. 1992). The Pannonian Basin System (Fig. 2), as a part of the Paratethys, had an independent geological history because of periodical isolations from open ocean connections. Endemic faunal assemblages are the reason for the development of different regional stage systems (Seneš 1971, 1979; Rögl & Steininger 1983; Rögl 1996, 1998). According to Jamičić et al. (1987) the studied part of the Miocene is Ottnangian, Karpatian and Badenian in age. During the Ottnangian, thin-bedded to laminated sandy and silty limestones and siltstones were deposited over the alluvial sediments. Jamičić et al. (1987) described these facies, without defining their depositional mechanisms, as representing a fresh water lacustrine environment. This lake was interpreted as having been increasingly influenced by marine conditions in the Karpatian, though, the Karpatian sediments are very similar to those deposited during the Ottnangian. On the basis of the benthic microfossil association, Jamičić et al. (1987) determined that the Karpatian sediments were deposited in a marine lagoon. The Badenian conglomerates and sandstones which on the southern slopes of Mt. Papuk (Fig. 3) overlie Karpatian sediments, were considered to represent a deltaic environment, but without citing any evidence (Jamičić et al. 1987).

The aim of the present study is to determine the detailed sedimentary processes involved in the development of these depositional environments and to discuss sequence stratigraphy, local relative sea-level changes and correlate the events with other Paratethys basins, in order to understand the evolution of this part of the Pannonian Basin System.

Geological setting and lithostratigraphy

During the Ottnangian (late early Miocene), lacustrine sediments were deposited in a basin croping out now on the southern slopes of Mt. Papuk (Fig. 1). Later, deposition occurred in marine (Karpatian, i.e. latest early Miocene, and Badenian, i.e. middle Miocene) and then in brackish environments (Sarmatian, i.e. late middle Miocene). In the Pannonian (latest middle Miocene and late Miocene) strong uplifting took place in this area followed by deposition of fresh-water sediments which gradually pass into brackish-water deposits (Jamičić et al. 1987). In the Pontian (latest Miocene) sedimentation was continuous (Jamičić et al. 1987). In Pliocene times, tectonic movements brought about significant structural changes in this area (Jamičić et al. 1987).

At the western, northern and north-eastern margins of the studied area, the Lower and Middle Miocene sedimentary complex is transgressive on Precambrian chlorite-sericitic schists, and Paleozoic metagraywackes and chloritoid schists. Along the south-eastern margin, the Badenian sediments are separated by a fault from the Upper Miocene (Pontian) depos-

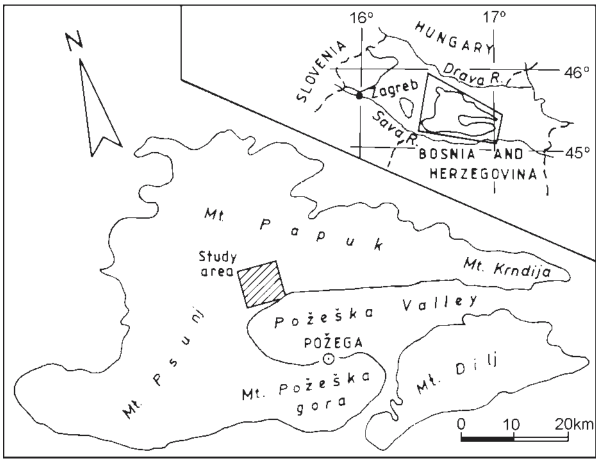

Fig. 1. Location map of the study area on the southern slope of Mt. Papuk, between the Drava and Sava Rivers (Northern Croatia).

its, while to the southwest, the Lower and Middle Miocene complex transgressively overlies garnet-staurolite gneiss, amphibolite and amphibolite schists of Precambrian age (Fig. 3).

In the southern part of Mt. Papuk, fine- to coarse-grained clastic rocks with ostracods and fresh-water macrofossils occur in the Ottnangian as well as intercalations of tuffs and tuffites. An Ottnangian age for these sediments is suggested by the superposition and continuous transition into marine Karpatian sediments with benthic foraminifers. The Badenian formations conformably overlie the Karpatian sediments, and unconformably Precambrian and Paleozoic rocks, and are represented by siliciclastic and carbonate rocks, with some pyroclastics. The Badenian age is indicated by foraminifers (Jamičić et al. 1987).

Mt. Papuk was faulted in a south-west to north-east direction during Miocene extension. The study area belongs to a small tectonic unit which developed from the Ottnangian to the Pliocene (Jamičić et al. 1987).

The Ottnangian to Badenian sediments in the neighbouring areas of Mt. Pozeška, Mt. Psunj and Mt. Krndija (Fig. 1), show differences in lithological features as well as in their depositional environments. The Ottnangian sedimentation is characterized by coarse clastics, comprising fining upward sequences of alluvial and fresh-water lacustrine deposits. Karpatian sediments mostly consist of marine marls. The Badenian sedimentation is marked by rapid lateral and vertical lithological changes in a shallow marine depositional environment (Šparica et al. 1980; Šparica & Buzaljko 1984; Jamičić et al. 1989; Korolija & Jamičić 1989).

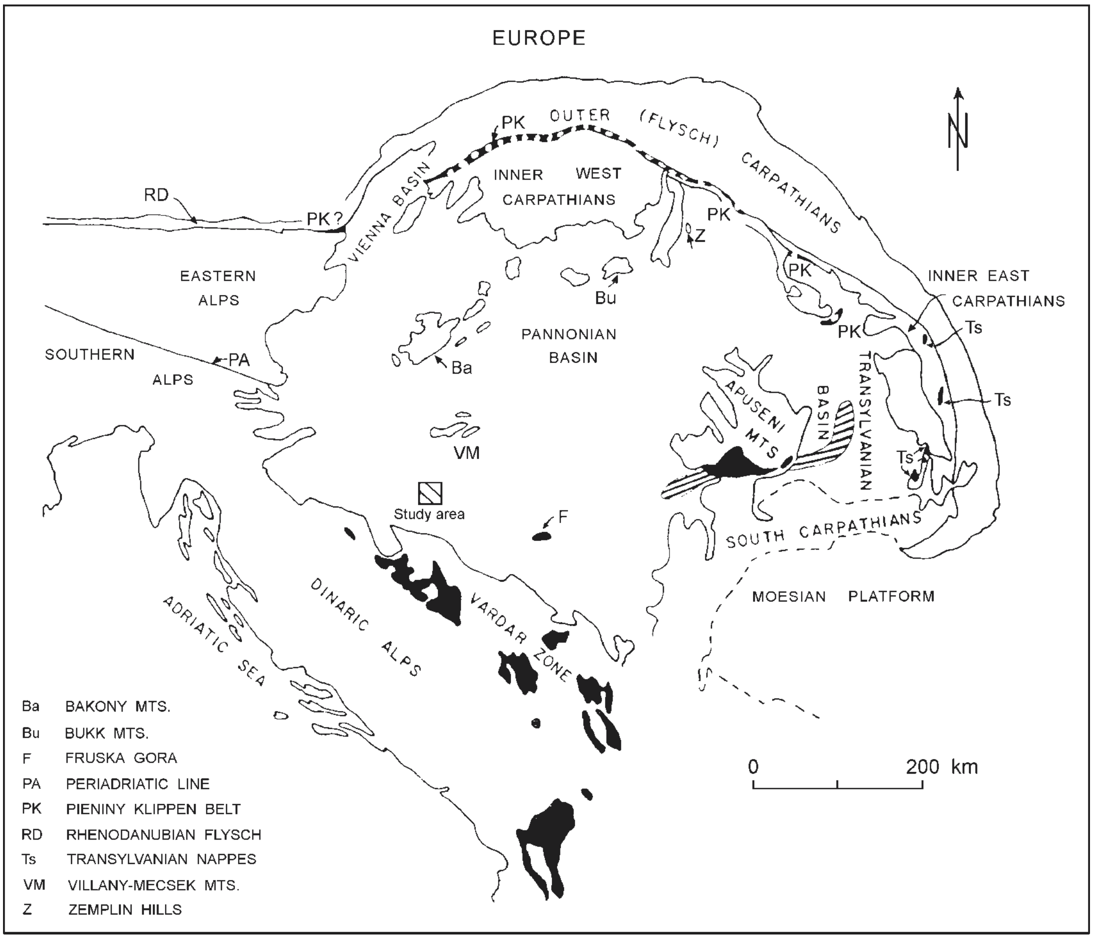

Fig. 2. Location map of the Pannonian Basin System and surrounding regions. Black indicates ophiolitic rocks, and black-and-white stripes near the Apuseni Mountains indicate subsurface ophiolites. Black with white dots indicates Pieniny Klippen Belt rocks, including the Wildflysch and Botiza nappes in the east and the Hauptklippenzone in the Eastern Alps (from Royden & Báldi 1988).

Facies analysis

The total thickness of the analysed deposits is aproximately 146 m. Three sections were measured (in further text s. A–C, Fig. 3). They were correlated in vertical succession during mapping of Mt. Papuk. The sediments are classified into 7 facies or facies associations: (1) laminated siltstones with sandstone intercalations, (2) horizontally bedded sandstones, (3) trough cross-bedded sandstones and horizontally laminated biocalcarenites, (4) horizontally bedded conglomerates and lenses of cross-bedded conglomerates, (5) trough cross-bedded conglomerates, (6) planar cross-bedded sandstones and conglomerates, and (7) marls with intercalations of biocalcarenites. The characteristics of the facies and their interpretation is summarized in Table 1.

Laminated siltstones with sandstone intercalations

The siltstone and sandstone facies is encountered in the lowest part of the succession (Figs. 4, s. A entirely, and 5, up to 13 m). *Siltstones* prevail (Fig. 6). They are well bedded or laminated with bed thicknesses reaching 2–3 cm. Siltstones are sporadically tuffaceous. Well preserved or fragmented leaves are abundant on bedding planes. While in the lowest part of the succession the ostracod *Amplocypris* occurs (Fig. 4, s. A, mfa 1), the first marine microfossil association was found somewhat higher up (Fig. 5, s. B, mfa 2) and contains benthic foraminifers (see Table 2). Higher up in the section (Fig. 5, s. B, mfa 3) the foraminiferal assemblage becomes more abundant and diverse (see Table 2). A change in the microfossil assemblage occurs in the sample taken directly above the previous one (Fig. 5, s. B, mfa 4) as miliolids are generally absent, with the exception of *Sigmoilopsis* cf. *asperula* (Karrer), while agglutinated types are common (Table 2). Foraminifers of all these three marine associations prove a Karpatian age and inner shelf (embayed or open) as environment.

The intercalated *sandstones* range in thickness from 5–25 cm (Fig. 6). The fine-grained types are laminated, and some beds are graded. The lower bedding planes are erosive. Some beds contain mud "rip-up" clasts (0.10–25 cm diameter) concentrated in the upper part of the bed (Fig. 7). Terrestrial plant fragments are found dispersed within the sandstones.

A massive sandstone bed (up to 80 cm thick) is found in the upper part of the described facies association (Fig. 5, in the level of 1 m), with a planar lower bedding plane. It is poorly sorted with larger clasts scattered above the base. Their diameter reaches up to 1 cm.

Interpretation

The prevailing *siltstones* (Figs. 4, s. A, and 5), have been deposited from suspension during long calm periods. This is proven by horizontal lamination of a suspension type and abundance of terrestrial plant fragments and leaves. The presence of tuffaceous material indicates synsedimentary volcanism (Jamičić et al. 1987).

The sharp lower bedding planes of the *sandstone* intercalations, their tabular geometry, occasional gradation and horizontal lamination can be interpretated as Bouma AB divisions. Sandstones which contain mud rip-up clasts could be deposits from sustained high-density turbidity currents (cf. Kneller & Branney 1995). Deposition may have resulted from sliding of previously deposited sand at shallower depths, or underflows emanating from delta channels.

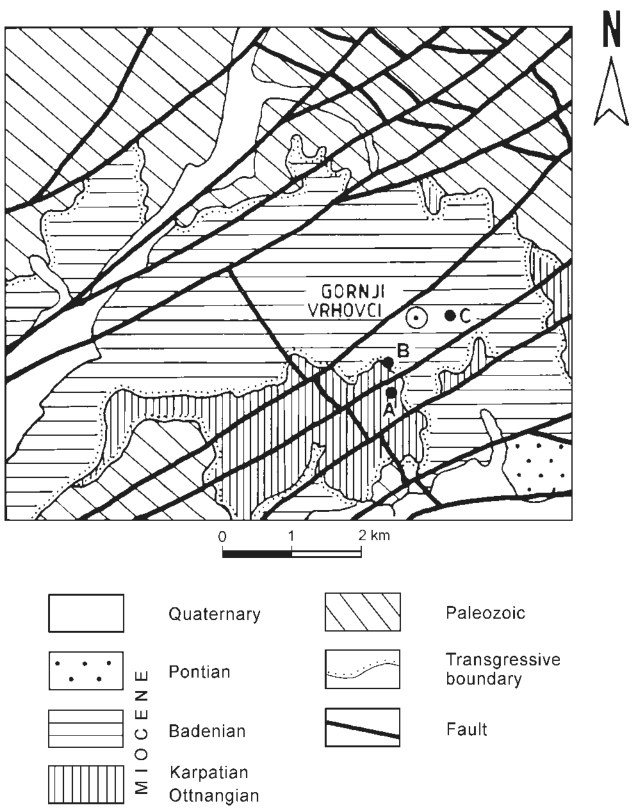

Fig. 3. Geological map of the study area (simplified, according to Jamičić & Brkić 1987), with marked sections A–C.

The poor sorting, scattered pebbles, large thickness and unorganized structure of the massive sandstone in the upper part of this facies association (Fig. 5, in the level of 1 m), point to resedimented deposits of a grain flow type (Lowe 1982, 1988), or deposition from high-density turbidity current during quasi-steady flow (cf. Kneller & Branney 1995).

On the basis of the fresh-water microfauna this facies association is considered to belong to a lacustrine environment. Sedimentation mainly occurred from suspension, with temporary interruptions by turbidity currents or grain flows. Such hydrodynamic processes are characteristic of offshore deposits in hydrologically open lakes (cf. Allen & Collinson 1989). The appearance of marine fauna, suggests transformation of the lacustrine environment into a marine one, which can be explained by relative sea-level rise during the Karpatian in the Paratethys (Rögl & Steininger 1983).

Horizontally bedded sandstones

Horizontally bedded sandstones make up the lower part of the succession (between 13 and 27 m in s. B, Fig. 5). The individual beds are 10–20 cm thick. Sandstones are graded and

Table 1: The characteristics and interpretation of facies associations.

Facies or facies association	Sections A-C (m)	Bedd-ing	Sediment structure and texture	Fossils	Paleo-current	Fig.	Transport mechanism	Depositional envi-ronment (age)
(1):-siltstones	A; B 0-13	-hori-zontal	-horizontal lamination	-fresh-water ostracods (A-mfa1); marine foraminifera (B-mfa 2-4)		-4,5	-suspension	-deep fresh-water lake (Ottnangian) and marine offshore (Karpatian)
-sandstones	A; B 0-2.5	-hori-zontal	-fine to medium grained, mud rip-up clasts or floatig out-sized pebbles, massive			-4,5, 6,7	-turbidity currents, grain flow	
(2):-sandstones	B 13-27	-hori-zontal	-fine to coarse grained, some pebbles, normal grading			-5,12	-turbidity currents	-marine offshore close to storm wave base
(3):-sandstones	B 26-54, 61-125 C 0-5	-cross-bedded cosets	-coarse to medium grained, large- to small- scale trough cross-bedding	-fragments of Corallinaceae, bryozoans, pelecypods and foraminifera	-landward (256^0)	-4,5, 8,12	-subaqueous 3-D dunes	-upper shoreface
-biocalcarenites	B 65-118	-hori-zontal	-coarse-grained, horizontal lamination			-5,9, 12	-traction-upper flow regime	
(4):-conglomerates	B 98.5-101.5	-hori-zontal	-clast- to matrix-supported, pebble and cobble gravels, b-axis imbrication, sandstone matrix		-landward (266^0)	-5,12	-traction from storm-generated currents	-upper shoreface
-conglomerates	B 99.5-101	-lenses	-clast-supported, pebble gravels, small scale trough cross-bedding	-fragments of Corallinaceae, bryozoans and pelecypods		-5,12	-subaqueous 3-D gravel dunes	
(5):-conglomerates	B 50-53, 119-125	-cross-bedded cosets	-clast-supported, pebble gravels, small scale trough cross-bedding	-fragments of Corallinaceae, bryozoans and pelecypods		-5,12	-subaqueous 3-D gravel dunes	-upper shoreface
(6):-sandstones	B 53-54.5	-cross-bedded cosets	-coarse grained, tangential cross-bedding		-seaward (102^0)	-5,10, 12	-avalanching	-stacked Gilbert-type fan deltas
-conglomerates	B 54.5-61	-cross-bedded cosets	-clast-supported, pebble gravels, tangential cross-bedding		-seaward (104^0)	-5,10, 12	-avalanching	
(7):-marls	C 13-15	-hori-zontal	-massive	-marine foraminifera (C-mfa 5)		-4,11, 12	-suspension	-offshore (Badenian)
-biocalcarenites	C 14-16	-hori-zontal	-normal grading, pebbles and cobbles in the lower part of bed, horizontal lamination in the upper part of bed			-4,11, 12	-seizmic or storm-generated turbidity currents	

poorly sorted. Grain diameters range from fine to medium in the lower part of this facies. Very coarse-grained sandstones occur in the upper part. Scattered pebbles are present. Biogenic particles include coarse, angular fragments of Corallinacea, bryozoans and pelecypods, and in rare cases sea-urchin plates.

Interpretation

Abundant skeletal fragments of shallow marine organisms within the siliciclastic material indicate marine reworking of the sediments. The grain-size composition of the sandstone, grading, and poor sorting, point to very rapid sedimentation. Deposition could have occurred from density-driven turbidity currents, which evolve from storm-generated currents and can transport and deposit sediment well below the storm wave base (cf. Walker 1984). The position of this facies (between the offshore zone and the shoreface), together with a lack of evidence of wave-reworking, suggests deposition in the offshore zone, but close to the nearshore.

Trough cross-bedded sandstones and horizontally laminated biocalcarenites

Trough cross-bedded sandstones were observed in the middle (Figs. 5 and 8) and upper parts of the succession (Fig. 4, s. C). They alternate with thinner beds of horizontally laminated biocalcarenites (Fig. 5). The direction of sediment transport was towards the west-northwest (285°) indicated by the dip of cross-beds and trough axes. Coarse-grained sandstones are moderately sorted. At the top of the individual trough, the grain-size decreases to medium-grained sandstones. Skeletal fragments are represented by Corallinacea, bryozoans, sea-urchin spines, pelecypods and foraminifers of the genus *Amphistegina*. The first occurrence of this genus of foraminifers is found in c.s. B (Fig. 5) at the level of 28 m.

Horizontally laminated biocalcarenites are found interbedded with the trough cross-bedded sandstones as sets reaching a thickness of 0.5 m (Fig. 9). Individual bed thickness varies between 1 and 3 cm. They consist mainly of whole and fragmented Corallinacea and bryozoans, in rare cases pelecypods and echinoderms. Biocalcarenites are mostly very coarse-grained.

Interpretation

Trough cross-bedding was formed by the migration of subaqueous 3-D dunes (Ashley & Symp. 1990). In marine environments, trough cross-bedded sets usually form on the upper shoreface (Elliott 1986). Similar forms in upper shorefaces were recognized in several different examples. Roep et al. (1979) classify "mega-cross-bedded" structures into the upper shoreface. Trough cross-bedded gravel sandstones as in the example of Miocene sediments in South West Oregon, were deposited by the migration of megaripples

Table 2: Microfossil associations of Karpatian (mfa 2–mfa 4) and Badenian (mfa 5) age and their bathymetric estimation. The stratigraphic position of mfa is shown in Fig. 3 and Fig. 4.

Microfossil association 2 — Karpatian	**Microfossil association 4 — Karpatian**
benthic species: *Quinqueloculina triangularis* d'Orbigny *Quinqueloculina akneriana* d'Orbigny *Quinqueloculina buchiana* d'Orbigny *Cycloforina contorta* (d'Orbigny) *Triloculina scapha* d'Orbigny *Triloculina inflata* d'Orbigny *Pappina bononiensis primiformis* (Papp & Turnovsky) *Pappina parkeri breviformis* (Papp & Turnovsky) *Cancris auriculus* (Fichtel & Moll) *Fursenkoina acuta* (d'Orbigny) **bathymetric estimation: inner shelf (bay)**	benthic species: Astrorhizidae (fragments) *Ammobaculites agglutinans* d'Orbigny *Ammoscalaria* sp. *Reticulophragmium venezuelanum* (Maync) *Dorothia gibbosa* (d'Orbigny) *Textularia mariae* d'Orbigny *Guttulina communis* d'Orbigny *Ammonia* gr. *beccarii* (L.) *Dyocibicides truncatus* (Egger) *Elphidium macellum* (Fichtel & Moll) **bathymetric estimation: inner shelf (open)**
Microfossil association 3 — Karpatian	**Microfossil association 5 — Early Badenian**
benthic species: *Quinqueloculina triangularis* d'Orbigny *Quinqueloculina akneriana* d'Orbigny *Quinqueloculina buchiana* d'Orbigny *Cycloforina contorta* (d'Orbigny) *Triloculina scapha* d'Orbigny *Triloculina inflata* d'Orbigny *Dorothia gibbosa* (d'Orbigny) *Dorothia* cf. *praelonga* (Karrer) *Textularia mariae* d'Orbigny Lituolidae *Pappina bononiensis* (Fornasini) *Ammonia beccarii* (L.) *Elphidium macellum* (Fichtel & Moll) *Amphycorina* sp. *Globulina* sp. planktonic species: *Globigerina ottnangiensis* Rögl *Cassigerinella boudecensis* Pokorny **bathymetric estimation: inner shelf (open)**	benthic species: *Reophax* sp. *Textularia mariae* d'Orbigny *Gaudryina mayerana* d'Orbigny *Lenticulina cultrata* (Montfort) *Lenticulina vortex* (Fichtel & Moll) *Lenticulina inornata* (d'Orbigny) *Stilostomella verneuili* (d'Orbigny) *Uvigerina pygmoides* Papp & Turnovsky *Cassidulina laevigata* d'Orbigny *Gyroidina soldanii* d'Orbigny *Cibicidoides ungerianus* (d'Orbigny) *Melonis pompilioides* (Fichtell & Moll) planktonic species: *Praeorbulina glomerosa* (Blow) *Globigerinoides trilobus* (Reuss) *Globigerinoides sacculiferus* (Brady) *Globorotalia mayeri* Cushman & Ellisor *Globigerina praebulloides* Blow **bathymetric estimation: outer shelf**

in the zone above the fair-weather wave in the upper shoreface (Leithold & Bourgeois 1984). Massari & Parea (1988) using the example of a medium to high-energy shoreline, also relate similar trough cross-bedded sands to the upper shoreface.

Horizontally laminated biocalcarenites are interpreted as being deposited by tractive transport in the upper flow regime, and represent an "upper plane bed" (cf. Reineck & Singh 1973). Clifton et al. (1971) classify sediments of similar texture in the upper part of the build up zone and lower part of the surf zone, i.e. shallower than the dune zone (outer planar facies). Howard & Reineck (1981) describe laminated sands of the high-energy shoreline in the upper shoreface and foreshore. Since these horizontally laminated biocalcarenites appear regularly at the top of small cycles that start with trough cross-bedded sandstones interpreted as upper shoreface, they are characteristic of the upper shoreface or the foreshore. The trough cross-bedded sandstones/horizontally laminated biocalcarenites show shallowing-upward trends, and form a stacking pattern.

The occurrence of *Amphistegina* foraminifera suggests a warm, tropical-subtropical climatic phase (Rögl & Brandstätter 1993). The stratigraphic position of the sediments of this facies association in the vertical succession suggests the Lower Badenian age.

Horizontally bedded conglomerates and lenses of cross-bedded conglomerates

Horizontally bedded conglomerates occur in section B from 98.5 m to 102.5 m (Fig. 5), interbedded with lenses of cross-bedded conglomerates.

The conglomerates are horizontally stratified and their bed thickness varies from 20–60 cm. Thick beds are usually amalgamated. The beds are mostly tabular with erosional lower and upper bedding planes. Horizontally bedded conglomerates are clast-supported to matrix-supported, with good segregation of pebbles and cobbles. The matrix is coarse-grained sandstones. The pebbles do not show any preferred orientation, but in some beds, b-axis imbrication of pebbles can be observed. The average dip of the b-axes is towards the east (86°), thus rolling-type transport should have been towards the west.

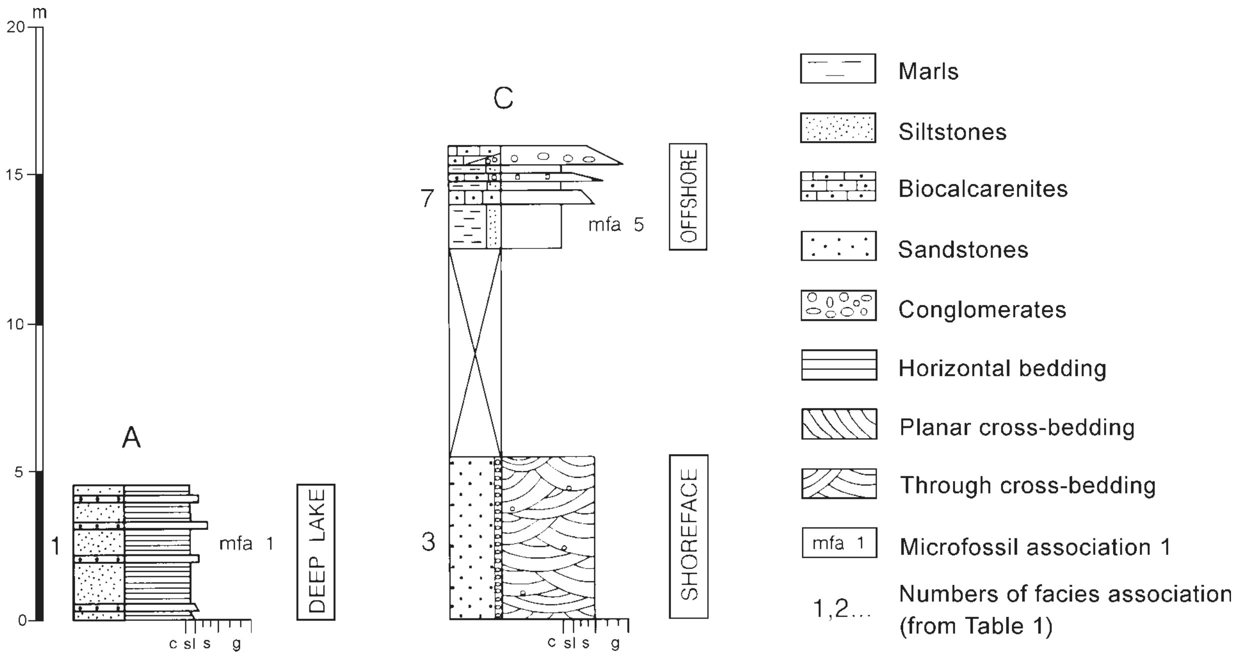

Fig. 4. Lithostratigraphic representation of sections A and C.

Lenses of *cross-bedded conglomerates*, which are found between tabular beds, are up to 3 m long, and up to 40 cm thick. Trough cross-bedding is found to be dominant. The conglomerates in these lenses are well-sorted clast-supported, with a minor amount of coarse-grained sand as matrix. Pebbles are very small with respect to other conglomerates.

Interpretation

Pebble- and cobble-sized conglomerates indicate very high energy conditions. Conglomerates show evidence of marine reworking by the mixing of terrigenous material with marine fauna and seaward imbrication. Successive beds with different degrees of sorting, pebble size and quantity of matrix are also indicators of a high-energy environment (Leithold & Bourgeois 1984) and frequent storms. Marine processes were the cause of reworking and resedimentation of the coarse material. These conglomeratic beds represent shoreface deposits, and very likely, the material deposited by storm waves or storm lag (Kumar & Sanders 1976). Erosional lower bedding planes in such conglomerates document the high-energy erosional processes acting along the coast (cf. Massari & Parea 1988). Imbrication of pebbles in some beds of horizontally bedded conglomerates, with a seaward dipping b-axis (land-basin distribution by Jamičić et al. 1987), is presumably formed by the action of shoaling waves in the surf zone, which is similar to the example given by Clifton (1981). During post-storm periods, waves and currents rework storm deposited gravel transferring it to the upper shoreface (Clifton 1973, 1981; Leithold & Bourgeois 1984; Swift et al. 1987). Low-energy waves rework only finer material. These processes are proved by (1) beds of single pebble thickness, which can be interpreted as poststorm lag (Clifton 1981), and (2) *trough cross-bedded fine-grained conglomerates*, that appear as small lenses within horizontally bedded conglomerates and also point to somewhat lower energy conditions. These two types of sediment are partially eroded during successive storms, as is suggested by their lenticular shape. Trough cross-bedded conglomeratic lenses (2) are small gravelly dunes often found above the waveline, the result of further reworking by waves. Similar dunes are described by Clifton (1981) in the Miocene sediments of California, and by Leithold & Bourgeois (1984) in the Miocene sediments of Oregon. The facies association of horizontally bedded conglomerates and lenses of cross-bedded conglomerates together with cross-bedded sandstones, are interpreted as sediments of the upper shoreface.

Trough cross-bedded conglomerates

Trough cross-bedded conglomerates were found in section B (Fig. 5) at 50–53 m, and 119–125 m. The sets of conglomerates are separated by an erosional boundary. Trough width is 0.5–0.7 m, the thickness of cross-bedded sets ranges from 20–30 cm. The largest pebbles occur near the trough bottom. Conglomerates are fine-grained and are clast-supported. The matrix of coarse sand is very rare.

Interpretation

Characteristic trough cross-bedding together with a coarse gravel lag, indicates that the gravel has been reworked into subaqueous 3-D dunes (according to Ashley & Symp. 1990). Similar to previous facies, these 3-D dunes are interpreted as upper shoreface deposits. The thickness of the conglomerates (3 and 6 m) without indications of storm interruptions suggests sedimentation on a wave dominated shore.

Planar cross-bedded sandstones and conglomerates

This facies only appears in the middle part of the succession (53–61.5 m in s. B, Figs. 5, and 10) and consists of seven cross-bedded units. The thickness of individual cross-bedded units varies from 0.5–2.8 m. Cross-beds are steep (20°–30°) and tangential. The dip of the cross-beds decreases upwards in the section parallel to an increase in grain size. Migration was directed towards the east. *The sandstones* are coarse-grained with scarce sparry calcite cement. They contain sparse rounded pebbles up to 3 mm diameter. *The conglomerates* are fine-grained and clast-supported with a coarse sandy matrix.

Interpretation

Steep planar cross-bedded sandstones and conglomerates indicate avalanching of detritus, and eastward migration suggests the transport of the material towards the sea. This facies could be compared with the foresets of small-scale marine Gilbert-type fan deltas (cf. Colella 1988; Massari & Colella 1988). The thickness of individual cross-bedded units suggests deposition in shallow water. The coarsening-upward tendency of facies shows general shallowing. Seven cross-bedded units form a vertical stacking pattern, which could be explained as a consequence of the repetitive activation of presumed basin marginal fault (sensu Colella 1988; Massari & Colella 1988; van der Straaten 1990).

Marls with intercalations of biocalcarenites

This facies association appears at the top of the succession (Figs. 4, s. C, and 11) with an apparent thickness of 4 m.

The marls are massive and occur in 2 levels, with thicknesses of 1.5 and 0.5 m. Within the marls tightly bounded irregular clusters of skeletal grains are common. A rich microfossil association was found (Fig. 4, s. C, mfa 5), containing benthic and planktonic foraminifers. The entire association indicates a Lower Badenian age (Lagenid zone) and outer shelf as the environment. Spines of sea-urchins, fragments of bryozoans and pelecypods are also common.

Three beds of *biocalcarenites* are intercalated within the marls (Figs. 4, s. C, and 11). They range in thickness between 30 and 105 cm, show normal grading in the lower part, and are terminated with horizontal lamination. The lower bedding planes are erosional. Biocalcarenites are fine- to coarse-grained sandstones and contain abundant densely packed skeletal material: fragments of echinoderms, bryozoans, Corallinacea, pelecypods, benthic and planktonic foraminifers. Pebbles and cobbles up to 10 cm in diameter also occur in the base and the cement is sparry calcite.

Interpretation

These *marls* were deposited from suspension in a calm environment as indicated by their massive appearance and great thickness. Abundant planktonic foraminifers indicate deposition on the outer shelf. Concentrations of skeletal grains in the form of cemented irregular aggregates can be explained as the consequence of bioturbation.

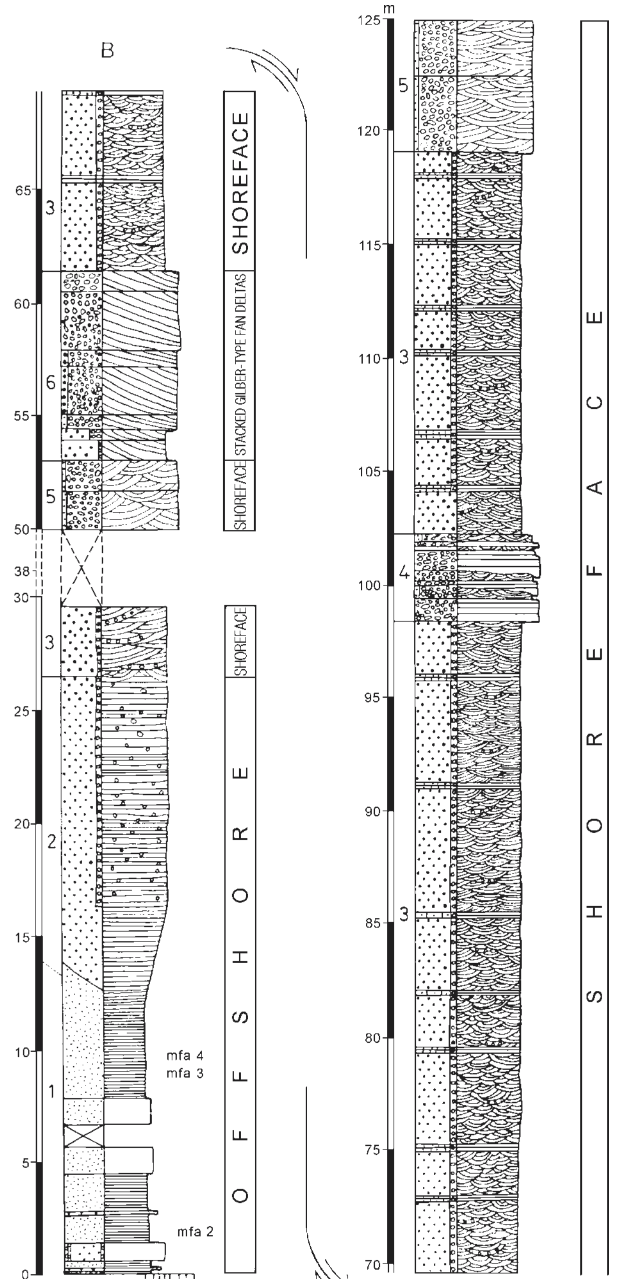

Fig. 5. Lithostratigraphic representation of section B. For legend see Fig. 4.

The beds of normally graded *biocalcarenites* (Fig. 3, s. C) can be interpreted as a $T_{a,b}$ Bouma sequence (Bouma 1962). These biocalcarenites were resedimented from the shallow sea and have been deposited by turbidity currents that could have been generated by catastrophic storms. This is supported by the presence of numerous fragments of shallow marine benthic fauna in the sediment and relatively large terrigenous pebbles and cobbles (up to 10 cm in diameter). Since no trace of wave action have been found, it can be concluded that the biocalcarenites were deposited beneath the fair-weather wave base, while their association with the marls locates them on the outer shelf.

Fig. 6. Facies association of laminated siltstones with sandstone intercalations. Horizontal lamination is very well developed in siltstones. Sandstone intercalations are at the level of the hammer (the hammer lenght is 31.5 cm).

Fig. 7. Mud "rip-up" clasts concentrated in the upper part of a sandstone bed (facies association of laminated siltstones with sandstone intercalations). The diameter of the lens cap is 5.5 cm.

Fig. 8. Trough cross-bedded sandstones, large forms.

Discussion

Alluvial sediments, that are overlain by lacustrine deposits, are the oldest Neogene deposits in Mt. Papuk, Mt. Psunj, Mt. Požeška, and Mt. Krndija, and belong to the Early Miocene. Based on the fresh-water fauna (*Congeria fuchsi* Pilar, *C. zoisi* Andrusov, *Dreissena* cf. *polymorpha* (Pallas), *Amplocypris* sp., and Characeae), as well as the stratigraphic position of the lacustrine sediments underlying Karpatian deposits, give their age as Ottnangian (Jamičić et al. 1987, 1989; Šparica et al. 1980; Šparica & Buzaljko 1984; Korolija & Jamičić 1989). The transition into the marine Karpatian offshore sediment (Jamičić et al. 1987) relates to the reopening of the Paratethys seaways (Rögl & Steininger 1983).

The marine sediments can be clearly divided into two depositional sequences (Fig. 12). In the first sequence, offshore sediments of the Karpatian age overlying freshwater Ottnangian beds (the upper part of the laminated siltstones and intercalated sandstones facies association) belong to a transgressive systems tract. The relative sea-level rise was connected with the opening of a Paratethyan seaway to the Mediterranean along the middle Slovenian corridor (Rögl & Steininger 1983; Rögl 1998) and can be correlated with the global sea-level rise (Haq et al. 1988). The highstand systems tract is composed of horizontally bedded sandstones facies, deposited in the offshore area, close to the storm wave base, and of cross-bedded sandy to pebbly shoreface and stacked Gilbert-type fan deltas deposits. The coarsening upward sequence indicates a rapid progradation and shallowing of the environment from offshore to upper shoreface and stacked Gilbert-type fan delta although the genus *Amphistegina* found in the upper shoreface (Fig. 12 in the level of 24 m) suggests the beginning of Early Badenian marine transgression (sensu Rögl 1998). The progradation and relative sea-level fall at the end of the first sequence could be explained by a high rate of sediment supply due a local decrease of tectonic subsidence (sensu Blair & Bilodeau 1988; Gawthorpe & Colella 1990; Heller & Paola 1992; summarized in Frostick & Steel 1993).

The beginning of the second sequence is characterized by a change into aggradational parasequence stacking pattern. According to Posamentier et al. (1988) and Posamentier & Vail (1988), at the transition from rapid progradation to aggradation the shelf margin systems tract is found bounded by a type 2 sequence boundary. Thus the shelf margin systems tract is built up mostly of facies units of trough cross-bedded sandstones and horizontally laminated biocalcarenites, and horizontally bedded conglomerates with lenses of cross-bedded conglomerates, and trough cross-bedded conglomerates.

Due the increase of tectonic subsidence the rate of sediment supply became low. This Early Badenian event resulted in deposition of marls with intercalations of biocalcarenites, composing a transgressive systems tract. These marls include benthic and planktonic species of foraminifers. The bathymetric estimation of these species indicates deposition in the outer shelf (Table 2, mfa 5). This sea-level rise can be correlated with the base of the TB 2,3 cycles of global sea level changes (Haq et al. 1988).

A similar situation in the Styrian Basin was described by Friebe (1993). However, he explained the rapid sea-level fall at the end of the Karpatian as a consequence of uplift, which was caused by block tilting within the crustal wedge in the eastern Alps east of the Tauern Window. In the Vienna Basin northeastern part, Kováč & Hudáčková (1997) suggest a tectonically controlled "costal onlap" on the Karpatian/Badenian boundary.

The vertical succession of alluvial-lacustrine-marine environments plus significant deepening of the sea towards the end of the succession, suggest subsidence of the basin. The subsidence model in this region is further elaborated by Pamić et al.

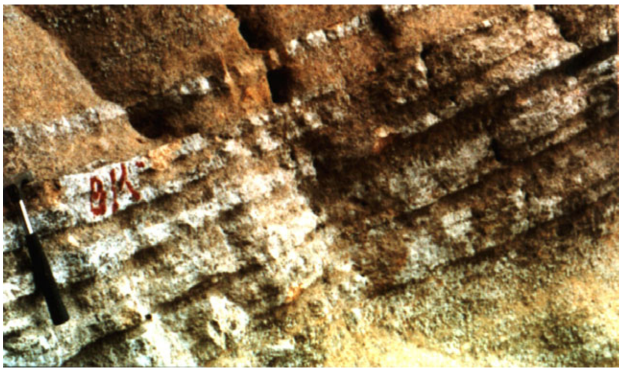

Fig. 9. Horizontally laminated biocalcarenites are clearly defined at the level of the hammer. A high content of shallow marine skeletons produces the white colour of biocalcarenites. (Beds are inclined due to the tectonics.)

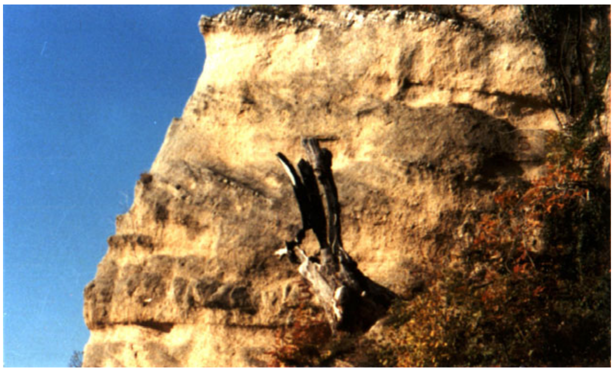

Fig. 10. Facies association of planar cross-bedded sandstones and conglomerates. Tangential cross-bedding is well developed. Total thickness of the outcrop is approximately 5 m.

Fig. 11. Bed of massive marl overlain by biocalcarenite intercalations.

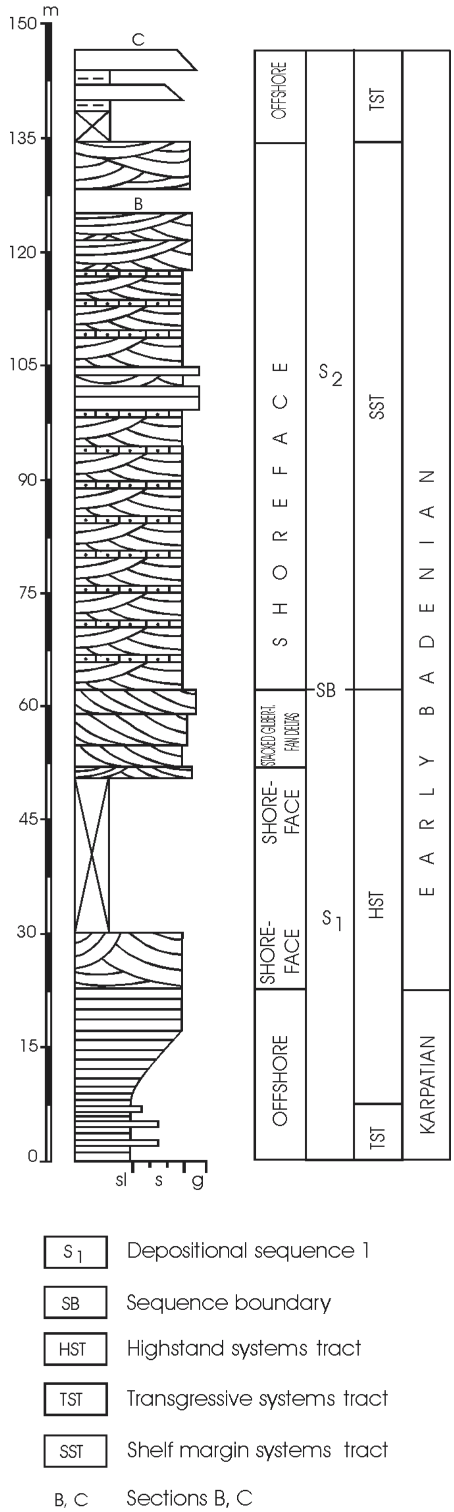

Fig. 12. Sections B (see Fig. 5) and C (see Fig. 4), and depositional sequences related to marine sediments.

(1992/1993), who pointed out that Lower Miocene trachyandesites (shoshonites) of neighbouring Mt. Krndija, have a postsubduction character and are related to the initial phase of extension. Ottnangian volcanic activity during the lacustrine sedimentation in the studied area (Jamičić et al. 1987), corresponds to the conclusion of Horváth (1995) that the general "rifting" in the Pannonian Basin System began by the appearance of the first tuff horizon of early Ottnangian age. Taking into account the age of these events (Ottnangian–Karpatian–Early Badenian), they could generally fit into the evolution of the Pannonian Basin System, which started to form by extension in the Early and Middle Miocene (Sclater et al. 1980; Horváth & Royden 1981; Horváth 1984, 1995; Royden et al. 1983; Royden 1988; Royden & Dövényi 1988; Kókai & Pogácsás 1991; Tari et al. 1992; Csató 1993).

Conclusion

In the Paratethys during the Karpatian, the isolated lake which evolved in the Ottnangian, was gradually transformed into a marine environment due to relative sea-level rise. Although the salinity and biota changed, sedimentation continued under the influence of the same depositional processes, most probably in the offshore area. With the proximity of land, grain size increases. The 63.5 m thick succession of sediments belonging to the upper shoreface indicates that sedimentation kept pace with the increase of accommodation space. The analyzed succession is terminated by sediments deposited in the offshore area.

In the study area, marine sediments are divided into two depositional sequences. Offshore sediments which belong to the Karpatian, represent a transgressive systems tract of the first sequence. From offshore to stacked Gilbert-type fan deltas, due the local decrease of tectonic subsidence on the Karpatian/Early Badenian boundary rapid progradation occurred, which is interpreted as a highstand systems tract. The following shoreface sediments are interpreted as a part of the shelf margin systems tract of the second sequence. The offshore sediments at the end of the succession represent a transgressive systems tract, as a result of the Early Badenian sea-level rise in the Paratethys, and the increase of the tectonic subsidence.

The vertical succession from the Ottnangian to the Early Badenian, suggests subsidence of the basin. It corresponds to the initial phase of the evolution of the Pannonian Basin System.

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