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Storm Influenced Shelf Sedimentation - An Example from the Lower Triassic (Scythian) Siliciclastic and Carbonate Succession near Knin (Southern Croatia and Western Bosnia and Herzegovina)

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Key words: Scythian, Siliciclastic-carbonate succession, Storm sediments, Inner and outer shelf, Proximality-distality trend, Transgressive sequence, Knin.

Abstract

Scythian sedimentary rocks exposed at Strmica and Plavno near Knin represent storm-generated deposits in inner (Lower Scythian) and outer (Upper Scythian) shelf settings. The Lower Scythian is represented by Siliciclastic facies which consists of two subfacies components - thin-bedded shale-siltstone-sandstone alternations attached to the distal part of the inner shelf, and a thick-bedded sandstone-oolite subfacies attached either to the proximal part of the inner shelf or to the shoreface. Repetitive alternation of these two subfacies which form the Siliciclastic facies is interpreted as high frequency sedimentary cycles possibly related to high-frequency sea-level changes which in turn induced wave-base oscillations. This is observed as a rapid introduction of high energy proximal inner shelf or shoreface deposits into a muddy, distal part of the inner shelf environment.

Upper Scythian sedimentary rocks are lime mudstones with marls in the Mud facies, and with marls and calcarenaceous siltstones in the Siltstone-mudstone facies. No obvious cyclic periodicity was observed within these two facies except the random occurence of punctuated storm layers with basal skeletal lag (Mud facies) and silty material input in normally mud dominated outer shelf sedimentary rocks (Siltstone - mudstone facies).

According to the facies characteristics the Lower Triassic succession near Knin is interpreted as a consequence of a low-term, possibly third-order sea level rise compared to the global sea level rise during the Scythian.

1. INTRODUCTION

The Lower Triassic sedimentary rocks in the area of Knin have been investigated previously during surveying for the geologic map (Knin sheet M 1:100 000) by GRIMANI et al. (1972, 1975) who defined the stratigraphy and assigned red clastic, oolitic and bioclastic sedimentary rocks to the Lower Scythian and gray limestones to the Upper Scythian. They also described their petrographic characteristics and interpreted them as shallow-marine deposits but noticed increasing water depth - "transgression" throughout the whole period which influenced the sedimentary succession. Many sedimentological issues were not dealt with in Grimani's investigation and remained unanswered, including the sedimentary conditions, determination of depositional environment and possible reasons for its change from siliciclastic to carbonate-dominated (Lower to Upper Scythian).

During the Lower Triassic (Scythian) shallow-marine sedimentation commenced and various clastic and bioclastic carbonate sediments were accumulated. The Lower and Upper Scythian sedimentary rocks described in this study suggest the importance of storm influence. As described in an earlier work (ALJINOVIĆ, 1991), storm affected sedimentation across a broad shelf environment far away from the near shore zone. Storm-related processes generated many structures and textures within the sedimentary sequence of Lower Triassic age at Strmica and Plavno in the vicinity of Knin. The role of storms, as an important depositional mechanism, is well known from recent and ancient shallow subtidal and open shelf examples (GOLDRING & BRIDGES, 1973; ANDERTON, 1976; KUMMAR & SANDERS, 1976; BOURGEOIS, 1980; KREISA, 1981; EINSELE & SEILACHER, 1982; AIGNER, 1985; SOEGAARD & ERIKSSON, 1985; HANDFORD, 1986; DUKE, 1990; SIMPSON & ERIKSSON, 1990; MYROW, 1992; JENNETTE & PRYOR, 1993; BRENCHLEY et al., 1993), and several storm indicators mentioned in these published works were also recognized in the Scythian deposits at Plavno and Strmica.

This study describes both the depositional history of the Lower Triassic succession with emphasis on the energy conditions and depth regime (proximality-distality trend), and the pattern and variation in cyclic sedimentation as a response to shallowing and deepening of the environment.

2. GEOLOGICAL SETTING AND STRATIGRAPHY

The study area is located in the Outer Dinarides (Fig. 1a). GRIMANI et al. (1972, 1975) determined mainly red clastic, oolitic and bioclastic sedimentary rocks as being of Lower Scythian age from the characteristic faunal assemblage, and gray clayey and sandy limestones and marls as Upper Scythian.

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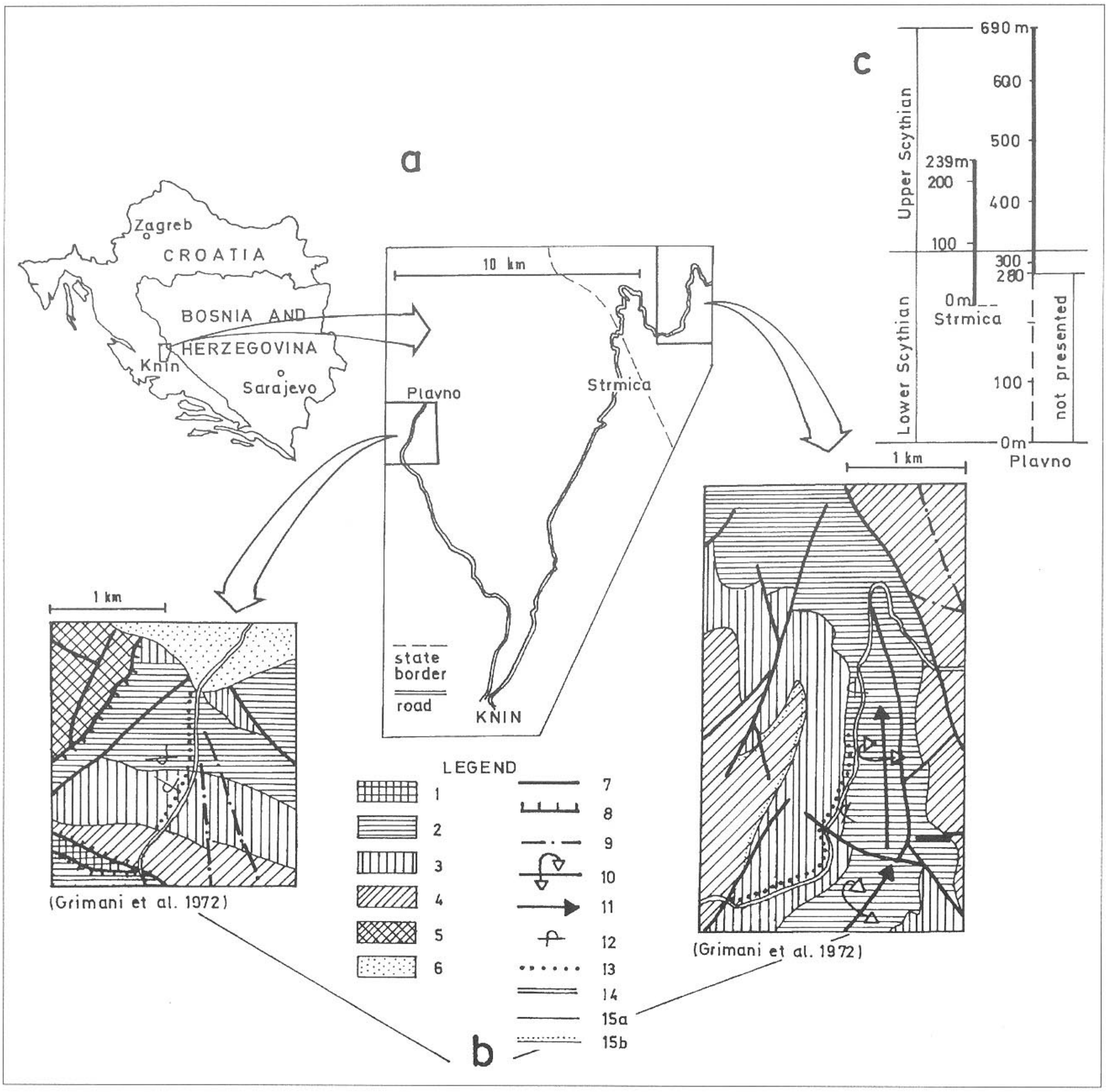


Fig. 1 a) Location map; b) Schematic geological map (modified after GRIMANI et al., 1972). Legend: 1) Permo-Triassic, gypsum; 2) Lower Scythian, shales, sandstones, ooid limestones and clayey limestones; 3) Upper Scythian, limestones, marls and dolomites; 4) Lower Anisian, limestones and dolomites; 5) Upper Anisian, marls, limestones, volcanoclastic sediments, sandstones, breccias, conglomerates, clays and rare intercalation of dolomites; 6) Quaternary; 7) fault; 8) thrust fault; 9) fault based on air-photo analysis; 10) overturned fold; 11) axis of the overturned fold; 12) overturned bed; 13) trace of the profile; 14) road; 15a) conformable boundary; 15b) disconformable boundary; c) Schematic vertical profile of the two outcrops studied.

Recently published works (ŠĆAVNIČAR & ŠUŠNJARA, 1983; TIŠLJAR, 1992) as well as some earlier ones (HERAK, 1973; ŠĆAVNIČAR, 1973) documented that at the end of the Permian and beginning of the Triassic there was a trend of tectonic uplift in the Outer Dinarides which resulted in differentiation of the sedimentary basin. This uplift represented the end of Hercynian diastrophism and generated large lagoons with evaporites (HERAK, 1973) or shallow epeiric marine basins (TIŠLJAR, 1992). The transition from Permian to Lower Triassic is debated: IVANOVIĆ et al. (1971) found a conformable succession between the Permian and Lower Triassic and considered it the product of the final acquiescence of tectonic activity, erosion of the uplifted area and infilling of depressions. GRIMANI et al. (1975) did not discover evidence of a conformable succession that is usually complicated with tectonic contacts and diapirism of evaporite complexes. The investigated sections are exposed in series of overthrusted sheets which formation was influenced by diapirism of evaporate (CHOROWICZ, 1977; GRIMANI et al., 1972, 1975; HERAK, 1973). Consequently the Lower Scythian sedimentary rocks described in this work form parts of the overthrust sheets Poštak and Ilica (CHOROWICZ, 1977; GRIMANI et al., 1972, 1975).

The transition from Lower Triassic to Anisian can be either conformable (Plavno) or unconformable (Fig. 1b; GRIMANI et al., 1972, 1975).

3. LOCATION OF STUDIED OUTCROPS

The data have been obtained from two road cuts near the villages of Strmica and Plavno (Fig. 1a). At Strmica (Fig. 1b) only part of the Lower Scythian and Upper Scythian succession is accessible and the measured succession is 239 m thick. The profile represents the southwestern limb of an overturned fold and the oldest deposits are not exposed. The contact of the Scythian and overlying Anisian limestones is tectonic (Fig. 1b; GRIMANI et al., 1975), and the succession is slightly disturbed by a strike-slip fault near the boundary between the Lower and Upper Scythian. Nevertheless, the succession can be easily traced.

At Plavno (Fig. 1b), the early Triassic succession is about 700 m thick. The lowermost part is overlain by Quaternary sediments. Upper Scythian rocks are conformably overlain by Anisian limestones. The facies characteristics correlatable with the Strmica profile occur in the upper 410 m of the column (Fig. 1c).

Quantitative data presented in this work have been collected from the Strmica profile and are also representative of sediments at Plavno (ALJINOVIĆ, 1991).

4. FACIES FRAMEWORK OF THE LOWER TRIASSIC (SCYTHIAN) SEDIMENTARY ROCKS

Three different facies were identified in the Scythian succession. These are: Siliciclastic (Lower Scythian), followed by Mudstone and Siltstone-mudstone (both Upper Scythian) (Fig. 2). There is a continuous transition from siliciclastic sedimentation in the Lower Scythian to lime mudstones and marls in the Upper Scythian. Increased amounts of lime mudstones and marl appeared. The thickness of beds generally decreases.

4.1. SILICICLASTIC FACIES

This consists of alternating thin-bedded siliciclastic-dominated intervals and thick-bedded mixed siliciclastic-carbonate intervals. Strata are therefore grouped into two relatively distinct subfacies: thin-bedded shale-siltstone-sandstone subfacies and thick-bedded sandstone-oolite subfacies (Fig. 3). The subfacies are regularly organised and form metre-scale sedimentary cycles (Figs. 2 and 3). Approximately 29 cycles are present within the Strmica column and 8 within the Plavno section.

4.1.1. Thin-bedded shale-siltstone-sandstone subfacies

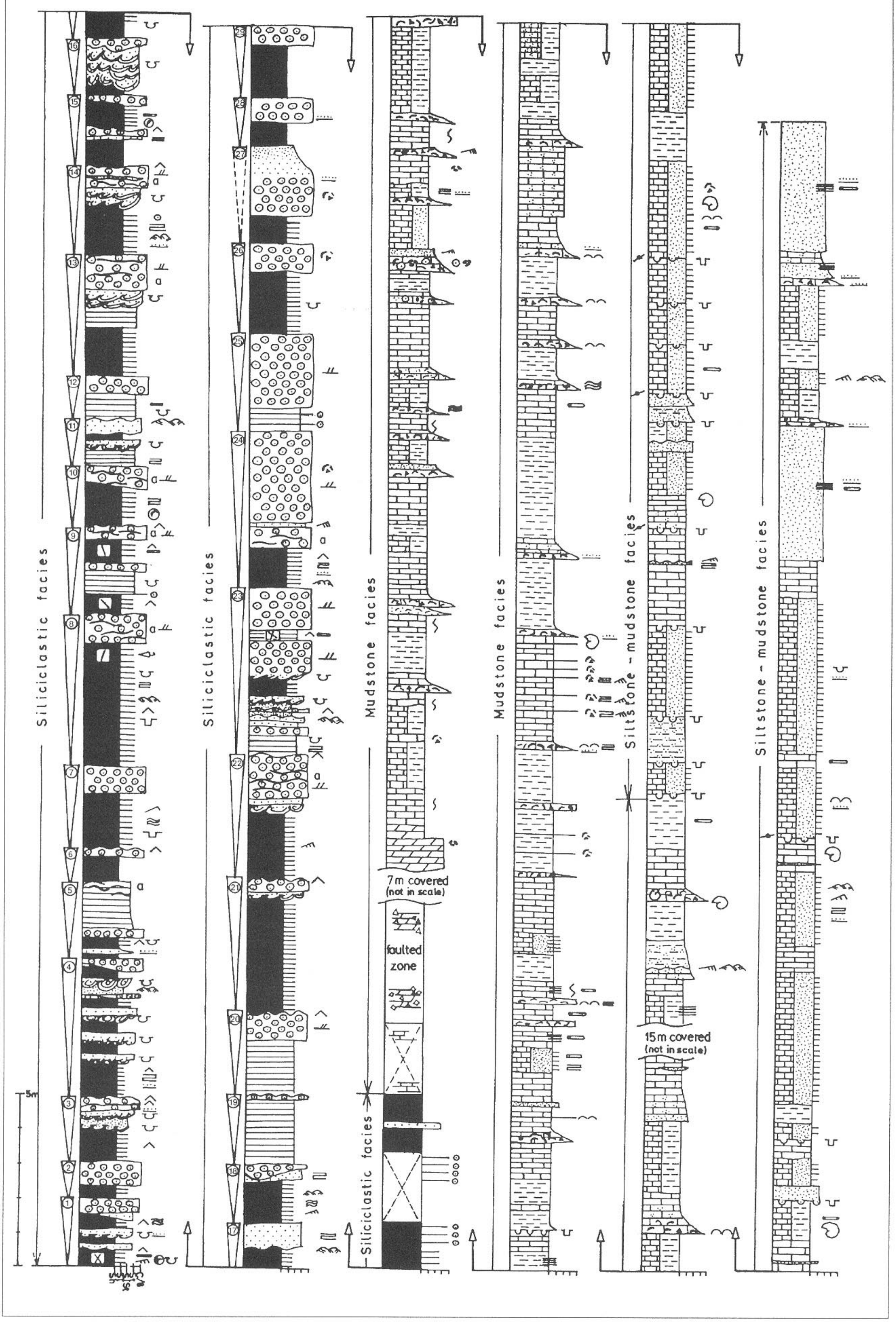
This subfacies is present in the lower part of the cycles, and it is composed of interbedded shales and sandstones or siltstones. The sandstone-siltstone/mud ratio increases upward within each cycle (Fig. 3). Petrographically the shale consists mostly of illite. Siltstones consist mainly of quartz grains and varying amounts of argillaceous minerals and calcite cement. They tend to contain lamina of fine mud, which increases in abundance upward. Sandstones are very fine to fine grained and vary from quartz arenite to arkose in composition. Micaceous sandstones with coarse 1-2 mm mica particles may occur. In general, the sandstones are matrix free, but determination of the relative abundance of primary matrix is hampered by the presence of neomorphic microspar in intergranular pores. Occasionally, bioclasts and ooid grains represent the dominant components. These types of rocks have been termed calcarenites or ooid rich calcarenites.

All sedimentary rocks are usually red or yellow coloured due to Fe-hydroxides, except the micaceous sandstone varieties which are gray. The alternation of all three types of sediments is shown in Fig. 7.

The sandstone and siltstone layers vary in thickness up to a maximum 10 cm. There are also lateral variations in thickness of particular beds. Some beds display pinch-and-swell geometry or lateral discontinuity. Lens shaped bedforms are common. The lower bed surfaces are usually sharp and flat. Thicker sandstone layers very often exhibit small, centimetre scale highly irregular load casts (Fig. 5). Loading could cause slight deformation of beds and their internal structures, but when loading is enhanced it may produce the deformation of the whole bed and the formation of the "nodular-like" beds. Ball & pillow structures are also present. Very rarely lower bedding planes show flute marks (Fig. 6). Shale interbeds are up to 10 cm thick and structureless, except for a well developed fissility. They contain well preserved small molluscan molds. The shells were lithified in convex-up position.

Sharp upper bed surfaces are present, as well as a gradational upward transition to finer grained sedimentary rocks. Ripples that appear on the upper bedding surfaces of some beds are symmetric with slightly sinuous crests and are interpreted as wave ripples. Two systems of ripple crests can be observed. They are almost perpendicular to one another and one system roughly trends NW-SE while the other trends NE-SW (Fig. 2). On the upper surface of some siltstone beds millimeter scale flat-crested ripples were found. Crestal wavelengths are 3-4 mm and ripple heights are about 1 mm. Crests are slightly sinuous. Trace fossils are well preserved on the upper and lower bed surfaces. According to their simple morphology and low diversity they are attributed to crawling organisms.

According to the specific internal structure several types of bed organization could be determined. A continuous transition from coarser to finer sedimentary rocks is common. Throughout, horizontal-planar laminated beds are the most abundant type. These layers are either evenly laminated or are developed as laminated rhythmites, in which the lower laminae are thicker and


Siliciclastic facies
Siliciclastic facies
Mudstone facies
Siliciclastic facies
Mudstone facies
Siltstone - mudstone facies
Siltstone - mudstone facies
5m
7m covered (not in scale)
faulted zone
15m covered (not in scale)
a
1
2
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coarser grained and grade upwards into thinner and finer-grained laminae. Sets of lamina may thicken and thin laterally causing a slight departure from the horizontal in the form of gentle, isolated undulations or irregularities. Beds that consist of sinuous undulated lamina sets are also common. Some beds are characterized by horizontal planar or undulated lamina sets passing upwards to ripple cross-lamination and further gradationaly to shale (Fig. 4b) or the whole bed may be cross laminated. Ripple cross lamination shows a simple internal structure such as unidirectional bounded laminae draped by form concordant parallel lamina (Fig. 4a), or bi-directional bounded lenses show offshooting (Fig. 4d). Small-scale hummocky cross-stratification shows a simple internal structure: planar laminations with scoured upper sets display external symmetrical swell geometry that is draped by form concordant siltstone or silty shale (Fig. 4c).

The alternation of muddy and silty or sandy material present in the thin-bedded shale-siltstone-sandstone subfacies represents a dominantly muddy marine environment interrupted by deposition of silt and sand. The sharp bases of the siltstone and sandstone beds suggest an abrupt commencement of deposition while the vertical grading from sandstone or siltstone to shales indicates deposition under waning energy conditions. The deposition of fines was possibly from suspension, while the deposition of silt and sand could be interpreted as periodic rapid events (supported by numerous loaded siltstone and sandstone bed surfaces). Such an organization of depositional structures indicates storm deposition (e. g. ANDERTON, 1976; KREISA, 1981). The vertical transition from sandstone or siltstone to shale indicates the deposition from a single storm and the return to fair weather sedimentation processes, as also

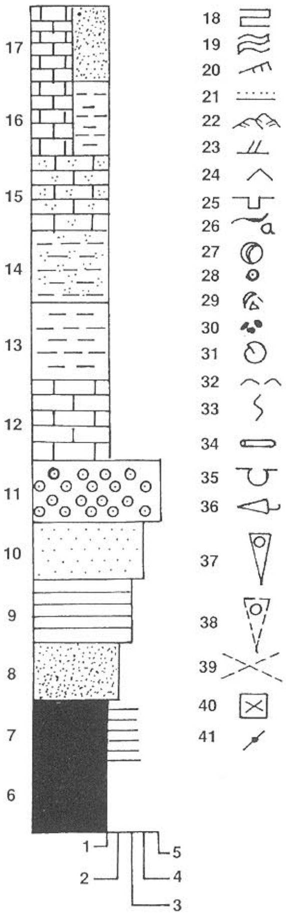

Fig. 2 Strmica section. Legend: **grain size:** 1) < 0,004mm; 2) silt; 3) silt/sand; 4) fine to medium sand; 5) coarse sandstone/gravel; **lithology:** 6) shale; 7) alternation of thin-bedded shale, siltstone and sandstone; 8) laminated to thin-bedded siltstone; 9) alternation of thin-bedded siltstone and sandstone; 10) sandstone; 11) ooid grainstone; 12) laminated to thin-bedded mudstone interval; 13) laminated to thin-bedded marl interval; 14) laminated to thin-bedded silty marl interval; 15) laminated to thin-bedded silty mudstone interval; 16) alternation of thin-bedded to laminated mudstone and marl interval; 17) alternation of thin-bedded to laminated mudstone and calcarenaceous siltstone interval; **textures and components:** 18) horizontal-plane lamination; 19) undulate lamination; 20) ripple cross-lamination; 21) vertical grading; 22) hummocky cross-bedding; 23) cross-bedding; 24) wave ripples; 25) gutter casts; 26) amalgamation; 27) shell molds; 28) ooids; 29) skeletal detritus; 30) intraclasts; 31) ammonites; 32) convex up shell position; 33) bioturbation; 34) trace fossils; 35) load casts and ball & pillow structures; 36) flute marks; 37) sedimentary cycle; 38) uncertain sedimentary cycle; 39) partly covered interval; palaeocurrent data: 40) ripple crests; 41) gutter casts.

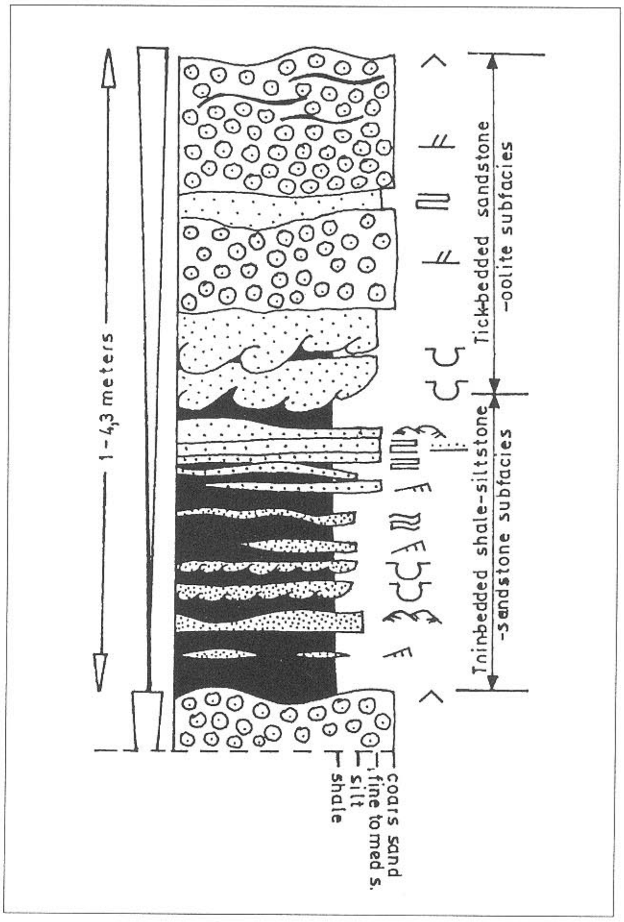

Fig. 3 Idealized sedimentary cycle in Siliciclastic facies: thin-bedded shale-siltstone-sandstone subfacies represents the interbedding of fair weather and storm layers deposited from waning energy storm events; thick-bedded sandstone-oolite subfacies is represented by amalgamated units and megaripples as a consequence of high-energy events. For legend see Fig. 2.

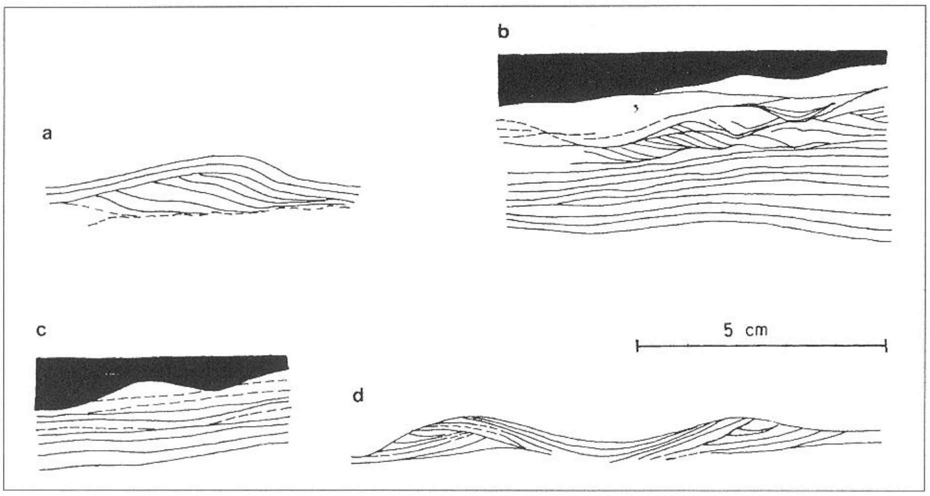

Fig. 4 Bed types in thin-bedded shale-siltstone-sandstone subfacies: a) simple ripple lamination of possible current origin shows unidirectional bounded lenses draped by form concordant parallel lamina set; b) complex bidirectional ripple lamination superimposed on parallel lamination (note upward increasing mud content); c) horizontal-planar lamination scoured forming hummocks overlaid by mud; d) bidirectional wave ripples lamination with offshooting lamina set in a rippled laminated beds.

indicated by numerous trace fossils preserved in the upper part of the shale units (BOURGEOIS, 1980; KREISA, 1981).

The siltstone and sandstone beds are considered to have been formed during storms capable of entraining sediment in turbulent suspension, transporting it and depositing it during the waning stage. Hummocky cross-stratification, as typical storm structure, could have been formed by deposition under combined or oscillatory storm flow components (DOTT & BOURGEOIS, 1982; DOTT, 1983; DUKE, 1985, 1987; SWIFT et al., 1987; CHEEL & LECKIE, 1993) or by simple scouring due to post depositional wave reworking.

Fig. 5 Load cast structures revealed as shallow protuberances on the lower bedding plane of a siltstone bed - thin-bedded shale-siltstone-sandstone subfacies; hammer for scale is 33 cm long.

Two types of ripple cross-lamination were identified: current ripple lamination (Fig. 4a) probably generated by unidirectional currents during storms (SNEDDEN et al., 1988; DUKE, 1990) while the draping laminae suggest further vertical accretion from suspension possibly after diminishing unidirectional current velocity during a period of moderately high suspension fallout (DeCELLES & CAVAZZA, 1992). Flute marks preserved on the lower bedding planes of some beds also bear witness to the strong unidirectional flow capable of scouring. Wave ripple cross-laminated beds (Fig. 4d) as well as undulate lamination are probably the result of wave generated oscillatory currents produced by storm waves (De RAAF et al., 1977). Millimetre-scale ripples are assigned to normal subtidal water depth and were formed aggradationaly, lamina by lamina due to very low speed flows which were only slightly faster than threshold velocities (JENNETTE & PRYOR, 1993).

Horizontal planar laminated sandstone and siltstone layers are considered storm beds as well, similarly as storm sand beds in mud shelf reported by GOLDRING & BRIDGES (1973) and REINECK & SINGH (1973).

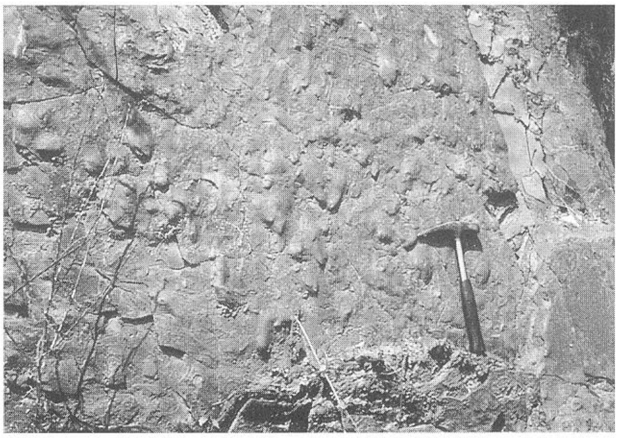

Fig. 6 Flute marks on the lower bedding plane of siltstone bed - thin-bedded shale-slitstone-sandstone subfacies; hammer for scale is 33 cm long.

4.1.2. Thick-bedded sandstone-oolite subfacies

Thick-bedded sandstone-oolite subfacies comprises the upper part of each cycle with the exception of cycle 23 which consists almost entirely of this subfacies. The subfacies is typified by thick layers of fine to medium sandstones and coarse ooid grainstones with minor siltstone and very rare thin interbeds of shale. Sandstones are fine to medium grained and consist of quartz and feldspar grains cemented by sparry calcite cement, and can be classified as quartz arenite, subarkose or arkose (ALJINOVIĆ, 1991). The content of silt and siliciclastic mud is small. Occasionally, the sandstones contain appreciable amounts of 1-2 mm mica particles. Coarse grained bioclasts and ooids can also be present.

Ooid grainstones are composed of coarse grained (0.6-1 mm) ooids, localy remarkable amounts of coarse grained to gravel-sized bioclastic material (shells, echinoderms, gastropods) and small amounts of siliciclastic sand grains. Two types of cements are present: fibrous calcite and blocky calcite (Fig. 8). Shell fragments or whole valves form the nuclei in many ooids but frequently nuclei are distorted by recrystalization and are replaced by blocky calcite or dolomite (Fig. 8). Cortices are usually concentric. Only in the thickest oolite bed radial and radialconcentric ones are present. Very often ooids show only a very thin, irregular, red rim (probably containing Fe-hydroxides) around the nucleus. The dolomitization of ooids varies from partial (only nuclei replaced) to complete. Appreciable amounts of bioclastic material occurs with ooids, thus making the transition to skeletal grainstones.

Siltstones contain quartz and minor amounts of argillaceous minerals which are cemented by sparrycalcite.

Shales appear as very thin layers or lamina sets. They do not differ from the shales mentioned in the previously described subfacies.

Sandstones, siltstones and shales are red colored while oolites are red, yellow or gray.

Individual sandstone, siltstone and ooid grainstone beds range in thickness from 10 cm to about 40 cm, but the upper thickness limit is not known because common amalgamation produced units that are up to 2 m thick. The thick units of all sedimentary types are commonly separated by shale partings which suggest that the thick units are the product of amalgamation. In most cycles, the siliciclastic portion of the facies is overlain by a thicker oolite bed. Although bed thickness is variable throughout the subfacies unit, a weak upward thickening trend can be observed. Amalgamation also increases upward in many cycles with the exception of cycle 27.

Beds are planar, but lower bedding surfaces may be planar or undulatory or exhibit sharp erosion into the underlying sediments. The upper surfaces of all beds may be planar, rippled or irregular. Irregularly shaped upper erosion surfaces are locally draped by irregular or undulous thin shale lamina.

Lenticular or irregularly shaped beds are common. Lenticular beds either have a convex down base while the top is flat or the base is flat and upper surface is convex up. The lengths of lenses range from a few tens of centimetres up to 3 m. The lower surfaces of sandstone and siltstone beds can be loaded, and some large deformations resemble ball and pillow structures although they are not strictly isolated in mud.

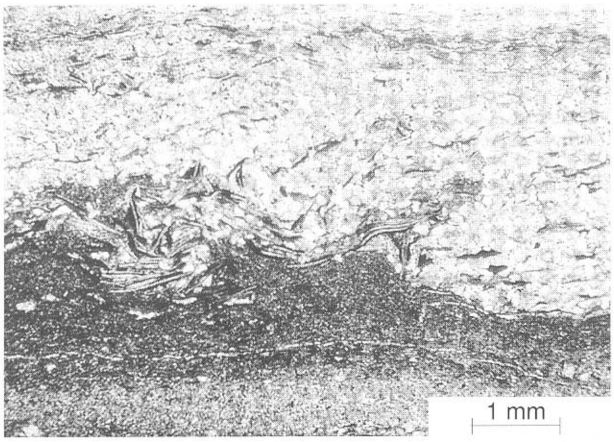

Fig. 7 Thin-section microphotograph - interlayers of sandstone (upper), shale (middle) and siltstone (lower part of photo). Note irregular contact between sandstone and shale depicting loading of upper positioned bed.

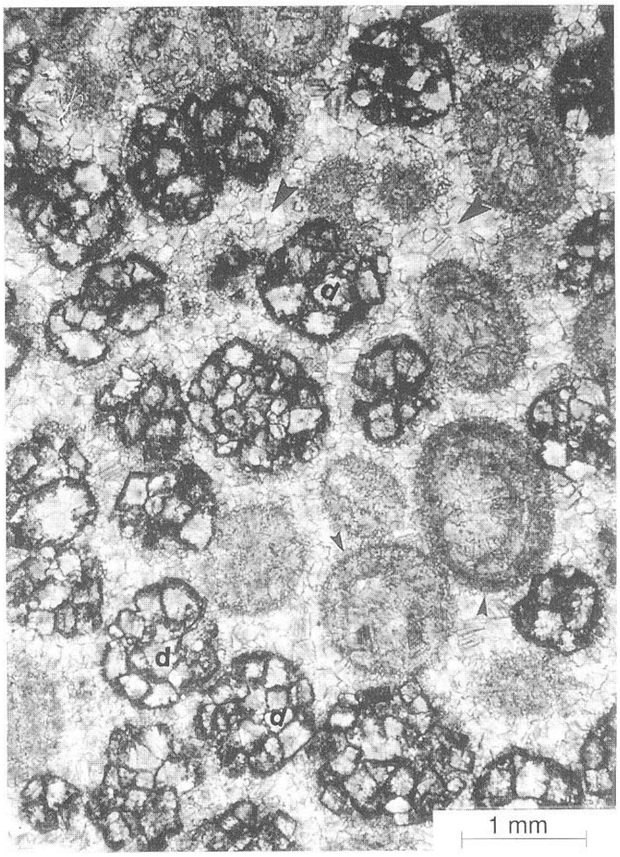

Fig. 8 Thin-section microphotograph - ooid grainstone. Note fibrous calcite cement (small arrow), and blocky calcite cement (big arrow). Ooids are partly destroyed by dolomitization process (d).

Several types of bed organization characterise this subfacies, including hummocky cross stratified sandstones. They display slightly undulous laminations that follow the irregularly or wavy scoured surface of the lower bed. These beds may be truncated forming another hummocky-like surface. Several truncated surfaces can be superimposed.

Sandstone and siltstone beds can display horizontal-planar lamination throughout. The same sediment types as well as ooid grainstones could be internally characterised by planar cross-bedding. Compound bodies consist of numerous sets (up to 40 cm thick) usually inclined in the same direction but oppositely inclined sets have also been observed. Both low-angle sets and steeply inclined sets occur. Cross-bedded ooid grainstones are very often capped by megaripples, the wave length of which varies from 30 cm to 1.5 m. In cross-section profiles a few well defined superimposed wavy bed sets separated by discontinuous thin, wavy shale drapes may appear.

Hummocky cross-stratified sandstones indicate the storm origin of the sedimentary structures. The appearance of amalgamated bed sets and increased amount of medium sand and coarse ooids indicates depositional processes in a shallow marine environment. In this shallow environment intense eroding and removing of sediment occurs due to a high energy regime. Consequently, these processes resulted in different sedimentary structures than those described for the thin-bedded shale-siltstone-sandstone subfacies. Though, widespread evidence of amalgamated beds envisaged as continuous thick layers with residual mud partings are the result of several storm events. The lenticular beds and multiple erosion surfaces witness also the repetitive reworking of sediments (SIMPSON & ERIKSSON, 1990; BRENCHLEY et al., 1993), with penecontemporaneous winnowing of fines.

Load casts and ball and pillow structures are considered to be a consequence of the rapid deposition of sand over a hydroplastic mud (DZULINSKY & WALTON, 1965; REINECK & SINGH, 1973; ALLEN, 1984).

Hummocky cross-stratification, as well as large scale cross-bedding associated with coarse grained megaripples, suggests the occurence of intense oscillatory and/or combined flows (DOTT & BOURGEOIS, 1982; DUKE 1985, 1987, 1990; CHEEL & LECKIE, 1993). Shallow or deep scouring indicate also the influence of storm generated unidirectional currents capable of scouring (DUKE, 1990; MYROW, 1992). Horizontal planar lamination of some thick sandstone and siltstone layers can be interpreted as the product of upper regime oscillatory or current flows associated with peak storm conditions in a very shallow environment, probably shoreface. Cross bedding, observed in medium sandstone and ooid grainstone beds, which resembles subaqueous sandwaves, could be compared to storm generated sandwaves of the Middle Atlantic Bight described by SWIFT et al. (1979). Formation of these shallow marine bedforms, according to SWIFT et al. (1979) is a response to wind driven unidirectional flows during storms, but coarse grained megaripples commonly found at the top of ooid grainstone beds seem to be the product of wave motions or at least of combined flows (MARKELLO & READ, 1981; LECKIE, 1988; DUKE, 1990; JENNETTE & PRYOR, 1993). Thus, the cross bedded sandstones and ooid grainstones with megaripples could be explained by the actions of geostrophic current and subsequent wave motions generated by storms. Wave conditions that form coarse grained wave ripples could be the result of large storms, but also of long period swells (LECKIE, 1988), which places this subfacies in a very proximal shallow water environment. When they occur in the same setting with medium and fine sand, coarse grained megaripples are reported in coarse grained sediments, while hummocky cross-stratification is expected in medium grained ones (LECKIE, 1988). This is apparent in thick-bedded sandstone-oolite subfacies, where coarse grained ripples appear in the oolite (coarse grained sediment), while hummocky cross-stratification is restricted to medium and fine sandstones. The absence of characteristic tidal features (cross-bedding, neap-spring cosets, mud drapes, etc.) led to the dismissal of tidal currents in process interpretation, at least as an important factor in forming the sedimentary structures, and the inference of

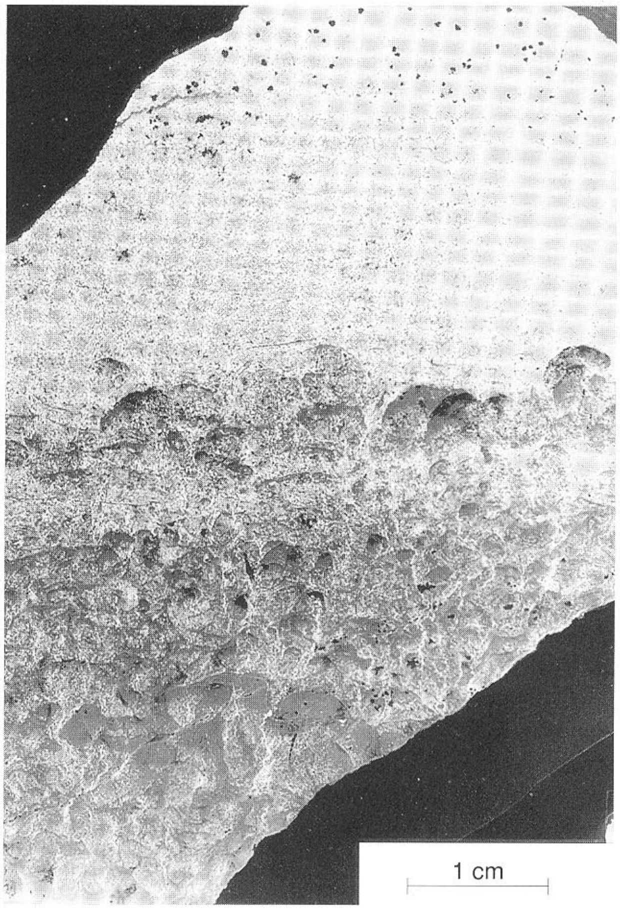

Fig. 9 Skeletal lag in mudstone layer (Mudstone facies). Note vertical grading and increasing mud content; dark grey spots are shell valves; acetate peel.

currents and waves due to storms in forming the dominant sedimentary structures.

The genesis of ooids is related to the occurrence of carbonate rich shallow marine shoals which were affected during storms. Storm-driven currents or waves influenced the shoals as described in recent examples from the Bahama Bank (HINE, 1977). Nevertheless, storm currents were not capable for transporting coarse material over long distances in onhshore direction, so that most coarse ooids stayed restricted within the shallow parts of sedimentary basin while, on the contrary, the negligible amount of only fine and medium grained ooid rich calcarenites could be found in the thin-bedded shale-siltstone-sandstone subfacies.

4.2. MUDSTONE FACIES

An increase in lime mud related to the siliciclastic mud and a lack of sandstones and ooid grainstones characterize the Mudstone facies. No cyclicity was defined. Rather irregularly organized layers are present.

This facies consists of laminated units of marl or lime mudstone. Marls consist of $CaCO_3$ component (approximately 65-75%) and illitic clay material. A very small amount of bioclastic material is present. The carbonate component is represented by recrystallized matrix.

Lime mudstones contain carbonate mud which is usually recrystallized. The argillaceous component is low. Well preserved fossils (ammonites, molluscs and echinoderms) can be present and are usually dispersed in mud.

Silty marls and silty lime mudstones occur occasionally. They contain appreciable amount of siliciclastic silt sized particles, mainly quartz.

Marls or lime mudstone are occasionally enriched in coarse grained bioclastic or intraclastic material (sometimes >2 mm). Coarse particles are accumulated as a basal lag a few centimeters thick (Fig. 9). Fossils are well preserved. Whole valves are dominantly oriented parallel to bedding in convex up position. Large, usually coarse grained intraclasts of lime mud and peloids can also be concentrated as lags. In each unit the upward transition to pure mudstone is gradational and an upward increase in the carbonate component can be observed.

Evenly laminated lime mudstones and marls are sometimes disturbed due to intense bioturbation. Trace fossils preserved at the top of numerous beds are assigned to crawling organisms.

The dominantly fine grained sedimentation in the Mudstone facies suggests deposition in a tranquil, deeper environment related to the environment proposed for Siliciclastic facies. Units which consist of coarse size well preserved skeletal and intraclastic lags overlain by laminated or bioturbated marls and/or lime mudstones are considered storm deposits in offshore environment similar as described by KREISA (1981). It is well known that storms affect sedimentation across a broad shelf environment far away from the nearshore zone (SMITH & HOPKINS, 1972; BEARDSLEY & BUTMAN, 1974; VOS, 1977; BUTMAN et. al., 1979). The intense bottom-shear conditions during the storm peak can concentrated shells of living and dead organisms from the sea either by burying them by sudden influx of storm suspended fines or by exhuming previously buried shells by ripping up underlying weakly consolidated lithologies and form lag deposits (KREISA, 1981). Therefore, the whole-fossil walves dominantly oriented parallel to bedding in convex-up position are interpreted as storm layers because storms preferentially preserve whole fossils by burying them and protecting them from normal destructive processes (KREISA, 1981). Further-more, winnowing and suspension of fine sediment by storm turbulence resulted in deposition of the upward fining units consisting of fine grained sedimentary rocks deposited from suspension superimposed on a coarse lag material. As the storm wanes more mud is deposited from suspension and upward grading reveals. No strict structural characteristic could trace the lull of storm and reversal to normal basinal sedimentation except increased amount of lime mud.

4.3. SILTSTONE - MUDSTONE FACIES

This facies consists of very thin-bedded or laminated layers of marl and lime mudstones but contains increased amounts of carbonate silt material forming calcarenaceous siltstone layers. Silty marls and silty lime mudstones are also present. Marls, silty marls, lime mudstones and silty mudstones are petrographically similar to those described in previous facies but occasionally marls and silty marls are enriched in ammonite molds. Calcarenaceous siltstones are composed of skeletal particles (usually echinoderm fragments or shells and minor amount of ammonites and foraminifera) and siliciclastic quartz grains (Fig. 14). Sparry calcite component is also present.

Calcarenaceous siltstones are common, forming thick (1-20 cm) laminated layers. The layers have very sharp lower surfaces. Basal laminae embrace coarser skeletal particles and are overlain by parallel or slightly undulous silt laminae. The silt laminae gradationaly thin upward, as the mud content increases (Fig. 10). In some beds weakly defined cross lamination appears. The skeletal particles in the lowermost laminae of siltstone beds are sometimes medium sand-sized. Siltstones are overlain by laminated or bioturbated silty marl, marl and/or lime mudstone. Occasionally hummocky cross-stratified siltstone layers appear (Fig. 11).

Intense bioturbation produced the massive structures of mudstones, while on the exposed bedding planes numerous crawling trace fossils are preserved. Some escaping burrows were noticed in siltstones layers, too.

Well preserved gutter cast structures are common on the lower bedding planes of silty marls and siltstones. In vertical profile the gutters are shallow, 1-3

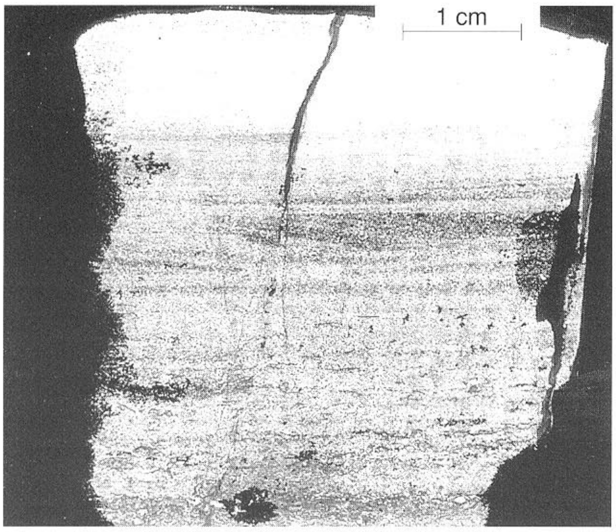

Fig. 10 Graded rhythmites in calcarenaceous siltstone layer (Siltstone-mudstone facies). Note weak grading at the bottom of the layer, parallel and cross lamination in the middle and upward thinning of laminae and increasing mud content; acetate peel.

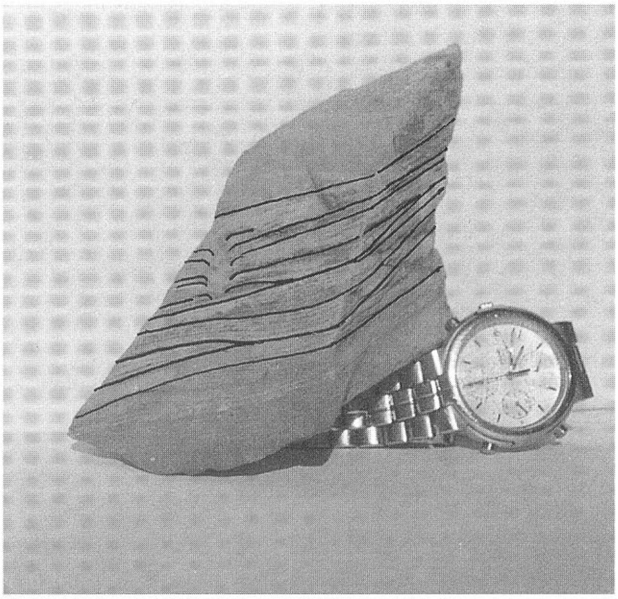

Fig. 11 Hummocky cross stratified calcarenaceous siltstone bed (Siltstone-mudstone facies). Lamina sets have been highlighted by pencil. Note escaping burrow on the left of photo.

cm, and about 5-7 cm wide and are flat bottomed or wide with "U" shaped profiles. In plain view gutters are straight, linear (Fig. 12) or show an anastomosing pattern (Fig. 13). The Gutters strike NE-SW.

Interbedded lithologies containing varying proportions of silt sized particles and fine grained sediments, fossil-lag material, as well as gutter cast structures, undulatory lamination and hummocky cross-stratification as described here, can serve as evidence for storm activity in the deeper outer shelf environment (KREISA, 1981). Similarly as described by Kreisa, thin siltstone interbeds in marl and lime mudstone units superimposed on basal lag, as described in this facies, may represent distal expressions of storm activity The increased content of silt created the variability of storm generated layers as compared to the storm layers of the Mudstone facies. Thus, laminated silty interbeds which show trends of upward increasing matrix, thinning laminae and weak grading and resemble graded rhythmites are the result of silt input probably from the nearshore area by storm generated currents (REINECK & SINGH, 1972). The sharp bed surfaces of silty marl and siltstone beds which very often show well preserved gutter casts suggest an abrupt commencement of sedimentation with the influx of silty material (BRIDGES, 1972; WHITAKER, 1973; BLOOS, 1976; KAZMIERCZAK & GOLDRING, 1978; AIGNER, 1979; DUKE, 1990). The escape burrows in siltstones also provide the evidence of the rapid input of silt material and deposition from single event (GOLDRING & BRIDGES, 1973; VOS, 1977; BOURGEOIS, 1980). Undulating laminations in siltstones as well as hummocky cross-stratification (Fig. 11) were probably formed under combined or oscillatory storm currents (GOLDRING & BRIDGES, 1973; De RAAF et al., 1975; HARMS et al., 1975; BLOOS, 1976; HAMBLIN & WALKER, 1979; BOURGEOIS, 1980), while the gutter casts are attributed to a near bottom storm flow component (DUKE, 1990) associated with some helicoidal movements (WHITAKER, 1973).

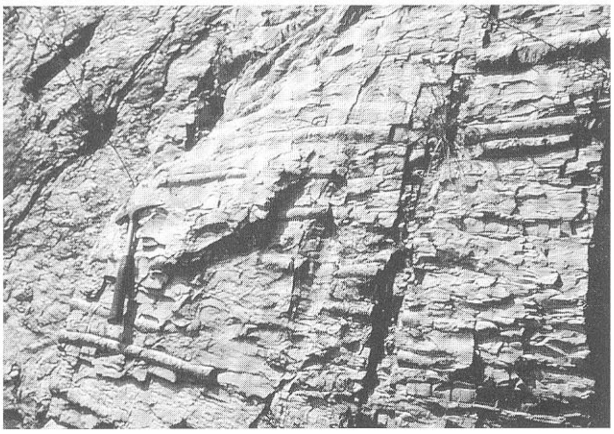

Fig. 12 Lower bedding plane of calcarenaceous siltstone bed displaying linear gutter cast (Siltstone-mudstone facies); hammer for scale 33 cm.

According to the progressive increase in thickness and abundance of laminated beds of siltstones toward the end of Plavno and Strmica sections a relatively shallower water environment is proposed for this facies in relation to the Mudstone facies.

5. DISCUSSION

5.1. DEPOSITIONAL ENVIRONMENT

The structural characteristics of many beds found in Strmica and Plavno sections defined storm induced processes which alternate with beds that represent sedimentation between storms. The event deposits show the

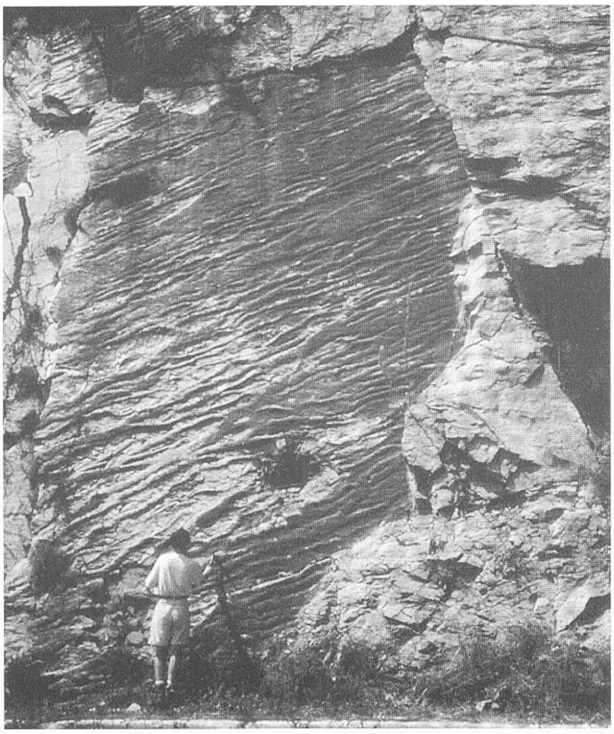

Fig. 13 Lower bedding plane of calcarenaceous siltstone bed showing anastomosing gutter cast pattern (Siltstone-mudstone facies).

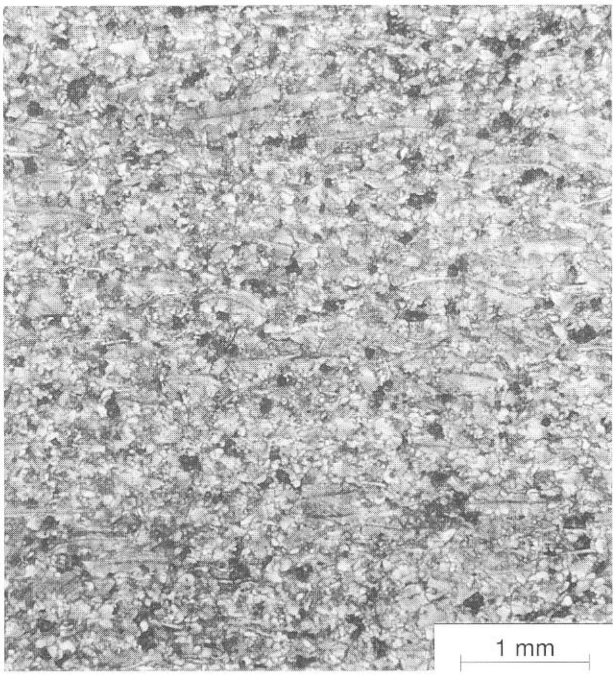

Fig. 14 Thin-section microphotograph - parallel laminated calcarenaceous siltstone containing an appreciable amount of shell fragments. Note that the orientation of shells are parallel to lamination.

evidence of storm wave and current components while the time gap between storms was generally discerned according to the increased activities of crawling organisms and preserved ichnofossils. The influence of storms has been manifested differently according to water depth. The depth related concept of storm generated layers has its general consequence in forming remarkably different structural characteristics among Lower and Upper Scythian sedimentary rocks. The different storm induced sedimentary structures that are documented within Lower and Upper Scythian facies are interpreted as depth related storm influence on the wide shelf area. The assumption of a wide shelf is supplemented by the earlier hypotheses of continuous sedimentation of Permian and Triassic sediments (IVANOVIĆ et al., 1971) in tectonically inactive phases on the edges of an epeiric see (TIŠLJAR, 1992), shallow sea (ŠĆAVNIČAR & ŠUŠNJARA, 1983) or in the large lagoons (HERAK, 1973). The differences among Lower and Upper Scythian facies imply the changing of water depth in favor of deepening of the environment or the rising of sea level i.e. a transgressive trend which has also been assumed in previous work by GRIMANI et. al. (1975). There is no evidence of sedimentation hiatus in the investigated profiles, so continuous sedimentation throughout the whole Scythian is inferred.

The depth related concept assumes that the effect of storms decrease toward deeper water (AIGNER, 1985). Different storm induced sedimentary structures will be discussed in the context of storm induced processes in proximal and distal parts of the shelf.

The characteristics of the Siliciclastic facies (amalgamated intervals, overlapping sets of coarse grained megaripples, as well as discrete storm sand layers interspersed in red shales) point to a shallow water environment where the wave and current storm component or multiple episodes of storm reworking were active. The shallow proximal part of the shelf or inner shelf and shoreface where the storm winds create vigorous circulation and surface waves is proposed for this facies. The inner shelf is defined according to HARMS et al. (1982). On the contrary, the deposits of the Mudstone and Siltstone-mudstone facies imply a lower energy environment where periodic winnowing of the host sediment caused accumulation of a fragile epifauna at the bottom of storm beds (Mudstone facies) or sudden influx of storm suspended silt create graded and laminated silty storm layers (Siltstone-mudstone facies). Both these characteristic layers represent the distal expressions of storm currents. Storm layers in both facies alternate with the intervals of normal, slow, muddy basinal sedimentation in the deeper outer shelf environment.

In the Siliciclastic facies there is a sequentially shallowing facies assemblage represented by the transition from thin-bedded shale-siltstone-sandstone subfacies to thick-bedded sandstone-oolite subfacies. The repetitive changes of these two subfacies create metre-scale sedimentary cycles. In each cycle there is an upward increase of amalgamation and large scale structures (cross-bed sets and megaripples), thickness of beds and the abundance of coarse material (coarse sand and ooids). All these characteristics establish a proximalization trend (SIMPSON & ERIKSSON, 1992; BRENCHLEY et al., 1993; JENNETTE & PRYOR, 1993). In addition to the proximalization trend within each cycle the two subfacies types represent further depth related differentiation. Therefore, thin-bedded shale-siltstone-sandstone subfacies showing discrete storm layers separated between fair weather muds indicates relatively deeper parts of inner shelf or the depths where storm wave and currents create specific sedimentary structures such as graded rhythmites and hummocky stratification and have insufficient strength to remove all mud deposited between storms. Thus, the shale content may serve as bathymetric indicator and appears to be indicative of the more distal part of the shelf (e.g. ANDERTON, 1976; SWIFT et al., 1987; BRETT, 1983; MYROW, 1992). Therefore, the thin-bedded shale-siltstone-sandstone interval reflects sedimentation in distal deeper part of the inner shelf. The upward incre-asing amount of sand and decreasing shale noticed in the vertical profile of each cycle indicated the periodic shallowing of the environment. Apparently, due to shallowing, the thick-bedded sandstone-oolite intervals which overlie thin-bedded shale-siltstone-sandstone intervals have all of the characteristics of high energy processes which could be attributed to intense reworking and eroding due to a shallower water depth. The structural characteristics of thick-bedded sandstone-oolite subfacies provide the conclusive evidence that deposition occured in the proximal part of the inner shelf or, at least partly, in a shoreface.

5.2. ORIGIN OF MATERIAL

Appreciable amounts of feldspar particles present in the sandstones leads to the assumption of preferential mechanical weathering of uplifted rock masses in arid or semiarid climate conditions. The assumption relies upon the similarity with other Scythian sediments. An arid or semi arid climate in the Scythian period was suggested by ŠĆAVNIČAR & ŠUŠNJARA (1983).

The appreciable amount of sand and silt which accumulated in the Lower Scythian allows the assumption that the sand and silt were possibly supplied to the strand plain by short lived flows that occurred as a result of floods emanating from alluvial fans that fringed the basin edge (SMOOTH, 1983).

The increasing amount of carbonate and mixing of carbonate and siliciclastic material with minor calcarenaceous silt deposited throughout Upper Scythian could be explained as the result of 1) entrainment of coarse sand and oolite sediments in a nearshore area or more probably 2) the changing of source area possibly caused by increased carbonate production in the nearshore zone and transportation of the finest carbonate particles offshore.

5.3. GENERAL CHARACTERISTICS OF THE CYCLIC SUCCESSION

From the base of the succession, which is described in detail in the Strmica section and compared to the Plavno section (Fig. 15), the same vertical arrangement of the facies have been observed. After initial transgression which have probably drowned underlying evaporite complexes, a marine conditions have been established. The main characteristic of the vertical sediment succession, envisioned as groups of cycles, indicates a general transgressive trend in the shallow shelf environment. Among the Siliciclastic facies coarsening and thickening upward cycles were noticed. The upward increase of coarse grained sediments (sand, ooid) and the increasing thickness of thick-bedded sandstone-oolite subfacies, which represent deposition in the proximal inner shelf or shoreface, could be possibly interpreted as the transition from an aggradation trend in the shallow shelf environment finally to progradation (Fig. 15). The progradation pattern could be caused by autocyclic or allocyclic processes (VAIL et al., 1991), i.e. enlarged amount of sediment available or changes in sea level rise. This study does not provide enough conclusive evidence to distinguish between these as the cause of progradation. Nevertheless, the appreciable amount of coarse grained material (especially ooids) which abruptly appeared in the upper part of the lower Scythian manifested as very thick amalgamated oolite layers, designates this change in favour of allochthonous processes due to favorable conditions of ooid formation. Increasing amount of shale that appears in the upper part of the Siliciclastic facies could be attributed to change of progradation in favor of transgression. Further increasing amounts of lime mud and a fining upward trend in Mudstone facies were explained as a transgressive facies (Fig. 15). Increasing silt component related to carbonate mud could be explained as transition from the transgressive Mudstone facies to aggradational deposition depicted by Siltstone-mudstone facies.

In this simplified analysis (Fig. 15) the genetic succession of different order cycles can be applied but must be treated with reserve. The lack of precise biostratigraphic data prevents any determination of the time of deposition within the sections and therefore even the duration of the smallest units (cycles) cannot be discerned. Nevertheless the vertical superimposition of metre scale cycles could be possibly termed 5th order cycles or parasequences according to their resemblance with the similar mode of determination made by BRENCHLEY et al. (1993) and JENNETTE & PRYOR (1993). Thus, using the hierarchical classification of GOLDHAMMER et. al. (1990), which fundamentally relies on the bedding-cycle stacking pattern, a genetic succession of cycles could be discerned as parasequence sets or 4th order cycles and the increasing water depth during Scythian age could be related to low-term 3rd order global sea level rise (HAQ et. al., 1987).

6. CONCLUSION

A detailed study of the vertical succession at Strmica and Plavno allows the following interpretation of the deposits:

Sedimentation in the Lower Scythian is represented by Siliciclastic facies characteristics. The facies is composed of metre scale depositional cycles. Two well defined subfacies make up the cyclic assemblage each showing evidence of storm origin. According to the high frequency sea level changes that are assigned to glacio-eustasy (GOLDHAMMER et al., 1990) the repetitive rising or falling of sea level appeared and caused the repetitive shift of subfacies in a basinward or coastal direction. Thus, the distal inner shelf mud rich sedimentation, represented by thin-bedded shale-siltstone-sandstone subfacies, was episodically punctuated by a rapidly shallowing hydrodynamic system that displaced the proximal environment (thick-bedded sandstone-oolite subfacies) in a basinal direction.

The thin-bedded shale-siltstone-sandstone subfacies is characterized by storm generated siltstone and sandstone layers interbedded with fair weather shale layers deposited in a slightly deeper part of the inner shelf. Storm layers reveal the characteristics of settling from suspension as the storms wane and the depositional structures that are assigned to storm produced currents and waves. The thick-bedded sandstone-oolite subfacies, that overlies thin-bedded shale-siltstone-sandstone subfacies is assigned to storm processes in a proximal inner shelf or shoreface. Thick layers were the product of multiple amalgamation. Increased energy conditions due to combined flows restricted to shallow shelf environments prevented fine sediment accumulation so the facies lacks shale units. Wind drift currents, surface waves and bottom currents responsible for the rapid deposition and genesis of structures such as tabular cross bedsets inclined preferentially in one direction, hummocky cross-stratification, coarse grained ripples and ball & pillow structures (JOHNSON, 1977; SWIFT & NUMMEDAL, 1987; SNEDDEN et al., 1988; DUKE, 1990).

The outer shelf sedimentation processes are typified by two facies characteristics. The Mudstone facies records deposition that continued from Lower Scythian sedimentation and Siltstones-mudstone facies comprise the upper part of the Upper Scythian. No strict periodicity in the cyclic pattern due to a proximality-distality trend was established within these two facies. They are characterized by the random unpredictable occurence of storm layers that emphasized the role of storm in the deeper, outer shelf environment. In the Mudstone facies storm layers are represented by exhumed skeletal material from the mudstone host sediments that accumulated as skeletal lags. The mud rich unit of this facies records slow sedimentation in periods with no storms.

Storm layers in the Siltstone-mudstone facies contain calcarenaceous silt material that depicts silt transport by storm currents, indicated by the presence of graded rhythmites and hummocky cross-stratification produced by a single storm event.

Three scales of sedimentary cyclicity were recognized at Strmica. The smallest scale is that of the sedimentary cycles found in the Siliciclastic facies of the Lower Scythian which can be (with reservation) compared to fifth order eustatic cycles and high frequency

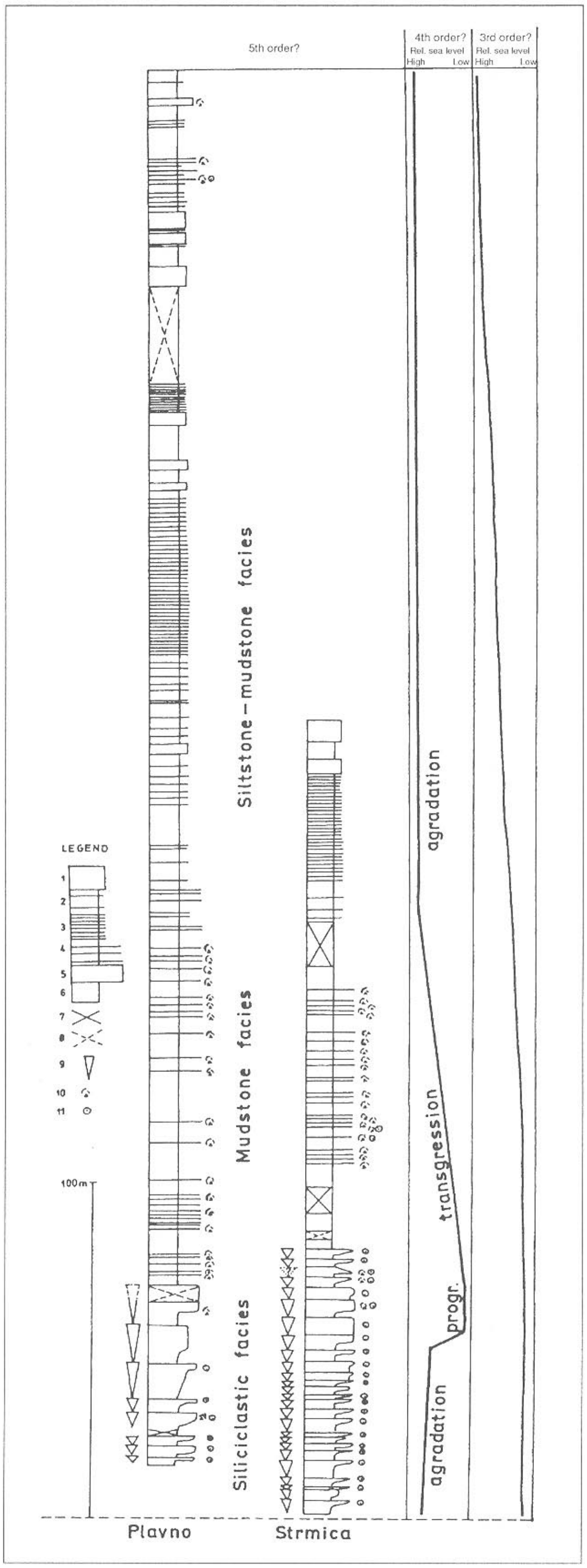

Fig. 15 Facies arrangement in the Strmica and Plavno section with the high and low frequency sea level oscillations observed in sediment setting. Legend: 1) siltstone dominated interval; 2) dominant muddy interval with sporadic intercalations of silt sized skeletal material; 3) siltstone-mudstone alternating interval; 4) dominant mudstone interval with sporadic coarse grained intercalations; 5) coarse grained interval; 6) mud dominated interval; 7) covered interval; 8) partly covered interval; 9) sedimentary cycle; 10) coarse skeletal material; 11) ooids.

sea level changes. Variations in the cycle stacking pattern forming the Siliciclastic facies could be interpreted as transition from an aggradation to progradation trend in the shallow shelf environment. The nonrhythmical cyclic characteristics of the Mudstone facies could be interpreted as a transgressive trend while the appearance of siltstones in the Siltstone-mudstone facies designate gradual transition from transgression to aggradation. The Scythian facies arrangement could be inferred from a long term transgressive succession that corresponds to a third order global transgressive trend in the Scythian age (HAQ et al., 1987).

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7. REFERENCES

AIGNER, T. (1979): Schill-tempestite im oberen Muschelkalk (Trias, SW-Deutschland).- Neus. Jahrbuch F. Geol. u. Palaont. Abh, 157, 326-343.

AIGNER, T. (1985): Storm Depositional Systems: Dynamic Stratigraphy in Modern and Ancient Shallow-marine Sequences.- Lecture Notes in Earth Sci., 3, Springer-Verlag, New York, 173 p.

ALJINOVIĆ, D. (1991): Petrološke i sedimentološke karakteristike naslaga donjeg trijasa na području Plavno i Strmica (Petrological and sedimentological characteristics of Lower Triassic sedimentary rocks at Plavno and Strmica).- Unpublished M.Sc. Thesis, University of Zagreb, 93 p.

ALLEN, J.R.L. (1984): Sedimentary Structures; their Character and Physical Basis.- Developments in Sedimentology, 30, Elsevier, Amsterdam, Oxford, New York, Tokyo, 357-378.

ANDERTON, R. (1976): Tidal shelf sedimentation: an example from the Scottish Dalradian.- Sedimentology, 23, 429-458.

BEARDSLEY, R.C. & BUTMAN, B. (1974): Circulation on the New England continental shelf: response to strong winter storms.- Geophysical Research Letters, 1, 181-184.

BLOOS, V.G. (1976): Untersuchungen über Bau und Entstehung der Feinkornigen Sandsteine des Schwarzen Jura (Hettangium u. tiefstes Sinemurium) im Schwabischen sedimentations bereich.- Arbeiten aus dem Institut für Geologie und Paläontologie, Universität Stuttgart, 277 p.

BOURGEOIS, J. (1980): A transgressive shelf sequence exhibiting hummocky stratification: the Cape Sebastian sandstone (Upper Cretaceous), Southwestern Oregon.- Jour. Sed. Petrology, 50, 681-703.

BRENCHLEY, P.J., PICKERILL, R.K. & STROMBERG, S.G. (1993): The role of wave reworking on the architecture of storm sandstone facies, Bell Island Group (Lower Ordovician), Eastern Newfoundland.- Sedimentology, 40, 359-382.

BRETT, C.E. (1983): Sedimentology, facies and depositional environments of the Rochester shale (Silurian; Wenlockian) in western New York and Ontario.- Jour. Sed. Petrology, 53, 947-971.

BRIDGES, P.H. (1972): The significance of toolmarks on a Silurian erosional furrow.- Geol. Mag., 109, 405-410.

BUTMAN, B., NOBLE, M. & FOLGER, D.W. (1979): Long-term observations of bottom current and bottom sediment movement on the Mid-Atlantic continental Shelf.- Jour Geophys res., 84, C3, 1182-1205.

CHEEL, J.R. & LECKIE, A.D. (1993): Hummocky cross-stratification.- Sedimentology Review, 1, 103-122.

CHOROWICZ, J. (1977): Etude geologique des Dinarides le long de la structure transversale Split-Karlovac (Yougoslavie).- Publ. Soc. geol. Nord, Villeneuve d Ascq., 11, 331p.

DeCELLES, P.G. & CAVAZZA, W. (1992): Constraints of the formation of Pliocene hummocky cross-stratification in Calabria (Southern Italy) from consideration of hydraulic and dispersive equivalence, grain-flow theory, and suspended-load fallout rate.- Jour. Sed. Petrology, 62, 555-569.

De RAAF, J.F., BOERSMA, J.R. & VAN GELDER, A. (1977): Wave generated structures from a shallow marine succession, Lower Carboniferous, County Cork, Ireland.- Sedimentology, 24, 451-483.

DOTT, R.H. (1983): 1982 SEPM Presidental address: Episodic sedimentation - how normal is average? How rare is rare? Does it matter?- Jour. Sed. Petrol., 53, 5-23.

DOTT, R.H. & BOURGEOIS, J. (1982): Hummocky stratification: Significance of its variable bedding sequences.- Geol. Soc. of America Bull., 93, 663-680.

DUKE, W.L. (1985): Hummocky cross-stratification, tropical hurricanes, and intense winter storms.- Sedimentology, 32, 167-195.

DUKE, W.L. (1987): Hummocky cross-stratification, tropical hurricanes, and intense winter storms (Reply).- Sedimentology, 34, 344-361.

DUKE, W.L. (1990): Geostrophic circulation or shallow marine turbidity currents? The dilemma of paleoflow patterns in storm-influenced prograding shoreline systems.- Jour. Sed. Petrology, 60, 870-883.

DZULINSKI, S. & WALTON, E.K. (1965): Sedimentary Features of Flysch and Graywackes.- Developments in Sedimentology, 7, Elsevier Publ. Co., Amsterdam, London, New York, 133-169.

EINSELE, G. & SEILACHER, A. (eds.) (1982): Cycles and Event Stratification.- Springer-Verlag, Berlin, Heidelberg, 536 p.

GOLDHAMMER, R.K., DUNN, P.A. & HARDIE, L.A. (1990): Depositional cycles, composite sea-level changes, cycle stacking patterns, and the hierarchy of stratigraphic forcing: Examples from Alpine Triassic platform carbonates.- Geol. Soc. of America Bull., 102, 535-562.

GOLDRING, R. & BRIDGES, P. (1973): Sublitoral sand sheets.- Jour. Sed. Petrology, 43, 736-747.

GRIMANI, I., ŠIKIĆ, K. & ŠIMUNIĆ, An. (1972): Osnovna geološka karta SFRJ, 1:100 000, list Knin.- Institut za geološka istraživanja Zagreb, Savezni geol. zavod Beograd.

GRIMANI, I., ŠIKIĆ, K. & ŠIMUNIĆ, An. (1975): Osnovna geološka karta SFRJ, 1:100 000, Tumač za list Knin (Abs.: Geology of the Knin sheet).- Institut za geološka istraživanja Zagreb, Savezni geol. zavod Beograd, 61 p.

HAMBLIN, A.P. & WALKER, R.G. (1979): Storm-dominated shallow marine deposits: The Fernie Kootenay (Jurassic) transition, southern Rocky Mountains.- Canadian Jour. Earth Sci., 16, 1673-1690.

HANDFORD, C.R. (1986): Facies and bedding sequences in shelf-storm-deposited carbonates - Fayetteville Shale and Pitkin Limestone (Mississippian), Arkansas.- Jour. Sed. Petrology, 56, 123-137.

HAQ, B.U., HARDENBOL, J & VAIL, P.R. (1987): Chronology of fluctuating sea levels since the Triassic.- Science, 235, 1156-1167.

HARMS, J.C., SOUTHARD, J.B. SPEARING, D.R. & WALKER, R.G. (1975): Depositional Environments as Interpreted from Primary Sedimentary Structures and Stratification Sequences.- Soc. Econ. Paleontologists Mineralogists Short Course, 2, 161p.

HARMS, J.C., SOUTHARD, J.B. & WALKER, R.G. (1982): Structures and Sequences in Clastic Rocks.- Lecture Notes for Short Course, 9, 8-1 - 8-51.

HERAK, M. (1973): Some tectonical problems of the evaporitic area in the Dinarides of Croatia.- Geol. vjesnik, 26, 29-40.

HINE, C.A. (1977): Lily Bank, Bahamas: History of an active oolite sand shoal.- Jour. Sed. Petrology, 47, 1554-1583.

IVANOVIĆ, A., ŠĆAVNIČAR, B., SAKAČ, K. & GUŠIĆ, I. (1971): Stratigrafski položaj i petrografske karakteristike evaporita i klastita okolice Drniša i Vrlike u Dalmaciji (Stratigraphic possition and petrographical characteristics of the evaporite and clastic deposits in the environs of Drniš and Vrlika (Dalmatia)).- Geol. vjesnik, 24, 11-33.

JENNETTE, D.C. & PRYOR, W.A. (1993): Cyclic alternation of proximal and distal storm facies: Kope and Fairview formations (Upper Ordovician), Ohio and Kentucky.- Jour. Sed. Petrology, 63, 183-203.

JOHNSON, H.D. (1977): Shallow marine sand bar sequences: an example from the late Precambrian of North Norway.- Sedimentology, 24/2, 245-270.

JOHNSON, H.D. & BALDWIN, C.T. (1986): Shallow Silicicastic Seas.- In: READING, H.G. (ed.): Sedimentary Environments and Facies. Blackwell Sci. Pub., Oxford-London, 229-282.

KAZMIERCZAK, J. & GOLDRING, R. (1978): Subtidal flat-pebble conglomerate from the Upper Devonian of Poland: a multiprovenant high energy product.- Geol. Mag., 115, 359-366.

KREISA, R. (1981): Storm generated sedimentary structures in subtidal marine facies with example from the Middle and Upper Ordovician of Southwestern Virginia.- Jour. Sed. Petrology, 51, 832-849.

KUMAR, N. & SANDERS, J.E. (1976): Characteristics of shoreface storm deposits: modern and ancient examples.- Jour. Sed. Petrology, 46, 145-162.

LECKIE, D. (1988): Wave-formed, coarse-grained ripples and their relationship to hummocky cross-stratification.- Jour. Sed. Petrology, 58, 607-622.

LEVELL, B.K. (1980): Evidence for currents associated with waves in Late Precambrian shelf deposits from Finnmark, North Norway.- Sedimentology 27, 153-167.

MARKELLO, J.R. & READ, J.F. (1981): Carbonate ramp-to-deeper shale shelf transitions of an upper Cambrian intrashelf basin, Nolichucky Formation, Southwest Virginia Appalachians.- Sedimentology, 28/4, 573-597.

MYROW, P.M. (1992): Bypass-zone tempestite facies model and proximality trends for an ancient muddy shoreline and shelf.- Jour. Sed. Petrology, 62, 99-115.

REINECK, H.E. & SINGH, I.B. (1972): Genesis of laminated sand and graded rhythmites in storm-sand layers of shelf mud.- Sedimentology, 18, 123-128.

REINECK, H.E. & SINGH, I.B. (1973): Depositional Sedimentary Environments.- Springer-Verlag, Berlin, 75-81.

SIMPSON, E.L. & ERIKSSON, K.A. (1990): Early Cambrian progradational and transgressive sedimentation patterns in Virginia: an example of the early history of a passive margin.- Jour. Sed. Petrology, 60, 84-100.

SMITH, J.D. & HOPKINS, T.S. (1972): Sediment transport on the continental shelf off Washington and Oregon in light of recent current measurements.- In: SWIFT, D.J.P., DUANE, D.B. & PILKEY, O.H. (eds): Shelf Sediment Transport: Process and Pattern. Dowden, Hutchinson and Ross Inc., Stroudsburg, Pa., 143-180.

SMOOT, J.P. (1983): Depositional subenvironments in an arid closed basin; The Wilkins Peak Member of the Green River Formation (Eocene), Wayoming, U.S.A.- Sedimentology, 30, 801-827.

SNEDDEN, J.W., NUMMEDAL, D. & AMOS, A.F. (1988): Storm and fair-weather combined flow on the central Texas continental shelf.- Jour. Sed. Petrology, 58, 580-595.

SOEGAARD, K. & ERIKSSON, K.A. (1985): Evidence of tide, storm, and wave interaction on a Precambrian siliciclastic shelf: the 1,700 M.Y. Ortega Group, New Mexico.- Jour. Sed. Petrology, 55, 672-684.

SWIFT, D.P. & NUMMEDAL, D. (1987): Hummocky cross-stratification, tropical hurricanes, and intense winter storms (Discussion).- Sedimentology, 34, 338-344.

SWIFT, D., HUDELSON, M.P., BRENNER, L.R. & THOMPSON, P. (1987): Shelf construction in a foreland basin: storm beds, shelf sandbodies, and shelf slope depositional sequence in the Upper Cretaceous Mesaverde Group, Book Clifs, Utah.- Sedimentology, 34, 423-459.

SWIFT, D.J.P., FREELAND, G.L. & YOUNG, R.A. (1979): Time and space distribution of megaripples and associated bedforms, Middle Atlantic Bight, North American Atlantic Shelf.- Sedimentology, 26, 389-407.

ŠĆAVNIČAR, B. (1973): Klastiti trijasa u Gorskom kotaru (Clastic Sediments of the Triassic in the Gorski Kotar Region).- Acta Geologica, VII/3, 105-106, Zagreb.

ŠĆAVNIČAR, B. & ŠUŠNJARA, A. (1983): The geologic column of the Lower Triassic at Muć (Southern Croatia).- Acta Geologica, 13, 1-25, Zagreb.

TIŠLJAR, J. (1992): Origin and depositional environments of the evaporite and carbonate complex (Upper Permian) from the central part of the Dinarides (Southern Croatia and Western Bosnia).- Geol. Croatica, 45, 115-127.

VAIL, P.R., AUDEMARD, F., BOWMAN, S.A., EISNER, P.N. & PEREZ-CRUZ, C. (1991): The Stratigraphic Signatures of Tectonics, Eustasy and Sedimentology - an Overview.- In: EINSELE, G., RICKEN, W. & SEILACHER, A (eds.): Cycles and Events in Stratigraphy. Springer-Verlag, Berlin, 617-660.

VOS, R.G. (1977): Sedimentology of an Upper Paleozoic river, wave and tide influenced delta system in southern Morocco.- Jour. Sed. Petrology, 1242-1260.

WELLER, J.M. (1974): Stratigraphic Facies, Differentiation and Nomenclature.- In: STEIN, J.B. (ed.): Facies and the Reconstruction of Environments. AAPG Reprint Series, 10, 609-639, Tulsa, Oklahoma.

WHITAKER, J.H.McD. (1973): "Gutter cast", a new name for scour-and-fill structures: with examples from the Llandoverian of Ringerike and Malmoya, southern Norway.- Norsk Geologisk Tidsskrift, 53, 403-417, Oslo.

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