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CROSS-BEDDED SANDSTONES DEPOSITED BY TIDAL CURRENTS IN THE EOCENE OF THE OUTER DINARIDES (ISLAND OF RAB, CROATIA)

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Key words: Tidal deposits, shallow-marine deposits, dunes, Eocene, the Island of Rab, Dinarides.

Ključne riječi: Tidalni sedimenti, plitkomorski sedimenti, dine, eocen, Rab, Dinaridi.

Within the Eocene clastic sequence of the Rab Island the cross-bedded sandstone facies has been recognized. Cross-bedded sandstones have been deposited by migration of dunes and large-scale compound forms. Features indicating tide-ebb, and spring-neap periodicities, together with paleocurrent directions, indicate tidal currents as the main factor of bedform dynamics and origin of cross-bedded sandstones. The Rab portion of the ancient tidal sea was dominated by tidal flows directed towards SW. The greatest part of sediments constituting the Rab Eocene clastic succession is of shallow-marine origin.

Unutar eocenskog klastičnog slijeda otoka Raba prepoznat je i opisan facijes koso slojevitih pješčenjaka. On je nastao migracijom jednostavnih dina i velikih složenih dina. Poludnevna i dvotjedna periodičnost taložnog režima, kao i smjerovi struja upućuju na tidalne struje kao na glavni faktor dinamike taložnih formi i postanka koso slojevitih pješčenjaka. Dominantni tidalni tokovi tadašnjih rapskih okoliša bili su usmjereni prema jugozapadu. Značajke ostalih klastita eocena Raba, zajedno s tidalnim karakterom koso slojevitih pješčenjaka, indiciraju plitkomorski karakter okoliša za veći dio klastičnog slijeda.

1. INTRODUCTION

During the Early to Middle Eocene the widespread shallow marine carbonate deposition in the Outer Dinaric realm was replaced by clastic deposition. The Eocene clastics occur in two main zones : (1) the inner (northeastern) zone is generally characterized by marine to continental conglomerate-bearing deposits commonly designated as the Promina Beds; (2) the outer (southwestern) zone, dominatly consisting of marine sandstones and mudstones, is considered to reflect flysch-type deposition (AUBOUIN & al., 1972, MARINČIĆ, 1981, Fig. 1). Details documenting flysch-type deposition have been presented for certain parts of the outer clastic zone (e.g. MAGDALENIĆ, 1972 for central Istria, BABIĆ & ZUPANIČ, 1983 for the Benkovac area near Zadar, MARJANAC, 1989 for the Split environs). The relevant data for other parts of the same zone are mostly lacking, and the purpose of this work is to provide data about the Eocene clastic deposition in such an area situated in the Northern Adriatic: the Island of Rab (Fig. 1). It will be shown that the Rab Eocene clastics are mostly shallow-marine deposits. Particularly, the cross-bedded sandstone facies will be described, and data will be presented that suggest the dominant role of tidal currents in its origin.

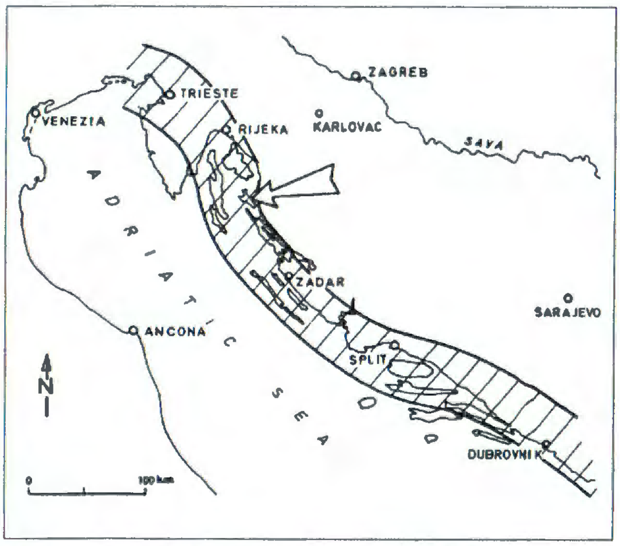

Fig. 1 Situation of the Island of Rab (arrowed), and the Eocene flysch belt after MARINČIĆ (1981; simplified).
Slika 1 Smještaj otoka Raba (strelica) i prostiranje Eocenskog fliškog pojasa prema MARINČIĆ (1981; pojednostavljeno).

2. GEOLOGICAL SETTING AND OUTLINE STRATIGRAPHY

The Island of Rab consists of two large superposed units corresponding to two contrasting lithologies: (1) Upper Cretaceous and Paleogene carbonates, and (2) Eocene clastics (WAAGEN, 1904, 1908, 1911, MAMUŽIĆ, 1962). Besides, Tertiary breccia patches and Quaternary cover occur in several parts of the island. The tectonic structure of the island is generally characterized by two folds. Upper Cretaceous and Paleogene carbonates are exposed in two anticlinal zones while Eocene clastics appear in two synclinal zones (Fig. 2). Numerous faults, not shown in Fig. 2, and particularly those paralleling the fold axes, and occurring at or near the boundary between carbonates and clastics, may complicate the structure (MAMUŽIĆ, 1962).

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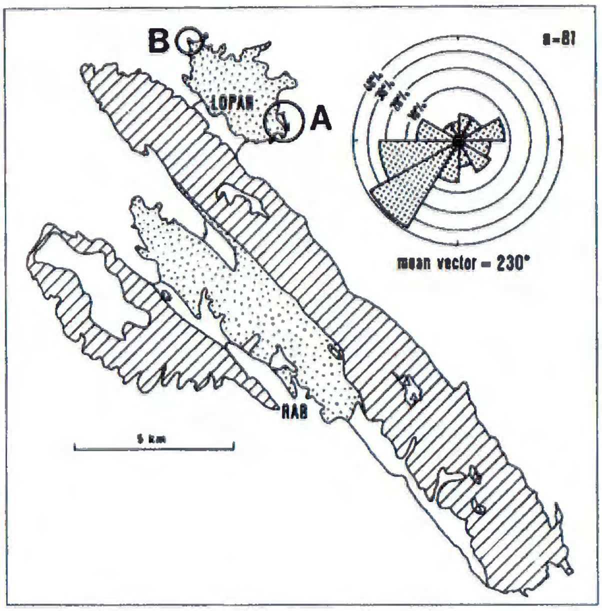

Fig. 2 Geological map of the Island of Rab (after MAMUŽIĆ 1962; simplified). Lines: Late Cretaceous and Paleogene carbonates. Dots: Eocene clastics. Triangles: Tertiary breccia. Blank: Quaternary. A and B: location of logs in Fig. 3. *Insert*: Azimuths of foreset dip directions in Eocene cross-bedded sandstones, Rab Island, plotted in a rose diagram. Criteria for rose diagram construction after NEMEC (1988). Vector magnitute = 58 %; Standard deviation = 53°.
Slika 2 Geološka karta otoka Raba (prema MAMUŽIĆ, 1962; pojednostavljeno). Crte: karbonatni sedimenti mlađe krede i paleogena. Točke: eocenski klastiti. Trokuti: tercijarna breča. Bijelo: kvartar. A i B: smještaj stupova na sl. 3. *Umetak:* Azimuti smjerova nagiba kosih slojeva u eocenskim koso slojevitim pješčenjacima otoka Raba, uvršteni u ružin dijagram. Kriteriji za konstrukciju ružinog dijagrama prema NEMECU (1988). Mean vector = srednji vektor; Magnituda vektora = 58 %; Standardna devijacija = 53°.

Transitionally overlaying shallow-marine limestone with *Alveolina* and *Nummulites* is more than 500 m thick Eocene clastic succession, consisting of sandstones, mudstones, and very rare conglomerates. These sediments were laid down during the Late Lutetian and Bartonian, and possibly earliest Priabonian (WAAGEN, 1904, MAMUŽIĆ, 1962, MULDINI - MAMUŽIĆ, 1962 - the names of time-stratigraphic units are adopted from modern usage, e.g. BERGGREN & al., 1985). MAMUŽIĆ (1962) and MULDINI - MAMUŽIĆ (1962) have subdivided the sequence into a basal marly unit ("lower flysch") and a main sandy unit ("upper flysch").

3. DESCRIPTION OF CROSS-BEDDED SANDSTONE FACIES

3.1. GENERAL DATA

The vertical succession of the Rab Eocene clastic deposits is not easily observed in the field and the existence of numerous faults calls for caution in the reconstruction of a complete sequence as well as its thickness. The same is also true when the vertical position of cross-bedded sandstone facies within the overall clastic succession is estimated. Preliminary observations suggest that most occurrences of this facies are within some 200 or 300 m thick upper portion of the clastic succession.

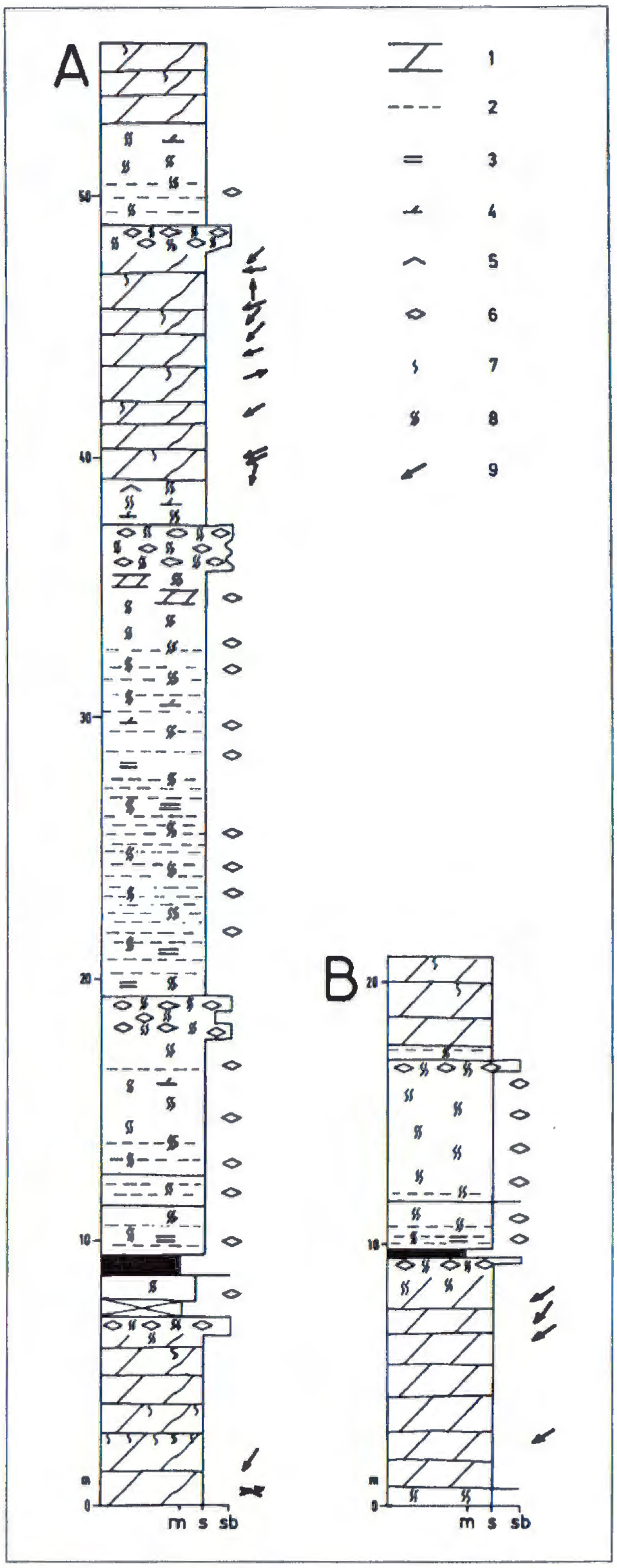

Fig. 3 Logs A, and B containing complex cross-bedded sandstone units, and associated sediments. Locations in Fig. 2. 1-cross-bedded sandstone, 2-mudstone laminae including their relics, 3-horizontal laminae, 4-current-ripple lamination, 5-wave ripples, 6-skeletal remains, mostly nummulites and mollusks, 7-burrows, 8-strong bioturbation, 9-paleocurrent direction, sb-skeletal beds.
Slika 3 Stupovi A i B prikazuju složene koso slojevite jedinice i s njima udružene sedimente. Smještaj na sl. 2. 1-koso slojeviti pješčenjak, 2-lamine mulja i njihovi relikti, 3-horizontalna laminacija, 4-laminacija strujnih riplova, 5-valni riplovi, 6-skeletni ostaci, uglavnom numuliti i mekušci, 7-bušotine, 8-jaka bioturbacija, 9-smjer struje, skeletni slojevi.

There, cross-bedded sandstones appear repeatedly. Although the facies is present within both northern and southern clastic zones of the island, common occurrences and best outcrops are situated within the northern clastic zone. Two simplified logs containing cross-bedded sandstone facies and associated deposits are shown in Fig. 3. After describing cross-bedded sandstones a brief description of other Eocene clastics will be added.

3.2. MAIN FEATURES

Cross-bedded sandstone facies is represented by complex units (Fig. 3, and Pl. I, Fig. 4) consisting of cross-bedded sets. These complex units are mostly 2 to 6 m thick and may be traced for more than 600 m diagonally to the dominat current direction. The units may overlay and underlay various sediments but bioturbated sandstone and skeletal lags are most common. Basal contacts of the units may be characterized either by slight reworking of the underlying deposits as exemplified by reworked nummulites in small basal sets or thin streaks, by erosionally scoured surface (less than 0.4 m deep scours) that may be marked by chert-pebble conglomerate, or by a gradual transition from sandstone - mudstone alternation. Upper contacts of the complex units are mostly obscured by bioturbation.

Most of the surfaces separating cross-bedded sets are about horizontal or very gently inclined approximately in the dominant direction of the cross-bedded sets (Pl. I, Fig. 4). Foreset orientations have been measured in a number of complex cross-bedded units (Fig. 2 - Insert), and a conspicuous maximum of paleocurrent directions towards southwest (mean vector = 230°) has been obtained. "Herringbone" structures do occur, but not frequently (Pl. I, Fig. 3). The thickness of the cross-bedded sets varies from 0.04 to 1.5 m, and mostly from 0.07 to 0.40 m. Their form may be planar (tabular or wedge-shaped), or trough-shaped, but departures from the "regular" forms are common being caused mostly by erosion or by the "overtaking" by an overcoming set. The largest troughs observed are 4 m wide and 0.6 m thick. The sets may be separated by siltstone to mudstone laminae or by a few centimeters thick sandy-silty deposit that displays wavy, current ripple, or wave ripple lamination. These interset sediments are commonly observed to represent a down current extension of toesets.

3.3. INTERNAL OGANIZATION OF INDIVIDUAL CROSS-BEDDED SETS

Sets are internally characterized by specific features that have been observed within the majority of complex cross-bedded sandstone units. These features are: (1) systematic succession of the foreset laminae bundles, separated by discontinuities or reactivation surfaces, (2) periodic changing of the character of bundles and discontinuities within the lateral succession.

Bundle thickness may attain more than 0.4 m and those bundles that are less than about 15 mm thick can be hardly discerned. Foreset laminae within bundles may have angular or tangential basal contacts (Fig. 4). Thin

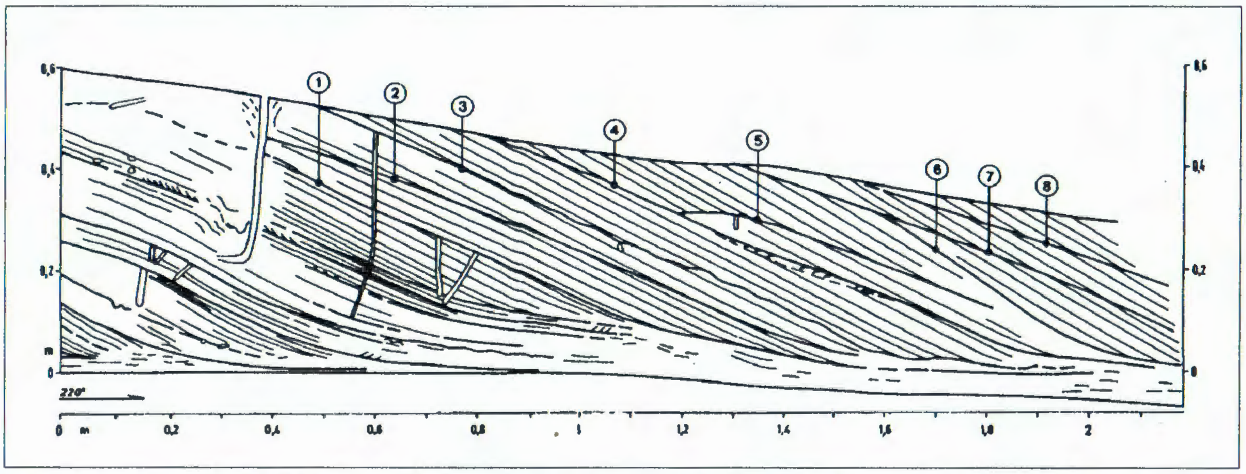

Fig. 4 Example of a cross-bedded set showing reactivation surfaces (thick lines), and bundles consisting of foreset laminae (thin lines). Both lower and upper set boundaries (also represented by thick lines) are inclined in the direction close to direction of former dune migration. Thick bundles are bounded by reactivation surfaces characterized by erosional truncation (middle and right part of the drawing), and correspond to spring-tide stage. Earlier portion of the sequence probably includes several thin, less clearly discernible neap-stage bundles having higher set base, and (below 0.3 m vertical scale-left) several spring-stage bundles. Numbers of reactivation surfaces correspond to those in Pl. I, Fig. 1. Downslope directed small-scale current-ripple foresets (at 0.15 - 0.45 m and at 0.5 m) represent a " reactivation structure" formed during the "acceleration stage" of the relevant tidal flow (BOERSMA & TERWINDT, 1981). Oppositely directed small-scale current ripple foresets produced by subordinate tide are locally seen in toesets (at 0.6 and 1.05 m), and foresets (at 1.45 m). Tubes are *Ophiomorpha* burrows. Loc. B in Fig. 2.

Slika 4 Primjer koso slojevitog niza, koji pokazuje reaktivacijske plohe (debele crte) i svežnjeve zaklonih lamina (tanke crte), bilježeći poludnevne periode plime i oseke. Donja i gornja granica niza (također debele crte) nagnute su u sličnom smjeru poput smjera migracije dine.Zaklone lamine riplova, usmjerene niz padinu dine (kod 0.15 - 0.45 m i 0.5 m) predstavljaju "reaktivacijsku teksturu" nastalu u vrijeme "stadija ubrzanja" odnosnog tidalnog toka (BOERSMA & TERWINDT,1981). Nasuprotno usmjerene zaklone lamine strujnih riplova, proizvedene podređenom tidom, vide se mjestimice u podnožju lamina (kod 0.6 i 1.05 m) i u sredini kosine (kod 1.45 m). Debeli svežnjevi razmeđeni reaktivacijskim plohama s erozijskim presijecanjem (sredina i desni dio crteža) odgovaraju najvišim tidama. Brojevi reaktivacijskih ploha odgovaraju onima na tab. I, sl. 1. Raniji dio slijeda vjerojatno uključuje nekoliko svežnjeva stadija niskih tida, koji imaju povišenu bazu niza, te (ispod 0.3 m na vertikalnoj skali - lijevo) nekoliko svežnjeva stadija visokih tida. Cijevi su rovanja tipa *Ophiomorpha*, Lok.B u sl..2.

(3 - 10 mm) and mostly indistinct current ripple laminated unit may rarely occur at the very base of the bundle in its foreset region. If discernible, the direction of the ripple migration in this unit was down the lee slope of the former dune (Fig. 4). Similar but oppositely directed current ripple units and lenses may be found within toesets, and at the top of rare bundles in their foreset portion (Fig. 4). Bundles may merge into bottomset deposits (Fig. 4) that are represented by sandstone to muddy sandstone. These deposits are either massive, indistinctly laminated, or wavy, current ripple and wave laminated, locally showing a flaser structure. In the case of current ripples they are directed oppositely to the foreset direction of cross-bedded sets. The external geometry of bundles is defined by the geometry of bounding reactivation surfaces.

The discontinuities or reactivation surfaces separating bundles (Figs. 4, and 5; Pl. I, Fig. 1) are characterized either by erosional truncation of previously accreted deposits, by mud drape, or by both of these features. These surfaces are either parallel to, or more gently inclined than, the adjacent foreset sand laminae. Only rare reactivation surfaces are steeper than sandy foresets. The difference in the attitudes of sandy foresets and reactivation surfaces coincides with the erosional type of discontinuities. Measurements made at the outcrop shown in Fig. 4, and Pl. I, Fig. 1 have yielded 16 to 21 degrees (exceptionally 31) for the reactivation surfaces in contrast to 27 to 34 degrees for the foreset laminae. Otherwise, both of these structural elements may be inclined at lower angles than in the example mentioned above, and particularly the reactivation surfaces may be very gently inclined. As a rule, the basal contacts of reactivation surfaces are tangential. They may join the top surface of the underlaying set or loose their identity within the bottomsets. Their continuation into the bottomset package may be characterized by an irregular or wavy shape.

As mentione above, the lateral succession of bundles and associated discontinuities may show periodic changing in their character (Fig. 5, and Pl. I, Fig. 2). The most conspicuous change consists in alternating tendencies of increasing and decreasing bundle thicknesses. Erosional truncations are mostly associated with thicker bundles in contrast to mostly non-erosional surfaces between thinner bundles. Lower set boundary is higher in the case of thinner bundle succession, and falls below thicker bundles. Selected examples have shown some 13 to 18 bundles per thickening-thinning period.

3.4. TRACE FOSSILS

Vertical to slightly oblique *Ophiomorpha*-type shafts (Fig.4), commonly showing knobby walls, are typical ichnofossils in cross - bedded sandstones. Their length may attain 1 m. Their tops may be either at the upper surface of the cross-bedded sets, or at the reactivation surfaces. Thin vertical shafts (*Skolithos?*) have also been observed. Small scale burrows may disturb the top of sets and bundles. Bottomset and interset deposits locally contain horizontal *Ophiomorpha* burrows.

3.5. PETROGRAPHY

The sandstone constituting the cross-bedded sets is mostly fine-grained (over 0.125 mm), and subordinately medium-grained. Coarse-grained sandstone may also be found locally, and laminae of granules or nummulites, as well as scattered molluscs and pebbles, appear here and there.

The particle composition of sandstone is dominated by quartz (mono- and polycrystalline), and by carbonate grains including lithoclasts and subordinate skeletal remains, mostly derived from molluscs and benthic foraminifers. Plant detritus may be common, particularly in toesets and bottomsets.

4. SHORT DESCRIPTION OF THE DEPOSITS OTHER THAN CROSS-BEDDED SANDSTONES

Besides cross-bedded sandstones there are several types of clastic deposits occurring within the Eocene clastic succession of the island. Parts of these deposits appear in graphic logs in Fig. 3.

Prominent sediment types are ***skeletal beds*** and ***chert-pebble conglomerates*** which form stringers, thin sheets, and lenses.

Bioturbated sandstone to muddy sandstone is quite common. It may contain scattered nummulites and molluscs, and locally shows relics of cross-bedding, ripple lamination, horizontal lamination, and skeletal lags.

There are also ***thin-bedded sandstone-mudstone alternations*** with erosionally based sandstone beds locally showing horizontal laminae, skeletal stringers, and ripple lamination at their tops.

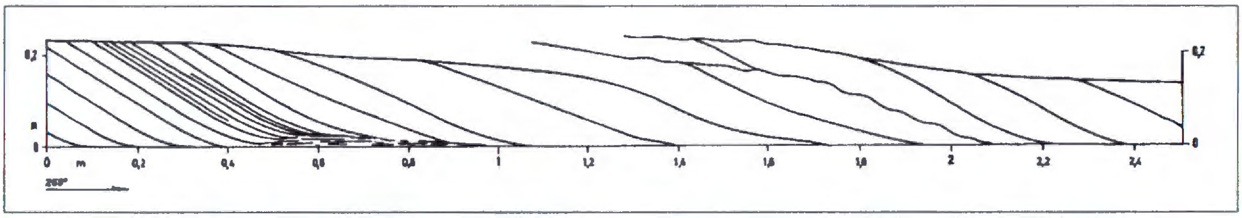

Fig. 5 Example of a spring-neap-spring sequence of bundles. Neap-stage bundles are thin, partly hardly discernible (simplified in the drawing), and have a higher set base. Loc. B in Fig. 2.

Slika 5 Primjer slijeda svežnjeva taloženih u razdoblju od najviših,preko niskih, do ponovno najviših tida. Svežnjevi stadija niskih tida su tanki, djelimice teško razlučivi (na crtežu pojednostavljeno), a njihova baza je povišena. Lok. B u sl. 2.

Another group of deposits includes ***thin- to-thick-bedded massive to laminated sandstones***. They are erosionally based, and some of them may locally display horizontal laminae or hummocky cross-stratification.

Representatives of all these groups may closely alternate with cross-bedded sandstones. The last two groups seem to include sediment types that are likely to occur unrelated to cross-bedded sandstones.

5. DISCUSSION

5.1. THE ORIGIN OF INDIVIDUAL CROSS-BEDDED SETS

The geometry and structure of cross-bedded sets described above have been produced by migration of 2-D and 3-D dunes (terminology after ASHLEY - symp. chairperson, 1990). The measured set thicknesses (0.04 to 1.5 m) depend on primary dune heights and various degrees of their reduction due to erosional processes, but it is likely that dunes of various heights and spacings existed. The greatest set thickness of 1.5 m proves the existence of dunes with a spacing between 20 and 100 m, classified as "large dunes" (Ashley - symp. chairperson, 1990). The internal structure of the majority of cross-bedded sets is well comparable to those described from modern tidal environments. In Rab examples, periodically recurrent "continuous"deposition of foreset sand laminae alternating with correspondingly periodal processes generating reactivation surfaces, resulted in the formation of lateral sequence of bundles, and such regime has been explained by semidiurnal tidal flow reversals, and by alternation of dominant and subordinate tidal flows (BOERSMA, 1969, DE RAAF & BOERSMA, 1971, BOERSMA & TERWINDT, 1981). In contrast to the dominant tidal flows depositing foreset laminae, the subordinate flows, having lower average strenght may only be able to erosionally modify previous deposits, and possibly to deposit smaller volumes of sediments that will mostly or completely be removed by subsequent dominant flows. Observations on Rab deposits show that subordinate flows either modified preceding sediments and bedforms, and produced the erosional type of discontinuity, or left them practically intact. The relevant tidal environments were dominated by tidal flows generally directed towards the southwest (Fig. 2 - Insert). This is the reason why the resultant, dominantly unidirectional orientation of superposed cross-bedded sets is so obvious and common, when observed in the outcrops (Pl. I, Figs. 4 and 5). This is in accordance with the results of studies of modern and ancient tidal deposits that have shown the dominance of either ebb or flood tidal flows in separate parts of a tidal realm (NIO & al., 1981, DE BOER & al., 1988). Oppositely directed flows might become more important only during certain short time intervals, as recorded by infrequent appearance of "herringbones"(Pl. I, Fig. 3), and by the paleocurrent directions shown in logs (Fig. 3), and diagram in Fig. 2 - Insert.

Thin current-laminated unit observed to occur at the very base of some bundles (Fig. 4) must have been produced by migration of small-scale ripples down the lee face of the dune at the very beggining of the activity of the dominant tidal flow. This early phase of tide invasion precedes full vortex development, and ripples arriving at the top edge of the dune lee face will retain their identity and move down the slip-face, instead of feeding their sand to an avalanche (BOERSMA & TERWINDT, 1981). That is why these authors have used the term "reactivation structures" for this and other related structures, and the term "accelaration stages" for corresponding tidal flow stages. Similar but oppositely directed small scale structures in toesets and bottomsets, including rare examples found at the very top of the bundle in the foreset region (Fig.4), are well known and easily explained as a result of the action of subordinate tidal flows. Other small-scale structures observed in bottomset deposits reflect weak flows and an influence of waves. Mud drapes marking reactivation surfaces have been deposited during periods of dune stillstands.

Besides the record of the tide-ebb periodicity, successive bundles and reactivation surfaces also display a larger-scale periodical arrangement. It is most conspiciously defined by alternating trends of bundle thickening and thinning, that are accompanied by variation in the character of reactivation surfaces (Fig. 5 and Pl. I, Fig. 2). This type of periodicity reflects increase and decrease of flow strength during each spring-neap period (two weeks), which ideally produces 28 bundles (VISSER, 1980). During spring-tide stage in the relevant part of the ancient Rab tidal sea, dominant tidal flows supplied higher quantities of sand to the dune lee-slope, that resulted in deposition of thick bundles. Subordinate flows of the same spring tide stage might be capable to erode and truncate the dune lee-side, that caused the formation of the erosional (truncation) type of discontinuities. During neap-tide stage dominant flows supplied less sand and deposited thinner bundles. As subordinate flows were mostly unable to erode during neaps, foreset parallel (or very slightly erosional) reactivation surfaces resulted. Weaker flows during neap-tide stages were also responsible for a better preservation of toeset-bottomset extensions, and a consequent rise of the set base (Fig. 5).

When the flow strength drops so low as to stop the sand supply to the dune lee-face, the dune becomes stationary during one or several ebb-flood cycles, as reported from recent tidal environments (DE RAAF & BOERSMA, 1971, ALLEN & FRIEND, 1976, BOERSMA & TERWINDT, 1981). Such hydrodynamic conditions are reflected in the deposition of a smaller number of bundles per spring-neap cycle than ideal (28), The feature has been observed in Rab tidal bundle sequences, and particularly in neap stage portions of the sets that documents dune stillstands during a certain number of ebb-tide cycles within neap stages.

The high-energy environments, characterized by shifting sand and quickly alternating erosional and depositional activities described above, were hostile to most benthic organisms. In response to such conditions only rare suspension feeders have constructed vertical and rather deep shafts, such as vertical *Ophiomorpha*-type burrows (FREY & al., 1987, FREY & PEMBERTON, 1984), which are the most commonly observed trace fossils in Rab cross-bedded sandstones. On the other hand, the same authors stated that horizontal *Ophiomorpha* burrows were constructed in lower energy environments, that corresponds to their occurrences in bottomset and interset deposits of the Rab examples. The location of small-scale burrows in bottomset and interset sediments, as well as their connection with set upper surfaces and reactivation surfaces, also suggest lower energy conditions, including dune stillstand, during their constructions.

5.2. ORIGIN OF COMPLEX CROSS-BEDDED SANDSTONE UNITS

The existence of gently inclined bounding surfaces being directed in the same or similar sense like cross-bed foresets (Pl. I, Fig. 4), indicates migration of the relevant dunes down the larger-scale gentle slopes, and that these slopes were laterally accreting by the successive descending cross-bedded sets with rare intervening climbing sets. Then, the dunes migrated down the lee slope of several meters high low-angle compound forms. These forms are comparable to modern low-angle "compound dunes" (term after ASHLEY-symp. chairperson, 1990), or low-angle compound "sand waves", which are characterized by superimposed smaller bedforms, namely dunes. Many authors have applied the term "sand waves" for complex bedforms with low-angle slopes, but the same term has also been used for simple bedforms here described as dunes. This reflects a part of the confusion existing in bedform terminology, and the use of the terms "dune" and "compound dune" in the present work is consistent with the classification of large-scale subaqueous bedforms recently proposed by an expert panel (ASHLEY-symp. chairperson, 1990), as already mentioned at the beginning of the discussion paragraph.

In modern subaqueous environments the sides of compound bedforms mentioned above are rarely steeper than 10°, and can slope as low as 1° (review in ALLEN, 1984). It means that many cross-bedded sandstone units occurring in the Rab clastic succession, having about horizontal bounding surfaces, might have also been generated by processes related to the dynamics of the large-scale low-angle compound dunes.

5.3. ORIGIN OF SEDIMENTS OTHER THAN CROSS-BEDDED SANDSTONES - A SHORT REVIEW

The depostion of ***skeletal beds*** and ***chert-pebble conglomerates*** must have been related to higher energy events above storm wave base, based on their own features (reviews in JOHNSON & BALDWIN, 1986, and ELLIOT, 1986), as well as on the alternation with tidal cross-bedded sandstones. ***Hummocky cross-stratified units*** are well known products of storm related processes. A part of relict features (cross-bedding, skeletal lags), observed in ***bioturbated sandstones***, are indicative of shallow water processes, and strong bioturbation is highly suggestive feature for shallow water environments.

Considering that representatives of ***sandstone-mudstone alternations*** and ***massive to laminated sandstones***, both containing skeletal intercalations and reflecting waning flow conditions, may alternate with tidal cross-bedded sandstones, at least a part od sediments of these groups are also genetically related to storm processes (op.cit.). The other part, having recorded waning flow conditions during their deposition, might represent either storm beds, or turbidites.

Therefore, the sediments other than cross-bedded sandstones are mostly shallow-marine.

5.4. THE CHARACTER OF THE EOCENE CLASTIC SUCCESSION OF THE ISLAND OF RAB AND SOME IMPLICATIONS

The data concerning depositional environments presented above will be now put together and considered within the whole Eocene Rab clastic succession.

Clastic environments succeded carbonate platform envionments. The change occurred gradually around the middle of the Lutetian, and caused the installation of a "deeper marine environment", where a basal marly unit has been deposited (chiefly "lower flysch" of MAMUŽIĆ, 1962, and MULDINI - MAMUŽIĆ,1962)

The basal marly deposits were followed by deposits of the main sandy unit ("upper flysch" of MAMUŽIĆ, 1962, and MULDINI - MAMUŽIĆ, 1962), consisting of various facies including cross-bedded sandstones described here. As discussed above, cross-stratified sandstone facies indicates the action of tidal currents that governed the dynamics of dunes, larger-scale compound dunes ("sand waves"), and related depositional features. Such tidal bedforms are known from various settings ranging from estuarine to coastal, and to shelf environments. As vertical position of cross-bedded facies is largely within some 200 (300 ?) m thick upper portion of clastic succession, repeated occurrence in this facies together with alternating storm-related deposits in this part of the succession clearly indicates it's shallow-marine character.

The lower and not clearly defined portion of the succession, which might be some 200 to 300 m thick, includes several occurrences of reliable storm-related deposits, but it is not clear if some occurrences of tidal deposits also belong to this part of succession. In any case, parts of the lower portion of the clastic succession have also been deposited above the storm wave base. Other parts, as already noted, might be either storm-related sediments deposited above the storm wave base, or tubidites. Consequently, and keeping in mind the poor knowledge of the complete vertical sequence, two possibilities are available as to the origin of the lower part of the clastic succession: (1) the whole lower portion is shallow-marine, and (2) a part is shallow marine, and another part reflects deeper marine environments.

Now, if the entire Eocene Rab clastic succession is considered, it follows that it is either shallow-marine as a whole, or shallow-marine for the most part. If the second is correct, the subordinate deeper water sediments must occur in parts (lower?) of the lower portion of the clastic succession.

It is to be noted that MAMUŽIĆ (1962) and MULDINI - MAMUŽIĆ (1962), in spite of treating the main sandy unit as flysch (their "upper flysch"), have already pointed out its shallow-marine origin, based on foraminiferal taxa determined, and the domination of larger foraminifera in particular. However, it is well known that flysch-type sediments may contain rich fauna of displaced larger foraminifera.

The character of shallow marine clastic environments interpreted for the most part of the Rab Eocene clastics suggests a considerably larger extent of the relevant shallow sea in comparison to the small present day Rab clastic areas. It means that an important part of the Outer Dinaric clastic realm was then occupied by a shallow sea. Taking into account a flysch-type deposition in some other parts of the MARINČIĆ's (1981) "flysch" zone (Fig. 1), we are faced with a complex clastic depositional realm characterized by variability of the depositional environments and resultant facies and depositional systems, as well as by the complex topography and evolution. Therefore, the data about Rab clastics support the opinion that we are dealing with a topographically dissected belt in both longitudinal and transversal directions (BABIĆ & ZUPANIČ, 1990). It also means that the interesting idea about separate small clastic basins (based on biostratigraphic study; PICCOLI & PROTO DECIMA, 1969) should be kept in mind as a warning against premature generalizations.

6. CONCLUSION

1. Within the Eocene clastic succession of the Island of Rab cross-bedded sandstone facies has been recognized. It is represented by complex cross-bedded sandstone units consisting of stacked cross-bedded sets. The component cross-bedded sets have been produced by migration of 2-D and 3-D dunes of various sizes, including large ones. Complex cross-bedded units have been generated (at least some of them) by migration of large-scale composite forms carrying simple dunes on their surface. These forms had very gentle slopes. The structure of many individual cross-bedded sets has recorded tide-ebb and spring-neap periodicities, and consequently deposition by tidal currents. In the Rab portion of the ancient tidal sea one tide was dominant, and it was generally directed towards the southwest.

2. Besides the cross-bedded sandstones, the greatest part of other sediments constituting Eocene Rab clastic succession are also of shallow-marine origin. A part of the lower portion of the succession could possibly represent turbidites, but might also be shallow-marine.

3. The Eocene Outer Dinaric clastic realm was complex as to the types of depositional environments, resultant facies and depositional systems, topography, and evolution.

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KOSO SLOJEVITI PJEŠČENJACI TALOŽENI TIDALNIM STRUJAMA U EOCENU VANJSKIH DINARIDA (OTOK RAB, HRVATSKA)

J. Zupanič i Lj. Babić

Slijed eocenskih klastita otoka Raba nadostavlja se na plitkomorske karbonatne taloge, kao i u najvećem dijelu Vanjskih Dinarida. Promjena nastupa oko sredine luteta s početnim taloženjem lapornih sedimenata; na njima slijede prevladavajući pješčani talozi, debeli više od 500 metara, koji su bili taloženi u vrijeme mlađeg luteta i bartona te eventualno najstarijeg priabona (MAMUŽIĆ, 1962, MULDINI - MAMUŽIĆ, 1962). Ti klastiti Raba smatrani su flišem i dijelom dugačke zone fliša priobalja i otoka istočnoga Jadrana (sl. 1, MAMUŽIĆ, 1962, AUBOUIN & al., 1972, MARINČIĆ, 1981). Kako o karakteru tih sedimenata Raba nema podrobnijih podataka, poduzeta su istaživanja koja su pokazala plitkomorski karakter taložnih okoliša za veći dio klastita. U ovom radu opisan je facijes koso slojevitih pješčenjaka dok su drugi sedimenti spomenuti ukratko.

Koso slojeviti pješčenjaci javljaju se višekratno u sukcesiji, no prvenstveno u njenom gornjem dijelu (sl. 3). To su jedinice koje se sastoje od planarnih i koritnih koso slojevitih nizova. Granične plohe nizova uglavnom su približno horizontalne do veoma blago nagnute u smjeru dominantne orijentacije kosih slojeva (sl. 3 i tab. I, sl. 4). Značajke upućuju na višekratno ponavljanje uvjeta pri kojima su migrirale dvodimenzionalne i trodimezionalne dine, kao i velike složene dine (termini prema ASHLEY - predsjedatelj simp., 1990), odnosno "pješčani valovi", s blagim stranama.

Unutarnja građa koso slojevitih nizova pokazuje sistematsko ponavljanje bočnih priraštajnih jedinica, koje čine svežnjevi zaklonih lamina, odijeljenji reaktivacijskim plohama (sl. 4 i tab. I, sl. 1). Ta pojava nastala je periodičkim poludnevnim preobrtanjima tidalnog toka, pri čemu su naizmjence djelovale dominantna i podređena tida (BOERSMA, 1969, DE RAAF & BOERSMA, 1971, BOERSMA & TERWINDT, 1981). U eocenskim tidalnim okolišima Raba dominirala je jedna tida i ta je bila generalno usmjerena prema jugozapadu (srednji vektor = 230°, sl. 2 - umetak). To je uzrokovalo izrazitu zastupljenost tog dominantnog smjera kosih slojeva, odnosno mali udio koso slojevitih jedinica orijentiranih podređenom tidalnom strujom (sl. 3 i tab. I, sl. 3, 4 i 5). Druga specifičnost građe je periodičnost promjene karaktera svežnjeva i reaktivacijskih ploha. Lateralni slijed svežnjeva pokazuje naizmjenične tendencije stanjivanja i podebljavanja svežnjeva, a istovremeno, slijed reaktivacijskih ploha pokazuje naizmjenične tendencije slabljenja i jačanja erozijskog presijecanja (sl. 5 i tab. I, sl. 2). I ta vrsta periodičnosti karakteristična je za režim tidalnih struja i tumači se dvotjednim periodama slabljenja i jačanja tidalnih stuja u vezi s lunarnim ciklusom (VISSER, 1980).

Drugi sedimenti klastičnog eocena Raba također su znatnim dijelom plitkovodnog karaktera i većim su dijelom bili taloženi pomoću procesa vezanih za oluje. Među njima su ulošci koncentriranih skeletnih ostataka, pretežno numulita i mekušaca, zatim intenzivno bioturbirani pješčenjaci i humčasto koso slojeviti pješčenjaci. Dio klastita u donjem dijelu slijeda mogao bi, međutim, predstavljati turbidite, ukoliko i taj dio nije plitkovodan.

Plitkovodan karakter najvećeg dijela eocenskih klastita Raba upućuje na oprez u razmatranju cjeline eocenskih klastičnih predjela Vanjskih Dinarida. U svakom slučaju, plitkovodni okoliši zapremali su znatno veći prostor nego što je predio rapskih izdanaka. Kako pak u drugim predjelima klastičnog eocena, odnosno MARINČIĆEVOG(1981) pojasa "fliša" (sl. 1), ima podataka o sedimentima fliškog tipa, potvrđuje se mišljenje da je veliki predio klastičnog eocena Vanjskih Dinarida bio složen (BABIĆ & ZUPANIČ, 1990), odnosno veoma raznolik kako u pogledu taložnih okoliša, te facijesa i taložnih sustava, tako i u pogledu topografije i evolucije.

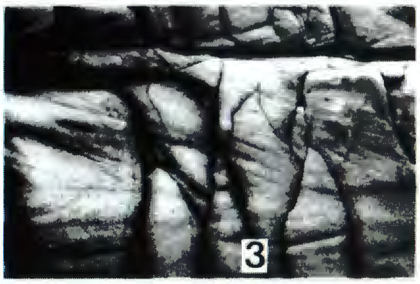
PLATE - TABLA I

Fig. 1 Tidal bundles and reactivation surfaces of a spring-tide stage. Base and top of the cross-bedded set are indicated by small and large triangles respectively. The set base is overlain first by massive to laminated bottomset deposits. Reactivation surfaces have been arrowed and numbered, the numbers corresponding to those in the drawing (Fig. 4 with additional explanations), which shows the same outcrop. Reactivation surfaces with mud drapes are most conspicious. Width of the field view = 1.5 m. Loc. B.
Fig. 2 Example of spring-neap-spring sequence of bundles. The drawing of the same outcrop is presented in Fig. 5. Hammer is 28 cm long and is laying on a younger cross-bedded set. Loc. B.
Fig. 3 "Herringbone" structure. Width of the field view= 0.4 m.
Fig. 4 Complex cross-bedded sandstone unit showing dominantly unidirectional orientation of component cross-bedded sets, that apparently descend similarly oriented and very gently inclined surfaces of a large compound dune (= "sand wave"). The massive uppermost portion of the cliff comprises bioturbated top portion of the complex cross-bedded unit, and a part of the overlaying bioturbated skeletal bed (storm deposits). The skeletal bed appears more gently inclined than the bounding surfaces within the cross-beded unit, although the shape of the cliff top surface is partly due to weathering. The cliff is about 5 m high in the middle of the picture. Loc A, 40 - 48,6 m in logA, Fig. 3.
Fig. 5 Typical appearance of stacked unidirectionally oriented cross-bedded sets. Loc. B. Hammer is 28 cm long.

Slika 1 Primjer tidalnih svežnjeva i reaktivacijskih ploha stadija najviših tida. Baza i vrh koso slojevitog niza označeni su malim, odnosno većim trokutima. U dnu niza najprije je masivni do laminirani sediment = "bottomset". Reaktivacijske plohe označene su strelicama, te brojevima kao na crtežu (sl. 4 s dodatnim tumačenjima), koji prikazuje isti izdanak. Ističu se one s izrazitom muljnom prevlakom. Vidljiva širina = 1.5 m. Lok. B.
Slika 2 Primjer slijeda svežnjeva u razdoblju od najviših, preko niskih, do ponovo najviših tida. Kladivo je dugo 28 cm i leži na jednom mlađem koso slojevitom nizu. Lok. B.
Slika 3 Tekstura "riblje kosti". Širina vidnog polja = 0.4m.
Slika 4 Složena jedinica koso slojevitog pješčenjaka s dominantnom jednosmjernom orijentacijom gradivnih koso slojevitih nizova, koji silaze niz slično orijentirane i veoma blago nagnute plohe nekadašnje velike složene dine (= "pješčanog vala"). Najgornji, masivni dio stjenovitog zida sadrži bioturbirani vrh složene koso slojevite jedinice i dio bioturbiranog skeletnog sloja (olujni talozi). Skeletni sloj pokazuje nešto blaži nagib od graničnih ploha koso slojevitih nizova, iako je oblik vršne plohe zida djelimice nastao trošenjem. U sredini slike zid je visok oko 5 m. Lok. A, 40 - 48,5 m u stupu A, sl. 3.
Slika 5 Tipični izgled jednosmjerno orijentiranih superponiranih koso slojevitih nizova. Lok. B. Kladivo je dugo 28 cm.


1


2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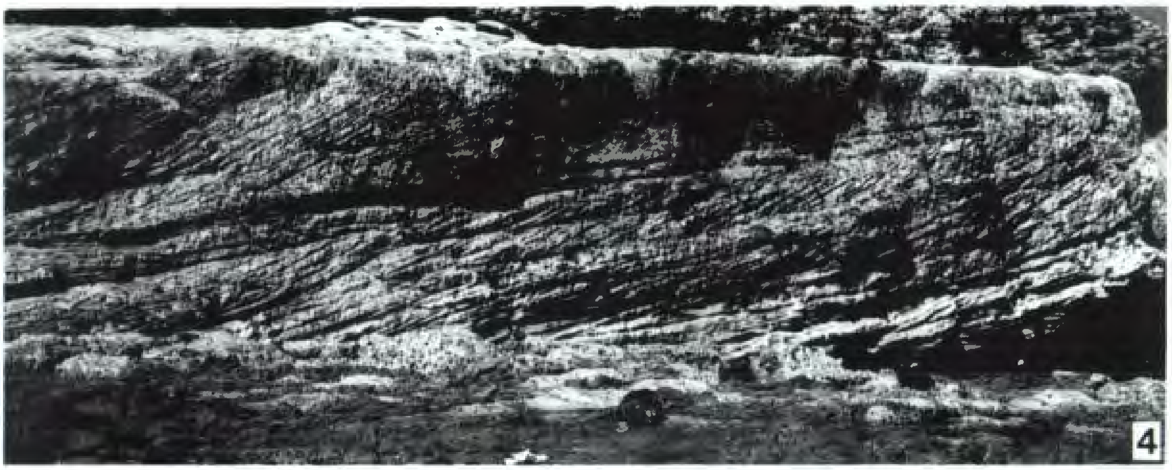
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