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Nearshore Deposits in the Middle Eocene Clastic Succession in Northern Dalmatia (Dinarides, Croatia)

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Key words: Nearshore clastics, Shoreface, Beachface, Delta, Flysch, Molasse, Eocene, Northern Dalmatia, Croatia.

Abstract

The Middle Eocene clastic succession in the Radovin Syncline is approximately 900 m thick and consists of hemipelagic and flysch-type deposits in its lower part, and shallow-marine sediments in its upper portion. The upper portion embraces a unit of sandstones and conglomerates, which is represented by several facies. Flat- and low-angle laminated, and hummocky cross-stratified sandstones (S1) originated by storm-related processes in the shoreface. Cross-bedded sandstones (S2) reflect longshore, offshore, and onshore flows also in shoreface settings. Flat-laminated sandstones with planar truncations (S3) reflect swash processes. Some sandstones possibly originated in the offshore transition zone. Conglomerate-sandstone couplets (CS) originated by storm-induced flows in the shoreface. Main conglomerates (CM) mostly reflect various processes and modifications performed in upper shoreface and beachface settings of a reflective coast. Most Cross-bedded conglomerates (CX) reflect longshore flows and dissipative conditions. There are also conglomerates which have possibly been deposited by gravity flows related to river floods. The shoreline was oriented NW-SE.

The architecture of the sandstone-conglomerate unit is thought to result from the interfingering of deltas and nearshore sandy systems. Deltas were of the shelf-type, and were predominantly "wave-dominated". The sediments studied reflect molasse-type deposition, which was induced by early post-flysch changes in basin evolution and the palaeogeography of the Palaeogene clastic basin in the coastal Dinarides.

1. INTRODUCTION

Palaeogene clastic deposits in the coastal Dinarides overlie Mesozoic to Middle Eocene platform carbonates. In northern Dalmatia, these clastics are 2.8 km thick, and are represented by two large, superimposed units (review in BABIĆ & ZUPANIČ, 1983; BABIĆ et al., 1995). The lower unit is some 900 m thick, and its age corresponds to the middle-late part of the Middle Eocene (SCHUBERT, 1905a; MAJCEN & KOROLIJA, 1970, 1973; MULDINI-MAMUŽIĆ, 1972; IVANOVIĆ et al., 1976). This unit comprises the sediments described here. The upper unit of the Palaeogene clastics in northern Dalmatia is represented by the 1900 m thick Promina Beds, which are late Middle Eocene to Early Oligocene in age (IVANOVIĆ et al., 1976; SAKAČ et al., 1993), and is not discussed here.

The lower clastics were the subject of different opinions concerning their origin. Above a basal deeper-water marl, SCHUBERT (1905a, 1909; in SCHUBERT & WAAGEN, 1913) recognised sandstones, marls, and conglomerates of shallow-marine and nearshore origin, which would reflect sea level oscillations. After MARINČIĆ (1981), these clastics are recognised as flysch sediments, which are part of a long flysch belt striking along the Dinarides. Other reports are concerned with two specific areas of northern Dalmatia. In the Zadar-Radovin area (Fig. 1), the lower clastics have been called flysch by MULDINI-MAMUŽIĆ (1972), while MAJCEN & KOROLIJA (1973) regarded these sediments as a molasse, which reflects the alternation of deep and shallow-marine conditions. The same lower clastic unit exposed to the Southeast in the Benkovac area (Fig. 1), has been regarded by IVANOVIĆ et al. (1969) as flysch, and by IVANOVIĆ et al. (1976) as deep-sea deposits. For ŠIKIĆ (1969), these sediments (above the basal marl) may be called "Flysch-like Deposits".

The works on the lower clastic unit in northern Dalmatia mentioned above provide little evidence in support of the various opinions. Only the lower portion of these clastics from a restricted area (railway section in the Benkovac area - BABIĆ & ZUPANIČ, 1983) has been described in detail. There is a need therefore to improve the knowledge of these sediments, which represent a record of the sedimentary and structural evolution of the Dinaric chain after platform carbonate deposition ceased. Data presented here indicate that the lower unit of the Palaeogene clastics in the Radovin-Zadar area, northern Dalmatia, contains sediments which originated in nearshore environments, as already proposed by SCHUBERT (1905a, 1909). The interpretation of these environments is supported by a description of the sedimentary features and relevant facies, which have not been previously described either from the study area, or from elsewhere in the Eocene of the coastal Dinarides.

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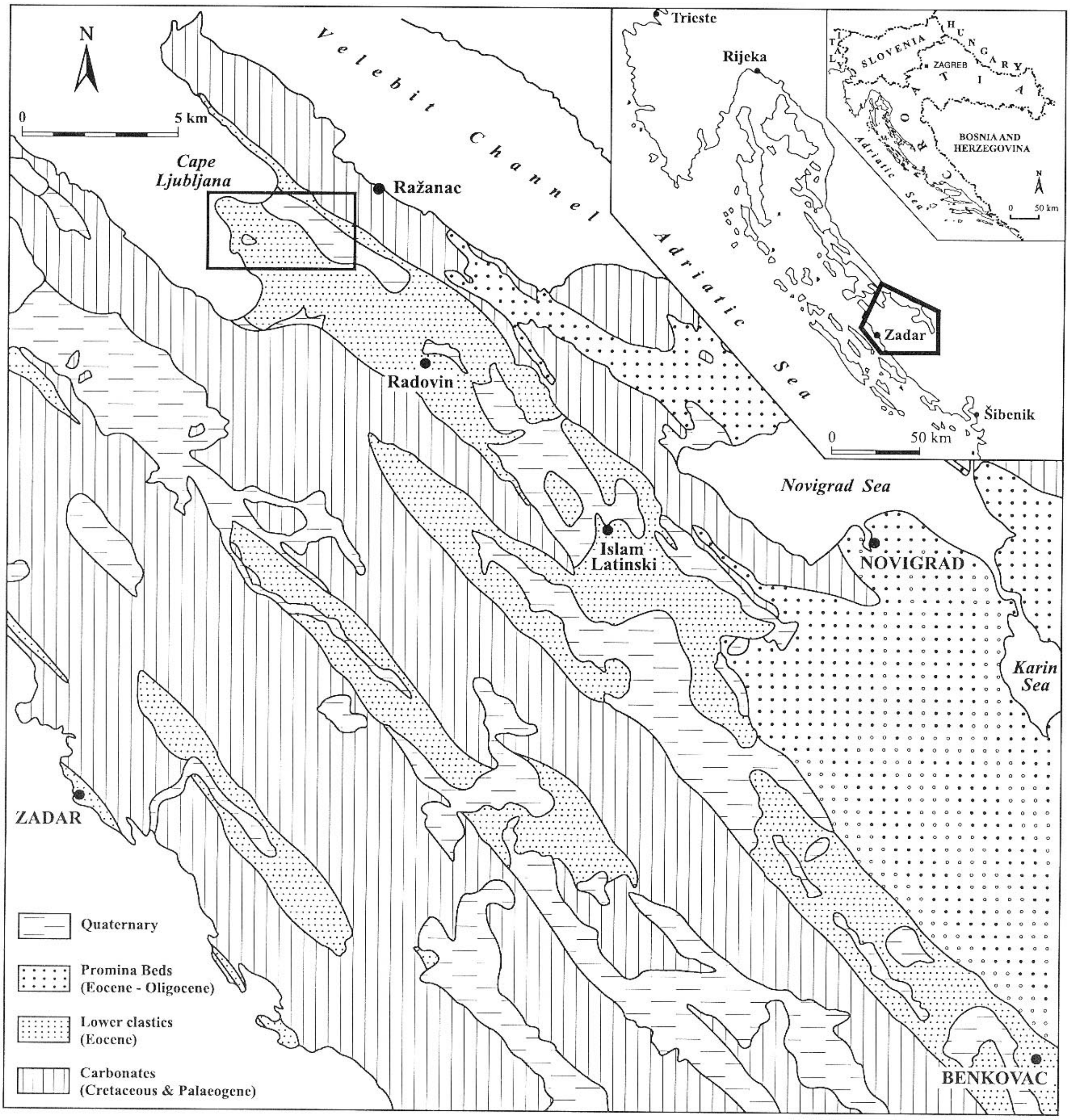


Fig. 1 Geological setting of the Radovin Syncline, which strikes between Cap Ljubljana and Islam Latinski, and comprises the sediments described here. Besides being covered by Quaternary sediments, the Palaeogene lower clastics are largely covered by undifferentiated soil. The framed area is shown in Fig. 3. Geological map after MAJCEN et al. (1970), and IVANOVIĆ et al. (1973), simplified. The extent of Quaternary sediments is partly after SCHUBERT (1909) and SCHUBERT & WAAGEN (1912). Two inserts show the overall situation.

2. STUDY AREA AND THE SITUATION OF SEDIMENTS STUDIED

The sediments studied occur in the Radovin Syncline, which is situated in the northern part of northern Dalmatia (Fig. 1). In this area, late Middle Eocene clastics are underlain by Cretaceous and early Palaeogene limestones. The thin basal portion of the clastic succession is represented by deep-water marls (SCHUBERT, 1903, 1905a, 1909; SCHUBERT & WAAGEN, 1913). After SCHUBERT (op. cit.) and MAJCEN & KOROLIJA (1970, 1973), the main portion of the clastic succession consists of sandstones, marls, and minor conglomerates.

Field work data suggest a preliminary subdivision of the 900 m thick succession into four informal units (Fig. 2). The third unit of this subdivision consisting of sandstones and conglomerates shows the features described here. The occurrence of conglomerates makes this unit different from both the underlying and overlying units which consist of sandstones.

Numerous and variously oriented faults dissect the area of the Radovin Syncline, and disturb the sedimen-

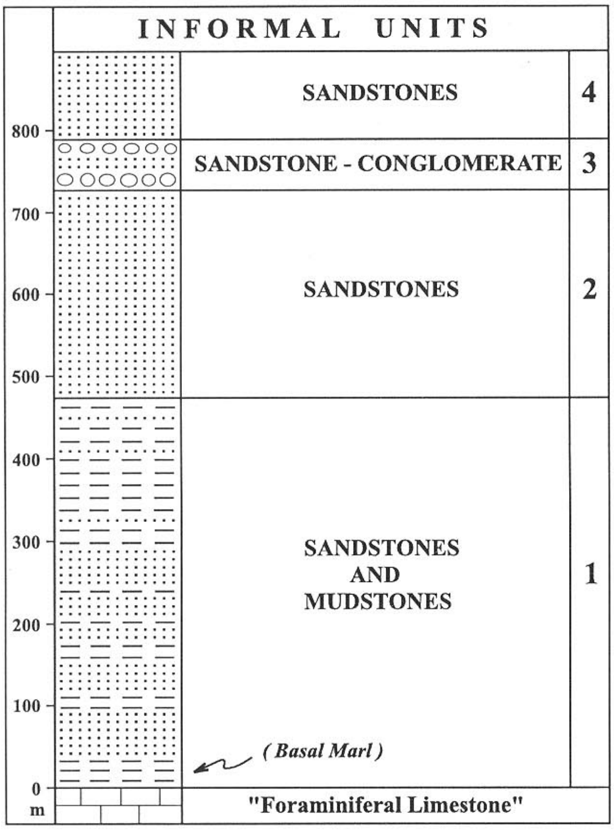


Fig. 2 Schematic log of the Eocene clastics in the Radovin Syncline showing informal subdivision of the sedimentary succession. The sandstone-conglomerate unit (3) is described here. The clastic succession is underlain by the Eocene shallow-water carbonates ("Foraminiferal Limestone").

tary succession (SCHUBERT, 1905b, 1909, 1910), but the importance of these faults is mostly obscured, due to extensive cover of Palaeogene clastics by Quaternary deposits and soil. Some of these faults have been shown on the geological map made by MAJCEN et al. (1970).

3. TERMINOLOGY

The term "sandstone" is used here for sediments consisting of sand-sized particles regardless of the proportion of non-carbonate and carbonate particles. Sandstones containing an important proportion of nummulites are called "nummulitic sandstones".

The term "nummulitic conglomerate" is used here for those conglomerates containing an important proportion of nummulites, and the term "nummulite conglomerate" for rarely occurring sediments consisting of packed nummulite tests.

When discussing nearshore depositional environments of gravelly beach complexes, the geomorphological terminology is adopted following suggestions by LEITHOLD & BOURGEOIS (1984) and definitions of terms by MASSARI & PAREA (1988). Specifically, the term "beachface" is used for the zone of the beach from the highest berm to the landward boundary of the shoreface, and the term "lower beachface" for that part of the beachface, which develops below the intertidal zone.

4. GENERAL FEATURES OF SEDIMENTS STUDIED

Lateral tracing of beds and bed packages, as well as the study of sedimentary successions of the sandstone-conglomerate unit, were difficult due to extensive cover and numerous faults. Most observations were made on scattered, "good quality" outcrops showing small parts of the entire vertical succession, situated in different parts of the Radovin Syncline. Some large exposures, such as those in the Ražanac-Zadar road cut (Fig. 3, Section A), provided little adequate data on sedimentary structures and fabric. The thickness of the unit studied is greater than 30 m, and smaller than 130 m, and is probably inpersistent laterally (Fig. 4).

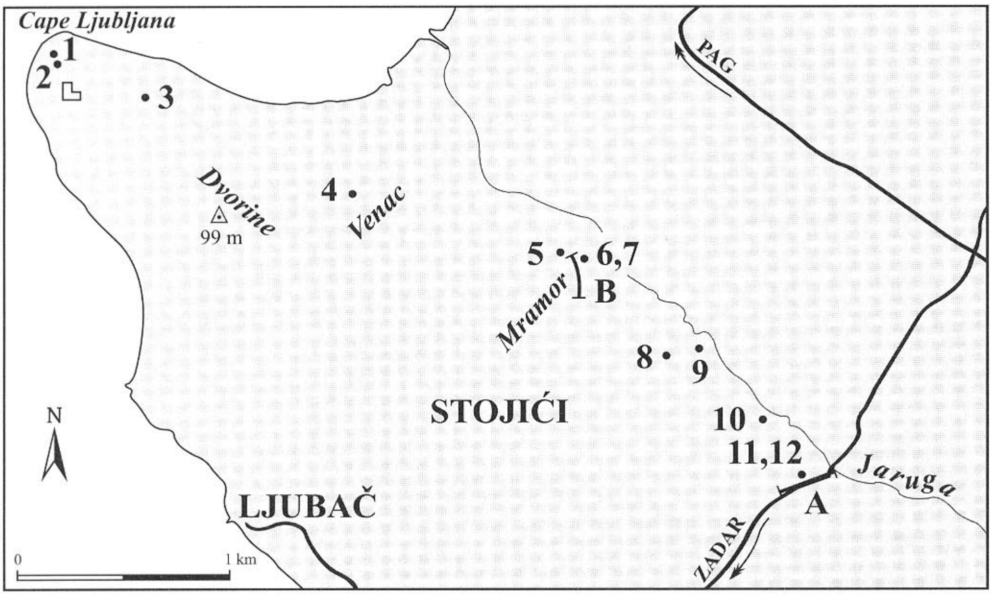


Fig. 3 Location of logged sections and outcrops. See also framed area in Fig. 1.

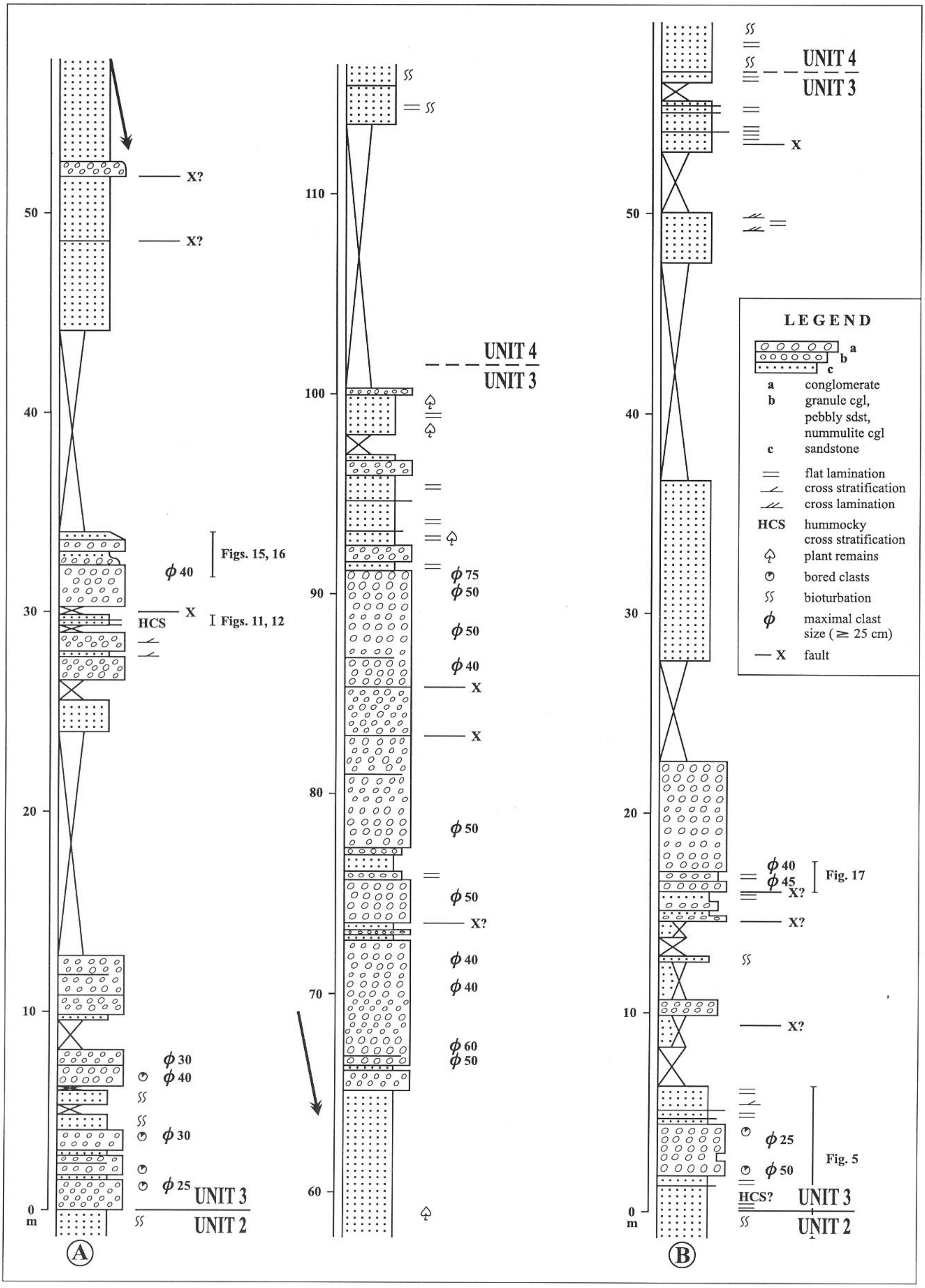


Fig. 4 Simplified logs A and B of the sandstone-conglomerate Unit 3. Differences in thickness and facies in the two logs are partly due to faults. Lateral changes are also due to differences in depositional setting as suggested by lateral changes in some conglomerate packages locally recognised at short distances. See text for discussion. Nummulites may be common to abundant in most parts of the succession, and their occurrences are not indicated. Note the dominance of sandstones not showing any structures due to weathering ("weathered sandstones" in text). See Fig. 3 for location of sections A and B.

Sandstones are fine- to medium-grained, and locally coarse-grained. Typical sandstones have 45% to 60% carbonate particles in composition, the rest being non-carbonate particles, predominantly represented by quartz and chert. Carbonate particles include skeletal particles and limestone clasts. Nummulites may be scattered in sandstones or be an important component of sandstones ("nummulitic sandstones").

Conglomerates consist of clasts of limestones, sandstones, subordinate chert, and sand matrix. Limestone clasts are partly Palaeogene in age, including those with *Alveolina*, nummulites, and those containing miliolids, and some clasts were derived from the Late Cretaceous succession. Clasts of Eocene sandstones vary in composition from dominantly non-carbonate to dominantly carbonate varieties, and both types may contain nummulites. In the finer-grained conglomerates, nummulite tests may be important constituent particles ("nummulitic conglomerate"), or may rarely be the highly predominant to exclusive particle type ("nummulite conglomerate"). In coarser-grained conglomerates, nummulites are common in the sandy matrix. Rare conglomerate beds contain a high proportion of bivalves, gastropods, and other marine macrofossils.

5. UNDERLYING AND OVERLYING SEDIMENTS

The following description and interpretation refer to approximately 10 m thick sequences, which appear just below and above the sandstone-conglomerate unit, and belong to the underlying and overlying sandstone units (Units 2 and 4 in Fig. 2) respectively. Field data suggest that transitions between these sediments and the sandstone-conglomerate unit are gradual (Figs. 4 & 5).

Description

The underlying sediments are sandstones, which are mostly massive, and may contain nummulites, echinoderms, pelecypods, and plant detritus. Their massive appearance is a consequence of thorough bioturbation. Locally, the sandstones display horizontal laminae, which may be marked by nummulites and other skeletal particles.

Sediments overlying the sandstone-conglomerate unit are dominantly massive, bioturbated sandstones with subordinate horizontally laminated sandstones locally containing nummulites and plant detritus.

Interpretation

Thorough bioturbation combined with occasionally preserved laminations reflects alternating periods of high-energy sand deposition and bioturbation. As a greater part of the physical structures have been destroyed, the depositional rate was generally slower than the rate of homogenisation by bioturbation. Such conditions correspond either to the offshore transition zone, or to the lower shoreface, in both of which sand layers deposited by storm-induced flows can be partly or strongly homogenised by organisms (GHIBAUDO et al., 1974; HOWARD & REINECK, 1981; HOWARD & SCOTT, 1983; DUPRÉ, 1984).

Thus, the deposition of the sandstone-conglomerate unit was both preceded and followed by deposition of sands in shallow-marine environments.

6. SEDIMENTS OF THE SANDSTONE-CONGLOMERATE UNIT

The sedimentary facies encountered may be grouped into sandstone facies and conglomerate-dominated facies.

6.1. SANDSTONE FACIES

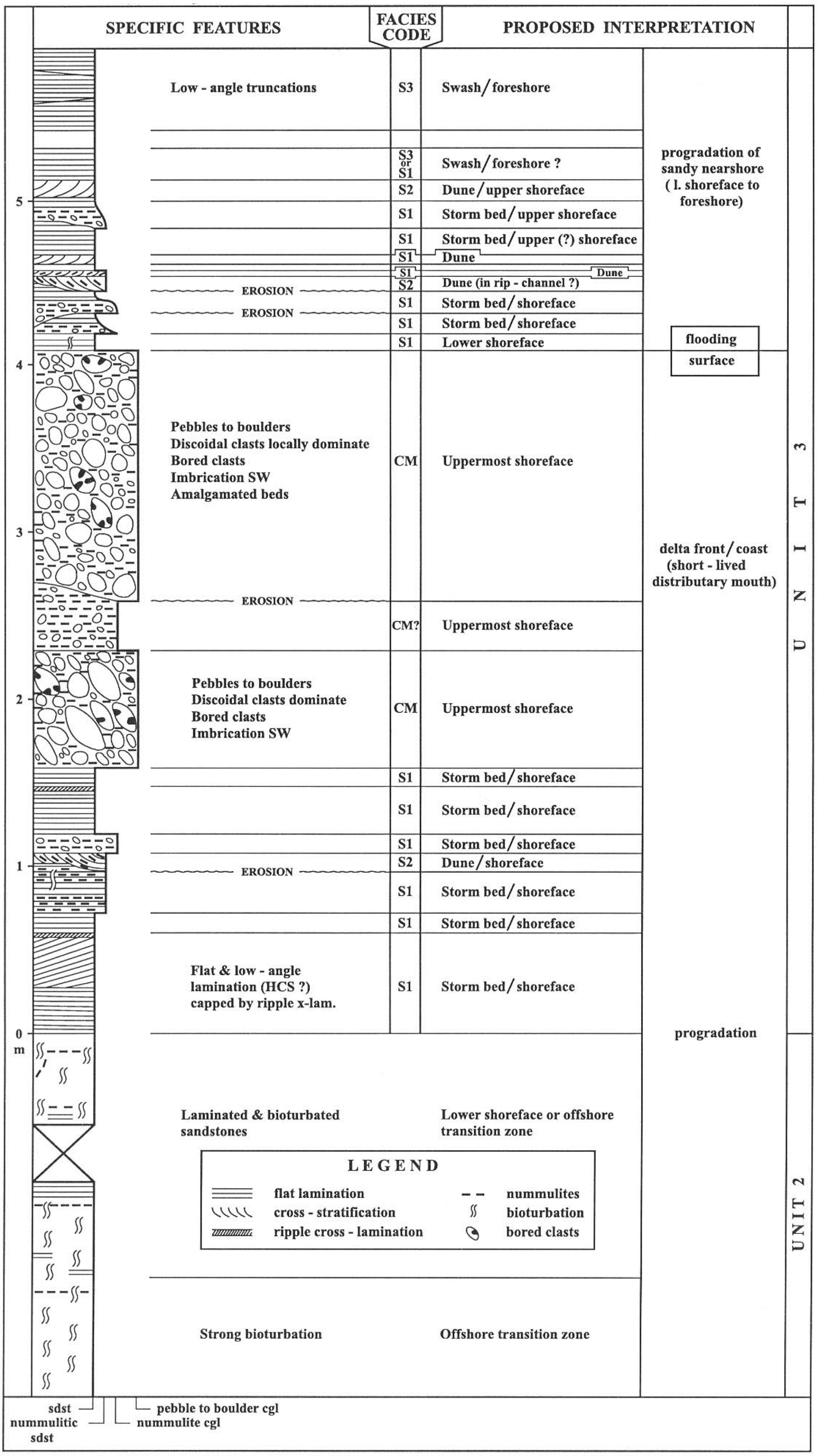
Description

Sandstones form both individual beds and packages up to 12.5 m thick, which alternate with conglomerates (Fig. 4). The most common facies recognised are Flat- and low-angle-laminated, and hummocky cross-stratified (HCS) sandstones (S1). Other types are Cross-bedded sandstones (S2) and Flat-laminated sandstones with planar truncations (S3). It is to be noted that most sandstones encountered in the Radovin Syncline are strongly weathered, and their structures are obscured (see also Fig. 4).

(S1) Flat- and low-angle-laminated, and HCS sandstones. The lower contact of the beds is erosional, they may be rich in plant detritus, and are represented by several bed types and the transitions between them.

One of the bed types (S1a) (Figs. 6 & 7) shows a relief on the basal surface of less than several centimetres. Beds are 0.05 to 0.8 m thick, mostly show flat laminae, and locally, low-angle inclined laminae. Sandstones locally contain scattered nummulites, which may be imbricated, and more nummulites and/or rare scattered granules and pebbles may occur at the base of some beds. Some of these beds are capped by a ripple cross-laminated interval several centimetres thick.

Another bed variety (S1b) is 0.4 - 1.2 m thick, and shows basal scouring up to 0.2 m deep. The basal portion of the bed, which is up to 0.15 m thick, is composed of either pebble to granule conglomerate, nummulitic conglomerate, or well-sorted nummulite conglomerate. This basal layer may vary in thickness and particle type composition laterally, and even pinch out or form wide lenses. The basal layer is sharply overlain by, or grades upwards into sandstone, which may show either flat lamination (Fig. 8), low-angle inclined laminae, or, in places, HCS. This sandstone may contain nummulites commonly aligned along the lamination. Flat and low-angle lamination may include thick laminae and several centimetre thick intercalations of nummulite conglomerate or nummulitic sandstone. Nummulite tests may be imbricated. Beds are rarely capped by thin ripple cross-lamination.


SPECIFIC FEATURES
FACIES CODE
PROPOSED INTERPRETATION
Low - angle truncations
S3
Swash/foreshore
S3 or S1
Swash/foreshore ?
S2
Dune/upper shoreface
S1
Storm bed/upper shoreface
S1
Storm bed/upper (?) shoreface
S1
Dune
S1
Dune
S2
Dune (in rip - channel ?)
EROSION
S1
Storm bed/shoreface
EROSION
S1
Storm bed/shoreface
S1
Lower shoreface
progradation of sandy nearshore (l. shoreface to foreshore)
flooding surface
5
4
Pebbles to boulders
Discoidal clasts locally dominate
Bored clasts
Imbrication SW
Amalgamated beds
CM
Uppermost shoreface
3
delta front/coast (short - lived distributary mouth)
EROSION
CM?
Uppermost shoreface
2
Pebbles to boulders
Discoidal clasts dominate
Bored clasts
Imbrication SW
CM
Uppermost shoreface
S1
Storm bed/shoreface
S1
Storm bed/shoreface
S1
Storm bed/shoreface
1
S2
Dune/shoreface
EROSION
S1
Storm bed/shoreface
S1
Storm bed/shoreface
Flat & low - angle lamination (HCS ?) capped by ripple x-lam.
S1
Storm bed/shoreface
0 m
progradation
UNIT 3
Laminated & bioturbated sandstones
Lower shoreface or offshore transition zone
LEGEND
flat lamination
cross - stratification
ripple cross - lamination
nummulites
bioturbation
bored clasts
UNIT 2
Strong bioturbation
Offshore transition zone
sdst
nummulitic sdst
pebble to boulder cgl
nummulite cgl

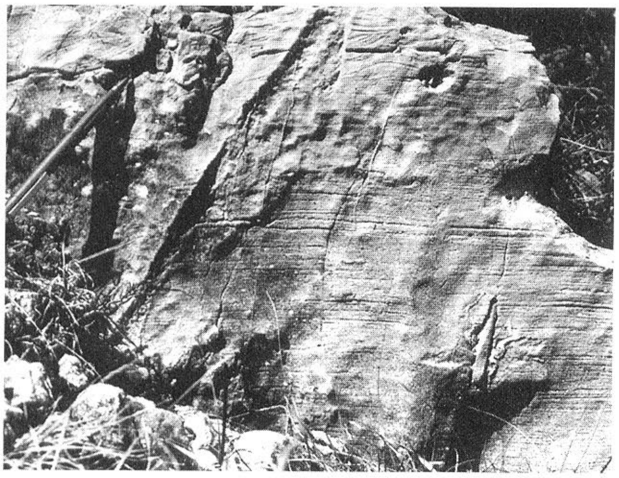


Fig. 6 Sandstone bed showing flat lamination and partly visible small-scale cross-lamination in its uppermost portion. Visible thickness is 0.35 m. The base of the bed is not seen. An *Ophiomorpha* burrow cuts the entire bed (parallel to the pencil). Locality 5 in Fig. 3.

Several sandstone beds (S1c) show either HCS, a lateral transition from flat or low-angle lamination to HCS, or a transition from HCS to cross-bedded sandstone. The basal portions of these beds may contain more nummulites or scattered pebbles.

In most S1 beds bioturbation is either absent or represented by rare individual, mostly vertical *Ophiomorpha* burrows and other shafts (Figs. 6 & 8). In some beds, the lamination may be disturbed by dispersed vertical (highly predominant), diagonal, and horizontal *Ophiomorpha* burrows, and by V-shaped escape burrows tapering downward, and being marked by downwarping lamination. Burrows may be marked by nummulites, and some burrows show tubes armoured with nummulite tests. Rare beds show more intense bioturbation with some 20-60 % of the lamination obliterated (e.g. Fig. 7).

(S2) Cross-bedded sandstones (Fig. 10) are mostly represented by solitary sets, and occasionally by two to three superimposed sets. Individual sets are 0.05 to 0.18 m thick, and may contain scattered nummulites. Beds may show an erosional base up to 5 cm in relief, and nummulites concentrated at the base, as well as a basal layer (several centimetres thick) of nummulite conglomerate or nummulitic sandstone. Some cross-beds show preserved brink points and topset laminae (Fig. 9). Occasionally, cross-beds continue laterally into HCS, or form complex structures including HCS and cross-beds (Fig. 9).

Several measurements reveal E- and NW-directed migrations of bedforms. Furthermore, very rough estimates provide approximate directions towards NW, SE, S, and E.

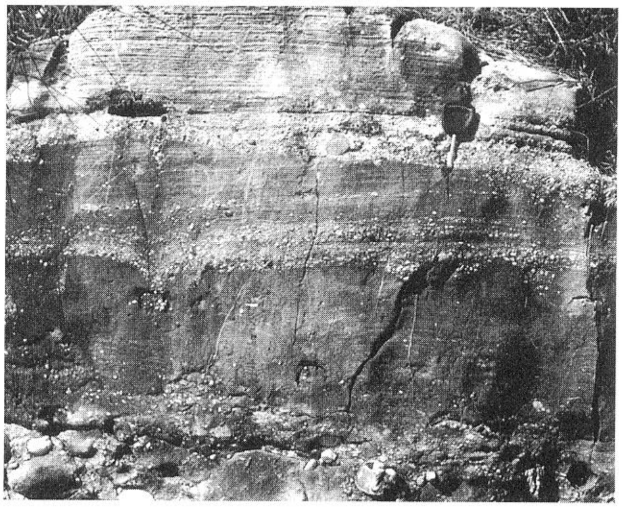


Fig. 7 Three superimposed sandstone beds inferred to represent storm deposits in the shoreface. The lower one overlies a conglomerate bed, and shows only relict flat laminae due to bioturbation (*Ophiomorpha*). The intermediate bed is sharply based and shows nummulite conglomerate at the base, and nummulites marking some laminae. The lamination is very gently inclined to the left. Nummulite tests fill burrows in the underlying sandstone. The base of the upper bed truncates the lamination of the underlying bed. Basal nummulite conglomerate of the upper bed contains rare pebbles. The following flat laminated sandstone contain rare nummulites. The key is 6.7 cm long. Locality 10 in Fig. 3.

(S3) Flat-laminated sandstones with planar truncations (Fig. 5). These sandstones are characterised by even laminae and gently inclined, planar erosional surfaces separating sequences of laminae. Laminae sequences may slightly differ in attitude, usually by less than 10°.

Interpretation

Deposition of all varieties of **(S1) Flat- and low-angle-laminated, and HCS sandstones** was preceded by erosion induced by high-energy turbulent flows. Gravel-sized clasts (including nummulites) deposited at the base and followed by sand, reflect decreasing energy conditions during storms. Occasional HCS suggests storm-related depositional processes, and the various associations of HCS, low-angle lamination, flat lamination and cross-bedding suggest a storm-induced origin of such associations, and the same may be true for these structures when found individually. Low-angle inclined laminations could represent part of larger-scale HCS structures, and may also be regarded as a form of HCS (NOTTVEDT & KREISA, 1987; WINN, 1991). Lateral transitions from flat laminae to HCS observed in the

Fig. 5 Detailed log showing specific features and proposed interpretations for the uppermost portion of the sandstone unit 2 and the lowermost part of the sandstone-conglomerate unit 3, which are exposed at locality 6 (Fig. 3). For vertical position see log B in Fig. 4. Note transitional contact between units 2 and 3, and the dominance of storm-related S1 facies in sandy deposits.

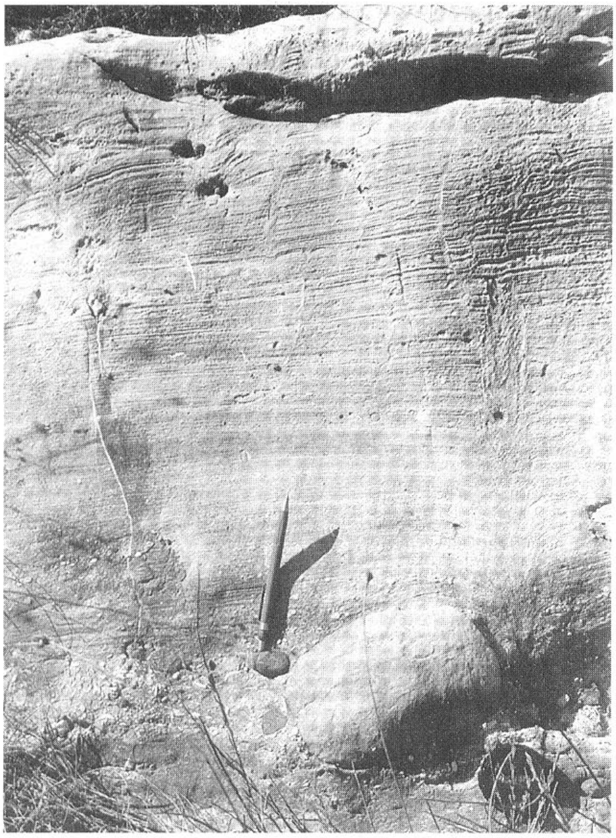


Fig. 8 Flat laminated sandstone bed showing a 0.1 m thick basal conglomerate layer, which consists of pebbles, nummulites (white particles), and rare cobbles. One cobble occurs right, below the pencil, which is 13.5 cm long. Lowermost laminae contain scattered nummulites. The sandstone shows rare *Ophiomorpha* burrows in the upper left and left centre, and a vertical, escape burrow to the right. Locality 9 in Fig. 3.

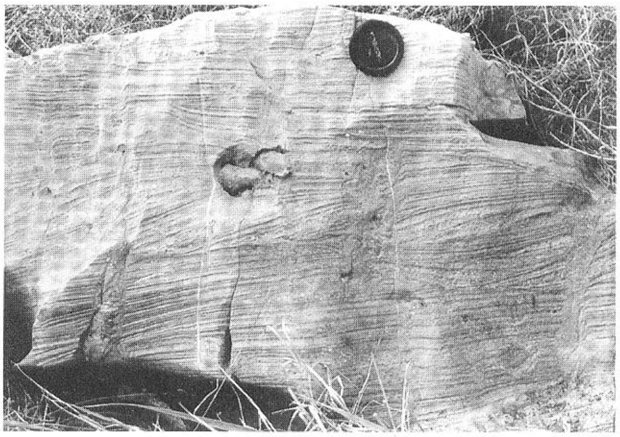


Fig. 9 Low-angle laminated (probable HCS) sandstone bed in the lower part shows repeated small-scale scouring and filling at its top right. It is overlain by low-angle to high-angle cross-bedded sandstone with preserved topsets. The upper part of the outcrop consists of low-angle and flat laminated sandstone. Sandstones contain coarse particles (mostly nummulites) locally concentrated in laminae and lenses. An *Ophiomorpha* shaft is seen in the centre, and less distinct vertical (escape?) burrows also occur. Lens cap is 5.8 cm in diameter. Locality 9 in Fig. 3.

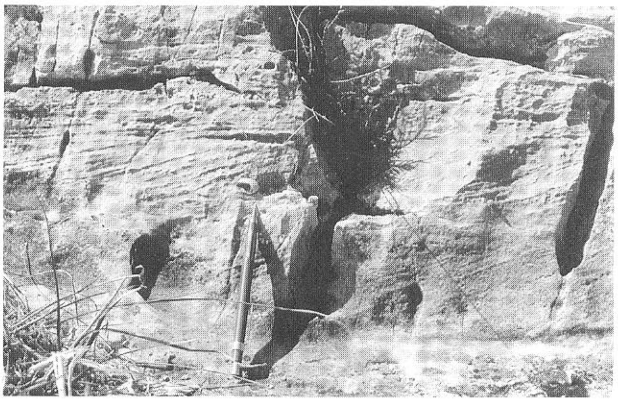


Fig. 10 Two superimposed cross-bedded sandstone sets overlying a conglomerate bed (hardly recognisable in the picture), and underlying flat-laminated sandstone bed. Pencil is 13.5 cm long. Locality 5 in Fig. 3.

Radovin Syncline are known elsewhere in the sedimentary record (e.g. DUPRÉ, 1984) suggesting deposition of both by storm-related flows. This also means that flat laminated sandstones found alone may have originated by the same processes. In fact, combined flows may produce either flat lamination or cross-bedding depending on the relationship between the velocities of unidirectional and oscillatory components of the flows (MYROW & SOUTHARD, 1991).

Basal scouring must have been related to peak storm conditions and probably resulted from the action of storm-induced rip currents. These erosional surfaces and related beds consisting of thin basal gravel and overlying sand, may be compared to similar beds in the superbly exposed Pleistocene beach-shoreface complexes, inferred to represent a record of the alongshore migration of rip channels and associated low-relief bars (MASSARI & PAREA, 1988). Similar sediments have also been described by DUPRÉ (1984), who related them to storm conditions in the upper shoreface of a barred nearshore.

Gravel-sized skeletal particles, which are the common to exclusive components of basal gravel, as well as the lensoid and sheet-like shapes of such gravel deposits, are well-known features of storm beds, ranging from siliciclastic to carbonate in composition (KUMAR & SANDERS, 1976; KREISA, 1981; SHORT, 1984; HOBDAY & MORTON, 1984).

The ripple-laminated upper portion of some beds resulted from small-scale unidirectional or oscillatory flows, induced either by the final affects of the waning storm, by minor storms, or possibly, by fair-weather processes.

Highly predominant vertical, deep *Ophiomorpha* shafts in S1 sandstones reflect the ability of this relevant suspension feeder to use the shortest time interval compared to other burrowers to settle, burrow and construct tube walls, before the next erosional and depositional events occurred (FREY et al., 1978; PEMBERTON et al., 1992). This indicates a high frequency of erosional/depositional events, i.e. frequent storms and a high deposition rate. Such conditions are also indicated by escape burrows.

Part of the sandstone beds of this facies (S1) may be considered to represent the depositional record of a storm-dominated upper shoreface. The upper shoreface setting is deduced from the combination of their vertical situation closely below foreshore sandstones (S3; Fig. 5), perfectly preserved and intact primary physical structures (bioturbation almost absent), and the lack of mudstone interbeds or drapes. Another part of the S1 sandstones lacks a close association with foreshore sandstones (S3; Fig. 5), includes both well-preserved physical structures and partially bioturbated beds, also lacks mudstone interbeds, and reflects less frequent depositional and erosional events compared to the upper shoreface storm beds mentioned above. These sandstones may represent the depositional record of the lower shoreface. Most gravel-based sandstones (S1b) belong to this group, and they resemble sandstone beds interpreted by MASSARI & PAREA (1988) as lower shoreface deposits.

(S2) Cross-bedded sandstones. Although dunes (megaripples) may be produced by fair-weather currents in recent shoreface environments (CLIFTON et al., 1971), most (if not all) cross-beds in the Radovin examples probably originated during higher-than-"normal" energy conditions, i.e. by storm-induced flows. NW, SE, and S directions of bedform migration could suggest probable longshore and offshore currents. These currents could result from storm-related flows along shore-parallel troughs associated with a bar and rip channel morphology (DAVIDSON-ARNOTT & GREENWOOD, 1974; DUPRÉ, 1984). This is consistent within the depositional context of the Radovin clastics, i.e. with overall domination of storm beds in sandy deposits. Preserved brink points and topsets, which indicate sand-rich flows, fit storm conditions well. Those cross-beds, which probably reflect onshore (E) transport, may reflect either onshore-directed dune migration during fair-weather periods (CLIFTON et al., 1971) and recovery, or onshore-directed bar migration during storms (DAVIDSON-ARNOTT & GREENWOOD, 1974; DUPRÉ, 1984). Rip-currents were probably responsible for the basal scouring in some beds.

The occasional close association of cross-beds and HCS represents a feature known for a long time (DOTT & BOURGEOIS, 1982), which suggests a variation of the importance of unidirectional and oscillatory components in storm-induced combined flows (MYROW & SOUTHARD, 1991).

Cross-bedded sandstones commonly originate by dune (megaripple) migration in the upper shoreface (READING & COLLINSON, 1996). However, apart from tide-dominated settings, dunes have also been observed farther offshore and have been considered to have been active in ancient lower shoreface and shelf settings (SHORT, 1984; reviews in WALKER & PLINT, 1992; JOHNSON & BALDWIN, 1996). These cross-beds, which alternate with well-preserved storm sandstone beds and are vertically situated closely below sandstones inferred to record an ancient foreshore (S3), probably originated in the upper shoreface. Other cross-bedded sandstones have probably been deposited somewhat lower in the shoreface, as they are intercalated between storm sandstone beds inferred to reflect such an environment (see above).

(S3) Flat laminated sandstones with planar truncations reflect deposition by swash processes, and intermittent erosion and/or other changes in shoreline conditions, after which the attitude of subsequent laminae may change (CLIFTON, 1969; REINECK & SINGH, 1980).

Some of the **weathered sandstones** the structures of which are obscured, and which are common in the Radovin Syncline (Fig. 4), might represent nearshore deposits based on close association with sandstone and conglomerate facies inferred to represent nearshore deposits. Other weathered sandstones may have originated in the offshore transition zone.

6.2. CONGLOMERATE-DOMINATED FACIES

Conglomerate-dominated facies include (CS) Conglomerate-sandstone couplets, (CM) Main conglomerates embracing several facies varieties, (CX) Cross-bedded conglomerates and sandstones, and "Other conglomerates".

(CS) Conglomerate-sandstone couplets

Description (Figs. 11 & 12).

An erosional base up to 0.1 m in relief, is overlain by up to 0.4 m of polymodal to moderately sorted pebble to granule (rarely to cobble) conglomerate, containing nummulites and sandy matrix. This conglomerate may be overlain either directly by a sandstone division, or there may be an intermediate, graded, pebbly-nummulitic conglomerate to granule sandstone up to 0.1 m thick, which may show horizontal stratification. The sandy division is up to 1 m thick, and its primary thickness has commonly been reduced by subsequent erosion. This sandstone shows either flat laminae, low-angle inclined laminae, or HCS, occasionally marked by scattered nummulites, and may be rich in plant detritus including leaves.

Interpretation

Vigorous erosion of underlying sediments preceded the emplacement of gravel during high-energy conditions, which were followed by the lowering of energy related to the grading and deposition of sand. Structures in the sandstones suggest storm-related flows were responsible for the origin of entire couplets in a manner discussed above for the conglomeratic S1 sandstones. Beds are otherwise comparable to erosionally based, up to 0.5 m thick gravel overlain by laminated sand described from the modern shoreface and from ancient successions by KUMAR & SANDERS (1976). According to these authors, erosion and deposition of a gravel

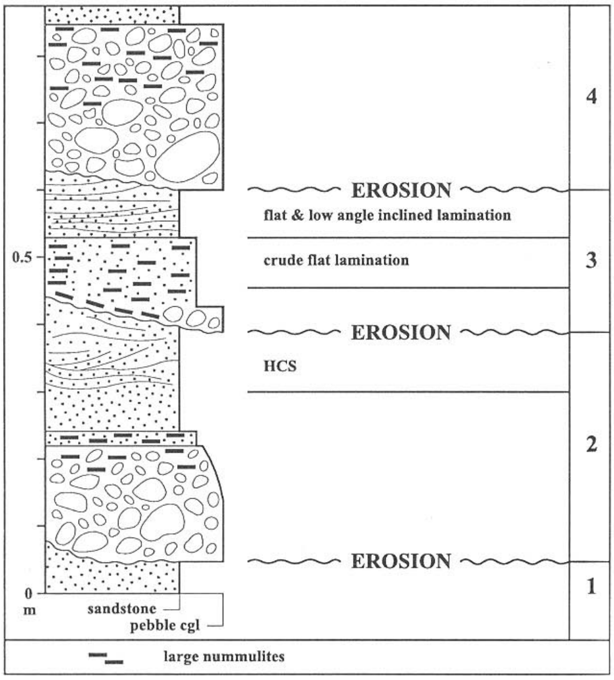


Fig. 11 Main features of several, superimposed conglomerate-sandstone couplets (SC) (1 to 4) inferred to reflect storm-induced processes in the shoreface. Besides large nummulites indicated in the log, the conglomerates contain smaller nummulites in sandy matrix. For explanation see text. See also Fig. 12. Locality 11 in Fig. 3. Vertical position in log A, Fig. 4.

Fig. 12 Conglomerate-sandstone couplets (CS) shown by log in Fig. 11. The sandstone below the hammer is erosionally overlain by conglomerate, which grades upwards into a finer-grained conglomerate with large nummulites (white, up to 3 cm in diameter), and then into HCS sandstone (2 in Fig. 11). This sandstone is erosionally overlain by the next couplet (3 in Fig. 11) consisting of conglomerate (poorly exposed, marked by 13.5 cm long pencil), followed by granule conglomerate to nummulite sandstone, and then by low-angle inclined (HCS?) sandstone. The upper part of the succession is represented by an erosionally based conglomerate. Hammer is 28 cm long. Locality 11 in Fig. 3. Vertical position in log A, Fig. 4.

lag occurred in the shoreface, by strong, storm-induced flows, and the overlying sand was deposited during the waning stage of the same storm event. DUPRÉ (1984) has also discussed a storm-related origin of similar gravel/sand couplets deposited in the upper shoreface.

(CM) Main conglomerates

Description

The above title embraces several facies, and includes combinations of superimposed conglomerate beds, which differ from one another mainly in clast size and shape. Transitional sediment types from fine-grained conglomerates to sandstones may also be associated as well as rare coarse sandstones. Outcrops being of limited extension and usually showing strike-parallel sections, display parallel bedding the primary (depositional) attitudes of which may have been either horizontal or gently inclined perpendicularly to their strike. Conglomerates contain sand matrix, and nummulites are present in most cases and may be abundant. Examples of these conglomerate associations are described below.

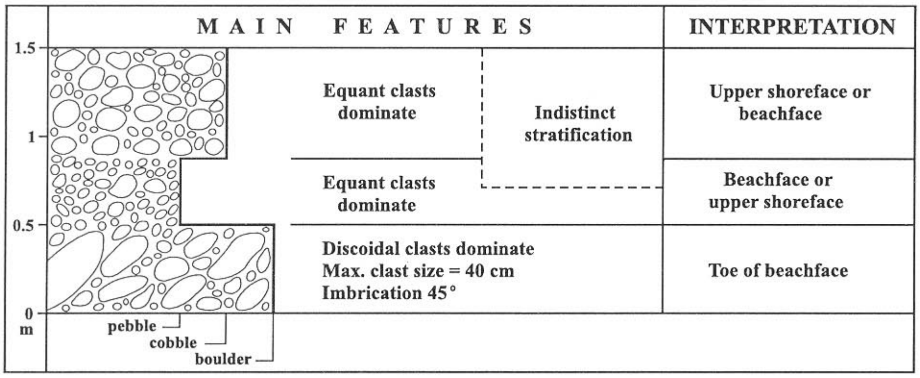


Fig. 13 Main features and proposed interpretations for three superimposed conglomerate layers. For explanation see text. The matrix of conglomerates is nummulitic sandstone. Imbrication of large discoidal clasts in the lower layer dips towards NE (45°). Locality 2 in Fig. 3.

Fig. 14 "Imbricate-disc" conglomerates of the beachface. Bedding is gently inclined to the right. Two adjacent beds show oppositely dipping imbrication, and the lower bed displays imbrication in opposite directions occurring laterally. The imbrication is locally very steep. Note the sand matrix and well-sorted and rounded clasts. Lens cap is 5.8 cm in diameter. Locality 1 in Fig. 3.

(1a) The outcrop at locality 2 (Fig. 13) shows a 1.5 m thick succession consisting of (A) cobble to boulder conglomerate with steep imbrication of large discoidal clasts dipping towards the NE, (B) small-pebble conglomerate with scattered large pebbles and small cobbles; equant clasts dominate, and (C) moderately sorted pebble to cobble conglomerate with dominant equant clasts.

(1b) Elsewhere, coarse polymodal conglomerates show imbrication of large clasts dipping towards the SW. They may contain abundant nummulites, and some of them contain lithophaga-bored cobbles and boulders (Fig. 5).

(2) A typical "imbricate-zone" (BLUCK, 1967) conglomerate succession consists of superimposed 5-10 cm thick beds of well-packed, imbricated, dominantly discoidal pebbles (Fig. 14). The imbrication in two superimposed beds, as well as in adjacent parts of the same bed may dip in opposite directions. In places, the imbrication may be very steep. The directions of imbrication dips were 45° and 225°. Clasts are well-rounded and well-sorted, which apart from the imbricate structure, make these conglomerate beds outstanding compared to most other conglomerates observed. The conglomerates contain sand matrix.

(3) Couplets consisting of a lower, coarse member and upper, fine member (Figs. 15-17). The coarse member is represented by erosionally based (relief up to 0.3 m) 0.15 to 0.5 m (or more) thick bimodal or polymodal conglomerate, which predominantly consists of pebbles and cobbles, and also contains scattered boulders, nummulites, granules and sand. This member may display indistinct or crude stratification with several layers showing different size distributions. In bimodal varieties modes are in the pebble/cobble and granule/sand size classes. In some cases, the uppermost portion of the lower member shows the gravel frame infilled by finer material identical to the sediment of the upper

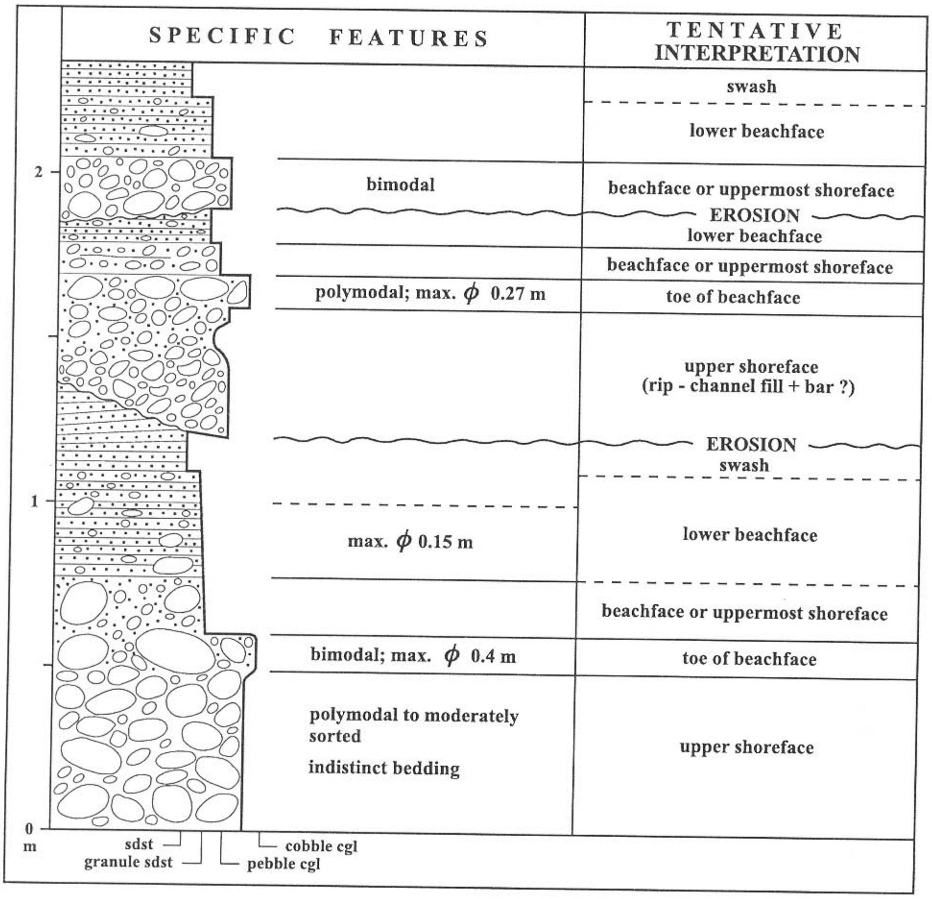


Fig. 15 The main features and tentative interpretations of processes and settings for the succession exposed at locality 12 (Fig. 3). For discussion and alternative interpretations see text. Vertical position in log A, Fig. 4.

Fig. 16 Interval 0.3-1.7 m of the log in Fig. 15. The polymodal conglomerate at the base is overlain by bimodal sediment consisting of large clasts dispersed in granule conglomerate to granule sandstone. This sediment grades upwards into granule sandstone showing flat lamination. The conglomerate in the upper part of the photograph (above the pencil, which is 13.5 cm long), is erosionally based (scours seen laterally up to 0.4 m deep). For interpretation see text and Fig. 15. Locality 12 in Fig. 3. Vertical position in log A, Fig. 4.

Fig. 17 The lower part is represented by polymodal, pebble-cobble conglomerate. A boulder is partly seen at the top of this conglomerate, to the left. The conglomerate is overlain by laminated granule sandstone and conglomerate containing trains of pebbles. The laminated unit is erosionally overlain by pebble to cobble conglomerate. All lithologies are rich in nummulites. Lower and upper conglomerates are inferred to represent the upper shoreface, and the laminated unit could represent a lower beachface setting. For discussion see text. Hammer is 28 cm long. Locality 7 in Fig. 3. Vertical position in log B, Fig. 4.

member and differing from the matrix of the lower member (Fig. 17). In other cases, the lower member is capped by a discontinuous layer of bimodal conglomerate containing large clasts (cobbles, boulders), which may be dispersed in granule conglomerate to granule sandstone (Fig. 15 - 0.5-0.6 m). These clasts are the largest found in the sandstone-conglomerate unit, and may attain 1.4 m in diameter. The upper member is 0.3 to 1 m thick, and consists of laminated pebbly sandstone, granule conglomerate and/or granule sandstone, and coarse sandstone, which may contain discontinuous, one-clast thick pebble layers, dispersed pebbles and common nummulites (Fig. 17).

(4) Discontinuous trains of cobbles are intercalated in crudely stratified, poorly sorted, fine to coarse nummulitic pebble conglomerates (Fig. 18).

Interpretation

Associations of sediments differing in clast shape and/or size, similar to those described above, commonly result from sorting processes on gravel beaches *sensu lato* (BLUCK, 1967; ORFORD, 1975; MASSARI & PAREA, 1988; POSTMA & CRUICKSHANK, 1988; POSTMA & NEMEC, 1990), but may also be generated in the upper shoreface (MASSARI & PAREA, 1988). Directions of imbrication dips towards the NE and SW indicate a general NW-SE strike of the ancient shoreline. Seaward directed clinostratification usually characterising beach gravel complexes, may be present in the sediments studied, but could not be identified due to the limited extension of exposures, and the usual orientation of exposed sections parallel to the palaeoshoreline.

Specific features and conglomerate associations are discussed below.

(1a) Coarse imbricated clasts in the lower layer (A) at locality 2 (Fig. 13) might reflect a concentration of the largest available clasts at the toe of the beachface, where imbrication may dominantly dip landwards (MASSARI & PAREA, 1988) as in the case described here. They also resemble the "large-disc zone" (BLUCK, 1967) i.e. the upper berm, or high storm berm gravel described by POSTMA & NEMEC (1990), but this setting seems less probable as there is a dominant seaward imbrication. The middle layer (B) resembles bimodal conglomerates, which may have originated by mixing and single-event deposition in the upper shoreface, or by two or more depositional, erosional, and/or reworking events in the beachface and upper shoreface settings (MASSARI & PAREA, 1988). Finally, the upper layer (C) dominated by equant clasts and moderate sorting could be compared to the "infill zone" of BLUCK (1967) and POSTMA & NEMEC (1990), i.e. to the beachface in general, and similar gravel may also be generated in the upper shoreface as previously discussed in relation to the middle layer (B).

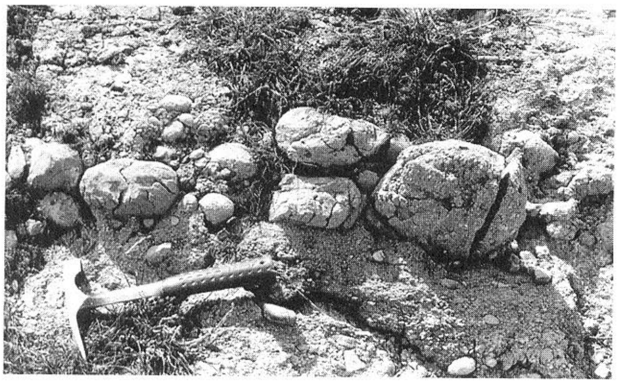


Fig. 18 Train of cobbles intercalated in finer grained nummulitic conglomerates. The cobbles are inferred to represent a lag deposit in the uppermost shoreface. Hammer is 28 cm long. Locality 3 in Fig. 3.

(1b) Coarse polymodal, nummulitic conglomerates showing seaward (SW) imbrication probably originated in the upper shoreface because of their mixed clast population and concentration of marine fossils (nummulites). Although landward imbrication directions predominate in this zone, seaward imbrication may also be produced (MASSARI & PAREA, 1988).

(2) "Imbricate-zone" conglomerates may be regarded as the single, best criterion for identifying a gravel beach in the fossil record (BOURGEOIS & LEITHOLD, 1984). Among four shore-parallel zones identified by BLUCK (1967) on a gravely coastline, the gravel consisting of imbricate discoidal pebbles characterised the "imbricate zone", which formed in an upper part of the beachface. Opposite directions of imbrication dips, such as in the Radovin examples, reflect both landward and seaward traction processes, and backwash-induced sieving (BLUCK, 1967; MASSARI & PAREA, 1988). Based on a detailed study of excellently exposed sections of Pleistocene beach complexes in Italy, MASSARI & PAREA (1988) found similar imbricated gravels in both the inferred lower and upper beachface divisions. Gravels assigned by these authors to the lower beachface were moderately well-sorted and steeply imbricated, usually landwards, while those inferred to have been deposited in the upper beachface showed better sorting, usual seaward or opposed (seaward and landward) imbrication, and steep imbrication angles are rare. The examples described here seem to more closely resemble imbricate gravel in the upper beachface of MASSARI & PAREA (1988). Imbricate-disc facies in the Holocene gravels of Crete has been regarded as a moderate wave-energy deposit of lower storm berms (POSTMA & NEMEC, 1990), which is consistent with the setting proposed above.

(3) The erosional contact at the base of the lower member resulted from strong flows, which removed some of the previous sediments, and were related to the peak of storms or to swells. The coarser fraction of the lower member may have been deposited by less vigorous storm waves, and has been mixed with smaller clasts, resulting in a polymodal to bimodal size distribution (BLUCK, 1967; MASSARI & PAREA, 1988). In the case of crudely/indistinctly stratified conglomerates, individual layers could have been produced either by single resedimentation events moving beachface gravel into the shoreface, or by repeated reworking and mixing. This also explains the origin of the open framework (into which finer sediment was deposited during subsequent lower energy conditions, either passively or by active mixing) (Fig. 17), and the concentration of large clasts at the top of the coarse member (Figs. 15 & 16).

Polymodal varieties of the lower member containing coarse cobbles and boulders (Fig. 15: basal conglomerates; Fig. 17: lower and upper conglomerates), probably originated in the upper shoreface, and the concentration of large clasts capping the lower member may represent the toe of the beachface, and were possibly related to minor storm waves or long-period waves (MASSARI & PAREA, 1988). These large clasts may also be compared to "storm lags" in the lower beachface of POSTMA & NEMEC (1990).

Particles of the upper, fine member may have been re-mixed with the underlying gravel, or infilled the gravel frame, and these processes reflect lower-energy conditions. Laminated sediment contaning dispersed pebbles and discontinuous, one-clast thick pebble layers may have originated by the transport of gravel from the upper shoreface, or lower beachface into the swash zone, and also by partial reworking of berms or cusps, and mixing of different size populations within the swash zone, during lower-energy conditions (MASSARI & PAREA, 1988). However, stringers of equant pebbles may have resulted from the transport of such pebbles from the upper shoreface into the lower beachface by shoaling long-period waves (MASSARI & PAREA, 1988). Laminated sand of the uppermost part of the fine member could possibly have been produced by swash processes.

Concerning the sediments shown in Figs. 15 and 16 other interpretations should also be mentioned. One of these includes storm-related processes and deposition in the upper shoreface as discussed above related to (CS) Conglomerate-sandstone couplets. This origin seems less probable for the origin of the lower couplet because of the large clast size present, but may be possible in the case of the upper two couplets. Another possible origin involves the deposition of the coarse, lower member by a non-cohesive debris flow, and the fine member by turbulent flow, both related to river flood. Delta-front sediments of such origin are known from the geological record (e.g. KLEINSPEHN et al., 1984), and the presence of a marine fauna (nummulites) can not exclude this interpretation.

(4) Discontinuous trains of cobbles within nummulitic fine to coarse pebble conglomerates (Fig. 18) may be explained as lags, which resulted from reworking in the uppermost shoreface during minor storm or

Fig. 19 Set of cross-bedded, fine-grained conglomerates and granule sandstones underlain by polymodal pebble to cobble conglomerate, and overlain first by thin horizontally laminated, granule to nummulitic sandstone and sandstone, and then by cobble to boulder conglomerate of the probable upper shoreface. Cross-beds are inclined towards the NW, and are interpreted as having been deposited in a longshore trough following the peak of a storm. Hammer is 28 cm long. Locality 4 in Fig. 3.

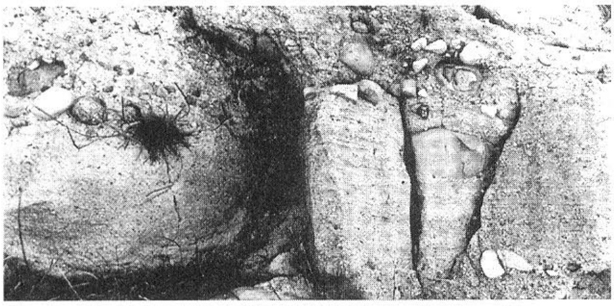


Fig. 20 In the lower part of the photograph there is a horizontally stratified granule conglomerate (visible thickness=20 cm) of probable beachface/uppermost shoreface setting. The conglomerate contains scattered pebbles in its lower part and a cobble in its upper portion. This conglomerate is overlain by cross-bedded conglomerate to granule sandstone (dipping right) inferred to have originated by a longshore migrating bedform. Locality 8 in Fig. 3.

swell conditions (see MASSARI & PAREA, 1988). This is consistent with the probable upper shoreface setting of the associated nummulitic conglomerate.

(CX) Cross-bedded conglomerates

Description

This facies (Figs. 19 & 20) is represented by singular sets up to 0.4 m thick, which may show an erosional base and are erosionally truncated. Cross-beds consist of granule to pebble conglomerates, granule sandstones, and sandstones. They are intercalated in pebble to boulder conglomerates, which may show imbricated clasts and probably represent upper shoreface deposits. Sets are mostly planar, with tangential and angular lower contacts, and the inclinations range up to the angle of repose. Nine out of a total of twelve measurements indicated NW, and SE to E directions, two were towards the ENE, and one towards the S.

Interpretation

The dominant directions of bedform migration towards the NW and SE reflect longshore flows. These were probably related to a shoreline-parallel rhythmic topography and related dissipative conditions generated during storms, and related longshore transport in troughs (DUPRÉ, 1984; LEITHOLD & BOURGEOIS, 1984; MASSARI & PAREA, 1988). Longshore transport of gravel has also been documented by HART & PLINT (1989). S-directed flow (one measurement) may have been related to the end of the seaward-opened trough, or to the rip-channel fill. Directions towards the ENE (2 measurements) may represent either onshore bar or dune migration in the recovery stage (DUPRÉ, 1984), or a longshore dune migration in the case of a shoreline with an irregular profile.

"Other conglomerates"

In some places (e.g. Fig. 4, A, between 65 and 90 m), there are conglomerates showing more than 0.5 m thick beds, which commonly contain boulder-sized clasts, and may contain nummulites. The matrix is sandy. This conglomerate type may have been deposited by debris flows at the distributary mouths.

Another conglomerate type shows overall graded, composite beds up to 1.3 m thick (e.g. Fig. 4, A, at 52 m), and consists of pebble conglomerate in the lower part and flat laminated pebbly sandstone to sandstone in the upper part both containing nummulites. They are intercalated in "weathered sandstones", which may be deposits of the nearshore or offshore transition setting (see above). Such beds could possibly represent storm-related, nearshore deposits, or products of flood-related, gravity-flows.

7. THE GENERAL CHARACTER OF NEARSHORE SETTINGS RECORDED BY THE SANDSTONE-CONGLOMERATE UNIT

Descriptions and interpretations presented above depict nearshore settings, which were of two types: one was dominated by gravel, and the other by sand.

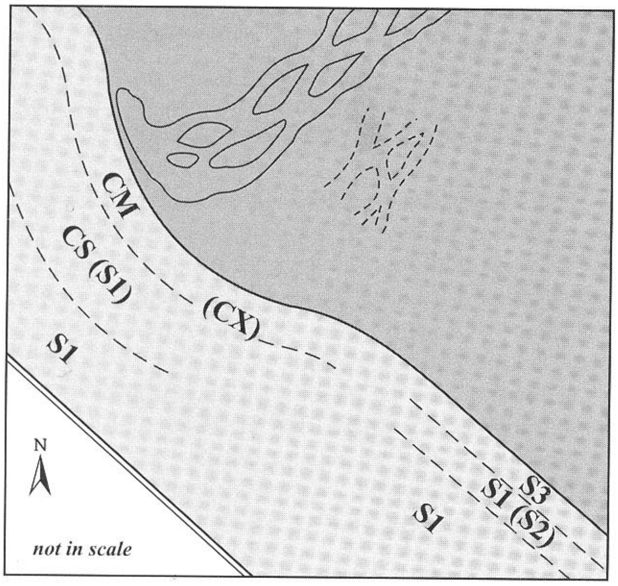


Fig. 21 Conceptual picture showing the palaeogeography and idealised distribution of the dominant depositional facies during deposition of the sandstone-conglomerate unit studied in the Radovin Syncline. Facies codes as in text. Codes in brackets are subordinate components. For discussion see text. When the fluvial system was temporarily not active, the mouth could have been barred by marine processes. A previous position of the stream is also shown.

The most common sediments among the conglomerate-dominated facies are those included in the (CM) Main conglomerates, which are interpreted here as upper shoreface and beachface deposits. The characteristics of these facies resulted from processes related to minor storms, declining- and post-storm periods, swell, and fair-weather conditions. These features describe the predominant reflective character of the coast during such conditions. Processes related to the high stage of major storms were responsible for the origin of most erosional surfaces. High-stage to declining storm periods were probably responsible for longshore-oriented flows and strong rip currents, which resulted in deposition of most (CX) Cross-bedded conglomerates indicating a bar and trough topography, i.e. the establishment of dissipative conditions. The storm conditions were also responsible for the origin of (CS) Conglomerate-sandstone couplets. The origin of some conglomerates may be related to gravity flows during river floods.

Conglomerates may be rich in boulder- and cobble-sized clasts, which were unlikely to have been transported far along the coast. The gravel therefore, especially the boulder gravel, reflects the close proximity of the mouths of river distributaries, and also the mouths themselves. Thus, the gravel-dominated beachface and shoreface may be regarded as the shoreline and shallow subaqueous parts of coarse-grained fan-delta or braid-delta complexes fed by high-gradient braided streams (Fig. 21).

As described above, coarse-grained delta sediments are associated with shallow-marine sandstones, both within the sandstone-conglomerate unit, and within the overall succession of the Radovin Syncline. Therefore this delta is comparable to the shelf-type model of fan-deltas differentiated by ETHRIDGE & WESCOTT (1984), based on differences in basin margin gradients, or to the relevant braid deltas later recognised by McPHERSON et al. (1987). In respect to the dominant processes operating at the delta front (NEMEC & STEEL, 1988; COLELLA & PRIOR, 1990), a major part of the Eocene deltas in the Radovin Syncline may be assigned to the "wave-dominated" type of fan-deltas or braid deltas, as the material brought by ancient rivers to the sea shore was reworked by marine processes. During some time intervals, some deltas may have been dominated by mass-flow deposits.

The sandstone facies S1, S2, and S3 originated in the lower shoreface, upper shoreface, and foreshore settings respectively. In shoreface settings (facies S1 and S2) of the ancient Radovin area, erosion, deposition and the biogenic disturbance of sediments were strongly influenced by storm-induced processes. Fair-weather processes including reworking during minor-storm periods, and bioturbation are scarcely recorded in these sediments. The associations of various S1 and S2 facies described here may be compared to Recent amalgamated storm sand beds described by AIGNER & REINECK (1982) from a storm-dominated sandy shoreface. In such settings, sedimentary structures, which could have been produced by fair-weather processes, have mostly been obliterated by storm-related processes (KUMAR & SANDERS, 1976; DUPRÉ, 1984). The relevant ancient environments therefore were characterised by a high frequency of storms and high depositional rate.

Apart from gravel-dominated delta-fronts, there were pure sandy nearshore settings, which can be deduced from sandy progradational sequences such as the upper sandstone segment in Fig. 5. Such sandy settings could have been situated laterally to gravel-dominated delta mouths, at distances greater than those attainable by the wave-driven longshore drift of gravel. It is also possible that there were intervals when only sand was deposited along the entire nearshore belt of the former Radovin Syncline area. A part of storm-related sandstones was probably deposited seawards of the gravel-dominated river mouths (Fig. 21), and these sandstones would represent distal delta-front deposits.

The depositional architecture of the sandstone-conglomerate unit can be inferred from the facies analysis presented above taking into account (1) the entire sandstone-conglomerate unit in the Radovin Syncline consisting of alternating sandstones and conglomerates; (2) all sediments showing depositional structures and fabric reflecting nearshore settings (these sediments appear in small, isolated outcrops and up to 10 m thick successions scattered throughout the unit and within the whole Radovin area, while larger continuous exposures, which would show vertical successions, lateral changes and facies relationships, are absent) (3) conglomeratic sediments and packages change their thickness laterally, which implies a lateral change in thickness of the sandstones. Based on these features the overall architecture may be described as interfingering and overlapping deltas and nearshore sandy systems. Those sandstones, which could have been deposited in the offshore transition zone, may be added to the above scenario. The architecture of the sandstone-conglomerate unit was generated by an interplay of external factors such as sediment supply, tectonics, and sea-level changes, and internal factors including the lateral shifts of deltas or delta distributaries, and changes in fluvial input. Details of the related trends of depositional dynamics are rarely clearly observed, the best example being shown in Fig. 5, where an overall progradational succession ranging from offshore to foreshore settings includes two small-scale, sandy progradational sequences, and an intermediate gravel package. The top of the gravel package is a flooding surface reflecting a relative sea-level rise.

8. THE SANDSTONE-CONGLOMERATE UNIT AND THE EVOLUTION OF THE PALAEOGENE CLASTIC BASIN IN NORTHERN DALMATIA

The evolution of the Palaeogene clastic basin in northern Dalmatia began in the middle of the Middle Lutetian with the drowning of the previous carbonate platform, and deposition of hemipelagic marls over the platform carbonates (SCHUBERT, 1905a; review in BABIĆ & ZUPANIČ, 1983). These marls are followed by flysch-type sediments (Unit 1, Fig. 2).

Post-flysch evolution is characterised by development of shallow-marine environments in the previous flysch-basin domain, as revealed by shallow-marine character of the overlying sandstones and subsequent deposits (Fig. 2). The sandstone-conglomerate unit described here (Unit 3, Fig. 2) includes coarse-grained delta front deposits, which must have been connected with high-gradient streams, and the dissected topography of the source area situated in the vicinity of the coast. Powerful transverse flows brought the detritus from land to the north-east to the NW-SE oriented shoreline, and this palaeogeography corresponds to the "model 2" of typical alluvial basin-fill patterns summarised by MIALL (1996). Lithoclast types in the conglomerates reflect sediment supply from an emerged area, where Eocene and Late Cretaceous sediments were exposed, as already reported by QUITZOW (1941) and MAJCEN & KOROLIJA (1973). The supply of coarse-grained detritus may have been related to the Middle Eocene tectonic deformation, which was recognised by QUITZOW (1941).

Middle Eocene shallow-water clastics may be regarded as molasse deposits, which postdate flysch-type deposits and predate the Promina Beds. Thus, this molasse was generated very early in the evolution of the north Dalmatian Palaeogene clastic basin. This is in confirmation of previous propositions on early changes in the palaeogeography of the coastal Dinaric clastic belt (BABIĆ & ZUPANIČ, 1990; ZUPANIČ & BABIĆ, 1991; BABIĆ et al., 1993).

9. SUMMARY AND CONCLUSION

The Middle Eocene clastic succession in the Radovin Syncline, northern Dalmatia is approximately 900 m thick and consists of basal hemipelagic marl and flysch-type deposits in its lower part, and shallow-marine sediments in its upper part. Identification of shallow-marine deposits in the upper part of the successions confirms the view presented by Schubert at the beginning of this century (SCHUBERT, 1905a, 1909).

Within the upper, shallow-marine portion of the clastic succession in the Radovin Syncline, there is a distinct stratigraphic unit consisting of sandstones and conglomerates. The overall architecture of this unit may be described as the interfingering of deltas and nearshore sandy systems. The unit was generated under the influence of several internal and external factors, and the most important of these were sediment supply and changes in relative sea level. Deltas were of the shelf-type, and were predominantly "wave-dominated". The sand and gravel were transported by high-gradient streams and possibly by gravity flows from emerged areas. Final deposition mostly occurred within the nearshore environments of a high-energy coast. Most sandstones originated by storm-related processes in the shoreface. Conglomerate-dominated facies mostly resulted from various and successive erosional, depositional and reworking processes in the shoreface and beachface settings.

The sediments studied document important post-flysch changes in the basin evolution and palaeogeography of the Palaeogene clastic basin in the coastal Dinarides, and the earliest post-flysch emersion of an inner part of the basin.

Acknowledgement

Constructive criticism by Prof. Francesco MASSARI helped greatly in clarifying and presenting the facies interpretations. An anonymous reviewer suggested improvements in petrographic terminology. We also thank M. KLADNIČKI for careful drawings. The work has been supported by the Ministry of Science and Technology of the Republic of Croatia, through the Project 119302.

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