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Original Scientific Paper

An Association of Marine Tractive and Gravity Flow Sandy Deposits in the Eocene of the NW Part of the Island of Pag (Outer Dinarides, Croatia)

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Key words: Marine clastics, Cross-bedded sandstones, Cross-laminated sandstones, Gravity flow deposits, Eocene, Island of Pag, Outer Dinarides

Ključne riječi: Marinski klastiti, koso slojeviti pješčenjaci, koso laminirani pješčenjaci, talozi gravitacijskih tokova, eocen, Pag, Vanjski Dinaridi

Abstract

The Eocene clastics of the NW part of the island of Pag overlie carbonate platform deposits and are dominantly sandy. Besides minor components, they include cross-laminated and cross-bedded sandstones produced by marine tractive flows, mostly directed toward E, and ESE, and dominantly massive sandstones probably deposited by gravity flows. The area was situated close to sand-rich sources and river mouth(s). Possible settings include a delta-related shallow-marine area, and a sea strait. Structural deformation intervened very early in the history of a complex outer dinaric foreland realm and governed its subsequent evolution, in contrast to a simple foreland trough envisaged before.

Sažetak

Eocenski klastiti sjeverozapadnog Paga slijede na talozima karbonatne platforme i pretežito su pješčani. Osim manjih komponenata, ti klastiti uključuju koso laminirane i koso slojevite pješčenjake, proizvedene marinskim vučnim tokovima, većinom usmjerenim prema istoku i istoku-jugoistoku, te pretežito masivne pješčenjake, koji su vjerojatno nastali iz gravitacijskih tokova. Predio je bio smješten blizu pijeskom bogatih izvora i riječnih ušća. Moguće situacije uključuju plitkomorski predio povezan s deltom i morski prolaz. Strukturne deformacije utjecale su vrlo rano na povijest vanjsko-dinaridske kompleksne zone forlanda i upravljale su njezinim daljnjim razvitkom, nasuprot ranije zamišljenom jednostavnom forlandskom koritu.

1. INTRODUCTION

The main purpose of this work is to describe a peculiar clastic succession which overlies platform carbonates in the northwestern part of the island of Pag (Fig. 1). The sediments mainly consist of traction flow deposits including cross-laminated and cross-bedded sandstones, and dominantly massive sandstones, probably representing gravity flow deposits. Such an association has not been described before, either from Pag or from other Eocene dinaric successions, and departs from them considerably. Possible depositional settings will also be discussed.

2. GEOLOGICAL SETTING AND OUTLINE STRATIGRAPHY

The island of Pag is situated within the Northern Adriatic portion of the Outer Dinaric zone. The lower part of the Pag succession consists of Late Cretaceous and Lower-Middle Eocene shallow-marine carbonates that are separated by a karstified surface locally marked by bauxites (MAMUŽIĆ & SOKAČ, 1973; SOKAČ et al., 1976). These deposits correspond to the upper part of the several-kilometer-thick Mesozoic to Middle Eocene platform carbonate succession characterizing the Outer Dinarides. The carbonates are transitionally overlain by Eocene sandstones and marls (WAAGEN, 1909, 1914; SCHUBERT & WAAGEN, 1912, 1913; MAMUŽIĆ et al., 1970; MAMUŽIĆ & SOKAČ, 1973; SOKAČ et al., 1974; SOKAČ et al.,1976) that attain a thickness of about 350 m (SOKAČ et al., 1976). The transition from shallow-marine limestones, rich in larger foraminifera *Alveolina* and *Nummulites*, is marked by the several-meter-thick Transitional Beds, mainly represented by marly limestone, and containing benthic and planktonic foraminifera, and echinoids. They are considered to reflect a change from shallow to deeper marine conditions (MAMUŽIĆ & SOKAČ, 1973; SOKAČ et al., 1976).

The age of the Eocene clastic succession has been considered to correspond to the Late Lutetian and Early Bartonian by means of planktonic foraminifera (PICCOLI & PROTO DECIMA, 1969; MAMUŽIĆ & SOKAČ, 1973), and partly nannoplankton (BENIĆ, 1975), and to the Late Lutetian, Bartonian, and Priabonian (SOKAČ et al., 1976), also based on planktonic foraminifera. The clastic unit has been regarded to represent flysch-type deposits (MAMUŽIĆ et al., 1970;

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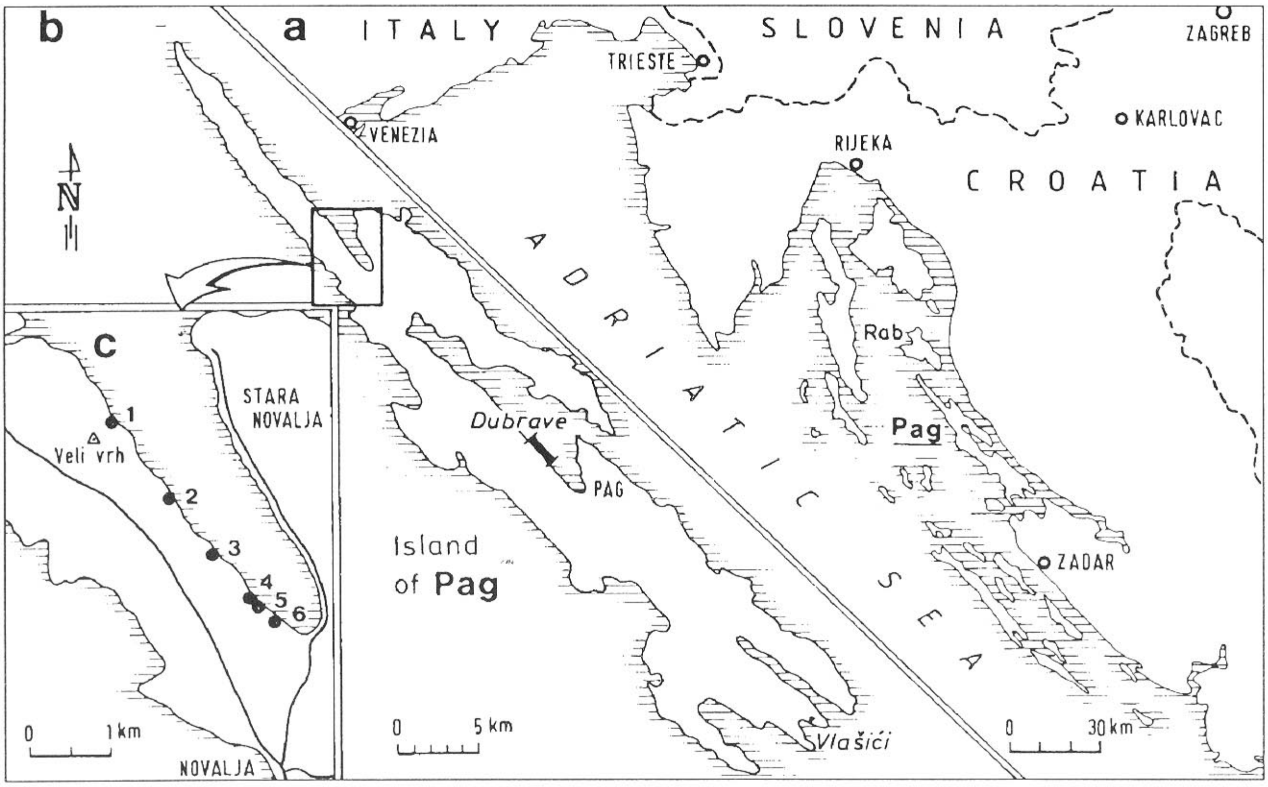


Fig. 1. Situation of the island of Pag (A), and the outcrops studied in the NW Pag area (B, and C, 1-6). The location of Vlašići and Dubrave is also shown in B.

Sl. 1. Smještaj otoka Paga (A) i proučenih izdanaka u sjeverozapadnom dijelu otoka (B i C,1-6). Položaj Vlašića i Dubrava vidi u B.

MAMUŽIĆ & SOKAČ, 1973; MARINČIĆ, 1981), and more precisely, "proximal flysch" (MARINČIĆ, 1981).

Some parts of the island contain Tertiary limestone breccias directly overlying Upper Cretaceous carbonates, then Neogene lacustrine to palustrine marls with coal seams, Pleistocene alluvial conglomerates and sands, and a Holocene cover (WAAGEN, 1909, 1914; SCHUBERT & WAAGEN, 1912, 1913; MAMUŽIĆ et al., 1970; MAMUŽIĆ & SOKAČ, 1973; SOKAČ et al., 1974; SOKAČ et al., 1976).

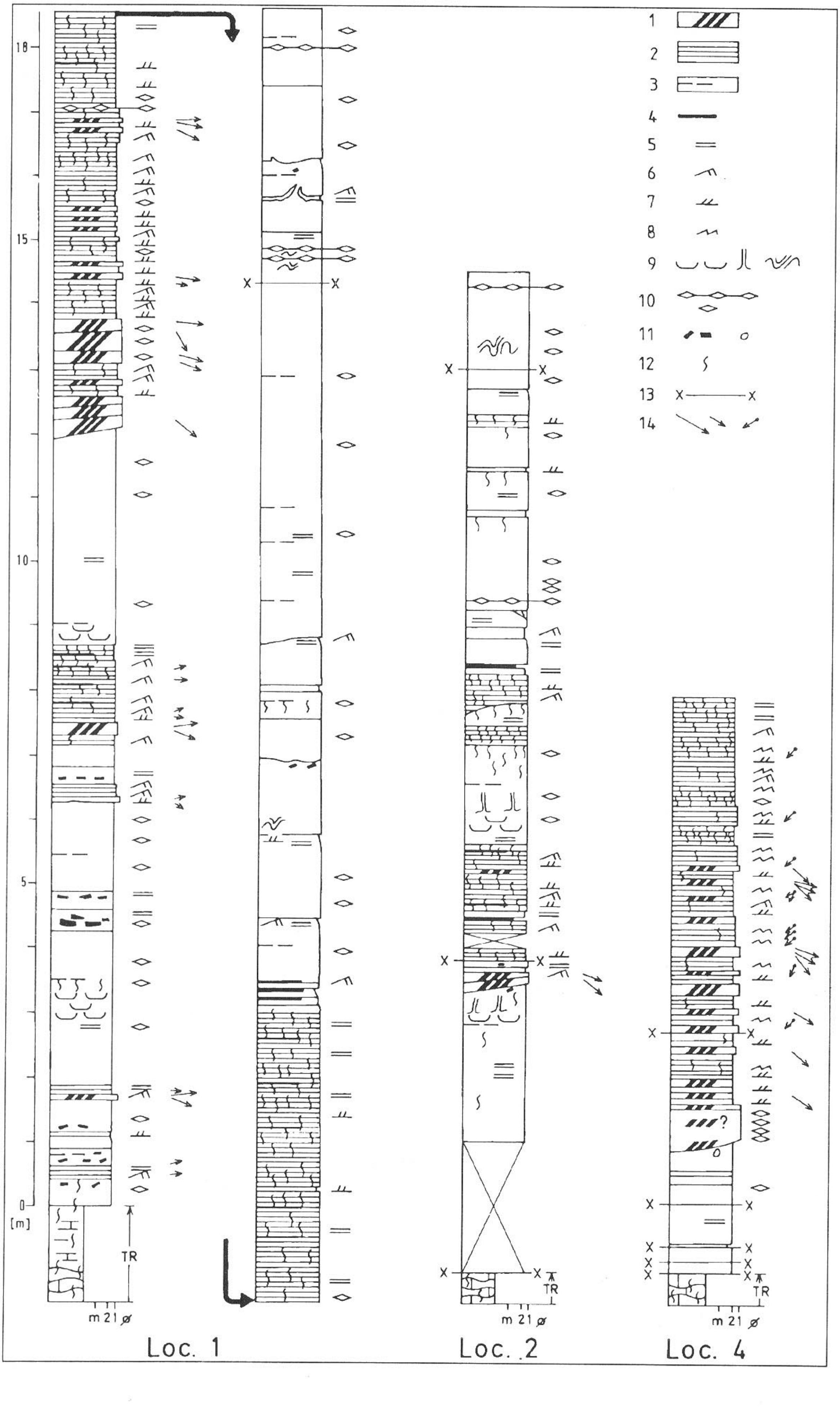
The main tectonic deformations produced NW-SE oriented folds and a number of faults. Carbonates are exposed in the anticlinal belts generally corresponding to topographic highs, while Eocene clastics occupy synclinal portions of the island, being mostly covered by Quaternary deposits in topographic lows, and by the sea in NW-SE oriented bays. For this reason, most outcrops of Eocene clastics, including those studied here, occur at the margins of longitudinal valleys and bays, where flanks of the folds are exposed.

3. GEOLOGICAL SITUATION OF THE OUTCROPS STUDIED

The sediments described here occur in the northwestern part of the island (Fig. 1). In this area Eocene clastics appear in short, narrow strips, bounded to the SW by carbonates, and to the NE by the sea. Clastic sequences similar to those occurring in this area have not been encountered during reconnaissance work in other parts of the island. At locality 1 (Figs. 1, and 2) the contact surface between the Transitional Beds and overlying clastics represents the original basal surface of clastics and, hence, the section measured at this locality comprises the beginning of Eocene clastic

Fig. 2. Three characteristic sections representing Eocene clastics in the NW Pag area (localities 1, 2, and 4 in Fig. 1C). m-mudstone, TR-Transitional Beds: dominantly marly limestone, 1-cross-bedded sandstones (symbol commonly represents several sets), 2-ripple-laminated sandstones, and laminated muddy sandstones in general (Fl, occasionally F3), 3-amalgamation, 4-thick mudstone laminae, 5-horizontal laminae, 6-ripples, 7-cross-lamination, 8-climbing ripple cross-lamination and associated sinusoidal lamination, 9-dish structures, pillars, and convolutions, 10-nummulites: organized in laminae, and dispersed, 11-mud clasts, and limestone pebbles, 12-bioturbation, 13-fault, 14-paleocurrent directions from cross-beds, cross-laminae, and climbing ripple cross laminae.

Sl. 2. Tri karakteristična slijeda eocenskih klastita sjeverozapadnog Paga. m-lapor, TR-Prelazne naslage: pretežito laporoviti vapnenac, 1-koso slojeviti pješčenjak (simbol obično predstavlja po nekoliko nizova), 2-pješčenjaci s laminacijom riplova i laminirani muljeviti pješčenjaci općenito (Fl, ponegdje F3), 3-amalgamacija, 4-debele lamine lapora, 5-horizontalna laminacija, 6-riplovi, 7-kosa laminacija, 8-kosa laminacija penjućih riplova i pridružena sinusoidalna laminacija, 9-zdjelaste i stupaste teksture, te konvolucija, 10-numuliti: organizirani u lamine i dispergirani, 11-muljni klasti i vapnenčke valutice, 12-bioturbacija, 13-rasjed, 14-smjerovi paleostruja iz kosih slojeva, kose laminacije i kose laminacije penjućih riplova.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deposition. Sediments studied at other localities in the same area (Figs. 1, and 2) are separated from the Transitional Beds by a bedding parallel fault. These sections are either correlatives of parts of the section at locality 1, or represent somewhat younger horizons. In any case, they are also situated very low within the clastic succession of the area. The works describing biostratigraphic results do not specifically mention the NW Pag area, and do not seem to include data which would have derived from it.

4. DESCRIPTION OF CLASTIC FACIES OCCURRING IN THE NW PART OF PAG

Clastic sediments appearing in the NW portion of the island have been studied at localities 1 to 6 (Fig. 1C), and three logs in Fig. 2 show the vertical sequences at three of them. Four facies have been differentiated and will be subsequently described and interpreted: (F1) Laminated sandstones and muddy sandstones, (F2) Cross-bedded sandstones, (F3) Thin bedded, laminated sandstones, and (F4) Dominantly massive sandstones.

The sandstones are fine- to medium-grained. Very fine-grained sandstones are not common. Non-carbonate and carbonate particles participate about equally in the sandstone composition, or non-carbonate grains may slightly prevail. Exceptions are a few massive sandstones containing an increased number of larger foraminifera and other skeletal particles, and having up to 70% carbonate particles. In general, most particles are terrigenous, including the carbonate ones, and skeletal particles are accessory. Skeletal particles include larger and smaller benthic foraminifera (dominant nummulites, rare miliolids and attached forms, and very rare *Alveolina* and planktonic forms), mollusc, corallinacean, and echinoid fragments, as well as others. In most cases, sandstones are carbonate cemented.

4.1. LAMINATED SANDSTONES AND MUDDY SANDSTONES (F1)

Several sediment types having thin layering and small-scale structures in common are assembled under the above heading. They will be described within two sediment groups.

(A) The first sediment group is dominantly sandy, containing between about 2-20% fine-grained component. The group embraces several sediment types:

(1) Mm- to cm-thick cross-laminated sandstone layers displaying ripples and ripple-like lenses with a maximal height of 20 mm, and a maximal length of up to 0.5 m (Figs. 3, and 4). Unidirectional foreset laminae as well as similarly oriented asymmetric ripples are common. Most of these ripples migrated in directions roughly between ENE and ESE (vector mean=89°; Fig. 5a). There are also ripples showing symmetric outline. Packets of these sandstone layers including tiny mudstone interlaminae may display wavy and flaser bedding. These sandstones (1) are most common at locality 1.

(2) 20 to 50 mm thick, and 0.5 to several-meter-long lenses and sheets of cross-laminated sandstones with unidirectional foreset laminae, in places showing ripples. Foreset laminae dip in directions between ENE and ESE.

(3) Several-cm-thick, rippled and unidirectionally cross-laminated sandstones, which mostly display climbing ripple lamination (type A, locally B/A transition), and alternate with several-cm-thick sinusoidal ripple lamination (Fig. 6) (terminology according to JOPLING & WALKER, 1968). The transitions between two alternating structures are sharp. The ripple length ranges from 50 to 160 mm, and ripple height is from 3 to 15 mm. Some ripples showing strongly tangential foreset and sometimes offshooting laminae, resemble wave-current generated structures (Fig. 7).

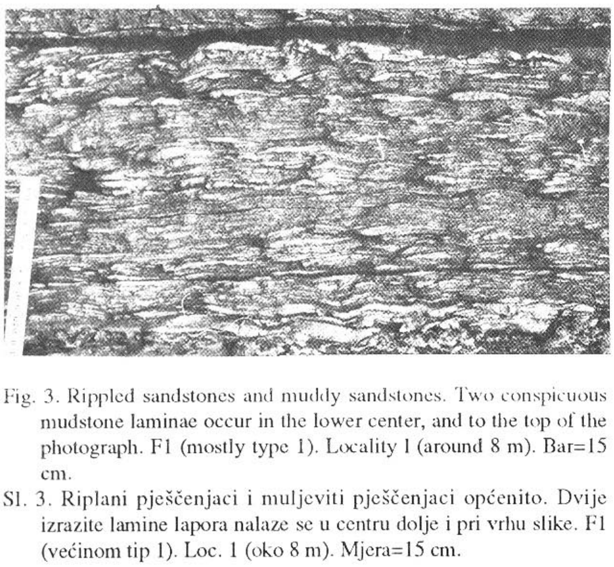

Fig. 3. Rippled sandstones and muddy sandstones. Two conspicuous mudstone laminae occur in the lower center, and to the top of the photograph. F1 (mostly type 1). Locality 1 (around 8 m). Bar=15 cm.

Sl. 3. Riplani pješčenjaci i muljeviti pješčenjaci općenito. Dvije izrazite lamine lapora nalaze se u centru dolje i pri vrhu slike. F1 (većinom tip 1). Loc. 1 (oko 8 m). Mjera=15 cm.

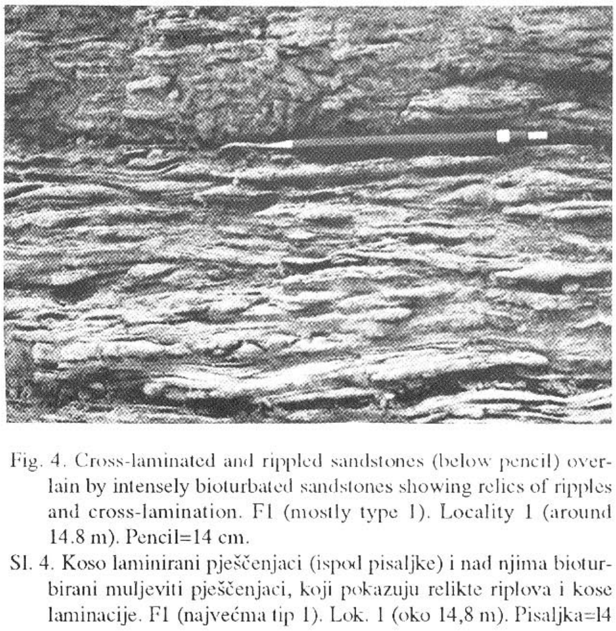

Fig. 4. Cross-laminated and rippled sandstones (below pencil) overlain by intensely bioturbated sandstones showing relics of ripples and cross-lamination. F1 (mostly type 1). Locality 1 (around 14.8 m). Pencil=14 cm.

Sl. 4. Koso laminirani pješčenjaci (ispod pisaljke) i nad njima bioturbirani muljeviti pješčenjaci, koji pokazuju relikte riplova i kose laminacije. F1 (najvećma tip 1). Lok. 1 (oko 14,8 m). Pisaljka=14 cm.

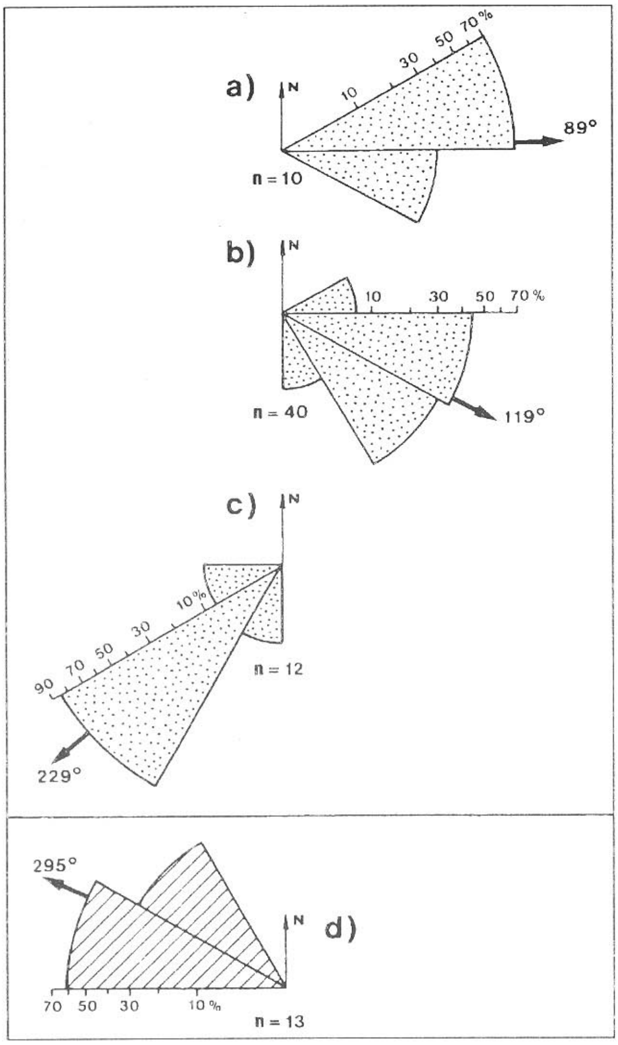

Fig. 5. Paleocurrent data plotted in rose diagrams. Arrows correspond to the azimuths of vector means. (a), (b), and (c)=NW Pag. (a)-unidirectional cross-lamination (locality 1), (b)-cross-bedded sandstones (localities 1-6), (c)-climbing ripple cross-lamination (localities 4 and 5), (d)-Dubrave; directional sole marks (mostly flutes). Magnitudes of mean vectors: a=97%, b=93%, c=99%, d=98%. Location in Fig. 1.

Sl. 5. Podaci o paleostrujama prikazani ružinim dijagramima. Strelice odgovaraju azimutima srednjih vektora. (a), (b) i (c)=NW Pag. (a)-jednosmjerno koso laminirani pješčenjaci (lok. 1), (b)-koso slojeviti pješčenjaci (lok. 1-6), (c)-pješčenjaci s kosom laminacijom penjućih riplova (lok. 4 i 5), (d)-Dubrave; teksture na donjim slojnim plohama pješčenjaka (uglavnom teksture tečenja). Magnitude srednjih vektora: a=97%, b=93%, c=99%, d=98%. Smještaj na sl. 1.

Very rarely present are intercalations of thin, lens-like sets of oppositely directed cross laminae. The ripples migrated toward SW (Fig. 5c). This type of rippled sandstone (3) is common at localities 4, 5, and 6 (Fig. 1C), where packets of these sandstones showing wavy appearance alternate with cross-bedded sandstones.

(4) More or less distinct mm- to cm-thick horizontal sandstone laminae. Internal structure is not visible, but some layers contain sporadic ripples.

(5) Tiny mudstone laminae, mostly thin films, that may separate sandstone layers (Figs. 3, and 4), and also ripples, and foreset laminae.

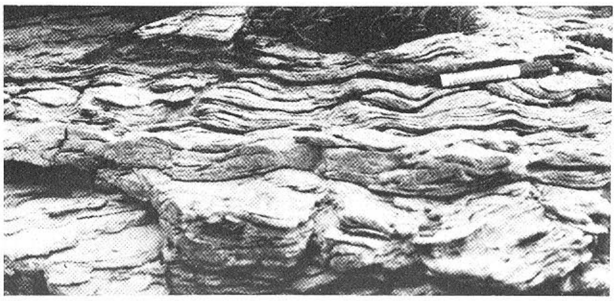

Fig. 6. Irregularly sinusoidal lamination with intercalations of unidirectional cross-laminated sets (just below marker) directed SW (to the right). F1 (type 3). Locality 4 (6,5 m). Marker=14 cm.

Sl. 6. Nejednolično sinusoidalna laminacija s uložcima jednosmjerno koso laminiranih nizova (pod markerom), orijetiranih prema SW (desno). F1 (tip 3). Lok. 4 (6,5 m). Marker=14 cm

Fig. 7. Probable wave-current ripples (section perpendicular to ripple crests). F1 (type 3). Locality 4. Visible part of pencil=7.5 cm.

Sl. 7. Vjerojatni kombinirani (valno-strujni) riplovi (presjek okomit na valne kreste). F1 (tip 3). Lok. 4. Vidljivi dio pisaljke=7,5 cm

Group (A) sediments may contain scattered nummulites and very rare echinoid debris. Some laminae, either oblique or horizontal, contain more nummulites. Plant debris may be common. Bioturbation intensity varies from slight to heavy in sediment types (1), (4), and (5), as well as in their combinations, and is low to absent in sediment types (2) and (3). The sandstones are mostly fine-grained, and are occasionally medium-grained.

(B) The second sediment group is represented by muddy, fine-grained sandstone containing some 10 to 20% mud component. The sediments may be described as interlaminated sandstone and mudstone, consisting of horizontal sandy laminae, 0.5 to 20 mm thick, and mudstone laminae that are mostly less than 1 mm thick. Tiny ripples are observed here and there. Bioturbation is mainly intense.

Various ichnofossils have been recognized in F1 sediments, and they illustrate the highest diversity of all the facies differentiated here. *Scolicia* is most commonly recognized (Fig. 8), and it may constitute dense populations. The ichnogenus *Planolites* is represented by several varieties differing in tube width. Also present are meniscate structures with concentrically circular cross-sections. There are several types of bilobate crawling traces, some of which are similar to *Curvolithus*, *Aulichnites*, and *Gyrochorte*, and irregular strap-like traces. *Thalassinoides* and *Chondrites* (Fig. 9) are also found. Locally present are vertical shafts with concentric linings, then *Ophiomorpha* (various orientations), and certain radiating traces (Fig. 10).



8 9 10

Fig. 8. *Scolicia* traces (parallel to bedding) in heavily bioturbated, laminated sandstones (F1). Locality 4. Bar=2 cm.

Sl. 8. *Scolicia* (paralelno slojanju) u jako bioturbiranim, laminiranim pješčenjacima (F1). Lok. 4. Mjera=2 cm.

Fig. 9. *Chondrites* traces (white; parallel to bedding) in heavily bioturbated, laminated sandstones (F1). Locality 1 (16 m). Pencil=14 cm.

Sl. 9. *Chondrites* (bijelo; paralelno slojanju) u jako bioturbiranim, laminiranim pješčenjacima (F1). Lok. 1 (16 m). Pisaljka=14 cm.

Fig. 10. Radiating trace on a thin rippled sandstone bed. Locality 1 (14.2 m). Eraser=3,2 cm.

Sl. 10. Radijalni trag na tankom riplanom pječenjaku. Lok. 1 (14,2 m). Brisaljka=3,2 cm.

4.2. CROSS-BEDDED SANDSTONES (F2)

Cross-bedded sets are dominantly planar, are mostly 0.05 - 0.2 m thick, and can reach a thickness of 1.3 m (Figs. 11, and 12). Compound bodies consist of stacked descending sets separated by gently inclined bounding surfaces or by ripple-laminated sandstone interbeds (Fig. 13). Reactivation surfaces have been observed within several sets. A preferred orientation of paleocurrent directions is towards ESE (vector mean=119°; Fig. 5b). Very rarely present are about 15-mm-thick, upslope climbing cross-laminae sets occurring in the lower parts of the foresets. Sandstones are fine- to medium-grained, and may contain nummulites.

The majority of the cross-bedded sets are either free of bioturbation, or show rare burrows, and the uppermost part of sets may be burrowed more intensely. More complete organic reworking is observed only in rare cross-beds, as well as in the toe portion of the largest sets. *Ophiomorpha nodosa* LUNDGREN (dominantly vertical), *Monocraterion*, *Planolites*, and *Chondrites* have been identified at some places.

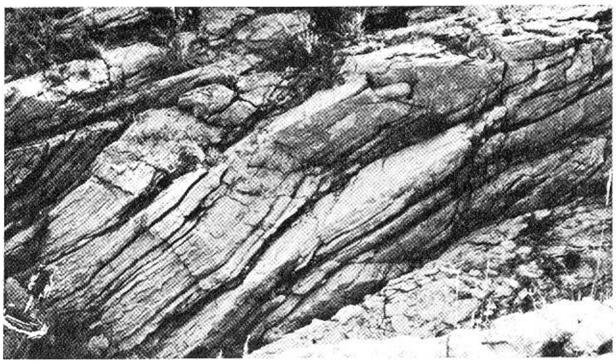

Fig. 12. Thick cross-bedded set. F2. Locality 6. Hammer (28 cm) for scale-lower left.

Sl. 12. Debeli koso slojeviti niz. F2. Lok. 6. Kladivo (28 cm) kao mjerilo-dolje lijevo.

Cross-bedded sandstones alternate with F1 (Laminated sandstones and muddy sandstones) (Fig. 2) described above. Complex cross-bedded units may wedge out and may also represent lenses (e.g. 2 x 0.4 m). In some cases a part of a cross-bedded sandstone body lies on a gently inclined truncation surface cut into F1 or F4 sediments. The depth of erosion varies from 0.1 to more than 0.5 m.

4.3. THIN-BEDDED, LAMINATED SANDSTONES (F3)

Only several beds of this facies have been found. The beds are 0.05 to 0.1 m thick, sharply based, and either horizontally laminated throughout (including gently undulating laminae) and covered by a mudstone lamina, or horizontal to very low-angle inclined laminae of the lower part are followed by a cross-laminated division, and by a thin mudstone cover. An overall upward decrease in the grain size may be present. The physical structures are mostly well preserved in contrast to the associated F1 sediments, which are mostly bioturbated (Fig. 14). These sandstones are more finely grained than most sandstones described here.

Fig. 11. Stacked cross-bedded sets with foresets reminiscent of tidal bundling. F2. Locality 4. Key=7 cm.

Sl. 11. Naslagani koso slojeviti nizovi s kosim slojevima koji podsjećaju na plimne svežnjeve. F2. Lok. 4. Ključ=7 cm.

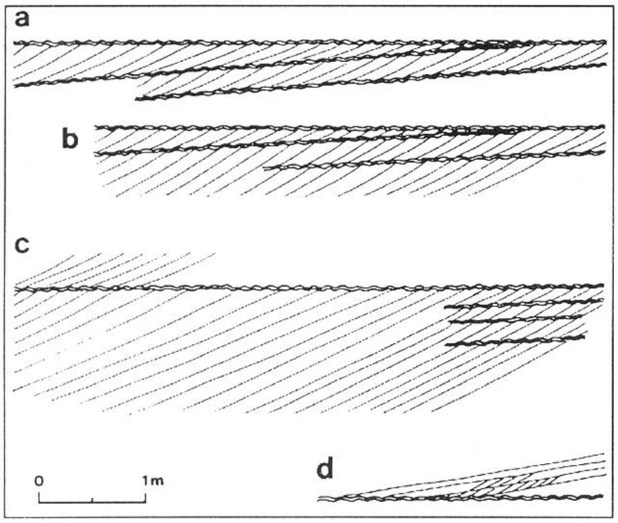

Fig. 13. Examples of compound cross-bedding. Descending and overtaking sets are represented. F2. (a) and (b)=Locality 6; (c) and (d)=Locality 1.

Sl. 13. Primjeri složenog kosog slojanja. F2. (a) i (b)=lok. 6; (c) i (d)=lok. 1.

4.4. DOMINANTLY MASSIVE SANDSTONES (F4)

Individual beds are 0.08 to about 0.5 m thick, and the upper thickness limit is not known because common amalgamation produced sandstone units of up to 5.6 m in thickness (Fig. 2). Only rare thinner sandstones thin and pinch out over distances of several meters. One exceptional example of an important thickness change occurs at locality 2 (middle part of the section, Fig. 2), and is represented by a lensoid sandstone bed with a plane base and a convex upward top (section 2 x 0.35 m); the bed pinches out and appears laterally again. The depressions are filled up with bioturbated cross-laminated sandstones.

The bed bases are sharp, flat to uneven, locally erosive with wide or narrow scours (less than 0.2 m deep). Current sole marks were not observed with certainty.

Most sandstone beds are massive (ungraded) throughout, and mostly occur within amalgamated packets (Fig. 2). Exceptionally rare are beds showing distribution grading. Vague to distinct parallel lamination or very gently inclined laminae appear in parts of the dominantly massive amalgamated packets. There are also beds consisting of a lower, thicker massive portion, and a comparatively thin (up to 0.15 m thick) laminated upper part (Fig. 15). The laminated portion consists either solely of horizontally laminated sandstone, or horizontal laminae are subsequently overlain by unidirectionally cross-laminated sandstone that is additionally followed by mudstone which is less than a cm thick. A separate and exceptionally rare bed type is represented by sandstones that are horizontally laminated throughout their thickness.

Nummulites are rare to common, and in some cases they are organized in laminae and bundles of laminae appearing within otherwise massive sandstone (Fig. 2). Mud clasts may be common in some beds, and in one case they reach a diameter of 0.2 m. In some cases the abundance of mud clasts produced a "slurried" level (MUTTI et al., 1978). Elongated *Alveolina*, some other larger foraminifera, bivalves including thick-shelled oysters, and well-rounded chert and limestone pebbles occur only exceptionally. Plant debris is common, and may be abundant in laminated divisions of sandstone beds consisting of lower massive and upper laminated parts.

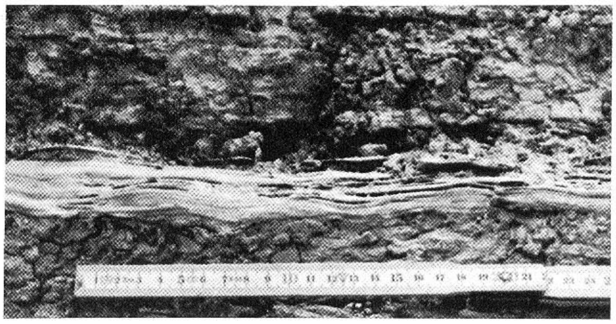

Fig. 14. Intercalation of F3 sandstone layer in F1 intensely bioturbated sediments. Sharp base of the bed, and gently undulating laminae are seen. Locality 1 (about 20 m). Scale in cm.

Sl. 14. Proslojak pješčenjaka (F3) u jako bioturbiranim sedimentima F1. Vidi se oštra baza sloja i valovite lamine. Lok. 1 (oko 20 m). Mjerilo u cm.

Here and there dish and pillar structures may be observed in massive sandstones. Some beds display soft sediment bending and convolutions. One example has been found showing a neck-like protrusion of sand into the overlying sandstone bed.

The intensity of bioturbation is variable. In several cases the bed top portion (about 0.05 to 0.1 m) is

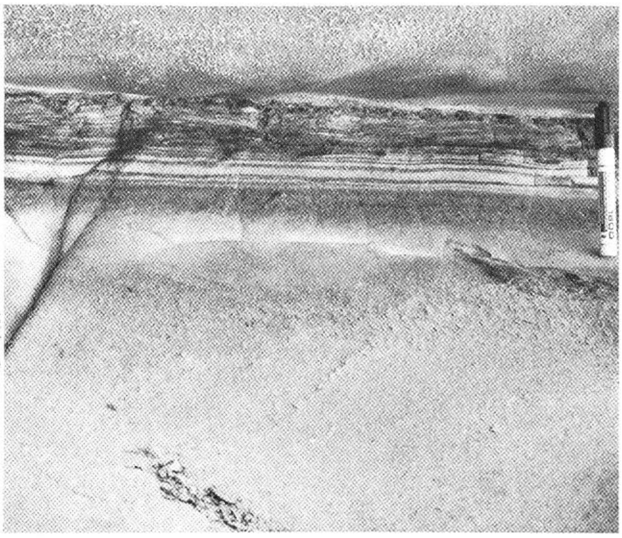

Fig. 15. Massive sandstone division in the lower part is overlain by horizontally laminated division, and less well discernible cross-laminated division of the same bed. F4. Marker's upper end is touching the base of the overlaying massive sandstone. Locality 1, upper unit. Marker=14 cm.

Sl. 15. Masivni dio pješčenjačkog sloja (dolje) pokriven je horizontalno laminiranim i slabo prepoznatljivim koso laminiranim pješčenjakom istog sloja. F4. Vrh markera dodiruje dno krovinskog masivnog pješčenjaka. Lok. 1, gornja jedinica. Marker=14 cm.

Fig. 16. Alternation of packets consisting of laminated muddy sandstones (mainly F1; dark), and dominantly massive sandstones (F4; light). Locality 1, lower unit; 6-10 m). Outstanding massive sandstone bed is 35 cm thick. A part of the upper laminated muddy sandstone packet is shown in Fig. 1.

Sl. 16. Izmjena paketa laminiranih muljevitih pješčenjaka (većinom F1; tamno) i pretežito masivnih pješčenjaka (F4; svjetlo) u donjoj jedinici lok. 1 (6-10 m). Istaknuti sloj masivnog pješčenjaka debeo je 35 cm. Dio gornjeg paketa laminiranog muljevitog pješčenjaka prikazan je na sl. 1.

intensely bioturbated. *Ophiomorpha*, *Chondrites*, and certain tube-like burrows may be common, and *Teichichnus* is rare. *Ophiomorpha* burrows with typical knobby walls (*O. nodosa*) may be either vertical to slightly inclined, or horizontal.

4.5. OVERALL ORGANIZATION OF FACIES AND SEDIMENT TYPES

The succession at locality 1, which is the thickest one, and which comprises the lowermost clastic deposits of the study area, will primarily be used for the following description. It consists of three informal units.

The lower unit of the succession at locality 1 (0-12 m, Fig. 2) shows a rather high frequency alternation of F1/F2 (including very rare F3 beds), and F4 sediments (Fig. 16). Thin-bedded packets, which are bounded by outstanding massive sandstones, may show diagonal to bedding-parallel shearing surfaces, squeezed sandy-muddy levels, and related thickening and thinning of parts of the packets. The disturbances only negligibly affect the bounding massive sandstones. The intensity of disturbances of the primary succession is likely to be small, and the succession might have been somewhat different prior to tectonic shearing. Nevertheless, at least a part of the high frequency alternation of sediment types represents a primary feature.

The middle unit of the succession at locality 1 (12-23 m, Figs. 2, and 17) is characterized by F1/F2 sediments. The base of the unit is sharp and slightly erosional over the massive sandstones. The lower part of the unit is dominated by F2 cross-beds, then F2 becomes subordinate, and occurs in lenses within F1. In these levels F1 is dominated by cross-laminated and

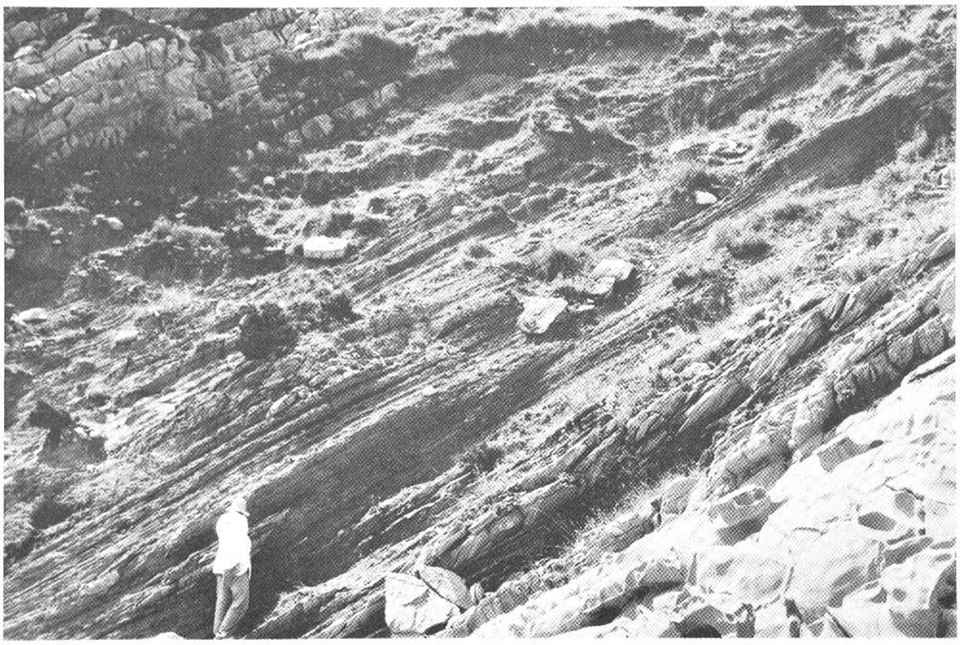

Fig. 17. A part of the succession of locality 1. Lower right (light): massive sandstones (F4) of the top portion of the lower unit. Main part of the photo: middle unit consisting first of predominating cross-bedded sandstones (F2), and then of predominating laminated sandstones and muddy sandstones (F1). Upper left: massive sandstones (F4) of the upper unit. See also log in Fig. 2.

Sl. 17. Dio slijeda naslaga lok. 1. Dolje desno (svijetlo): masivni pješčenjaci (F4) vrha donje jedinice. Glavni dio slike: srednja jedinica, koja se sastoji prvo pretežito od koso slojevitih pješčenjaka (F2), a zatim pretežito od laminiranih pješčenjaka i muljevitih pješčenjaka (F1). Gore lijevo: masivni pješčenjaci (F4) gornje jedinice. Vidi također stup u sl. 2.

rippled sandstones. Going upward, F1 is mostly represented by horizontal sandstone/mudstone laminae with rare ripples, and includes one F3 bed. Just below the overlying thick massive sandstone (F4) sequence, a few thin intercalated sandstone beds (F4) are present, one of them being graded.

The upper unit of the succession at locality 1 (23-38.5 m, Fig. 2) is exclusively composed of F4.

It is not known how successions exposed at other localities studied correlate with that of locality 1. The succession of locality 4 (Figs. 1, and 2) is similar to a segment of the main section (middle unit, locality 1), and possibly represents its correlative.

5. ON CORRELATABLE CLASTIC SUCCESSIONS IN THE SURROUNDING AREAS

After MARINČIĆ (1981), the islands of Rab and Pag (localities not quoted) and the locality of Murvica (NE of Zadar)(Fig. 1) show a common succession of Eocene early clastics that is otherwise considered to be widespread in coastal Dinarides: the Transitional Beds consisting of first nodular, then marly limestone are transitionally followed by a 10- to 30-m-thick marl unit ("Globigerina Marl"), which is in its turn overlain by flysch. The Eocene early clastics described here differ considerably from this description. Aside from the distant Murvica locality, successions similar to MARINČIĆ's (1981) description have been observed in the SE part of Pag, more than 25 km from the outcrops in NW Pag. For example, at the Vlašići locality (Figs. 1B, and 18) the upper part of the marl unit is intercalated by more and more thin sandstones going upward, and some of them show features similar to Bouma-sequences. After several meters of sandstone-marl alternation, the marl almost disappears, and massive sandstones become dominant.

A dominant portion of the Eocene clastics of the neighbouring island of Rab has been interpreted as shallow marine, produced by storm and tidal processes (ZUPANIČ & BABIĆ, 1991), but precise data on the lowermost clastic deposits have not been presented.

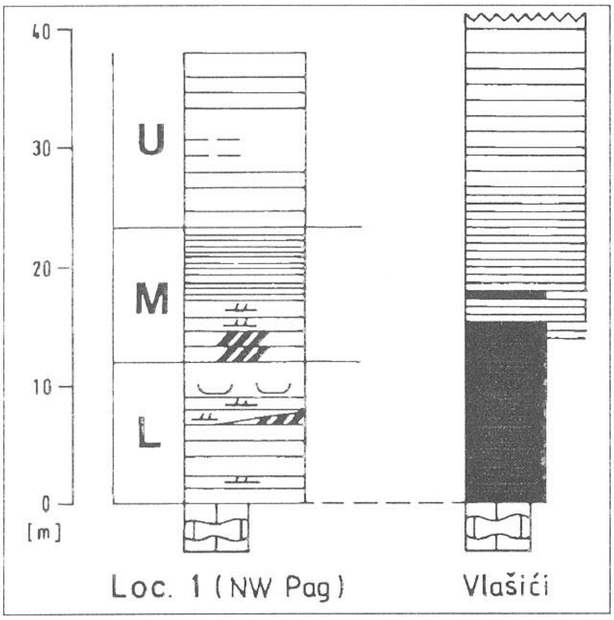

Fig. 18. Simplified columns showing Eocene lowermost clastics in the NW Pag area (locality 1; details in Fig. 2), and in the SE Pag area (Vlašići locality). Only selected structural features are shown. L, M, and U are lower, middle, and upper units of the succession at locality 1. Underlying sediments are the Transitional Beds.

Sl. 18. Pojednostavljeni stupovi najnižih eocenskih klastita sjeverozapadnog Paga (lok. 1; detalji u sl. 2) i jugoistočnog Paga (lok. Vlašići). Prikazane su samo izabrane teksturne značajke. L, M i U označuju donju, srednju i gornju jedinicu na lok. 1. Podinski sedimenti su Prelazne naslage.

6. ORIGIN OF CLASTIC FACIES OCCURRING IN THE NW PART OF PAG

6.1. LAMINATED SANDSTONES AND MUDDY SANDSTONES (F1)

(A) *The first sediment group* is rather heterogeneous. In general, small-scale depositional structures characterizing these sediments, as well as tiny mudstone laminae between sandstone layers, ripples, and foreset laminae, reflect the dominance of weak and intermittent depositing flows. The proximity of land is suggested by rather common plant debris.

Two current types and their relevant directions were clearly identified. The E-directed structures (more precisely: between ENE and ESE) have an orientation similar to that of the cross-bedded sandstones (F2)(Figs. 5a, and b), and have probably been generated by the same kind of currents (possibly tidal: see next paragraph). The symmetric outline of some ripples may, but need not, reflect a modification by waves.

The origin of SW-directed ripples mostly showing climbing geometry, and of intimately related sinusoidal lamination (Figs. 6, and 7; Fig. 5c), might be related to turbidity currents, but dilute, short-living, waning flows are not likely to have produced these structures. Namely, such flows may deposit Bouma C and D divisions that usually show clearly defined bed bases, as well as D division, which usually consists of silt, sandy silt, or sandy to silty clay, reflecting already decreased flow strength at this (D) flow stage. This is also the case with thin-bedded turbidites deposited in the channel-margin area of a deep-sea fan system described by MUTTI (1977), which otherwise resemble the relevant NW Pag sandstones. In contrast, most cross-laminated sandstones described here do not show clearly defined bed bases, and sinusoidal laminae are sandy, and form rather thick packets. This is more close to sands that can be deposited from sustained turbidity currents (density underflows), as described by JOPLING & WALKER (1968) based on the study of a kame delta. They have found that sand-rich flows produce climbing ripple lamination during dominant bed load movement, while sinusoidal ripple lamination originates during dominant suspension fallout. Rare intercalations of oppositely directed cross-laminae sets in NW Pag structures may reflect the influence of waves or flows of another origin interfering with deposition from underflows. In fact, the local similarity of climbing ripple structures occurring in NW Pag sandstone to wave-current ripples also suggests a possible influence of waves. The origin of sand-rich underflows might be searched in storm-induced rip-currents, bottom return flows, or in direct river-effluent generated flows. All of these are common in shallow seas.

B) *The second sediment group*. Horizontal sand laminae with interlaminated mud laminae might have originated in various ways: by tidal flows, by storm processes, by turbidity currents and other processes. The same is true for the horizontal sandstone laminae mentioned above within the first sediment group (A).

Biota. Nummulites must be mentioned separately because they might be either autochthonous including short distance displacements, or brought in from a different environment, and then reworked. Apart from nummulites, a number of other organisms were present. The skeleta of some of them were probably destroyed by scavengers or later dissolved; others were soft body organisms. Based on the numerous and locally densely populated *Scolicia* burrows (review in COLELLA & D'ALESSANDRO, 1988), as well as on meniscate structures, we can say that there were numerous endobenthic echinoids. The meniscate structures found here correspond to recent echinoid traces (e.g. DÖRJES & HERTWECK, 1975), and have been interpreted as originated by pushing back the sediment by oppositely advancing animals (SCHÄFER, 1972). Irregular strap-like traces have been produced by either gastropods, bivalves, or both, ploughing through the sediment (SCHÄFER, 1972). Gastropods probably produced bilobate crawling traces (HÄNTZSCHEL, 1962). Crustaceans are considered to have built *Ophiomorpha* and *Talassinoides* dwelling traces (EKDALE et al., 1984). *Planolites* and *Chondrites* burrows have been interpreted as produced by deposit-feeding animals with simple and complex programs respectively (EKDALE et al., 1984). Finally, concentrically lined vertical shafts represent domichnial burrows of several possible organism groups: bivalves, polychaetes, and others (SCHÄFER, 1972). Rare radiating traces have been made by a domichnial suspension or detritus feeding animal which is not known more specifically.

Diversified organism association indicates availability of food and oxygen within the depositional environment. The predominance of sediment-feeding organisms over suspension feeders, and the coexistence of infaunal and epifaunal elements of the biota are in accordance with generally lower-energy conditions including the intermittent weak flows discussed above. The intervals when, and places where, weak flows as well as sand transport and deposition occur more frequently were characterized by rare suspension-feeders, or burrowing did not even take place.

6.2. CROSS-BEDDED SANDSTONES (F2)

These sediments originated by the action of tractive flows that caused the migration of simple and complex subaqueous dunes (terminology of ASHLEY - symposium chairperson, 1990) toward ESE (vector mean=119°, Fig. 5b). The geometry of cross-beds largely corresponds to 2-D dunes with either straight or slightly curved crests, and only occasionally to 3-D dunes. The former existence of complex dunes (=sand waves p.p.) are indicated by stacked cross-bedded sets with gently inclined bounding surfaces, both dipping in the same or similar direction (Fig. 13). In addition, stacked sets with approximately horizontal bounding surfaces have probably also been generated by the migration of compound forms. The highest complex dunes (sand waves) were more than 1.3 m high, which corresponds to the category not smaller than "large dunes" (ASHLEY - symposium chairperson, 1990).

Rare upslope-climbing small cross laminae in the lower parts of some foresets closely resemble the back-flow ripple lamination in their position and in their evenly cut upper surface (BOERSMA et al., 1968). Despite the occurrence of reactivation surfaces, tidal bundles and neap-spring cycles have not been clearly observed. This could be due to the action of waves and non-tidal currents that have removed mud, and influenced tidal circulation in an open marine environment. Thus, tidal currents are possibly responsible, or at least influential, for the origin of cross-bedded sandstones, but conclusive evidence is lacking. Data from the neighbouring island of Rab (ZUPANIČ & BABIĆ, 1991) demonstrate that tidal currents were operating in the closely situated portion of the Middle Eocene sea, and were able to transport sand, and build simple and compound dunes. However, the position of the relevant Rab sediments is rather high within the clastic succession in contrast to NW Pag deposits.

Examples of close vertical and lateral association of cross-bedded sandstones with F1 sediments reflect a discontinuous, patchy arrangement of dunes and sand waves, with deposition of the representatives of F1 sediments between these forms, as well as above them at times when they were not active.

Erosional truncations observed below some cross-bed units and packages were scoured by the flows either of a character related to those having produced cross-beds (but of a higher strength), or by some other kind of flow (storm- or combined tide/storm-related).

Fast deposition and/or dune migration allow little or no time and possibility for endobenthic organisms to burrow, or for most traces to be preserved, thus bioturbation free cross-beds resulted. Where *Ophiomorpha* shafts appear alone, this is a consequence of the ability of the relevant domichnial suspension feeder to use the shortest time intervals (compared to other burrowers) to settle, burrow, and construct tube walls during which deposition or erosion was slow or was not occuring. The association of *Ophiomorpha*, *Planolites*, and

Chondrites may result from a gradual change of substrate conditions changing from soft to firm ground (EKDALE, et al., 1984), corresponding to dune disactivation. When this situation continued for a longer period, intense bioturbation resulted.

6.3. THIN-BEDDED, LAMINATED SANDSTONES (F3)

The features of these sandstones suggest waning flow conditions: erosional base, overall grading, horizontal laminae, which may be followed by ripple cross-laminae, and mud cover. Rare intercalations of these sandstones in F1 bioturbated sediments indicate an origin by rare and "unusual" processes that might have been related either to storms or to turbidity currents.

6.4. DOMINANTLY MASSIVE SANDSTONES (F4)

Massive to laminated beds, and massive beds. Beds showing sharp base, with or without observable erosional scouring, and massive main portion, followed by thin, either horizontally laminated, or horizontally laminated and cross-laminated divisions, were deposited by waning flows. The flows were turbulent at least in some travel segments, as inferred from rip-up mud clasts and erosional scouring. The mudstone layer occasionally covering the bed is supposed to have been laid down by the same depositional event, because otherwise a slow mud deposition would have enabled the biogenic destruction of primary structures in rather thin underlying laminated sandstone, and this did not happen; only individual burrows are locally observed within laminated divisions.

Sandstones, which are massive throughout their thickness, may be considered to represent lower portions of "massive to laminated beds" (their more proximal portions or top cut-out beds), or separate beds that were massive throughout their entire depositional extent. In contrast to beds ending with laminated divisions, the role of bioturbation may be important in massive beds, but it seems unlikely to account for the massive appearance of all such beds.

Beds exhibiting structural sequences mentioned above are comparable to Bouma-type sequences of structures AB, ABCE, and possibly ABD, and massive beds might correspond to A division only. The massive "structure" is not uncommon in turbidites, although "true massive" (=ungraded) sand beds common in NW Pag sections are probably not very common in general (GHIBAUDO, 1992). In gravity flow deposits, the massive (ungraded) beds may be explained by a high flow concentration, and suspension-stage deposition from a "high-density" turbidity current or a transition to liquefied flow (LOWE, 1979, 1982; SURLYK, 1984). However, massive appearance may have also been produced by pervasive dewatering processes to which gravity flow sands, deposited from cohesionless concentrated suspensions, are typically susceptible either during final mass settling or postdepositionally (LOWE, 1982). The example of sand protrusion into the overlying sand bed confirms that postdepositional liquefaction did occur in massive to laminated beds. Dish and pillar structures observed in amalgamated massive sandstones also document the operation of dewatering processes. However, it is to be mentioned that, in spite of being commonly found in gravity flow sandstones, dishes also occur in shallow-marine, delta front, fluvial, and other deposits (LOWE & LOPICCOLO, 1974; NILSEN et al., 1977), and can not be used as conclusive evidence for a gravity flow process.

A variant of gravity flow capable of producing massive sand beds (and massive division of compound beds) is more continuously fed by river effluent during periods longer than those by mass-failure related gravity flows. Such hyperpycnal flows are considered to have produced massive (and graded) sands building mouth bars at depths of several tens of meters in some Middle Ordovician marine fan-deltas in North Wales (ORTON, 1988). Flows of similar character deposit massive and graded sands in distal modern fan-delta environments, below shelf depth, in some fjords (PRIOR & BORNHOLD, 1990). Related ancient examples, where sands are associated with gravels and mostly connected with steeper slopes, have also been described (e.g. STANLEY, 1980). Consequently, both spasmodic and more sustained flows represent possible mechanisms for the emplacement of NW Pag massive sands, if their gravity flow origin is considered.

The upper, laminated portion of massive to laminated beds must have been deposited by a more dilute and waning flow.

However, massive to laminated beds show certain similarities to some sandstones inferred to have been deposited by storm-induced waning flows, and differ from them in showing an ungraded, rather than a graded, lower division (e.g. SWIFT et al., 1986, 1987). Massive sandstones (not homogenized by bioturbation) are only rarely reported from storm-related sequences (e.g. BRENCHLEY & NEWALL, 1982).

Mud clasts are not indicative of any specific depositional environment or depositional system. In submarine fan sandstones, mud clasts are mostly found in proximal sandy deposits (e.g. MUTTI & NILSEN, 1981). The hydrodynamic meaning of rare other outsized extraclasts (pebbles, oysters) remains obscure because its situation within amalgamated packets is not known.

Other bed types. It is not clear if horizontally laminated horizons occurring here and there within amalgamated packets of dominantly massive sandstones represent portions of thicker beds comparable to sandstones discussed above (but with thicker laminated divisions), or separate depositional units. In the second case, they could represent either turbidites (deposited by short-lived or continuous flows), or storm-related deposits. The same is true for well-defined but exceptionally rare, clearly separate, horizontally laminated sandstone beds, and equally rare normally graded sandstones. The lateral thinning and pinching out of some beds at short distances is connected with erosional truncation, the cause of which might be turbidity current or some other mechanism (storm-related flow?).

Although the comparisons of dominantly massive sandstones (F4) to gravity flow deposits and storm-related sediments presented above are not conclusive concerning their origin, they argue somewhat more in favor of a gravity flow interpretation. Besides, clear evidence of oscillatory flows being the most critical for distinguishing storm deposits from turbidites (HUNTER & CLIFTON, 1982) has not been recognized in F4 sandstones.

Relation to and character of sand sources. The almost exclusively sandy character of sediments, and common amalgamation suggest sources that were situated close to the depositional site, and were rich in sand. Common plant debris indicates riverine sources of sand. Nummulites and other, less common skeletal material may either have been picked up from the sea bottom, or have derived from slightly older clastics. The above inferences may be relevant to various settings dominated by gravity flow deposition (but also to storm-influenced settings). In submarine fan systems, both individual massive sandstones and packets of amalgamated, dominantly massive sandstones are known to represent canyon, and fan-channel fills in many formations (e.g. STANLEY et al., 1978; VAN VLIET, 1978; WALKER, 1978). On the other hand, such sandstones may also characterize those systems that were very closely connected to deltas (LINK, 1975; CHAN & DOTT, 1983; HELLER & DICKINSON, 1985), or even belong to delta (fan-delta) systems themselves (ORTON, 1988). These similarities also support a close relation of the depositional site to sand-rich sources, and, more precisely, a close connection to the mouth(s) of sandy river(s).

There are no data concerning the transport direction of sand in F4. MARINČIĆ (1981) measured an average paleotransport direction of 290° on Pag, but did not indicate locations. Outcrops appropriate for the measurements do not occur within less than a 13 km distance to the SE (Dubrave, Fig. 1B). The sediments there consist of dominant massive sandstones, occasional beds comparable to Bouma turbidites, and marls, and the paleotransport directions that we measured (Fig. 5d) are in accordance with MARINČIĆ's data (1981). Besides the distance to these outcrops, the position of the sediments in vertical succession (unknown more precisely) is also higher, which suggests caution in applying these measurements to sediments described here. This will be discussed further below.

Ichnofossils. Neither *Ophiomorpha* nor *Chondrites* can be used as depth indicators (cf. EKDALE et al., 1984). The attitude of *Ophiomorpha* tubes in massive sandstones can be used as a complementary indication of the depositional rate, which is in agreement with inferences made above: vertical shafts probably reflect a high rate of sand deposition by which the relevant organisms have only time to build vertical dwelling burrows, while longer intervals of non-deposition or slow deposition allow the construction of horizontal and variously oriented burrows (FREY et al., 1978).

7. DEPOSITIONAL SETTING AND EVOLUTION OF THE AREA

The character of the depositional setting and evolution of the area will be discussed primarily based on the most complete and well exposed succession at locality 1, and its three units. The discussion can gain little advantage from comparisons with surrounding areas, because of the scarcity of such data, as was already mentioned above. The discussion depends on data about processes and environments relevant to four differentiated facies, and its critical point is the choice between two possible interpretations of F4 (Dominantly massive sandstones). In the case of its storm-related origin and deposition in a shallow-water environment, the overall picture would be easy to describe. It was characterized by alternating storm events, and E and ESE-directed tractional (tidal? or storm/tidal?) flows (apart from other, subordinate, less important components), which varied in relative importance vertically, and operated in close vicinity to the mouth(s) of sand-rich rivers. However, the data collected from F4 sandstones tend to favor their origin by gravity flows, and hence, the following discussion will be based on such an inference.

Lower unit (location 1). The small thickness of alternating traction flow (F1 and F2), and gravity flow (F4) sandstones and their packets suggest a common depositional site. Ripples and rare dunes were moving toward ESE and from time to time the site was invaded by sandy gravity flows closely related to riverine sand-rich sources. Deposition and preservation of mud was very limited. In general, such an association may be explained by two variant situations (and a combination of them).

(1) The first variant situation is represented by a shallow marine setting (Fig. 19A). The initial deepening of the former shallow carbonate platform has been recorded by the Transitional Beds, the depositional depth of which was probably not below the neritic zone. A slight shallowing may have preceded clastic input, and even brought the area under the influence of erosional currents causing a certain erosional denudation.

East-directed ripples and rare dunes were migrating parallel to the coast under the influence of currents such as those that otherwise commonly operate in shallow sea, and which were possibly tidal in origin. The basin margin, situated to the NE (e.g. MARINČIĆ, 1981), was characterized by sand-rich sources including river mouths. From there, gravity flows were moving toward the present day NW Pag area. The relevant deltaic and fluvial sediments correlatable with NW Pag deposits are not known: they could have later disappeared either

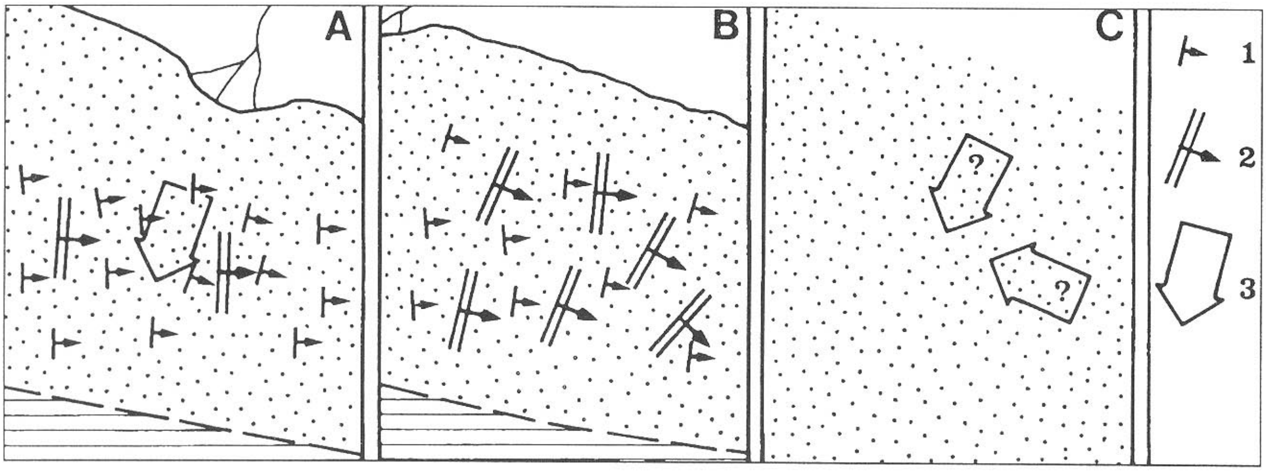

Fig. 19. A possible reconstruction of depositional setting and its evolution for the Eocene clastics studied at locality 1 (NW Pag). Conditions in wider central portion of sketches correspond to those of locality 1. A, B, and C correspond to lower, middle (lower part), and upper units of the succession at locality 1. 1-ripples, 2-dunes, 3-probable gravity flows. Dots-dominantly sand, horizontal lines-dominantly mud. Not to scale.

Sl. 19. Moguća rekonstrukcija nekadašnje situacije i njenog razvitka, na temelju eocenskih klastita lok. 1 (sjeverozapadni Pag). Prilike u širem srednjem dijelu crteža odgovaraju onima na lok. 1. A, B i C odgovaraju donjoj, srednjoj (donji dio) i gornjoj jedinici na lok. 1. 1-riplovi, 2-dine, 3-vjerojatni gravitacijski tokovi. Nije u mjerilu.

by erosion, by having been covered by advancing dinaric thrusts, or by both. Based on a study of late Middle Eocene clastics on the island of Rab, a storm- and tide-dominated shelf occupied a part of the present-day northern Adriatic realm (ZUPANIČ & BABIĆ, 1991). Although data on the origin of the lowermost clastics at the Rab Island were not presented specifically, their origin in a shallow sea is possible and even probable. The NW Pag area might represent a part of this shallow-marine realm, at least during early clastic deposition.

Further offshore from the NW Pag depositional site, hemipelagic marl was laid down as exemplified by the lower portion of the Vlašići section (Fig. 18), where the marl overlies the Transitional Beds. The difference in sedimentation between the two areas may have been related to differential subsidence, or to the formation of an inner subbasin dominated by sandy deposits to the NNE (NW Pag), and an outer realm with fine-grained deposition to the SSW (Vlašići). Both explanations, including a combination of the two, have the influence of structural changes in common. Alternatively, a hemipelagic marl packet (correlative to the marl in the Vlašići section) was also deposited in NW Pag area, and was subsequently removed by erosion or sliding. In this case, the lower unit (location 1) could be approximately correlated with the earliest sandstones at the Vlašići locality.

(2) The second variant situation which could explain the high frequency alternation of gravity flow and traction flow deposits in the lower unit of the main succession (locality 1), is comparable to conditions common in sea straits and passages, and closely connected areas. In such settings, strong bottom currents typically operate, and gravity flows could derive from both strait margins (COLELLA & D'ALESSANDRO, 1988). The depositional depth of the sediments described here may have been either neritic, or even upper bathyal, as in the case described by COLELLA & D'ALESSANDRO (1988), where specific bottom circulation is considered to have been responsible for environmental conditions otherwise typical for more shallow seas. The Pag strait would have been oriented roughly parallel to the direction of ripple and dune migration that is between W-E and NW-SE. As in the first variant, the site was fed with sand from sand-rich sources at NE. This paleogeography implies the existence of two topographic highs bounding the strait to the NE and to the SW, and this in turn implies a structural deformation before the beginning of clastic deposition. If the marl unit in the Vlašići section (Fig. 18) is a correlative of the lower unit of the main succession (locality 1), it represents an area that was beyond the paths of the sea strait currents, and other flows bringing sand.

The middle unit of the main section (locality 1) contains records of similarly directed dunes (ESE), and ripples (E), as in the lower unit, suggesting a similarity of the general morphology of this part of the basin to that which existed previously. The dominantly sandy character of the unit and rather common plant detritus reflect a continuation of a close relation to sand-rich sources and river mouth(s). On the other hand, gravity flows that were otherwise producing F4 sandstones did not invade the area during the relevant time interval, and must have taken other paths due to a change in the feeding system. Two variant situations mentioned for the lower unit are also possible here.

The lower portion of the middle unit displays an upward thinning trend (Fig. 2) reflecting a decrease in the strength and frequency of depositing fluid-driven flows. The upper portion of the middle unit is dominated by sand/mud alternating laminae (sand highly predominates) of problematic origin, and ends with a transition to exclusive gravity flow sandstones (F4) of the upper unit. These upward changes might have be-caused by a gradual deepening that has brought the area beyond the influence of dune and ripple-generating flows.

The upper unit of the main section (locality 1) contrasts the lower and middle units in that it consists exclusively of gravity flow sandstones (F4). This indicates a position just at the main paths of the sand-rich flows, which were building a larger sand body. As mentioned above, the depositional depth was possibly greater than before. As a general subsidence or eustatic sea-level rise would cause a decrease of sand supply by a shifting back of sand sources, such an intense supply must have been connected with a structural modification involving at least the source area. The same deformation may have also formed an appropriate local topography in order to accommodate the large volume of sand.

The direction of gravity flows is not known: they could have moved toward SW, as was tentatively proposed for the lower unit, or assumed the direction measured in younger sandstones at the distant Dubrave locality (Fig. 1B), which is WNW (Fig. 5d). The second direction was probably caused by a WNW-inclined trough- or funnel-shaped bottom, implying the existence of a certain topographic high to the SW.

Indications from the other two sections measured. The succession exposed at locality 4 (Fig. 2), which is a possible correlative of a segment of the main section (locality 1; most parts of the middle unit, Fig. 2), is specifically characterized by common SW-directed climbing ripples and associated sinusoidal lamination that alternate here with cross-bedded sandstones. The direction of flows (SW, Fig. 5c) and possible wave oscillations (SW-NE) are in accordance with the approximately NW-SE trending coast and related structural strike proposed above.

The section measured at locality 2 (Fig. 2) generally corresponds to other sections studied concerning individual features, but it is not clear if and how this section could be correlated with the main succession (locality 1). A correlation with the lower and middle units of the main succession would imply an important lateral change to the more important role of gravity flows at this location within the relevant time interval.

8. CONCLUSION

The Eocene (Upper Lutetian-Bartonian) clastics studied in the NW Pag area overlie carbonate platform deposits, and mainly originated by the migration of ripples and dunes (toward ESE), which produced cross-laminated and cross-bedded sandstones, and by gravity flows having generated dominantly massive sandstones. The interpretation of dominantly massive sandstones is not based on conclusive evidence, however the alternative interpretation, i.e. storm-related flows, seems less likely.

The sediments are very sandy in character, and were deposited in the proximity of sand-rich sources and river mouth(s). Possible settings include a delta-related shallow-marine area (later transformed into a deeper environment?), and a sea-strait (or a combination of them). At first, the area represented a part of the northern Adriatic Eocene clastic shallow sea, at least at the time corresponding to the lowermost clastics.

The sediments studied depart considerably from commonly reported and poorly known Eocene lowermost clastics developing from carbonates in the coastal Dinarides. They did not follow a simple drowning of the shallow carbonate platform, and the generation of a single foreland trough, as is commonly envisaged for the Eocene clastics of the Adriatic coastal belt. In contrast, structural deformation intervened very early in their history, and even before, and has dominantly influenced their subsequent evolution. Very early, a segmented outer dinaric foreland realm was generated, as has been already proposed (BABIĆ & ZUPANIČ, 1990; ZUPANIČ & BABIĆ, 1991).

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Udruživanje morskih pješčanih taloga vučnih i gravitacijskih tokova u eocenu sjeverozapadnog otoka Paga (Vanjski Dinaridi, Hrvatska)

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Eocenski klastiti sjeverozapadnog Paga leže na talozima karbonatne platforme i sastoje se od četiri facijesa (F1-F4). F1 (Laminirani pješčenjaci i muljeviti pješčenjaci) je izrazito pješčan s nešto mulja i karakteriziran kosom laminacijom, riplovima, ravnim pješčanim laminama, te tankim laminama muljnog sedimenta. Nastao je u uvjetima niske energije uz utjecaj povremenih slabijih tokova. Znatni dio nastao je migracijom riplova prema istoku. Jedan varijetet, koji pokazuje penjuće riplove i sinusoidalnu laminaciju, vjerojatno je nastao iz podržavanih mutnih tokova, te uz mogući utjecaj valova. F2 (Koso slojeviti pješčenjaci) sastoji se od jednostavnih i složenih koso slojevitih nizova, a nastao je nešto jačim vučnim strujama, možda plimskim, i to migracijom jednostavnih i složenih dina (pješčanih valova), prosječno u smjeru istoka-jugoistoka. F3 (Tanko slojeviti, laminirani pješčenjaci) vrlo je rijedak i pojavljuje se u obliku uložaka u F1. Slojevi su ravno i koso laminirani i katkada graduirani. Taložen je iz mutnih struja ili tokova izazvanih olujama. F4 (Pretežito masivni pješčenjak) obuhvaća masivne slojeve, te masivne slojeve s laminiranim vrhom, zatim horizontalno laminirane, te vrlo rijetke graduirane slojeve. Mjestimice se u masivnim slojevima javljaju zdjelaste i stupaste teksture. F4 je nastao vrlo blizu riječnih ušća i uz jaki donos pijeska, vjerojatno iz gravitacijskih tokova. Taloženje iz tokova izazvanih olujama čini se manje vjerojatnim načinom njihova postanka.

Klastiti sjeverozapadnog Paga mogli su nastati ili u plitkom moru (uz moguće kasnije produbljivanje) ili u morskom prolazu. Talozi bitno odudaraju od dosad poznatih najdonjih eocenskih klastita obalnih Dinarida, koji se razvijaju iz podinskih karbonata. Oni ne slijede jednostavno tonjenje plitkomorske karbonatne platforme i postanak jedinstvenog forlandskog korita, kako se obično zamišlja za obalni pojas. Naime, veoma rano u njihovoj povijesti djeluje strukturna deformacija, koja ima pretežit utjecaj i na daljnji njihov razvitak. Kako je već prije bilo predloženo (BABIĆ & ZUPANIĆ, 1990; ZUPANIČ & BABIĆ, 1991), veoma rano je bio stvoren jedan segmentirani dinaridski forlandski prostor.

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