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IMPORTANCE OF MEGABEDS FOR RECONSTRUCTION OF PALEOGENE FLYSCH BASIN IN SPLIT HINTERLAND (MIDDLE DALMATIA)

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Key words: Dalmatia, Paleogene, flysch, turbidites, palaeotransport, palaeotectonics

Ključne riječi: Dalmacija, paleogon, fliš, turbiditi, paleotransporti, paleotektonika

Megabeds in the explored sedimentary sequence of the Split - Kaštela area are constructing 1/4 to 1/3 of the total thickness of sediments, what indicates on their high importance for understanding of depositional history of the basin explored. Several bed types are covered under the term "megabed" (i.e. turbidites, composite turbidites and complex beds) and main attention was focused on beds with the evidence of flow reflections. Palaeotransport directions in environs of Split and Solin show notable differences, what indicates on relative isolation of Split and Solin depositional environments (sub-basins); and beds deposited from reflected flows indicate on complex bottom topography. Thick lutites of megabeds deposited from the ponded turbidity current tails, and overall large thicknesses of beds indicate a restricted basin. However the olistrostrome originating from a catastrophic collapse of shelf margin exceeds volume of local troughs and spread all over the basin floor between Solin and Split. During lowering of the sea-level prograded coarse grained fan deltas. Palaeotransport directions of younger turbidites indicate on debris supply from the north-west, north-east and the south-east first, and later on supply from the north-east only. Palaeotectonic reconstruction presents evolution of the basin during the extensional phase, and the oldest compressional phase.

Megaslojevi u istraženom slijedu sedimenata Splitsko - Kaštelanskog prostora zastupljeni su s 1/4 do 1/3 ukupne debljine, što ukazuje na njihov velik značaj za razumijevanje povijesti taloženja u istraženom prostoru. Nekoliko je tipova slojeva obuhvaćeno pojmom "megasloja" (npr. turbiditi, kompozitni turbiditi i kompleksni slojevi), a najveća pažnja posvećena je slojevima s paleotransportima koji ukazuju na taloženje iz tokova koji su trpjeli višekratne refleksije. Paleotransporti u okolici Splita i Solina pokazuju znatne razlike, što ukazuje na relativnu odvojenost Splitskog od Solinskog sedimentacijskog prostora (sub-bazena), a slojevi nastali iz reflektiranih tokova ukazuju na kompleksnu topografiju dna bazena. Debeli lutiti koji pripadaju megaslojevima nastali su u ograničenim bazenskim prostorima -sub-bazenima taloženjem iz "ujezerenih" repova mutnih struja, a sveukupno velike debljine slojeva ukazuju na ograničene dimenzije bazena. Olistostroma koja je nastala katastrofalnim rušenjem ruba šelfa volumenom nadmašuje volumen sub-bazena i istaložena je po cijelom dnu bazena između Solina i Splita. Tokom spuštanja razine mora prema bazenu su prodirali krupnozrnati klastiti *fan-delti*. Paleotransporti mlađih turbidita pokazuju prvo donos sa sjeverozapada, sjeveroistoka i jugoistoka, a kasnije samo sa sjeveroistoka. Paleotektonskom rekonstrukcijom prikazana je evolucija bazena samo tokom ekstenzijske faze, i najranije kompresijske faze.

1. INTRODUCTION

Very thick one-event beds that originated during exceptional sedimentary events were recognized in many flysch basins. Until recently their importance was understood in a span from pure registration and/or misunderstanding, to attribution of high importance so that in 1986 the AAPG/SEPM symposium on "megaturbidites" (DOYLE & BOURROUILH, 1987) took place. Today megabeds are considered to be good key-beds recognizable even on geophysical profiles providing they had sufficient thickness (BOUMA, 1987; MARCHETTI, 1957), and they may be traced as key-horizons all along the basin (ENGEL, 1970; JOHNS et al.,1981; LABAUME et al., 1983, 1987; PAREA & RICCI LUCCHI, 1975; RICCI LUCCHI, 1975; RICCI LUCCHI & VALMORI, 1980; etc.). Some of these beds were interpreted as seismoturbidites (MUTTI et al., 1984) that originated from seismically induced catastrophic collapse of a shelf margin. In petroleum-geologic context thick marly megabeds represent good isolating rocks as recognized already during the 50-es by Gulf-Italia (MARCHETTI, 1957).

The definition of megabeds is not unique; some authors take megabeds as several orders of magnitude thicker than average bed thickness in an explored area. Some authors, however, define certain critical thickness (starting from thickness of several meters), and MUTTI et al. (1984) define megabeds by volume that should exceed 1 km³ . In this paper megabeds are defined by thickness that exceeds 10 m, because these are markedly thicker than "average" beds within the sequence explored- what meets the first criterion for the use of "megabed" term proposed by BOUMA (1987).

Megabeds of Paleogene age were described in northeastern Italy by GNACCOLINI (1968) and TUNIS & VENTURINI (1985, 1987); near Anhovo in Slovenia by KUŠČER et al. (1976) and SKABERNE (1984, 1987); in Istria by ENGEL (1970); in Ravni Kotari by BABIĆ & ZUPANIČ (1983) and ZUPANIČ & BABIĆ (1980/81); and in Middle Dalmatia by MARJANAC (1985, 1986, 1987 a, b, 1990).

Due to "chaotic" structure and the presence of extrabasinal clasts, some megabeds were taken as "olistostromes", while the others were considered as "megaturbidites" due to structure sequences that correspond to those of "classical" turbidites. Base-of slope was considered a locus of their deposition by BABIĆ

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& ZUPANIČ (1983), MULLINS et al. (1984), NAYLOR (1981), PESCATORE (1978), SARTI (1981), ZUPANIČ & BABIĆ (1981); or a basin plain by DEBROAS et al. (1983), JOHNS et al. (1981), LABAUME et al (1983), and PAREA & RICCI LUCCHI (1975).

The sequence of structures in megabeds may be "classical" in the sense of Bouma-sequences (BOUMA, 1962) as indicated for a north Apennine Contessa megabed by PAREA & RICCI LUCCHI (1975) and Friuli flysch by Gnaccolini (1968); but sequences within a bed may be complex with repeating intervals as indicated already by BOUMA (1962), and illustrated by BOURROUILH (1987), DEBROAS et al (1983), SOUQUET et al (1987), and from late Pleistocene Adriatic by VAN STRAATEN (1970). However, in some megabeds directional structures (i.e. oblique lamination and ripples) may be opposed - the fact recognized already by PAREA & RICCI LUCCHI (1975), RICCI LUCCHI & VALMORI (1980) and others, and reinterpreted by HISCOTT & PICKERING (1984) and PICKERING & HISCOTT (1985)

The palaeotransport direction in many beds of this type was unknown, and inferred by comparison of debris lithologies. Attempts to explore palaeotransport directions according to internal structures were performed just recently (HISCOTT & PICKERING, 1984; MARJANAC, 1988 b, 1989, 1990; PICKERING & HISCOTT, 1985; RICCI LUCCHI & VALMORI, 1990).

The explored megabeds are exposed along the Kaštela bay and in the Solin - Split area. Megabeds are also exposed along the coast-line from Stobreč to Omiš and further to the southeast, and in Donji Dolac in the Mosor Mt. hinterland (Fig. 1).

The importance of megabeds in development of flysch is indicated by their role in total thickness of explored sediments in areas explored. As illustrated in Fig. 2, megabeds construct ca. 1/4 to 1/3 of sediment column; but since 1/3 of the section is being covered, it is possible that their role is even higher.

2. TYPES OF MEGABEDS IN MIDDLE DALMATIA

Recent exploration showed existence of several types of megabeds (Fig. 3) such as turbidites, composite turbidites, and complex beds (MARJANAC, 1986). These bed types were described elsewhere with special focus on sedimentary processes (MARJANAC, 1985, 1987a, b, 1988a, b, 1990), as well as palaeotransport

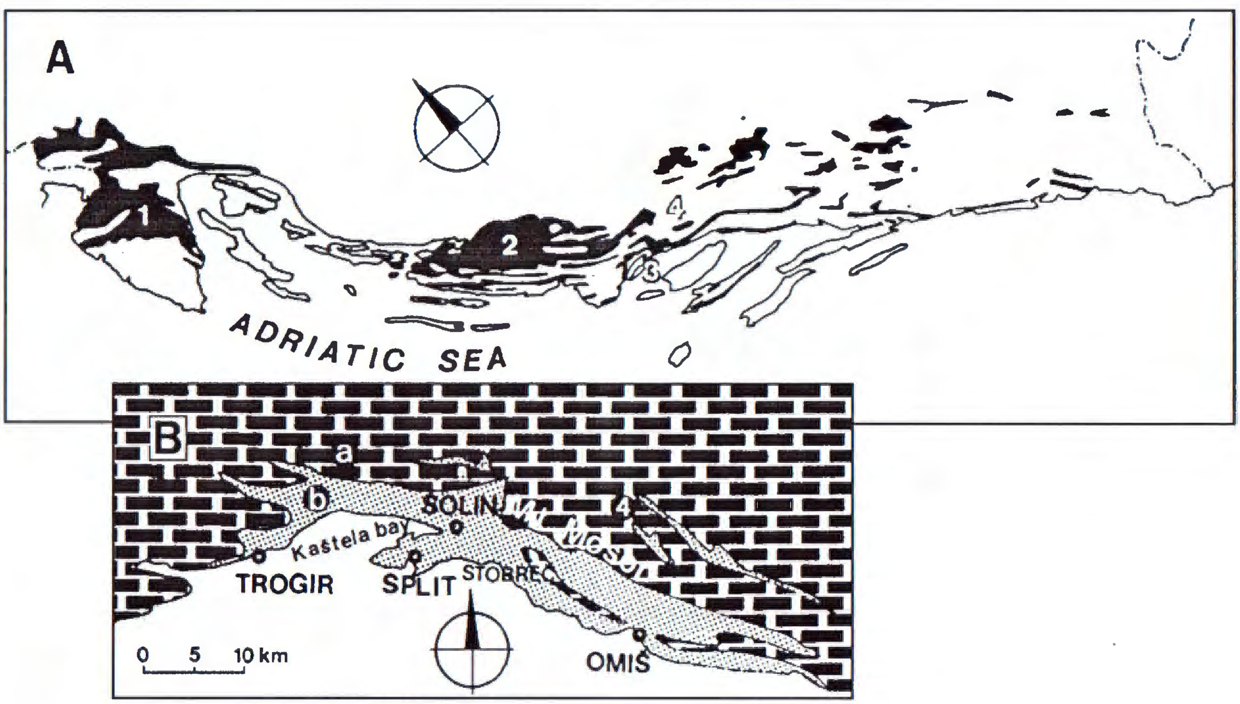

Fig. 1. A) Distribution of Paleogene deposits in Adriatic region. Numbers indicate flysch localities mentioned in text: 1. Istria; 2. Ravni Kotari; 3. Split region (Middle Dalmatia); 4. Donji Dolac. B) General geologic constitution of the explored area in Middle Dalmatia, very simplified.
Key: a. Mesozoic carbonates; b. Paleogene, predominantly flysch; 4. Donji Dolac locality. Map after Geological Map of SFR Yugoslavia 1:500000.
Slika 1. A) Raspored paleogenskih naslaga u jadranskom pojasu. Brojevi označavaju fliška područja koja su spomenuta u tekstu: 1. Istra; 2. Ravni Kotari; 3. Splitsko područje (Srednja Dalmacija); 4. Donji Dolac. B) Općenita geološka građa istraženog prostora u Srednjoj Dalmaciji, jako pojednostavljeno.
Legenda: a. mezozojski karbonati; b. paleogen, pretežno fliš; 4. Donji Dolac.
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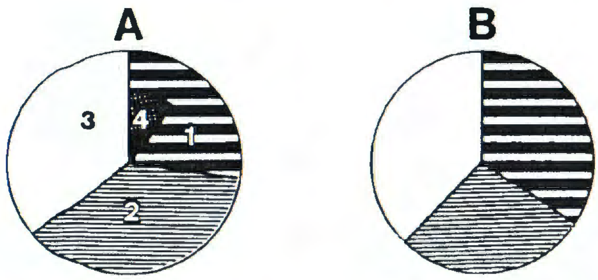

Fig. 2. Role of megabeds in sedimentary sequence of Solin (A) and Split (B) environs. Sedimentary sequence includes pre-olistostrome deposits and the K - S olistostrome.
Key: 1. megabeds; 2. thin-bedded turbidites and other lithologies; 3. covered section; 4. K - S olistostrome.
Slika 2. Udio megaslojeva u slijedu naslaga kod Solina (A) i Splita (B). Slijed sedimenata obuhvaća sedimente starije od olistostrome i olistostromu K - S.
Legenda: 1. megaslojevi; 2. tankouslojeni turbiditi i druge litologije; 3.pokriveni dio slijeda;4.olistostroma K-S.

directions (MARJANAC, 1988b, 1989, 1990).

The thickest megabed in explored area was 170m thick K-S olistostrome (complex bed, Fig. 3). It's arenite is known under the commercial name "plavac" and it has been widely used for paving in the old Split city, and lutite is the most important source of marl for the cement industry in Kaštela-Solin area (GRUBIĆ & KOMATINA, 1962/63; MARJANAC, 1987c).

The post-compaction volume of each of these beds is unknown, but for the K-S olistostrome it attains ca. 5 km^3 . Individual clasts may have extraordinary dimensions, so megaclasts (olistolites) of this olistostrome have volume up to 500.000 m^3; some of which had been recognized already in the 18th century by A. Fortis (BRATULIĆ, 1984) and shown on geological map by KERNER (1914).

During the recent exploration it was recognized that some megabeds had alternating structure sequences, opposing structure orientations, or both (MARJANAC, 1988a, 1989, 1990). Opposing internal directional structures (i.e. ripples) in turbidites were interpreted as antidunes (HAND et al., 1972; RICCI LUCCHI, 1985), but HISCOTT & PICKERING (1984) and PICKERING & HISCOTT (1985) showed that it was hydrodynamically easier to explain this feature as a consequence of turbidity current reflections as noted already by VAN ANDEL & KOMAR (1969). Reflections of turbidity currents are possible in topographically restricted parts of the sea-floor in sub-basins where voluminous flows reached the opposing slope and reflected backwards or sideways. The data from recent environmetns that support the above statement (rebounding and reflection of sub-recent flows, VAN ANDEL & KOMAR, 1969; HERSEY, 1965; HSÜ et al. 1980), as well as the data on flows with upslope direction (DAMUTH & EMBLEY, 1974), have been confronted to data on flows with high scatter of palaeotransport directions - interpreted as a characteristics of flows and their differentiation into several lobes with meandering flow directions (PARKASH & MIDDLETON, 1970). Since the first descriptions of sub-recent reflected turbidity currents were not followed by recognition of fossil sediments with the same features, several years have passed before the previously described sediments with "antidunes" were subjected to reinterpretation (see HISCOTT & PICKERING, 1984 and PICKERING & HISCOTT, 1985). Experimental evidence of turbidity current reflections date back to the early research of DZULYNSKI & WALTON (1965) who only mentioned them, but appropriate experiments started just recently (PANTIN & LEEDER, 1987 and KNELLER et al., 1991).

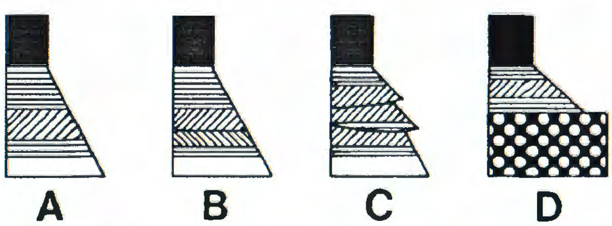

Fig.3. Types of megabeds. A. "classical" turbidites; B. "reflected" turbidites; C. composite turbidites; D. complex beds (debrite + turbidite).
Slika 3. Tipovi megaslojeva. A. "klasični" turbiditi; B. "reflektirani" turbiditi; C. kompozitni turbiditi; D. kompleksni slojevi (debrit + turbidit).

One of important characteristics of megabeds are accompanying marls that may reach thickness of several tens of meters.

Since flysch basins have been traditionally interpreted as wide basins with very long palaeotransport distances, probably under the influence of early researchers and actualistic examples from Pacific, such interpretations undoubtly lead to certain tectonic interpretations. Cartographically smaller flysch occurrences were frequently interprèted as erosional or tectonical remnants (HERAK, 1986; ŠIKIĆ, 1965). Reconstruction of a basin is hindered by controversial tectonic interpretations, tectonic compression and lack of preserved basin margins as already noted in northern Apennines (SESTINI et al., 1986).

Cognition that turbidites occur in restricted basins (i.e. HERSEY, 1965) besides in large "oceanic" basins, as well as in their parts, poses the need for selective interpretation of each explored area, as well as the same basin during the course of its evolution. Therefore understanding of turbidites and associated sediments might be of great help. In such a way SESTINI et al. (1986) presented hypothesis that north Apenninic flysch previously considered as deposit of large and wide basin, asynchronously deposited in 2 adjacent basins.

3. ORIGIN OF MEGABEDS

Transportational and depositional mechanisms of megabeds are presented in other papers, depending on bed type. However, formation of megabeds is governed by a ratio between the basin area (and volume) and volume of parent sediment gravity flows (BLANPIED & STANLEY,1981). That means that thickness of each bed is directly proportional to volume of parent sediment gravity flow (and vice versa!) if basin dimensions do not change during deposition, so that in wider basins we may expect thinner beds than in restricted - smaller basins with equally effective sources. Megabeds deposited from ponded turbidity currents with high initial volume (HISCOTT et al., 1986; RICCI LUCCHI & VALMORI, 1980), but only lutites deposit from thoroughly ponded turbidity current tails (cf. BLANPIED & STANLEY, 1981; KUENEN, 1986 p. 534; STANLEY & MALDONADO, 1981) directly indicating the basin confinement. From the above resoning it is possible to presuppose general basin dimensions according to bed thicknesses; if the sedimentary sequence consists of a large number of megabeds with thick lutites - basin was restricted, and if megabeds are infrequent or absent - basin was wider.

Olistostromes with huge clasts - olistolites, have a high importance for basin analysis because they point to exceptional initiation mechanisms. MUTTI et al. (1984) interpreted such beds as "seismoturbidites" originating from flows that were initiated by strong earthquake shocks, and they quote approximate magnitute M 7 for initiation of flow that deposited the Roncal-member in Pyrenees. Today the majority of authors support this idea, even though there are some other examples, i.e. cases described by MULLINS et al. (1986) and PRIOR et al. (1982). If we accept the seismic interpretation, there arises the question of the type of tectonics that caused seismicity. Some authors indicated that olistostromes have been initiated in front of advancing thrust sheets (ELTER & TREVISAN, 1973; LABAUME et al., 1983; MUTTI et al.,1984); but some other authors relate them to the extensional tectonics (BERNOULLI et al., 1981; NAYLOR, 1981; PAREA & RICCI LUCCHI, 1975).

4. CONSTITUTION AND EVOLUTION OF SPLIT-KAŠTELA BASIN

After emersion in Middle Dalmatia that lasted from Sennonian to Paleocene-Eocene (MAGAŠ & MARININČIĆ, 1973; MARINČIĆ et al., 1971), or from Maastrichtian to Middle Lutethian (Chorowicz, 1975, 1977), reestablished shallowmarine carbonate sedimentation that produced biogenic limestones (alveolina - and nummulite - limestones, KERNER, 1903). After deposition of foraminiferal limestones deposited "transitional" beds (ŠIKIĆ, 1965) with high content of glauconite, and globigerina - marls of Middle Eocene age (MARINČIĆ, 1981) or Lutethian age (MAGAŠ & MARINČIĆ,1973). Relation of "transitional" beds and underlying foraminiferal limestones on the northern slope of Marjan is characterized by slight angular unconformity of 15°. ŠIKIĆ (1965, 1968, 1969) interpreted relatively short break in sedimentation on the boundary of Lower and Upper Luthetian due to the change in thickness of globigerina-marls in area from Istria to Northern Dalmatia, and attributed it to the Istrian-Dalmatian orogenic phase. Nanno-analysis of sediments immediately overlying "transitional" beds indicate on the Upper Lutethian age (NP 17 nannnozone, BENIĆ, 1983) in environs of Trogir, identically as on the northern slope of Marjan (PUŠKARIĆ, 1985). Initiation of flysch deposition was determined as the Middle Lutethian (ŠIKIĆ, 1969), Upper Lutethian (BENIĆ, 1983; BLANCHET, 1972; CHOROWICZ, 1977; KERNER, 1903; MAGAŠ & MARINČIĆ, 1973), or a lower part of Middle Eocene (MARINČIĆ et al., 1971), and Upper Eocene (MARINČIĆ, 1981). ŠIKIĆ (1965) described unconformable contact with flysch and underlying sediments in the Northern Dalmatia, but later authors indicate continuous deposition of flysch over the underlying "transitional" beds (CHOROWITZ, 1975, 1977; MAGAŠ & MARINČIĆ, 1973; MARINČIĆ et al., 1971). While the above mentioned authors hold that presented sedimentary sequence resembled vertical succession, KERNER (1903) believed that foraminiferal limestones and flysch deposited simultaneously, and that white nummulitic limestones of Marjan structure present time - equivalents of the "middle" flysch zone (K - S olistostrome, MARJANAC, 1987b).

The opening of basin that allowed deposition of a thick clastic sequence CHOROWICZ (1977) explained by the flexural lowering of carbonate platform. MARINČIĆ (1981) stated that opening of the "initial" trough resulted from the Lutethian tectonic movements that dissected carbonate shelf and allowed deposition of "transitional" beds. It is traditionally accepted that flysch of Adriatic region, exposed in isolated occurrences in Istria, Ravni Kotari, Dalmatia and elsewhere originated in one unique sedimentary basin (HERAK, 1986; MAGDALENIĆ, 1971,1972; MARINČIĆ, 1981; ŠIKIĆ, 1965).

Detailed exploration of recent deep-sea basins showed highly differentiated bottom topography, similar to the spotted karst with numerous depressions and highs (BLANPIED & STANLEY, 1981; HERSEY, 1965; KASTENS & CITA, 1981; VAN ANDEL & KOMAR, 1969, etc.). While the exploration of bottom topography of recent basins today present relatively easy task thank to the modern high technology, exploration of "fossil" basins remains difficult one due to numerous restrictions such as the degree of exposure, degree of tectonical deformation, and difficulties in chronostratigraphical dating - especially in brackish basins or sediments that originated during the time-span of one or two biozones.

The important data most frequently used in basin analysis are palaeotransport directions of turbidites, as well as directions of submarine slides. Palaeotransport directions in the explored area are presented in more detail elsewhere (MARJANAC, 1988 b). For the purpose of this study only orientations of the polar structures are presented (i.e. flute marks and ripples) on current roses, in order to get the true directions more pronounced. Thus the palaeotransport directions of turbidites (excluding megabeds) in the explored area have wide dispersal and almost centripetal symmetry (Fig. 4), in contrast to predominantly longitudinal palaeotransportation indicated by MARINČIĆ (1981) for the biggest part of Adriatic flysch. Moreover local distribution of Bouma - sequences showed the big differences of Solin and Split areas (see map inserts B and C at Fig. 4), suggesting that palaeotransport directions should be studied independently, too. While the current rose for Split environs (insert C) is still almost circular with three maxima, the rose of Solin environs shows two almost opposite maxima. Since the roses present readings from one or several adjacent sections in inland region, an attempt has been made to show "exploded" view of directions by use of arrows that symbolize diretions and frequency of flows. In this way input directions became more pronounced, regardless some arrows had to be placed in the sea where no palaeocurrent readings were collected - but debris source had to be located somewhere in that direction. This study proved that Solin and Split environs acted as more or less independent sediment traps, and the later may be explained by existence of the two sub-basins developed at the basin floor.

However, palaeocurrents of some megabeds show a more complex pattern, because it was observed that orientations of internal directional structures (ripples and cross bedding) differ at different levels of the same

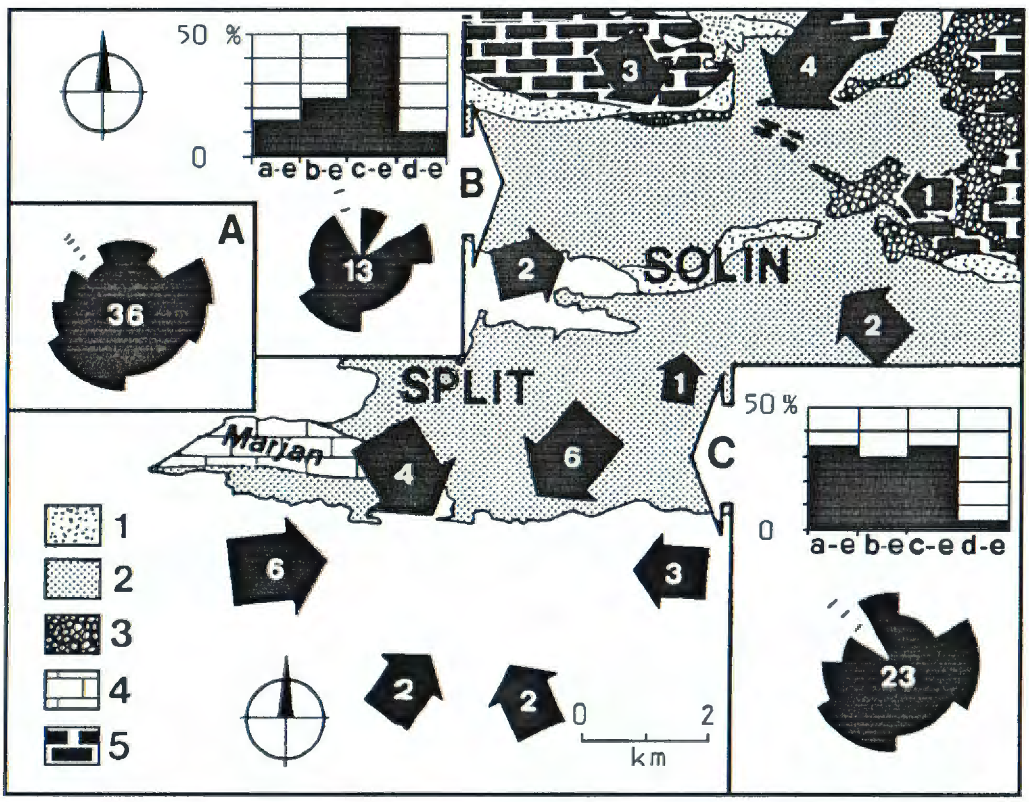

Fig. 4. Palaeotransport directions of turbidites in the Split-Solin region. The sizes of arrows and numbers indicate number of flows. The map insert A shows palaeotransport directions (only polar structures shown) in the sedimentary sequence underlying the K - S olistostrome for the whole area. Note nearly centripetal symmetry of the current rose. The map inserts B and C show distribution of Bouma - sequences and palaeotransport directions in Solin and Split environs.
Key: 1. Quaternary sediments; 2. Paleogene flysch;3. Paleogene coarse clastics; 4. Paleogene carbonates (foraminiferal limestones); 5. Mesozoic carbonates.
Map after KERNER (1914), simplified.
Slika 4. Smjerovi paleotransporta turbidita u Splitsko - Solinskom području. Veličina strelica i brojevi pokazuju broj tokova. Umetak A prikazuje paleotransporte (samo polarnih tekstura) u slijedu sedimenata u podini olistostrome K - S za cijelo istraženo područje. Izražena je skoro centripetalna simetrija paleotransporta. Umeci B i C pokazuju distribuciju Bouma - sekvencija i paleotransporte za područje Solina (B) i Splita (C). Obratite pažnju na razlike u distribuciji Bouma - sekvencija i smjerove paleotransporta.
Legenda: 1. kvartarni sedimenti; 2. paleogenski fliš; 3. paleogenski krupnozrnati klasiti; 4. paleogenski karbonati (foraminiferski vapnenci); 5. mezozojski karbonati.
Karta prema KERNERU (1914), pojednostavljeno.

bed (MARJANAC, 1988a, b, 1990). That posed the need to explore a cause of such distribution of palaeotransport directions. Since the opposing directional structures (such as ripples) could form only after the change of flow direction due to flow reflection on submarine obstacle or slope, it was necessary to define the possible location of these obstacles. Fig. 5 illustrates an attempt to reconstruct the positions of obstacles that caused reflections of sediment gravity flows that produced the megabeds explored. The regular inferred position of individual obstacles is striking, thus suggesting that obstacles are in fact faulted blocks (Fig. 6). Thick marls are capping all megabeds, and they could form only

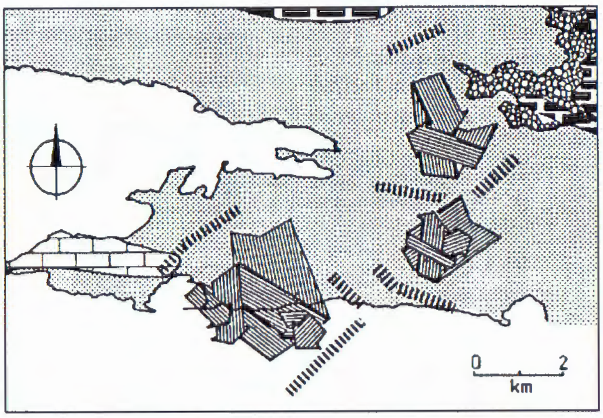

Fig. 5. Graphical reconstruction of flow reflections of several characteristic megabeds and inferred approximate positions of the intrabasinal obstacles. The megabeds shown deposited before the K - S olistostome.
Slika 5. Grafička rekonstrukcija refleksija tokova nekolicine karakterističnih megaslojeva i izveden približan položaj intrabazenskih prepreka.

from ponded turbidity current tails (BLANPIED & STANLEY, 1981; KUENEN, 1968; STANLEY & MALDONADO, 1981). The prerequisite condition is a restricted depocentre in a form of more or less isolated trough or depression. As presented megabeds formed

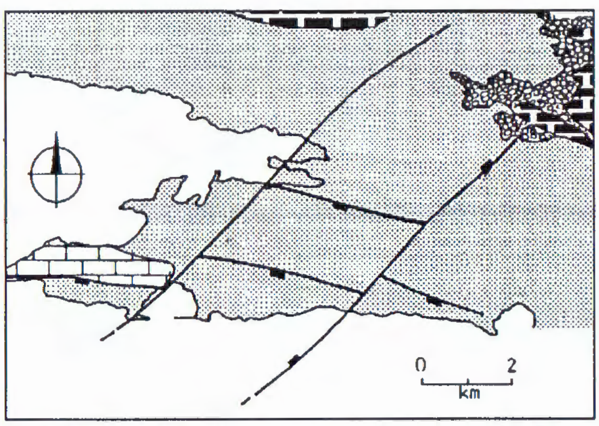

Fig. 6. Interpretative palaeogeologic map based on reconstruction at Fig. 5. The basin floor was dissected by the SW-NE trending faults that cut the listric normal faults, thus forming restricted sub-basins and troughs. The faults shown are located only approximately, because the map lacks palinspastic restoration.
Slika 6. Interpretativna paleogeološka karta prema rekonstrukciji na slici 5. Dno bazena presjecaju rasjedi pružanja JZ-SI koji presjecaju lističke rasjede i korita. Prikazani rasjedi su locirani samo približno jer karta nije palinspastički rekonstruirana.

during relatively long time span, their succession may indicate the basin dynamics because they present individual extremely short-lasting events that were considerably different from the "normal" basin sedimentation.

Fig. 7 illustrates 5 phases of evolution of the Split - Kaštela Paleogene basin, described below.

Phase 1.

During Cuisian to Middle Eocene (BLANCHET, 1972), Lower (?) to Upper Eocene (CHOROWITZ, 1977), or Paleocene and Lower Eocene (MARINČIĆ et al., 1977; ŠIKIĆ, 1968) in Middle Dalmatia acted deposition of lagoonal (unexposed in the Split - Kaštela area) and shallow marine carbonates on Adriatic carbonate platform (HERAK, 1986).

Phase 2.

During Lutethian (MAGAŠ & MARINČIĆ, 1973), Middle Eocene (MARINČIĆ et al., 1977), or lower Middle Eocene (ŠIKIĆ, 1968), deposited "transitional" beds in deeper intraplatform environment that still lacks typical basinal characteristics. According microfaunal assemblages JURAČIĆ (1980) interpreted the depositional environment of "marls with crabs" ("transitional" beds s.str.) as 60 - 100 m deep shelf at the beginning of deposition, and ca. 1000 m or more deep envirenment by the end of deposition, indicating progressive and high rate of deepening. The observed angular unconformity of 15° between underlying foraminiferal limestones and "transitional" beds indicate tilting of bottom, most probably related to activation of growth (listric) faults that mark the first step of disintegration of carbonate platform. High glauconite content suggests on deposition during a maximum flooding stage, and increasing role of planctonics indicate the increasing pelagic influence. Carbonate platform was disintegrated by listric normal faults during the extensional tectonic phase that formed strikingly asymmetric troughs - depocentres on tilted (rotated) blocks. These troughs acted as depocentres for this thick marls (globigerina-marls) with exclusively pelagic fauna and almost devoid of terrigenous influence. During marl deposition rotated blocks did not reach the subaerial exposure yet, so no resedimented fauna or lithic debris that might have originated from the rising blocks existed there.

Phase 3.

By the end of Lutethian carbonate platform was already disintegrated by listric normal faults. The pericontinental (eastern) block rotationally rose upward as well as the western block that came into emersion. Subaerial exposure and weathering of uplifted blocks produced high quantity of skeletal and lithic debris that occasionally resedimented by sediment gravity flows down to deep basin. These flows were most probably related to seismicity that followed active tectonics, continued subsidence and rotation of blocks. In this way depocentres deepened and allowed deposition of very thick beds (megabeds) from the ponded flows. Individual flows did not spread into all neighbouring sub-basins

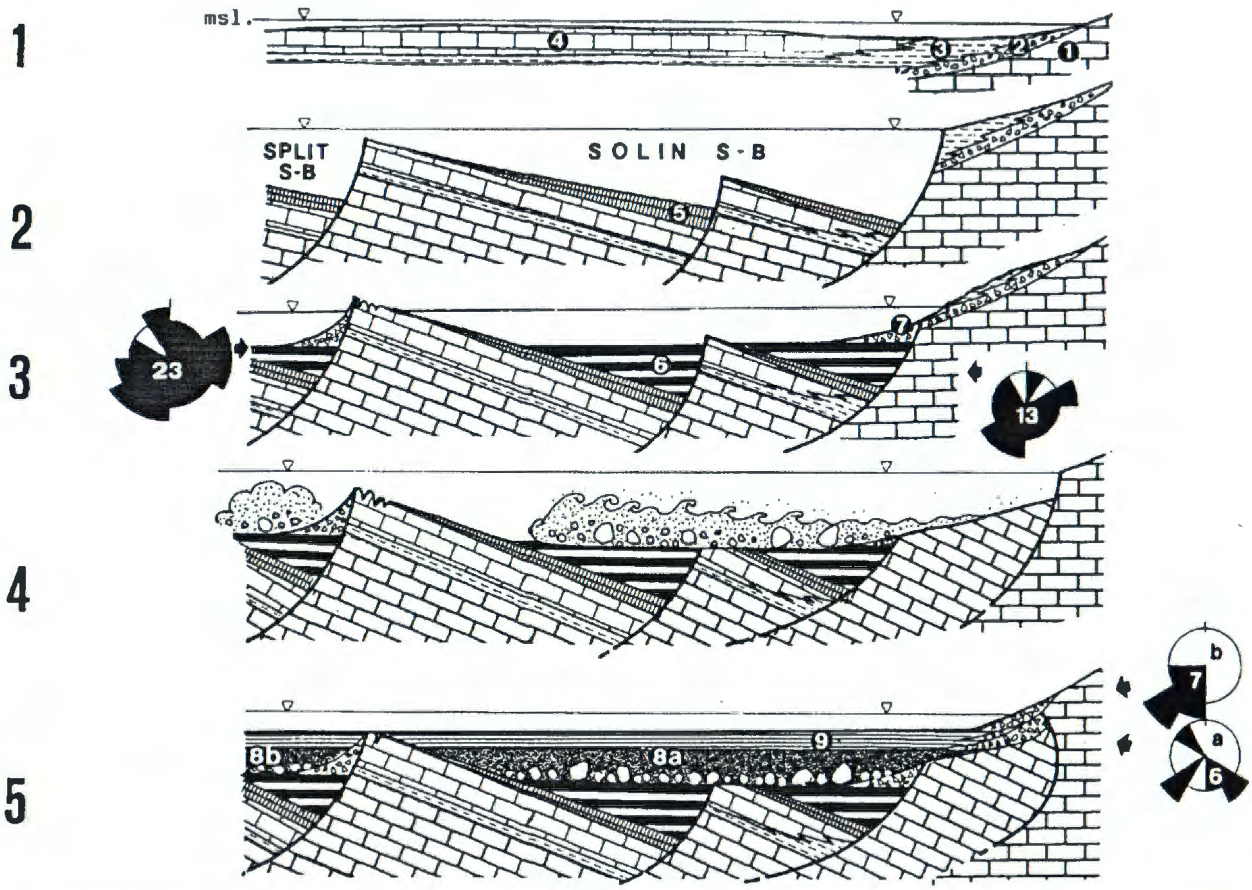

Fig. 7. Sedimentary and tectonic evolution of the Split-Solin area. For descriptions of Phases 1-5 see text. Palaeotransport directions of the pre-olistostrome sedimentary sequence in Phase 3 are shown by rose diagrams. Palaeotransport directions of thinbedded turbidites are shown for two post-olistostrome sequences, a (lower) and b (higher). Numbers indicate number of flows. Note predominance of the northeast source in level b. Not to scale.
Key: 1. Mesozoic carbonates; 2. coarse-grained clastics; 3. lagoonal deposits (hypothetical); 4. platform carbonates (foraminiferal limestones); 5. "transitional" beds; 6. megabeds; 7. coarse grained fan-deltas; 8. a=K-S olistostrome, b=SV megabed; 9. thinbedded turbidites.
Slika 7. Sedimentacijska i tektonska evolucija Splitsko-Solinskog prostora. Opis Faza 1-5 dan je u tekstu. Paleotransporti pred-olistostromnog slijeda sedimenata u Fazi 3 prikazani su rozetnim dijagramima. Paleotransporti tankouslojenih turbidita prikazani su za dva post-olistostromna slijeda: a (niži) i b (viši). Brojevi prikazuju broj tokova. Tek na nivou b dominira donos sa sjeveroistoka. Slika nije u mjerilu.
Legenda: 1. mezozojski karbonati; 2. krupnozrnati klastiti; 3. lagunarni sedimenti (hipotetski); 4. platformski karbonati (foraminiferski vapnenci); 5. "prijelazne" naslage; 6. megaslojevi; 7. krupnozrnate *fan-delte*; 8. a=olistostroma K-S, b=megasloj SV; 9. tankouslojeni turbiditi.

and troughs but reflected several times from surrounding basin walls and slopes. Through the course of time megabeds gradually infilled isolated sub-basins and troughs. Palaeotransport directions of thinner turbidites within this sequence show different patterns in Split and Solin environs also indicating on relative isolation of the two sub-basins (MARJANAC, 1988 b, 1990). By the end of Phase 3, progressive lowering of the sea-level caused local emersions and intensified weathering that supplied debris for prograding fan deltas.

Phase 4.

The consequence of increased tectonics, weathering and primary accumulation of debris (and overloading of shelf?) is the catastrophic collapse of shelf margin (and partly emerged area?) that in the Solin sub-basin initiated sediment gravity flow with exceptional volume and huge debris (megaclasts). The volume of this flow exceeded the volume of partly filled local depocentres so that it spread over the ridge that divided local troughs and infilled eastern sub-basin with more than hundred meters thick sediment - the K - S olistostrome (MARJANAC, 1985, 1987 b). The flow was locally erosive as indicated by numerous huge rip-up clasts of basinal sediments. Huge extrabasinal clasts were sliding, bouncing, and rolling along the bottom, so that some large blocks have well preserved tool marks (striations) indicating apparently N - S line of transport.

Phase 5.

After deposition of the K- S olistostrome the relief of basin floor was flattened, and sedimentary basin significantly widened. In spite of very close outcrops, no direct correlation was possible of the K-S olistostrome that outcrops in the Solin sub-basin and SV megabed that outcrops in the Split sub-basin. This is most probably due to the submarine ridge that divided the sub-basins. However characteristics of both beds are very similar, and so is the stratigraphic position. It is very likely that these beds if not present deposit of a single flow, present beds deposited from two independent flows but initiated simultaneously by the same triggering event of presumed seismic origin.

The overlying sediments at the eastern margin of basin are prograding coarsegrained fan deltas that indicate repeated lowering of the sea-level. During deposition of the coarsegrained deposits or soon afterwards (while the coarsegrained deposits were still unlithified) occurred the first compressional event as indicated by tectonically deformed pebbles (pitted grains sometimes with striations). This compression caused also deformations of strata on the western basin margin, but that is difficult to differentiate from deformations that originated during later compressions (the later did not affect pebbles).

Following the period of rising sea-level thinner turbidites with palaeotransport directions from the north-west and from the north- and south-east were deposited, and slightly higher in the section they were deposited predominantly from the north-east. Thinner beds were the result of extended basin width, and possibly of smaller volume of available debris because the previous erosion and rising of sea-level lowered gradient in emerged areas. However, the sea-level soon lowered again,and reestablished progradation of coarsegrained alluvial fans and fan deltas.

During evolution of the Split - Kaštela basin this phase lasted for a relatively long period of time, with several repeated risings and lowerings of the sea-level, but basinal sediments equivalent of the youngest fan deltas were not preserved.

Phase 6.

This phase is not illustrated in Fig. 7 because it presents final compressive phase in basin evolution that did not have importance for generation of megabeds that filled the explored basin. However that does not mean that it could not influence some other (younger) basins.

5. CONCLUSIONS

From the above discussions it is possible to derive several conclusions:

1. Thick lutites formed from the ponded turbidity current tails of voluminous flows, indicate restricted sedimentary environment at the basin floor that acted as a local depocentre.

2. Changes of palaeotransport directions within the same megabed indicate reflections of flow heads from the intrabasinal obstacles or from the counterslope. Multiple changes of palaeotransport directions and complex sedimentary sequences with repeated intervals indicate on relatively short distances from obstacles, and thus on the complex bottom topography.

3. Restricted basin floor with effective ponding is a favourable place for reflections of turbidity currents.

4. Turbidites deposited from reflected flows contain more data on palaeotransport directions and geometry of basin than do "classical" turbidites.

5. Palaeotransport directions in Split - Kaštela area were far more complicated than traditionally accepted, indicating that Solin and Split areas functioned as 2 isolated sub-basins divided by partly and temporarily emergent ridge. The Solin sub-basin was also subdivided into 2 smaller troughs divided by a submarine ridge.

6. The K - S olistostrome with dry volume that exceeds 5 km^3 infills both troughs in the Solin sub-basin and presents a good key-bed.

7. Flysch with megabeds in Middle Dalmatia deposited during the extensional tectonical phase contrary to hypothesis of HERAK (1986, 1989) that flysch of Adriatic region is being a product of "compressive dynamics".

8. The tectonical disintegration of carbonate platform opened a basin with tectonically influenced evolution and complex bottom topography.

ACKNOWLEDGMENTS

This paper presents the outcome of research of the Paleogene clastic basin of Middle Dalmatia, currently supported by the Ministry of Science of Republic of Croatia (Project 1-09-084). During the field work valuable help was provided by my students and friends as well as my wife Ljerka. The present paper benefited from one stimulating review.

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ZNAČAJ MEGASLOJEVA ZA REKONSTRUKCIJU PALEOGENSKOG FLIŠKOG BAZENA U OKOLICI SPLITA (SREDNJA DALMACIJA)

T. Marjanac

U mnogim fliškim bazenima uočeni su vrlo debeli slojevi što su nastajali pri izuzetnim sedimentacijskim događajima. Njihov značaj bio je do danas različito shvaćan, počev od puke registracije i/ili neshvaćanja pa do pridavanja velike važnosti tako da je 1986 godine održan i AAPG/SEPM simpozij o "megaturbiditima" (DOYLE & BOURROUILH, 1987). Megaslojevi su dobri stratigrafski reperi koji su vidljivi i na geofizičkim profilima (ukoliko su dovoljno debeli) (BOUMA, 1987; MARCHETTI, 1957) i mogu se pratiti duž cijelog bazena (ENGEL, 1970; JOHNS et al., 1981; LABAUME et al., 1983, 1987; PAREA & RICCI LUCCHI, 1975; RICCI LUCCHI, 1975; RICCI LUCCHI & VALMORI, 1980 i drugi). Navedeni slojevi nastajali su sedimentacijom iz gravitacijskih tokova velikog volumena, tako da je taloženjem nastao debeli sediment. Debljina tako nastalog sloja je funkcija volumena toka, ali i površine (i volumena) bazena (BLANPIED & STANLEY, 1981), odnosno depocentra. Tako se iz tokova podjednakog volumena u ograničenim depocentrima talože deblji sedimenti no u širokom bazenu. Na taloženje u ograničenom depocentru najdirektnije ukazuje debljina lutita koji su nastali taloženjem iz "ujezerenog" repa mutne struje (cf. BLANPIED & STANLEY, 1981; KUENEN, 1968; STANLEY & MALDONADO, 1981).

U Splitsko - Kaštelanskom području (sl. 1) registrirani su različiti tipovi megaslojeva i to turbiditi, kompozitni turbiditi i kompleksni slojevi (MARJANAC, 1986) (sl. 3), a njihova građa je prikazana u drugim radovima (MARJANAC, 1985, 1987a, b, 1988a, 1990). Najdeblji sloj je olistostroma K - S debela 170 m (MARJANAC, 1985, 1987b), a njen lapor predstavlja glavnu sirovinu za cementnu industriju u tom području (GRUBIĆ & KOMATINA, 1962/63). Po prvi puta opisao ju je već KERNER (1903) i 1914 g. izdvojio na geološkoj karti, ali su megaklasti (olistoliti) bili poznati i ranije, jer ih je opisao već A. Fortis u 18. stoljeću (BRATULIĆ, 1984).

Detaljna istraživanja u navedenom prostoru (MARJANAC, 1988b, 1989, 1990) pokazala su paleotransporte koji su odudarali od do sada poznatih smjerova i trendova (MARINČIĆ, 1981). Međutim uočeno je da se na različitim nivoima nekih slojeva vidi različita orijentacija strujnih tekstura (na primjer riplova) (MARJANAC, 1988a, 1988b, 1990) što je interpretirano kao odraz refleksija mutnih struja od prepreka u bazenu (sensu HISCOTT & PICKERING, 1984; PICKERING & HISCOTT, 1985). Analiza refleksija obrađena je u posebnom radu (MARJANAC, 1990), a prikazana na sl. 5, dok je paleotektonska rekonstrukcija prikazana na sl. 6.

Značaj megaslojeva u istraženom prostoru proizlazi iz činjenice da megaslojevi zapremaju cca. 1/4 do 1/3 ukupne debljine istraženog slijeda sedimenata (sl. 2), a kako je cca. 1/3 slijeda pokrivena, moguće je da je njihov udio i veći. Unutar skupine megaslojeva za rekonstrukciju prostora posebno su indikativni slojevi s tragovima refleksija mutnih struja jer sadrže više podataka o paleotransportima no "klasični" turbiditi. Na osnovi analize refleksija rekonstruirana je paleotektonska građa dijela bazena (sl. 6) koja je poslužila kao osnova za rekonstrukciju evolucije bazena na sl. 7.

Tradicionalno je prihvaćeno da je fliš jadranskog pojasa koji se vidi u izoliranim pojavama npr. Istre, Ravnih Kotara, Dalmacije i drugdje, nastao u jedinstvenom sedimentacijskom prostoru (HERAK, 1986; MAGDALENIĆ, 1971, 1972; MARINČIĆ, 1981; ŠIKIĆ, 1965); no detaljna istraživanja recentnih bazena pokazuju da je topografija današnjih bazenskih dna vrlo razvedena s brojnim depresijama (sub-bazenima) i hrptovima (BLANPIED & STANLEY, 1981; HERSEY, 1965; KASTENS & CITA, 1981; VAN ANDEL & KOMAR, 1969 i dr.), a rekonstrukcija paleotransporta u Splitsko - Kaštelanskom prostoru također ukazuje na izdvojene depocentre (MARJANAC, 1988 b, 1990).

Evolucija sedimentacijskog prostora između Splita i Solina prikazana je u 5 faza na sl. 7.

Faza 1.

Nakon emerzije koja je u srednjoj Dalmaciji trajala od mastrihta do sredine luteta (CHOROWICZ, 1975, 1977), odnosno od senona do paleocena (MAGAŠ & MARINČIĆ, 1973; MARINČIĆ et al., 1971), uspostavljena je plitkovodna karbonatna sedimentacija. Karbonatna sedimentacija na Adrijatičkoj platformi (HERAK, 1986) trajala je od donjeg (?) do gornjeg luteta (CHOROWICZ, 1977), kuizija do srednjeg eocena (BLANCHET, 1972), odnosno paleocena i donjeg eocena (MARINČIĆ et al., 1977; ŠIKIĆ, 1968) i taložene su tzv. "liburnijske" naslage te foraminiferski vapnenci.

Faza 2.

Iznad foraminiferskih vapnenaca tokom luteta (MAGAŠ & MARINČIĆ, 1973), srednjeg eocena (MARINČIĆ et al., 1977), odnosno donjeg dijela srednjeg eocena (ŠIKIĆ, 1968) taložene su "prijelazne" naslage (ŠIKIĆ, 1965) s visokim udjelom glaukonita i "globigerinski" lapori. Odnos foraminiferskih vapnenaca i "prijelaznih" naslaga je na sjevernoj padini Marjana karakteriziran blagom kutnom diskordancijom od 15°.

Otvaranje bazena koje je prethodilo taloženju fliša CHOROWICZ (1977) je vezao uz ugibanje karbonatne platforme, dok je MARINČIĆ (1981) držao da je otvaranje "inicijalnog" korita bilo izazvano lutetskim tektonskim pokretima. Kutna diskordancija između foraminiferskih vapnenaca i "prijelaznih" naslaga, te velika debljina "globigerinskih lapora" ukazuje na tektonsku rotaciju - naginjanje blokova i taloženje u relativno ograničenom depocentru. "Prijelazne" naslage taložene su u sve većoj dubini počev od cca. 60 - 100 m pa do više od 1000 m (JURAČIĆ, 1980) što ukazuje na postepeno tonjenje tektonskog bloka.

Faza 3.

Nano-analize neposredne krovine "prijelaznih" naslaga kod Trogira dale su gornjolutetsku starost, jednako kao i na sjevernoj padini Marjana (NP 17 nano-zona, BENIĆ, 1983; PUŠKARIĆ, 1985). Dok je većina autora do sada prihvaćala kontinuitet taloženja i vertikalnu sukcesiju naslaga od foraminiferskih vapnenaca do fliša, KERNER (1903) je pretpostavljao djelomično istovremeno taloženje foraminiferskih vapnenaca i fliša. Razbijanjem karbonatne platforme u ekstenzijskoj tektonskoj fazi formirani su Splitski i Solinski sub-bazeni i manja korita odnosno lokalni depocentri. Dok je jedan kraj bloka trpio izdizanje i mogao dospjeti u emerziju suprotni kraj je kontinuirano tonuo, što je vjerojatno pratila živa tektonika koja je periodički inicirala velike tokove što su prenosili detritus u bazen. Posebno veliki tokovi trpjeli su i više refleksija od podvodnih prepreka i oboda bazena, a nakon taloženja dali su megaslojeve koji postepeno zatrpavaju korita i sub-bazene. Paleotransporti u to vrijeme pokazuju znatne razlike između Solinskog i Splitskog sub-bazena što ukazuje na njihovu međusobnu izoliranost (MARJANAC, 1988b, 1990). Snižavanjem razine mora pred kraj ove faze bilo je pojačano trošenje emergiranog prostora i donos detritusa koji je doveo do progradacije *fan-delti* prema bazenu.

Faza 4.

Posljedica intenzivnog trošenja i primarne akumulacije detritusa i pojačane tektonike je katastrofalni kolaps ruba šelfa i dijela emergiranog prostora pri čemu je nastao gravitacijski tok velikog volumena kojim su u bazen dospjeli i izuzetno krupni klasti (olistoliti). Volumen ovog toka je nadmašio volumen djelomično ispunjenih lokalnih depocentara tako da je ispunio cijeli Solinski sub-bazen i taloženjem stvorio 170 metara debelu olistostromu K - S (MARJANAC, 1985, 1987b).

Faza 5.

Nakon taloženja olistostrome K - S, bilo je zaravnjeno morsko dno, a sedimentacijski prostor proširen tako da su mlađi turbiditi tanji. Unatoč bliskim izdancima, nije bila moguća direktna korelacija olistostrome sa megaslojem SV koji je istaložen u Splitskom sub-bazenu. To je najvjerojatnije uvjetovano postojanjem podmorskog hrpta koji je odvajao sub-bazene. Međutim, karakteristike oba sloja su vrlo slične, a takav im je i stratigrafski položaj, tako da oni - ako već ne predstavljaju sediment nastao iz jednog toka - predstavljaju sedimente nastale iz odvojenih ali istovremenih tokova pokrenutih istim uzrokom. Ponovnim spuštanjem razine mora povrh olistostrome na istočnom rubu bazena talože se krupnozrnati sedimenti *fan delta*. Tokom njihovog taloženja ili neposredno nakon taloženja (dok je sediment još bio nelitificiran) nastupila je prva kompresija koja je zahvatila samo rub bazena, na što ukazuju tektonski deformirane valutice i kontaktno otapanje na mjestima njihovog dodira te tragovi smicanja u vidu strija. Istovremeno je izazvana i deformacija slojeva, ali ju je teško razlikovati od kasnijih deformacija izazvanih mlađim kompresijama (ove kasnije nisu izazvale deformacije). Nakon izdizanja razine mora bili su taloženi turbiditi koji su transportirani sa sjeverozapada i sjeveroistoka te jugoistoka, a nešto više u stupu samo sa sjeveroistoka. Manja debljina turbidita može biti odraz manjeg volumenta detritusa u izvorištu što je vjerojatno u vezi sa smanjenim gradijentom izazvanim izdizanjem razine mora i dotadašnjim trošenjem na kopnu. Međutim, ubrzo se razina mora ponovo spustila pa su ponovo prema bazenu prodirale krupnozrnate *fan-delte*, no bazenski ekvivalent ovih najmlađih naslaga nije sačuvan.

Faza 6.

Ova faza nije prikazana na sl. 7 jer predstavlja kompresijsku fazu koja više nije imala značaj za nastanak megaslojeva koji su ispunjavali prikazani bazen, što naravno ne znači da se njen utjecaj nije mogao manifestirati u nekom drugom mlađem bazenu.

ZAKLJUČCI

Iz prikazane skraćene diskusije mogu se izvesti slijedeći zaključci:

1. debeli lutiti nastajali su iz "ujezerenih" repova mutnih struja što ukazuje na ograničeni taložni okoliš na bazenskom dnu koji je funkcionirao kao lokalni depocentar.
2. promjene smjera paleotransporta unutar istog megasloja ukazuju na refleksije čela tokova od podmorskih prepreka ili ruba bazena. Višestruke refleksije i ponavljanje slijedova sekvencija ukazuje na malu udaljenost od prepreka i na kompleksnu topografiju dna.
3. ograničeno dno bazena s efikasnim "ujezerivanjem" tokova je pogodno mjesto za refleksije mutnih struja.
4. turbiditi taloženi iz reflektiranih tokova sadrže više podataka o paleotransportima i geometriji bazena nego "klastični" turbiditi.
5. paleotransporti u Splitsko - Kaštelanskom prostoru su kompleksniji no što se tradicionalno mislilo i ukazuju da su u područjima Solina i Splita postojala 2 sub-bazena odvojena djelomično i povremeno izdignutim hrptom. Solinski sub-bazen bio je također podijeljen na dva jarka odvojena podmorskim hrptom.
6. olistostroma K - S sa "suhim" volumenom koji prelazi 5 km^3 ispunjava oba korita u Solinskom sub-bazenu i predstavlja dobar reperni sloj.
7. fliš s megaslojevima u srednjoj Dalmaciji bio je taložen tokom ekstenzijske tektonske faze nasuprot HERAKOVE (1986, 1989) hipoteze da je fliš jadranskog pojasa nastao kao produkt "kompresijske dinamike".
8. tektonska desintegracija karbonatne platforme otvorila je bazen s kompleksnom topografijom dna i tektonski uvjetovanom evolucijom.