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The Bottom Current Sediments (Contourites) in the Upper Cretaceus Deep-Water Deposits in the Northeastern Part of Žumberak (Croatia)

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Key words: contourites, contour sequences, bottom currents, turbidites, hemipelagites, deep-water deposits, Upper Cretaceous, Žumberak, Dinarides.

Ključne riječi: konturiti,konturitne sekvencije, turbiditi, hemipelagiti, pridnene struje, dubokomorski talozi, gornja kreda,Žumberak, Dinaridi.

The Upper Cretaceous deep marine deposits in NE part of Žumberak contain sediments deposited by bottom currents - muddy,sandy and sandy-gravelly contourites*. The complete (negative-positive) sequfences and incomplete (negative-positive) sequences have been observed. Apart from the sediments that have been deposited by bottom currents, several turbidite layers reworked by bottom currents occur.

U dubokovodnim sedimentima gornje krede u sjeveroistočnom Žumberku ustanovljene su naslage pridnenih struja - muljni, pješčani i pješčano - šljunčani konturiti*. Kod većeg dijela konturnih naslaga prepoznate su potpune (negativno - pozitivne) sekvencije. Osim naslaga nastalih taloženjem iz pridnenih struja, izdvojeni su i talozi nastali prerađivanjem turbiditnih sekvencija.

1. INTRODUCTION

The Upper Cretaceous sediments in Žumberak belong to the zone of deep-water clastic layers placed on the north-east side of the wide shelf carbonate belt spreading from Tolmin through Žumberak and Kordun to Banja Luka and further towards south - east (BLANCHET et al., 1970; AUBOUIN et al., 1972; CHARVET, 1972; CARON & COUSIN, 1973; BABIĆ, 1973, 1974; BABIĆ & ZUPANIČ, 1976). The clastic sediments are mostly composed of turbidites, hemipelagites and so far insufficiently examined sediments which are the subject of this paper. These sediments are here attributed to bottom currents but some of them represent turbidites and hemipelagites reworked by bottom currents. Although recent bottom currents have been revealed in submarine canyons and channels, their movements mainly follow slope isobaths or contour lines. The terms contour currents and *contourites* are therefore used for such kind of currents and their deposits, but, very often, also for the bottom currents and their deposits the movements of which did not necessarily occur along the slope. This paper deals with a detailed description of sediment characteristics originated by bottom currents, their origin and their possible palaeogeographic situation.

2. SITUATION, STRATIGRAPHIC SETTING AND GENERAL CHARACTERISTICS OF SEDIMENTS

The investigated outcrops are located in the north - east part of Žumberak in the nearby village Novo selo, right at the foot of local road Bregana - Kostanjevac and belong to the layers characterized by alteration of micrites and/or marly micrites with detrital components (mostly arenites and siltites) (Fig. 1). The layers are very close to lithologically similar outcrop which Albian - Cenomanian age has been established by pelagic foraminifers (BABIĆ, 1974).

The work was concentrated on three very close outcrops with total thickness of about 20 m (Fig. 2; pl. I, Fig. 1 and 2; pl. II, Fig. 1). Columns B and C have been disturbed by slumping. Because of vegetation cover, the outcrops are mutually isolated so that a complete reconstruction of slumping is impossible.The folded blocks are at a metre scale and are separated by slide surfaces from relatively undisturbed beds in columns. Layers in column B (Fig. 2; pl. I, Fig. 1) are reversed and might be a part of an overturned fold or a detached block.

The investigated layers belong to the deep-sea facies and for the most part consist of contourite sequences with only rare beds which represent fine-grained turbidite sequences and/or hemipelagic intervals (MRINJEK, 1988 a).

3. CONTOURITES

Muddy, sandy and sandy - gravelly contourites could be differentiated according to structures and textures (primarily grain size). Contourites display a peculiar regularity in vertical arrangement. Their mutual boundaries might be gradual, sharp and flat or irregularly erosional.

3.1. MUDDY CONTOURITES

Muddy contourites are the most common type of contourites. They cover nearly 60 % of the investigated succession. Their thickness varies between 3 and 22 cm. Their mutual contacts and contacts with hemipelagites

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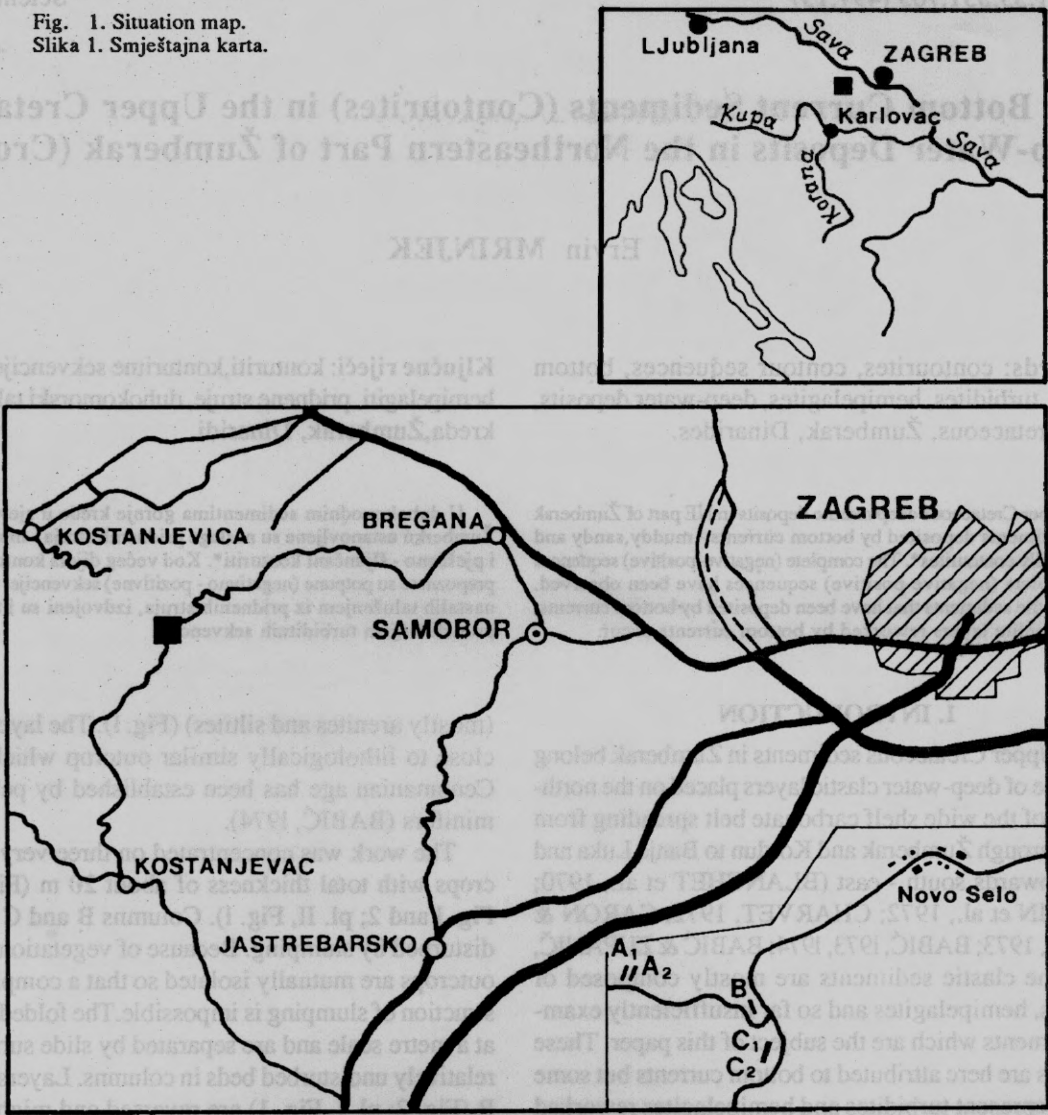
Fig. 1. Situation map.
Slika 1. Smještajna karta.



are mostly gradual whereas the boundaries are sharp and flat or irregularly erosional (Fig. 3, 4 and 5). Muddy contourites are composed of micrites with a variable admixture of clay. Silt-sized grains occur in thin laminae and minute lenses (inside contour beds) closely packed with micrites matrix (packstone) or more, infrequently (Fig. 3, 4 and 5) with sparite cement (grainstone) (pl. IV, Fig. 2). The grains are mostly carbonate skeletal fragments of globotruncanids, echinoderms, bivalves, gastropods, and more or less, the particles of quartz, muscovite, feldspars, chlorites, clay minerals and opaque minerals. The grains of the same composition and size are dispersed inside micrite. On the basis of clay portion, muddy contourites with less clay (calcilutites or micrites) can be distinguished from those with more clay (marly calcilutites or marly micrites).

The main sedimentary structure characteristics are horizontal laminae composed of fine to very fine arenites, siltites and micrites. The average thickness of laminae ranges from 5 mm to 0,5 mm but in some contour beds laminae up to 10 mm of thickness were ascertained. Apart from horizontal laminae, regular lenticular, discontinuous and indistinct laminae can be seen. The lenticular laminae have sharp and flat or irregularly erosional base. The tops of laminae are also sharp, and more or less flat and gradually change into massive micrites or marly micrites. Long axes of elongated grains are mostly parallel to the stratification but are slightly imbricated in the inner parts of some laminae. A weak, normal grading, and a very seldom inverse grading can be seen within laminae (pl. II, Fig. 2; pl. III, Fig. 1). Indistinct and discontinuous laminae are commonly very thin (from 0,1 up to 0,2 mm) and composed of fine silt and micrite with the gradual bases and tops. Some laminae have an irregularly convolute form ("wispy laminae"). Their interruption and disturbance have been caused

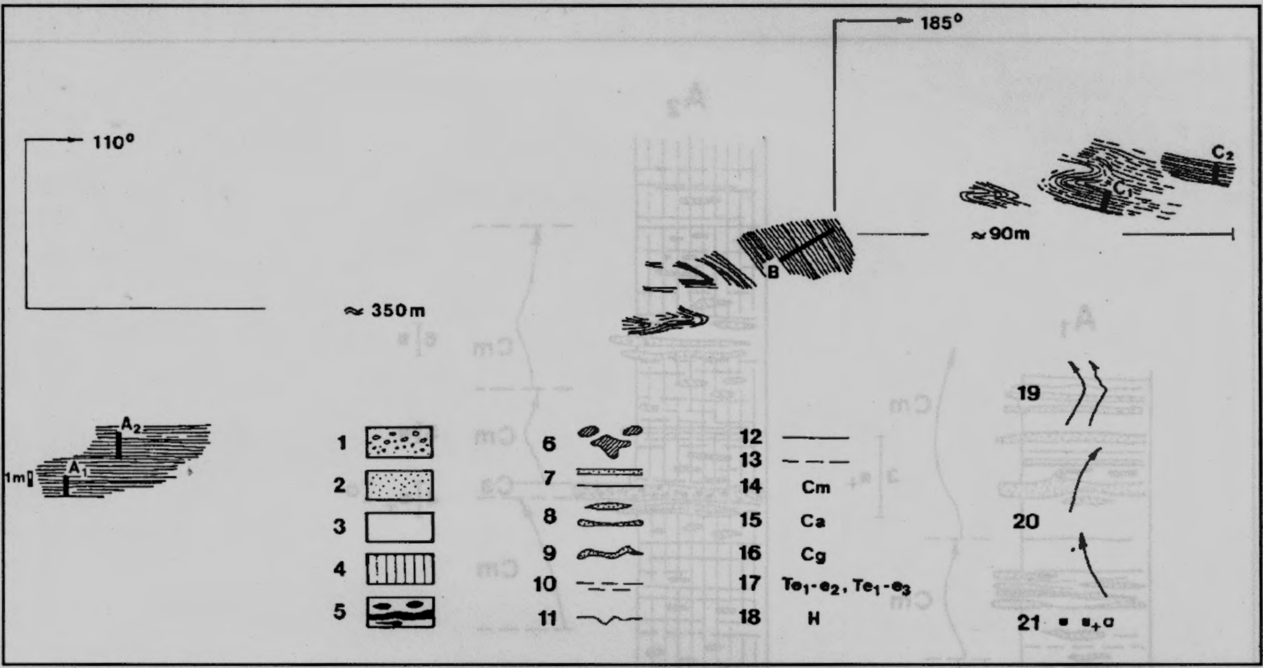


Fig. 2. Position of columns and a legend for Figs. 3, 4 and 5 :
1-granules and coarse arenites; 2-medium arenites and siltites; 3-micrites; 4-marly micrites; 5-chert lenses and lenticular bedding cherts; 6-lenticular and irregular burrows; 7-regular lamination; 8-lenses and lenticular lamination; 9-irregularly lenticular lamination; 10- indistinct and discontinuous lamination; 11-erosion and load structures; 12-sharp transition; 13-gradual transition; 14-muddy countourites;15-sandy countourites; 16-sandy-gravelly countorites; 17-fine-grained turbidites; 18-hemipelagites; 19-complete (negative-positive) sequences; 20-incomplete (negative) sequences and incomplete(positive) sequences; 21-polished sample, acetate peel, thin section.
Slika 2. Položaj stupova i legenda za sl. 3, 4 i 5:
1-granule i krupni areniti; 2-srednjezmati areniti i siltiti; 3-mikriti; 4-laporoviti mikriti; 5-leće i lećasti proslojci rožnjaka; 6-lećasti i nepravilni tragovi bušača; 7-pravilne lamine; 8-leće i lećasta laminacija; 9-nepravilno lećasta laminacija; 10-nejasna i isprekidana laminacija; 11-erozija i tragovi utiskivanja; 12-oštar prijelaz; 13-postepeni prijelaz; 14-muljni konturiti; 15-pješčani konturiti; 16-pješčano-šljunčani konturiti; 17-sekvencije sitnozrnatih turbidita; 18-hemipelagiti; 19-potpune (negativno-pozitivne) sekvencije; 20-nepotpune (negativne) sekvencije i nepotpune (pozitivne) sekvencije; 21-nabrusak, acetatna folija,izbrusak.

by dewatering processes or bioturbation (pl. II, Fig. 2 and pl. III, Fig. 1).

Isolated lenses composed of siltites and fine arenites are relatively frequent. Because of their shape and grain imbrication, some lenses could represent isolated and asymmetric ripples ("fading ripples"). Relatively long and thin climbing ripples with very gently climbing angle have been observed at a few places (pl. II, Fig. 2 and pl. III, Fig. 1).

Regular and lenticular laminae as well as isolated ripples composed of fine arenites and siltites are usually randomly placed between and above discontinuous and indistinct silt and micrite laminae. However, concentrations and frequency of the laminae are a characteristic feature of the middle and the upper part of beds.

One of the most typical features of numerous contourites is their extensive bioturbation which has modified or destroyed much of the primary sedimentary structures, partially or completely altered the nature of the contacts and is probably responsible for the mixing of arenite, silt and mud together with Fe-oxide mottles.Oxides occur in baggy or pocket-like form at a millimetre and centimetre scale. This suggest that bioturbation was a continuous process, probably with several superimposed episodes (Fig. 3, 4 and 5; pl. II, Fig. 2; pl. III, Fig. 1). Certain more regular or internally structured forms are also recognized and can tentatively be identified as specific trace fossils. They include the small (up to 2 mm) elongated lenses and tubes sporadically densely spaced, which probably present a form of *Chondrites*, more regular oval and ellipsoid forms that are mostly similar to *Planolites* or traces with chevron structure like *Scolicia*.

3.2. SANDY AND SANDY-GRAVELLY CONTOURITES

Sandy contourites are less common than the muddy ones. They are represented by less than 10 % in the whole succession and appear like irregular beds from 1 to 17 cm of thickness, (most frequently between 4 and 6 cm). Their lower boundaries are sharp or even erosional, with load deformations. Sandy contourites as a rule are embedded in muddy contourites (Fig. 3, 4 and 5). In the most cases, they do not display any internal order except for a slightly inverse or normal grading. However, sometimes a gentle coarsening can be seen in their middle part. Elongated grains are parallel in relation to the stratification but sometimes a weak imbrication can be also remarked.

Sandy contourites are composed of very coarse and coarse arenite sized grains and, more rarely, of fine sand-

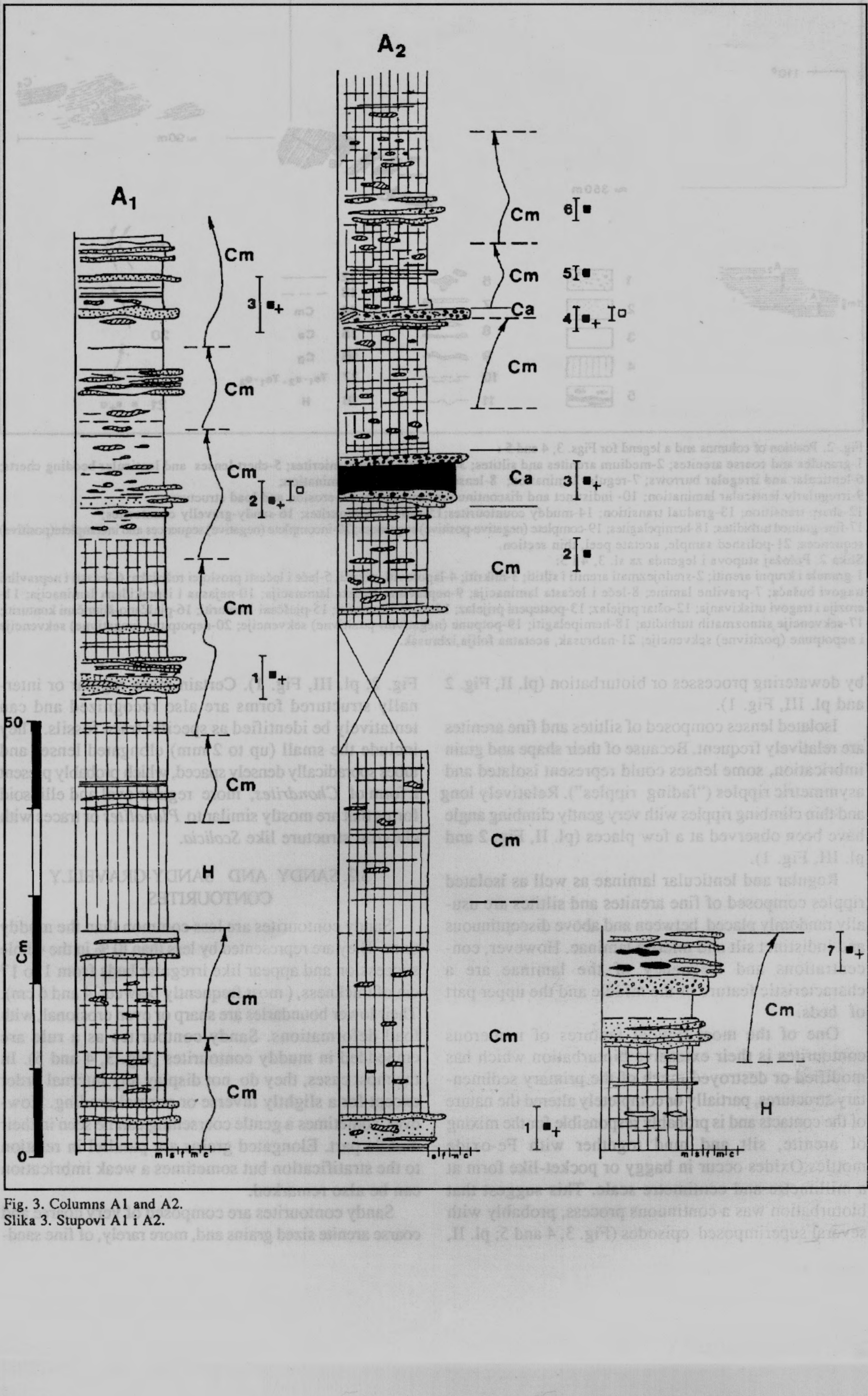


Fig. 3. Columns A1 and A2.
Slika 3. Stupovi A1 i A2.

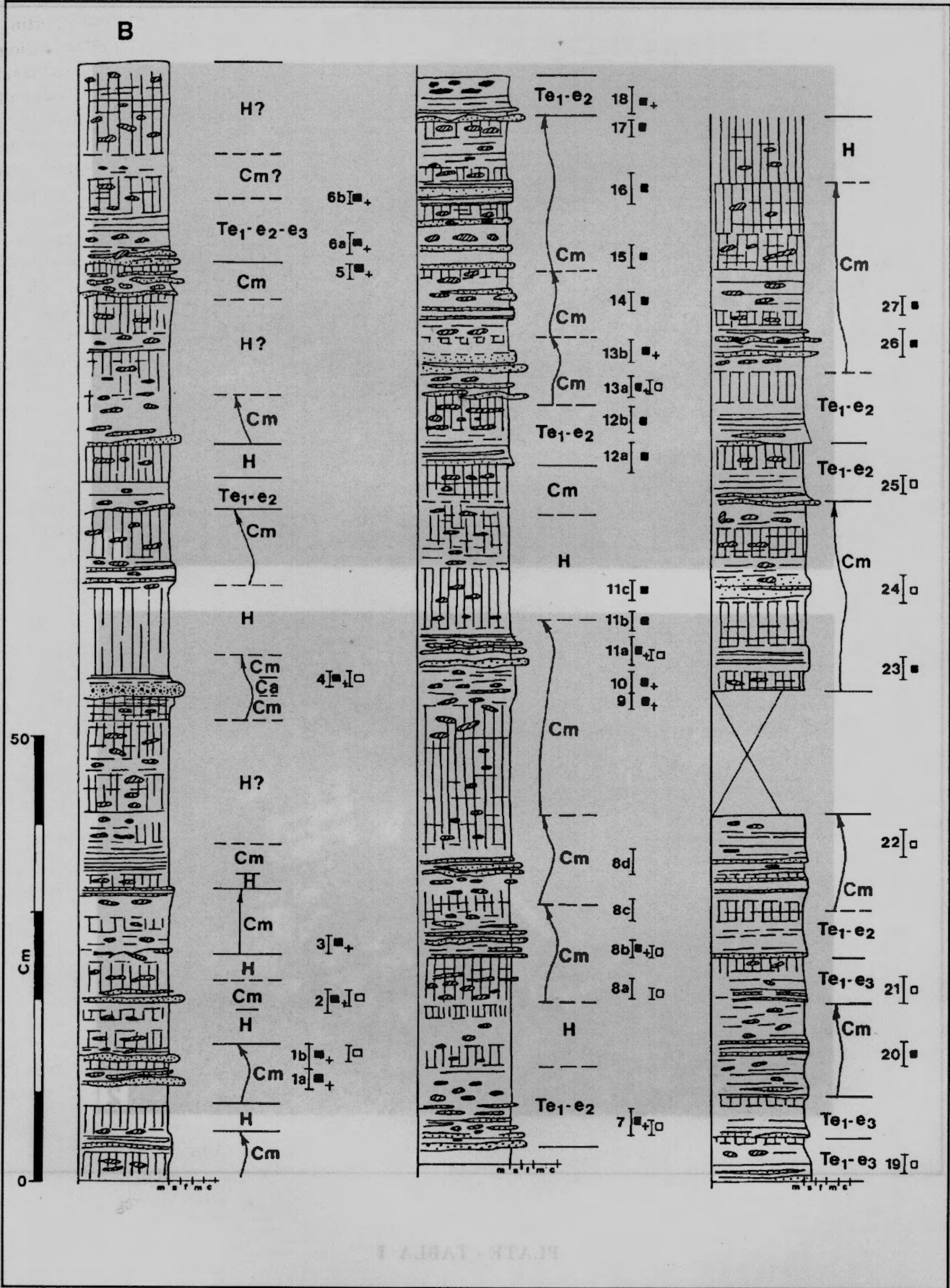


Fig. 4. Column B.
Slika 4. Stup B.

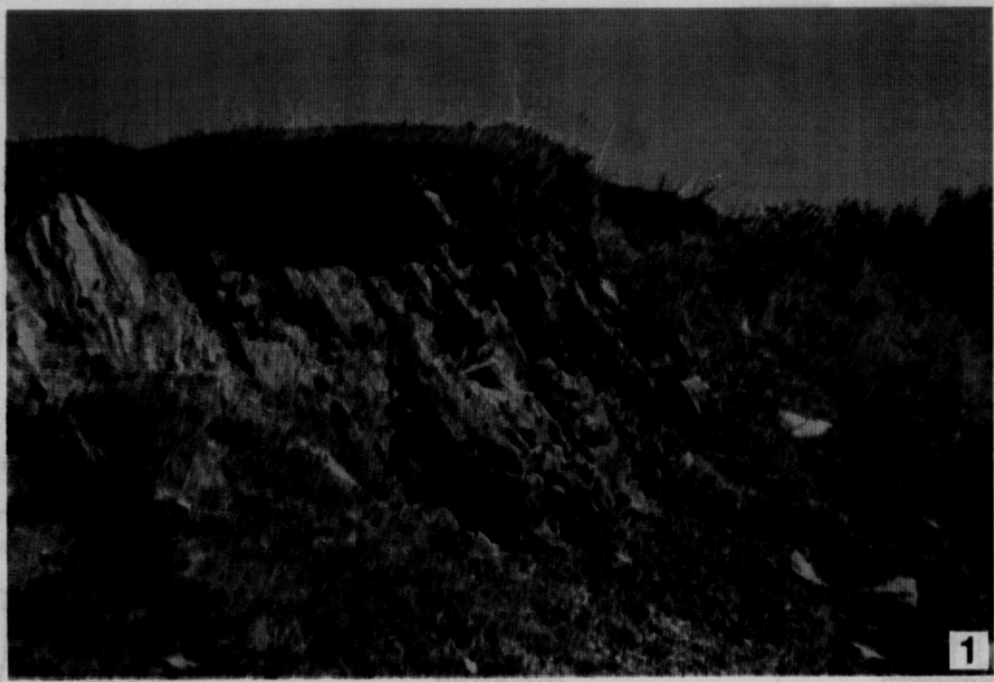
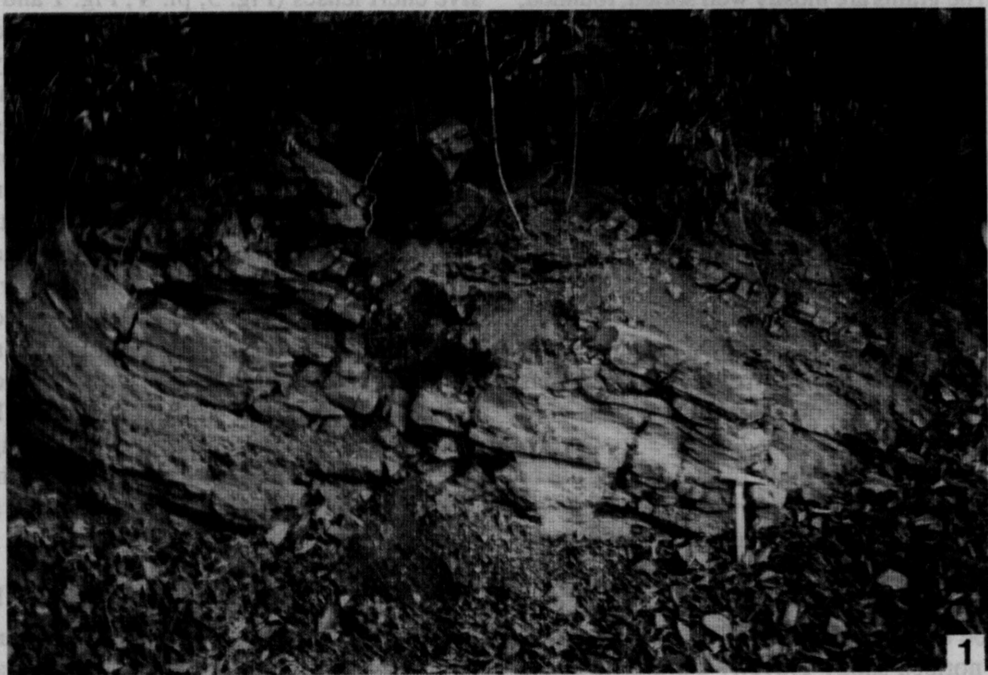


PLATE - TABLA I

1. Alternation of thinly bedded calcilutites and marly calcilutites. Column B (Fig. 2 and 4).
   Izmjena tanko uslojenih kalklutita i laporovitih kalklutita. Slijed B (sl. 2 i 4).
2. Alternation of thinly bedded calcarenites with calcilutites and marly calcilutites. Column C1 (Fig. 2 and 5).
   Izmjena tanko uslojenih kalkarenita s kalklutitima i laporovitim kalklutitima. Slijed C1 (sl. 2 i 5).



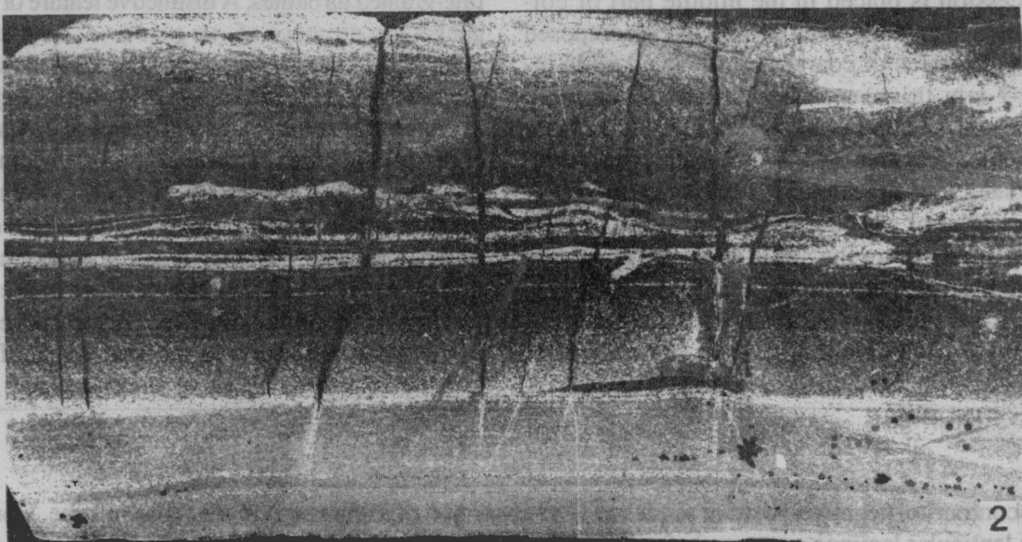


PLATE - TABLA II

1. Thinly bedded calcarenites with chert lenses. Layers have been folded by slumping. Column C1 (Fig. 2 and 5)

Tanko uslojeni kalkareniti s lećama rožnjaka. Naslage su u formi polegle bore nastale klizanjem rotacijskog tipa. Slijed C1 (sl. 2 i 5).

2. Muddy contourites, negative-positive sequence throughout the photo. Calcilutite (wackestone) with thin and indistinct laminae. Laminae composed of siltites and fine arenites are in the middle part of sequence (arrow). Thinly lenticular lamina of microquartz (black) can be seen between laminae. The sediment has been disrupted by numerous lenticular burrows filled with marlaceous micrites (light-grey).

Column B. Sample 8 D. Acetate peel; X 2,5.

Muljni konturit, negativno-pozitivna sekvencija prisutna kroz cijelu fotografiju. Donji i gornji dio sekvencije je kalklutit (wackestone) s tankim i nejasnim laminama silta. U sredini sekvencije su nepravilno lećaste i utiskivanjem poremećene lamine silta i finog arenita (strelica). Između lamina nazire se tanka lamina mikrokvarca (crno). Sediment je poremećen brojnim lećastim tragovima bušača ispunjenih laporovitim mikritom (svijetlosivo). Slijed B. Uzorak 8 D. Acetatna folija; X 2,5.

sized grains. The grains are mostly well sorted, rounded, weakly to moderately spherical, grain supported with point contacts and, more rarely, planar, interpenetrating or stylolitic contacts.

As in the case of muddy contourites, the grains are mostly fragments of micrites and recrystallized micrite. Some of fragments are partly clayey. Sparitic fragments and the fragments of pelagic foraminifers, bivalves and echinoderms have been rarely found. They are more or less micritized. Siliciclastic grains are rare. Quartz is much more usual than feldspar fragments. Numerous quartz grains have corroded rims. On the other hand, some are fragments of composite quartz. Rare pigments and mottles of authigenic hematite occur; the same goes for opaque mineral grains.

The grains are bound together by a drusy sparite or a microsparite or/and by micrite, while syntaxial rim cement is often seen on the echinoderm fragments. Rare poikilotopic cement and dispersed silt-sized quartz and hematite grains, inside the sporadically recrystallized micrite, can be remarked.

The only noticed sandy-gravelly contourite in the entire succession is placed in the middle part of column C1 in between sandy contourites, and is composed of multiple alteration of coarse arenite-sized grain intervals (4-7 mm thick) and fine arenite-sized grain intervals (about 10 mm thick). A few rudite-sized and weakly rounded fragments (2-7 mm) of micrite, marly micrite or skeletons are found in coarse arenite intervals with parallel or slightly inclined position of their longer axis in regard to the stratification. Transitions between intervals are very gradual and sporadically very indistinct. Rare rudite-sized fragments may be also remarked inside fine arenite intervals. Unfortunately, its lower and upper boundaries are masked by extensive chert lenses (Fig. 5; pl. V, Fig. 1 and 2). Except for poorly sorting, other grain characteristics like grain type, grain portion are nearly the same as they are in sandy and muddy contourites (pl. V, Fig. 1 and 2). The grains are bounded together by the drusy sparite and also, but more infrequently, by poikilotopic cement. Fibrous calcite cement may be seen around some fragments.

Dark-grey and dark-red nodular and lenticular chert, 0,5 to 6 cm thick, is a frequent diagenetic feature of sandy contourites. Silicification has usually taken place in the middle part of beds. The very rare chert lenses and nodules inside muddy contourites, mostly at a millimetre scale, have been originated by complete or partial silicification of silt and fine arenite laminae and lenses (Fig. 3 and 5, pl. II, Fig. 2; pl. IV, Fig. 1 and 2). Chert is composite of a microquartz with the dispersed rests of brownish sparite inside. Both chert and the spar particles are contaminated by Fe-oxides.

4. CONTOURITE SEQUENCES

The contourite sequences have a regular vertical arrangement although not so clearly developed as it is within fine-grained turbidites. A distinctive feature of a contourite packet is a presence of *negative sequences* in which the number and size of laminae and the size of grains increase upwards and of *positive sequences* in which these characteristics decrease upwards (STOW et al., 1984). Both sequences are often joined together into one *negative-positive sequence* or, in other words, in one *complete sequence*, but in this case the symmetry is not always present. Negative or positive parts can be more or less expressed or can be thinner or thicker. There is sometimes a problem in distinguishing positive sequences from fine-grained turbidite sequences. Negative sequences have gradual and

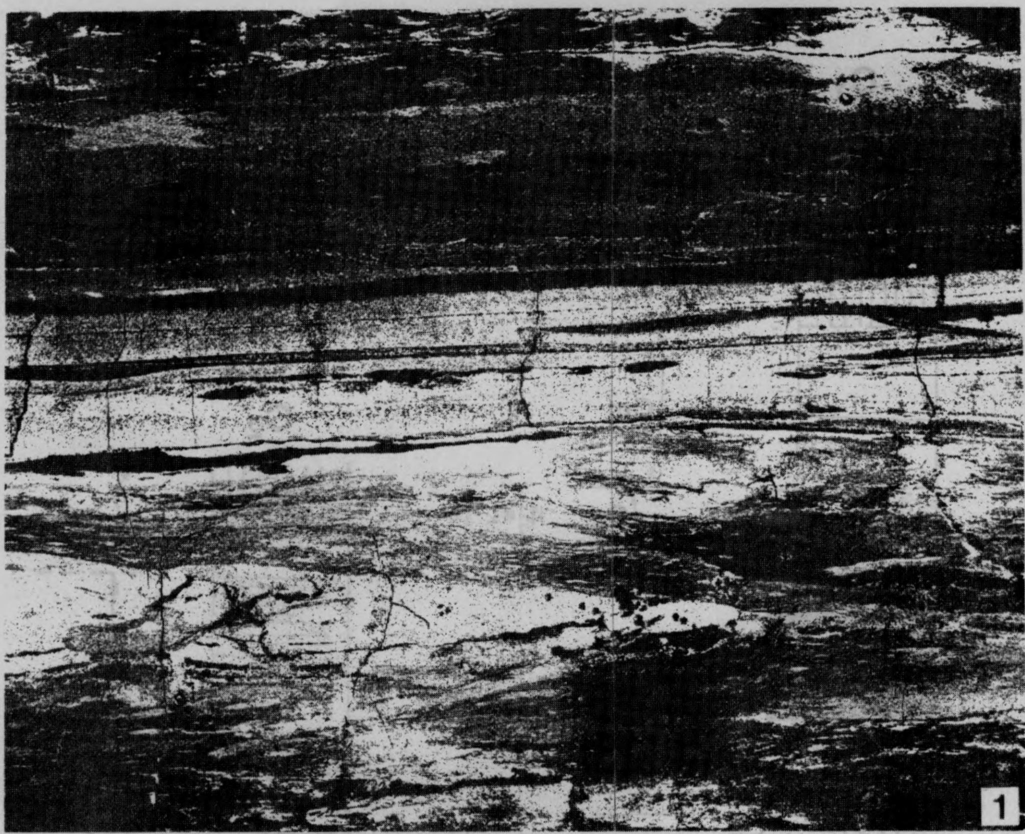
PLATE - TABLA III

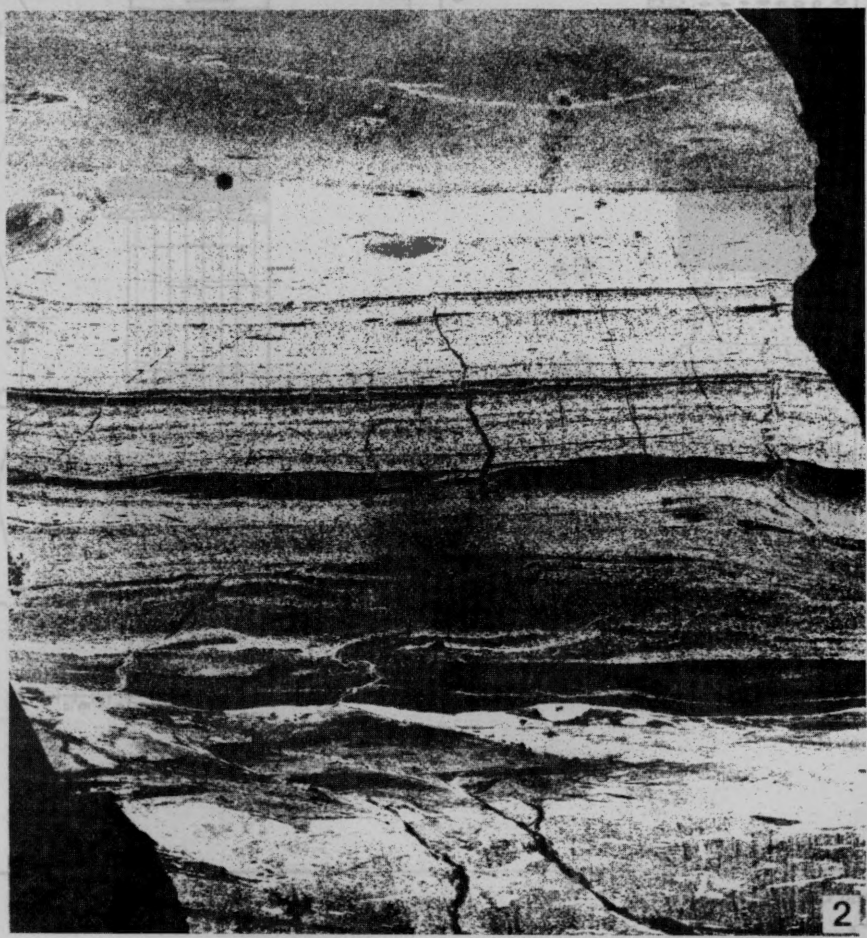
1. Muddy contourite, negative-positive sequence. The lower part of sequence is marlaceous micrite. Horizontal and irregularly lenticular laminae composed of calcilutites and very fine calcarenites are in the middle part of sequence (arrows). The laminae are sporadically disturbed by burrows. Numerous burrows and laminae composed of calcilutites may be seen in the upper part. The upper part is marlaceous micrite. In the lower, weakly reverse graded part there can be a normal grading. Column B.Sample 8 B. Acetate peel; x 2.

Muljni konturit, negativno-pozitivna sekvencija. Donji dio je laporoviti mikrit. U središnjem dijelu vide se horizontalne i nepravilno lećaste lamine kalksiltita i vrlo finog kalkarenita (strelice), mjestimice poremećene bušačima. U gornjem dijelu, također izgrađenom od laporovitog mikrita, naziru se lamine kalksiltita i prisutni su brojni tragovi bušača. Gornji dio je jedva primjetno graduiran za razliku od donjeg dijela koji je slabo inverzno graduiran. Slijed B. Uzorak 8 B. Acetatna folija; x 2,2.

2. Fine-grained turbidite sequence (Te_1-e_2-e_3). The lower part is marly micrite disturbed by multi-stage bioturbation (muddy contourite). The middle part begins with lenticular and deformed lamina composed of fine sand and silt (interval e_1) and is succeded by alternation of irregularly lenticular, regular and indistinct laminae also composed of fine arenite and siltite (interval e_2). The upper part is calcilutite (wackestone) with many lenticular and irregular burrows (interval e_3). Column B. Sample 6 A. Acetate peel; x 2,2.

Sekvencija sitnozrnatog turbidita (Te_1-e_2-e_3). Donji dio je laporoviti mikrit (muljni konturit) poremećen višestrukom bioturbacijom. Središnji dio (interval e_1) počinje lećastom i djelomično deformiranom laminom finog arenita i silta. Slijedi višestruka izmjena nepravilno lećastih, pravilnih i nejasnih lamina silta i finog arenita i nejasna normalna graduiranost (interval e_2). Gornji dio je kalklutit (wackestone) s brojnim lećastim i nepravilnim tragovima bušača (interval e_3). Slijed B. Uzorak 6 A. Acetatna folija; x 2,2.





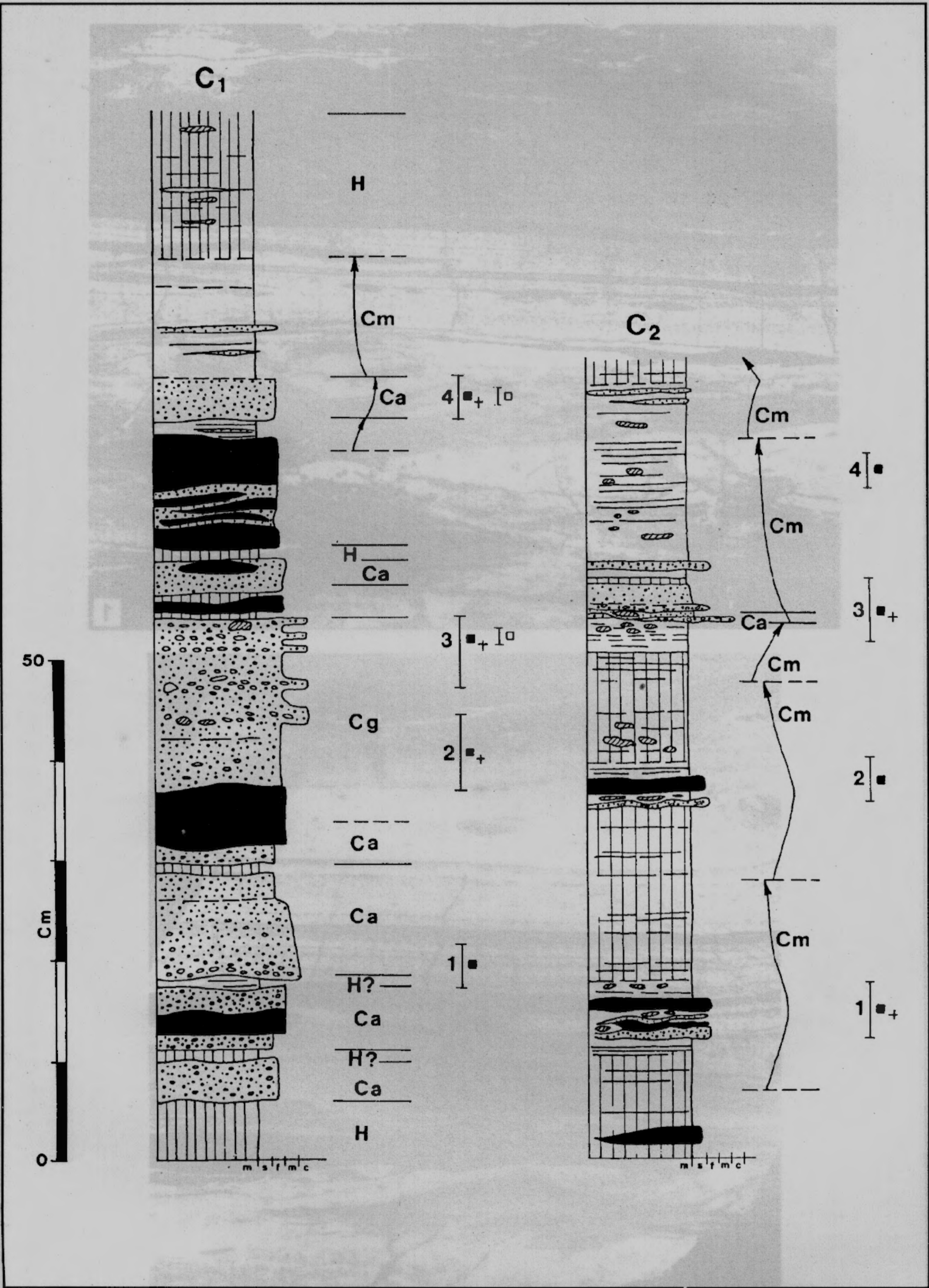


Fig. 5. Columns C_1 and C_2.
Slika 5. Stupovi C_1 i C_2.

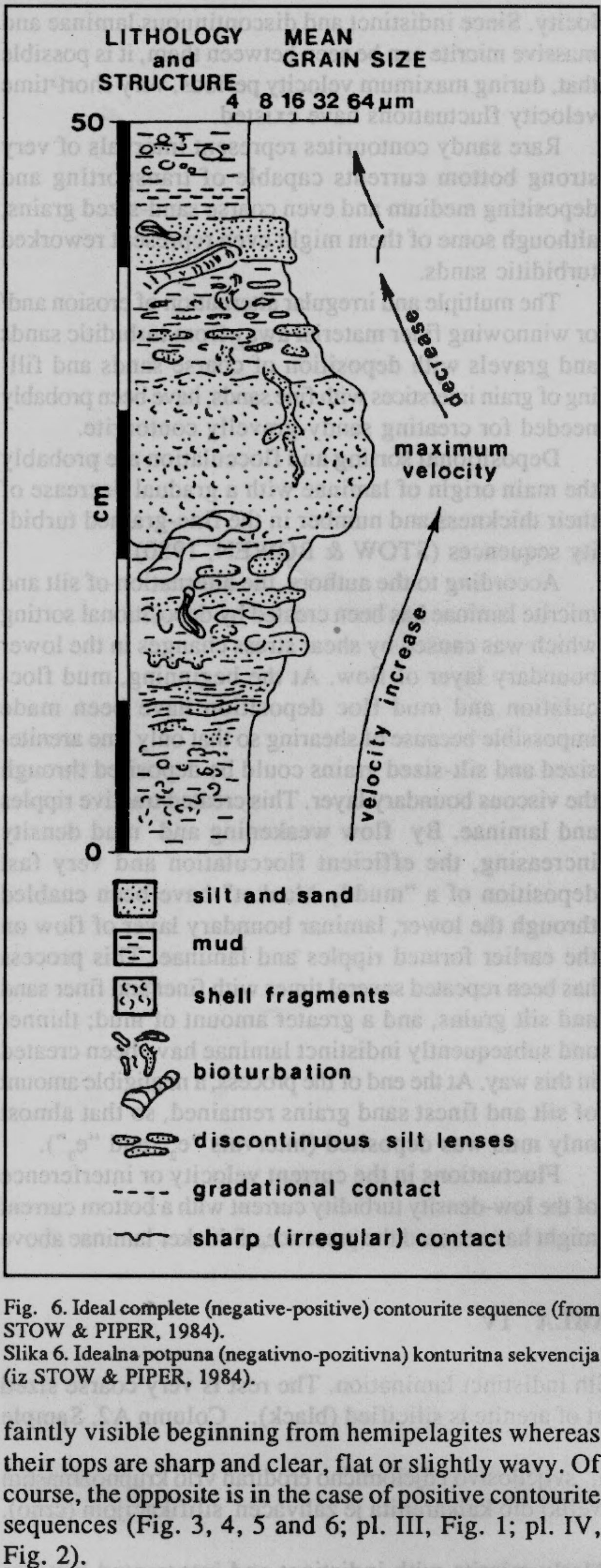


Fig. 6. Ideal complete (negative-positive) contourite sequence (from STOW & PIPER, 1984).
Slika 6. Idealna potpuna (negativno-pozitivna) konturitna sekvencija (iz STOW & PIPER, 1984).

faintly visible beginning from hemipelagites whereas their tops are sharp and clear, flat or slightly wavy. Of course, the opposite is in the case of positive contourite sequences (Fig. 3, 4, 5 and 6; pl. III, Fig. 1; pl. IV, Fig. 2).

Sandy contourites are commonly placed between muddy ones in the middle part of negative-positive sequences, but some of them are at the beginning of positive sequences or on the top of negative sequences. Sandy intervals can have a gentle reverse or a normal grading, or even a gently coarsening in their middle part (Fig. 3, 4, 5 and 6; pl. IV, Fig. 1).

The thickness of sequences varies from 5 up to 30 cm.

5. FINE-GRAINED TURBIDITES

The fine-grained turbidites are only present in the column B, and represent about 10% of all investigated successions. An ideal fine-grained turbidity sequence consists of three parts denoted by Piper's signs e_1, e_2 and e_3 (Piper, 1978). The complete sequences (Te_1-e_3) and top-cut-out sequences (Te_1-e_2) are approximately represented in similar amount. The mutual boundaries, and the boundaries between turbidites and the contourite sequences are usually sharp, even load-casted and erosional in some cases. The upper contact with hemipelagites is transitional instead. As in the case of muddy contourites, calcilutite sequences with less amount of clay and calcareous marl sequences with bigger amount of clay can be distinguished (Fig. 4; pl.III, Fig. 2).

I n t e r v a l "e_1" contains the same laminae and lens types as the muddy contourites - regular, irregular, lenticular, indistinct and wispy laminae of siltites and fine arenites. The internal frame of laminae and lenses and their grain kind and frequency are the same or nearly the same as with muddy contourites. The main distinction between them is in a vertical arrangement of type, size and number of laminae and lenses. Namely, their number and thickness gradually decrease towards the top of interval "e_1". Isolated and asymmetrical ("fading") ripples and long, thin climbing ripples are located in the lower part or even at the beginning of interval whereas indistinct, discontinuous and "wispy" laminae are placed as a rule in the upper parts of interval. Bioturbation is weaker than in other intervals (Fig. 4; pl. III, Fig. 2).

I n t e r v a l "e_2" is characterized by the gradually upwards decreasing amounts and size of silt-sized grains and fine arenite-sized grains. Besides the grading, there are numerous burrow traces (Fig. 4; pl. III, Fig. 2).

I n t e r v a l "e_3" is massive. There are only sparse silt-sized and fine arenite-sized grains. This part is also disturbed by vigorous bioturbation. Transitions between intervals are gradual and therefore hardly noticeable (Fig. 4; pl. III, Fig. 2).

6. HEMIPELAGIC INTERVALS

The hemipelagites are thin bedded, usually between 1 and 13 cm, and massive. They are composed of micrites and of greater amount of clay with rare and irregularly dispersed silt and fine arenite-sized grains of sparite, quartz, muskovite and feldspar. They have more vigorous bioturbation than muddy contourites and fine grained turbidites. Hemipelagic deposits represent about 18 % of the investigated succession. They are found on the top of fine-grained turbidites or between muddy and sandy contourites. Their boundary with muddy contourites is gradual , whereas the upper boundary between them and sandy contourites or fine-grained turbidites is usually irregular and erosional (Fig. 3, 4 and 5; pl. III, Fig. 2).

7. PROCESSES

Bottom currents have an important effect on nature and distribution of bottom sediments. They result from circulation caused by density differences between masses; their speed being in close relation with changes of climatic and oceanographic factors. Long-term current measurements show that bottom currents vary greatly in time and space, having tidal, seasonal and irregular periodicity and reversals (STOW et al., 1984). Vast areas of the oceans have been observed where currents are weak or negligible as well as areas where current velocity can reach over 100 cm/s for a short period of time. Bottom currents are capable of eroding, transporting and depositing sediments up to about medium sand sized grains, of reworking coarse-grained sands and winnowing finer material away from coarser-grained sandy and gravelly sediments (STOW et al.,1984). Bottom currents transport also fine material in suspension (average size about 0,012 mm) in thin to thick (even over 1500 m), very low concentration (0,01 to 0,3 mg/l) nepheloid layers, in some cases over thousands of kilometres (STOW et al., 1984). Suspended sediments enter the nepheloid layer from below by bottom current erosion, sediment resuspension due to burrowing organisms, internal waves, the fine tails of turbidity currents, and from vertical settling of hemipelagic and pelagic material through the water column. So in many cases the depositional process must be considered intermediate between bottom current, turbidity current, pelagic and hemipelagic.

The vertical variation in the described contourite sequences is probably related to variation in velocity of the transporting current rather than to variation in supply. Thus complete (negative - positive) sequences represent a gradual increase, a maximum and then gradual decrease in current velocity. Such fluctuations could be slow and progressive as shown by the thicker sequences or more rapid and sudden, as shown by thinner ones. The increase, however, in the current velocity could be gradual and decrease could be abrupt and rapid (incomplete, negative sequences), or gradual (incomplete, positive sequences).

Horizontal and lenticular silty laminae and thin climbing ripples are related to maximum current velocity. Since indistinct and discontinuous laminae and massive micrite can be seen between them, it is possible that, during maximum velocity periods, very short-time velocity fluctuations have existed.

Rare sandy contourites represent intervals of very strong bottom currents capable of transporting and depositing medium and even coarse sand-sized grains, although some of them might even represent reworked turbiditic sands.

The multiple and irregular alternation of erosion and/or winnowing finer material away from turbiditic sands and gravels with deposition of coarse sands and filling of grain interstices with fine sands, have been probably needed for creating sandy-gravelly contourite.

Depositional sorting and flocculation are probably the main origin of laminae with a gradual decrease of their thickness and number in the fine-grained turbidity sequences (STOW & BOWEN, 1980).

According to the authors, the alternation of silt and micrite laminae has been created by depositional sorting which was caused by shear stress changes in the lower boundary layer of flow. At the beginning, mud flocculation and mud floc deposition have been made impossible because of shearing so that only fine arenite-sized and silt-sized grains could be deposited through the viscous boundary layer. This created tractive ripples and laminae. By flow weakening and mud density increasing, the efficient flocculation and very fast deposition of a "muddy blanket" have been enabled through the lower, laminar boundary layer of flow on the earlier formed ripples and laminae. This process has been repeated several times with finer and finer sand and silt grains, and a greater amount of mud; thinner and subsequently indistinct laminae have been created in this way. At the end of the process, a negligible amount of silt and finest sand grains remained, so that almost only mud was deposited (intervals "e_2" and "e_3").

Fluctuations in the current velocity or interference of the low-density turbidity current with a bottom current might have caused the presence of thicker laminae above

PLATE - TABLA IV

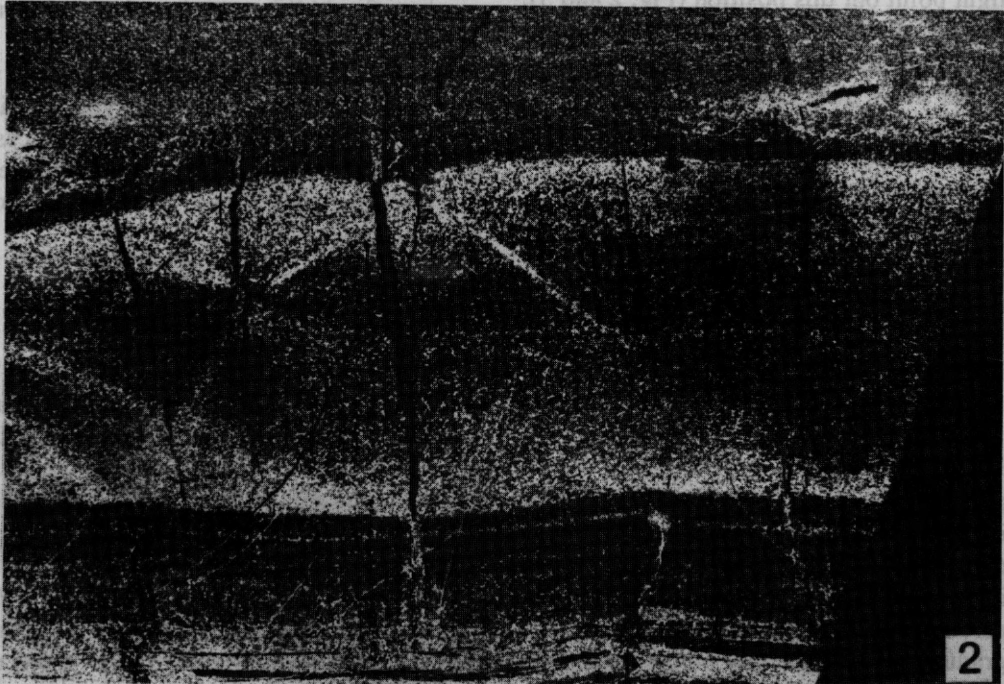
1. The lowermost level is partly eroded marly micrite with indistinct lamination. The rest is very coarse sized and reverse graded arenite (sandy contourite). A great part of arenite is silicified (black). Column A2. Sample 3. Acetate peel; x 1,6.

Najdonji dio je laporoviti mikrit s nejasnom laminacijom, svijetlosivo i djelomično erodiran vrlo krupnozrnastim i reversno graduiranim kalkarenitom (pješčani konturit), veliki dio kalkarenita je zahvaćen silifikacijom (crno). Slijed A2. Uzorak 3. Acetatna folija; x 1,6.

2. Sandy contourite in the complete contour sequence. Marly micrite with indistinct and interrupted laminae composed of siltites is in irregular sharp contact with a thick lens of fine-grained calcarenite. The lens is weakly reversely graded in the lowermost part. The upper part is a marly micrite with indistinct lamination and thinly lenticular burrows. Transition from lens to upper micrite is gradual. Column B. Sample 8. Acetate peel; x2,5.

Pješčani konturit unutar potpune konturne sekvencije. Donji dio koji je izgrađen od laporovitog mikrita s nejasnim i isprekidanim laminama silta je u oštrom i nepravilnom kontaktu s proslojkom finog kalkarenita. Proslojak je jedva primjetno inverzno graduiran u svom najdonjem dijelu. Gornji dio je laporoviti mikrit sa nejasnom laminacijom i tankim lećastim bušotinama. Prijelaz finoarenitnog proslojka u mikrit je postepen. Slijed B. Uzorak 8. Acetatna folija; x 2,5.


1


2

thinner or indistinct ones. Flocculation was less efficient in that case, because of greater amount of the carbonate grains with respect to the silicate grains. This is probably the reason why irregular and indistinct laminae are only present in some turbidity sequences.

Depositional sorting should be involved in the contourite origin because all possible transition between contourites, fine-grained turbidites and hemipelagites could be expected.

Fine-grained sediments are not so much characterized by the burrow varieties as they are by the intensity of bioturbation. Hemipelagites are nearly always entirely and multiply disturbed by burrows but, in most cases, laminae and other primary features are at least partly preserved whereas the traces of burrows are almost absent in sandy contourites. The most intensive bioturbation is also characteristic for higher parts of the fine-grained turbidite sequences.

8. PALAEOGEOGRAPHIC SETTING

Recent contourites are deposited on continental slopes, like well-laminated drifts spreading parallel with slope. They have been also noticed in basin plains (STOW & PIPER, 1984). Fine-grained turbidites have been found in very diverse areas like slopes, subaqueous fans and on basin plains (STOW & PIPER, 1984).

Columns C1 and C2 contain sandy and sandy-gravely contourites which have been originated by reworking and winnowing of turbidite sequences, and they probably belong to a slope or upper fan, relatively near a subaqueous canyon or channel mouth. Synsedimentary slumping might point out this position (Fig. 2 and 5). On the other hand, disturbed layers in column B have been probably deposited by sliding on a slope but relatively further away from channels (Fig. 2 and 4). The layers in columns A1 and A2 are likely to belong to the lower part of slope or even to a basin plain. Two petrographic types of lutites - calcilutites and marly calcilutites could be a proof of different material sources or respectively may point out different paleocurrent directions or changing in a clay share.

9. CONCLUSIONS

The contourites and sediments which have arisen from bottom currents, most probably contour currents, dominate in the Upper Cretaceous deep-water clastic zone in Žumberak.

Muddy, sandy and sandy-gravely contourites can be differentiated according to structures and textures (primarily grain size).

Muddy contourites, as a dominating member of the investigated succession, are characterized by a mutual alternation of horizontal, lenticular, indistinct and discontinuous fine arenite and silt laminae inside more or less marly micrite and, also, by vigorous bioturbation, mostly trough all their thickness.

Sandy contourites which are considerably more infrequent in regard to muddy contourites, appear as thin and irregular beds with erosional undersurfaces. They are mostly composed of coarse arenite-sized grains that can be gently reverse or normally graded.

Only one sandy-gravelly contourite composed of multiple alteration of coarse arenite-sized grain intervals and fine arenite-sized grain intervals could have been seen.

Muddy contourites and a great part of sandy contourites have been transported and deposited by bottom currents. A lesser part of contourites could be reworked turbiditic sands, whereas sandy-gravely contourite might represent a manifold alternation or erosion and winnowing of turbiditic gravels and coarse arenites during very strong currents.

In most contourites, one can see the vertical arrangement of laminae and lens type and size and also average grain sizes, or complete sequences (negative-positive) and incomplete sequences (negative or positive) respectively and whose origin is in the close relation to the current velocity.

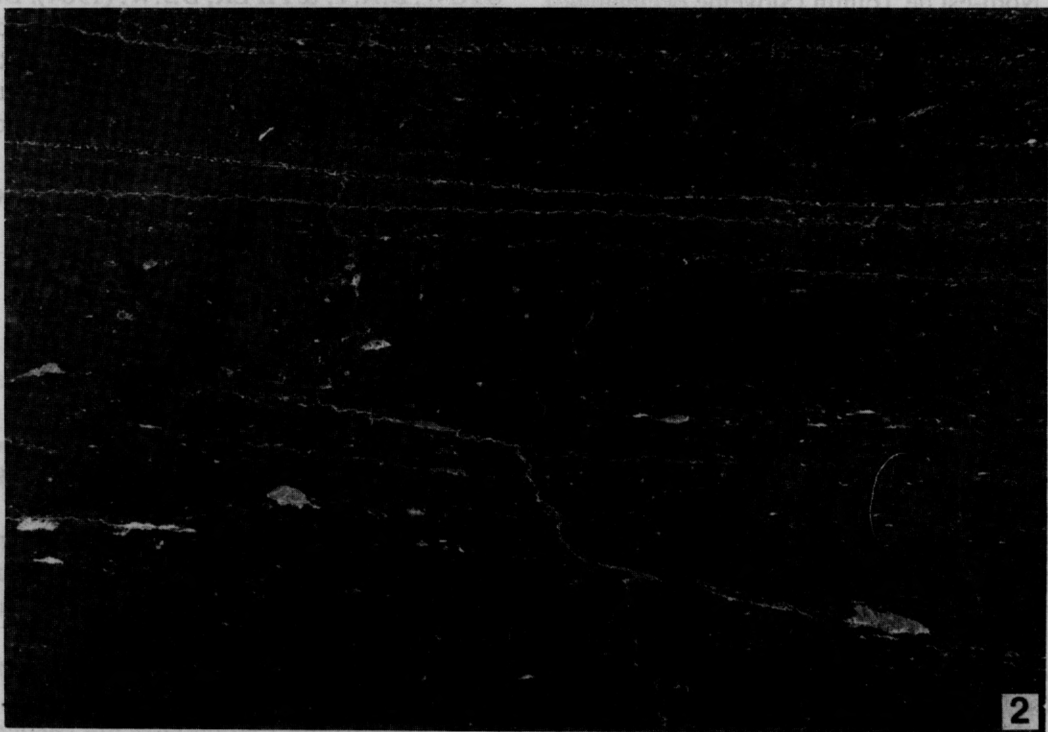
PLATE - TABLA V

1. Sandy-gravelly contourite. Alteration of coarse calcarenite intervals with fine calcarenite ones. Transitions are gradual and sporadically indistinct. Rare, poorly rounded and imbricated rudite grain can be seen inside the fine arenite intervals. Sample from the lower part of the sandy-gravelly contourite with initial silicification (black). Column C1. Sample 2. Acetate peel; x 2,7.

Pješčano-šljunčani konturit. Izmjena intervala krupnog kalkarenita s intervalima finog kalkarenita. Prijelazi između intervala su postepeni ili čak mjestimice nejasni. Unutar intervala finog arenita mogu se zapaziti slabo zaobljeni ruditni fragmenti blago kosog (imbriciranog) položaja u odnosu na slojevitost. Donji dio pješčanoŠšljunčanog konturita čiji je početak zahvaćen silicifikacijom (crno). Slijed C1. Uzorak 2. Acetatna folija; x 2,7.

2. Sandy-gravelly contourite. Alternation of coarse calcarenite intervals with fine calcarenite intervals. Transitions are gradual and sporadically indistinct. Rare, poorly rounded and imbricated rudite grains can be seen inside fine arenite intervals. The top of the sandy-gravelly contourite. Column C1. Sample 3. Acetate peel;x 2,7.

Pješčano-šljunčani konturit. Izmjena intervala krupnog kalkarenitaa s intervalima finog kalkarenita. Prijelazi između intervala su postepeni ili čak mjestimice nejasni. Unutar intervala finog arenita mogu se zapaziti rijetki, slabo zaobljeni ruditni fragmenti blago kosog (imbriciranog) položaja u odnosu na slojevitost. Završni dio pješčano-šljunčanog konturita. Slijed C1. Uzorak 3. Acetatna folija; x 2,7.



Sandy and sandy-gravelly contourites probably belong to a slope or upper fan environment, relatively near a subaqueous canyon or channels, while muddy contourites have been deposited on a lower part of slope, relatively farther away from channels or even on a basin plain.

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Sedimenti pridnenih struja (konturiti) u dubokovodnim naslagama gornje krede sjeveroistočnog Žumberka

E. Mrinjek

Istraživane naslage se nalaze u sjeveroistočnom dijelu Žumberka i pripadaju zoni gornjokrednih dubokomorskih taloga, smještenoj na sjeveroistočnoj strani prostranog karbonatnog šelfa (Vanjski Dinaridi, BABIĆ & ZUPANIČ, 1976).

Naslage karakterizira izmjena konturita te u mar joj mjeri sitnozrnatih turbidita i hemipelagita. Mogu se razlikovati tri tipa konturita - m u l j n i , p j e š č a n i i p j e š č a n o - š l j u n č a n i konturiti (sl. 3, 4 i 5).

Muljni konturiti, čija debljina varira od 3 do 22 cm, su najčešći tip. Međusobna granica između samih muljnih konturita i konturita i hemipelagita je postepena, dok je kontakt s pješčanim konturitima i finozrnatim turbiditima oštar ili čak oštro nepravilan (sl. 3, 4 i 5). Muljni konturiti su izgrađeni od mikrita s promjenjivom količinom gline kao i od karbonatnih i siliciklastičnih čestica veličine finog arenita i silta. Silikatne čestice su podređene u odnosu na karbonatne čestice. Njihova glavna teksturna karakteristika je prisutnost pravilnih, nepravilnih, lećastih i nejasnih lamina silta i finog arenita. Prosječna debljina lamina je od 0,5 do 5 mm iako lamines mogu biti između 0,1 do 0,2 mm tanke. Osim normalno graduirane, lamine mogu biti inverzno ili normalno-inverzno graduirane. Prisutni su brojni tragovi bušača koji su poremetili ili prekinuli lamine (tab. II, sl. 2; tab. III, sl.1).

Pješčani konturiti su rjeđi od muljnih konturita. Dolaze kao nepravilni slojevi, debljine 1 do 17 cm, izgrađeni su od karbonatnih i siliciklastičnih čestica veličine krupnog arenita. Njihova glavna karakteristika je blago inverzna ili normalna graduiranost, ili čak inverzno-normalna graduiranost (sl. 2, 4 i 5;tab. 1, 2 i 3).

Jedan jedini pješčano- šljunčani konturit se nalazi u srednjem dijelu stupa C1 i izgrađen je od višestruke izmjene intervala krupnog arenita debljine 4-7 mm i intervala finog arenita debljine oko 10 mm. Nekoliko ruditnih fragmenata (veličine 2-7 mm) mikrita, glinovitog mikrita ili skeleta nalaze se unutar krupnog arenitnog intervala. Prijelaz između intervala je vrlo postupan i mjestimično nejasan (sl. 5; tab.V, sl. 1 i 2).

Postoji u određenoj mjeri pravilna vertikalna uređenost unutar konturita, iako ne toliko jasna kao unutar finozrntih turbidita, pa se može govorti o negativnim sekvencijama u kojima broj i veličina lamina i veličina zrna rastu prema gore i o pozitivnim sekvencijama u kojim te karakteristike opadaju prema gore (STOW et al., 1984).

Često puta su obje sekvencije pridružene zajedno u jednu negativno- pozitivnu sekvenciju pri čemu simetrija ne mora biti uvijek prisutna, tj. negativni ili pozitivni dijelovi mogu biti jače ili slabije izraženi, odnosno deblji ili tanji (sl. 3, 4 i 5). Pješčani konturiti su obično smješteni između muljnih konturita u središnjem dijelu negativno-pozitivne sekvencije. Pješčani konturit (interval) je obično blago inverzno ili normalno graduiran ili samo blago pokrupnjuje u svom središnjem dijelu (sl. 3, 4 i 5; tab. IV, sl. 1, 2 i 3).

Sitnozrnati turbiditi su prisutni samo u stupu B. Istog su petrografskog sastava kao i konturiti ali za razliku od njih, njihove strukturne i teksturne karakteristike imaju pravilniji vertikalni raspored. Njihova idealna sekvencija se sastoji od tri dijela označenih Piperovim oznakama "e_1", "e_2" i "e_3" (PIPER, 1978).

Kompletne sekvencije (Te_1-e_3) i odrezane sekvencije (Te_1-e_2) su približno podjednako zastupljene u istraživanom slijedu (sl. 4). Njihova debljina je između 4 i 9 cm. Njihove međusobne granice i granice između njih i konturita su obično oštre i erozivne ili čak poremećene utiskivanjem, dok je krovinski kontakt s hemipelagitom prijelazan. Glavna karakteristika donjeg dijela sekvencije (interval "e_1") su pravilne, nepravilne, lećaste, nejasne i "wispy" lamine siltita i finog arenita. Osim lamina, interval "e_1" sadrži i izolirane riplove i tanke "penjajuće" riplove. Bioturbacija je slabije izražena nego u ostalim intervalima (tab. III, sl. 2). Postepeno smanjivanje količine i veličine siltnih i finoarenitnih čestica je glavna karakteristika intervala "e_2". Osim graduiranosti prisutni su brojni tragovi bušača (tab. III, sl . 2). Interval "e_3" je masivan sa samo rijetko raspršenim siltnim i finoarenitnim česticama. U pravilu je gotovo uvijek jako bioturbiran. Prijelazi između intervala su postepeni i stoga teško primjetni (sl. 4; tab. III, sl. 2).

Hemipelagiti su tanko uslojeni, obično između 1 i 13 cm tanki, masivni, s više gline i jače izraženom bioturbacijom nego muljni konturiti i sitnozrnati turbiditi. Nalaze se između muljnih konturita, muljnih i pješčanih konturita ili su kontinuirani. Pridnene struje imaju snažan utjecaj na distribuciju i sastav taloga dna današnjih oceana i mora. Za razliku od površinskih i pripovršinskih struja koje nastaju puhanjem vjetra uzrokovanog razlikama u gustoći, odnosno razlikama u pritisku zraka, pridnene struje nastaju termohalinom cirkulacijom uzrokovanom razlikom u gustoći pojedinih dijelova mora, te je stoga njihova brzina u uskoj vezi s promjenama klimatskih i oceanografskih faktora.

Dugotrajna praćenja i mjerenja pridnenih struja otkrila su značajna dnevna, sezonska ili vremenski nepravilna variranja njihovih brzina kao i velike promjene njihovog smjera kretanja (STOW et al., 1984). Također su otkriveni veliki dijelovi morskih dna sa slabim ili beznačajnim djelovanjem struja, kao i dijelovi dna sa snažnim djelovanjem struja gdje u kratkim vremenskim intervalima brzina struje može biti veća od 100 cm/sek., tako da su sposobne erodirati, transportirati i deponirati taloge sa zrnima do veličine srednjeg pijeska, prerađivati krupni pijesak ili ispirati sitnozrnati materijal iz šljunka i vrlo krupnog pijeska (STOW et al.,1984). Utvrđeno je da pridnene struje prenose finozrnatu suspenziju prosječne veličine zrna od oko 0,012 mm u tankim do debelim (čak i preko 1500 m) nefeloidnim slojevima vrlo niske koncentracije (0,01 do 0,3 mg/l) tisućama kilometara daleko. Suspendirani materijal potječe od taloga dna pokrenutog erozivnim djelovanjem pridnenih struja, a dio može potjecati i iz repa razrijeđene turbiditne struje kao i od pelagičkih i hemipelagičkih čestica zahvaćenih pridnenim strujama. Stoga takvo složeno porijeklo materijala nošenog pridnenim strujama može objasniti sve moguće prijelaze između konturita, sitnozrnatih turbidita i hemipelagita i/ili pelagita prepoznate i u istraživanim slijedovima.

Vertikalne varijacije konturnih facijesa uočene u istraživanim slijedovima prvenstveno su u vezi s promjenjivošću brzina pridnenih struja, dok je izvorište materijala moglo imati mali ili nikakav utjecaj. Opisane negativno - pozitivne sekvencije bi stoga predstavljale postepeni rast, maksimum i postepeni pad brzine struje. Takve fluktuacije su mogle biti relativno spore, na što ukazuju deblje sekvencije, ili pak brze i nagle, na što ukazuju tanje sekvencije. Porast brzine struje je mogao biti postepen, a slabljenje naglo (nepotpune negativne sekvencije) ili obrnuto, tj. nagli porast brzine, a zatim postepeno slabljenje (nepotpune pozitivne sekvencije). Horizontalne i lećaste lamine finog arenita i silta kao i tanki penjući riplovi vezani su za period maksimalnih brzina struja. S obzirom da između njih postoji i prostor ispunjen nejasnim i isprekidanim laminama kao i mikritom, očito je da su unutar perioda maksimalnih struja postojale kratkotrajne sekundarne fluktuacije brzina na što ukazuju i neke lamine s blago normalno ili blago reversno graduiranom građom. Rijetki pješčani konturiti mogu predstavljati intervale izrazito snažnih pridnenih struja koje prenose i talože srednji ili čak krupni pjesak, ali isto tako neki od njih mogu predstavljati manje ili više in situ prerađivane krupne turbidne pijeske.

Snažna ali i vrlo promjenjiva pridnena struja je bila potrebna za stvaranje pješčano - šljunčanog konturita kod čijeg je postanka vjerojatno postojalo višestruko i nepravilno izmjenjivanje procesa erozije i ispiranja turbidnog pijeska i šljunka s procesima taloženja krupnog pijeska i ispunjavanja međupornog prostora sitnim pijeskom.

Taloženju sitnozrnatih turbidita pripisivani su različiti načini (STOW & PIPER, 1984) ali se čini da najprihvatljivije objašnjenje daju STOW & BOWEN (1984). Po njima je izmjena lamina silta nastala depozicijskim sortiranjem zbog promjene sila naprezanja u donjem graničnom sloju. U početku naprezanje ne dopušta flokulaciju i taloženje mulja nego se kroz viskozni dio graničnog sloja talože čestice finog arenita i krupnijeg silta koje vučenjem formiraju riplove i lamine. Slabljenjem toka i povećanjem koncentracije mulja omogućena je uspješna flokulacija i vrlo brzo taloženje "muljnog pokrivača" kroz najdonji laminirani dio toka na već prije formirane riplove i lamine. Taj proces se ponavlja više puta ali sa sve sitnijim česticama silta i sve većom količinom mulja, tako da depozicijskim sortiranjem dolazi do sve tanjih, a zatim i nejasnih lamina silta. Nakon toga preostaje u toku neznatna količina silta i najfinijeg arenita pa se taloži mulj što odgovara srednjem i gornjem dijelu sekvencije (interval "e_2" i "e_3").

Kod promjena kod kojih nisu uvijek vidljive, a niti pravilno raspoređene karakteristike sitnozrnatih turbidita, moguće je da je došlo do miješanja djelovanja turbidne struje s pridnenom strujom ili pak do prevlasti djelovanja ove potonje. Također treba naglasiti da u sastavu istraživanih turbidnih sekvencija manje ili više prevladavaju karbonatne čestice što sigurno onemogućuje uspješnu flokulaciju i time depozicijsko sortiranje kako je bilo interpretirano analizom siliciklastičnih turbidita (STOW & BOWEN, 1980) pa je to moglo dovesti do razvoja nejasnih lamina i jedva primjetnog graduiranja. S druge strane mehanizam depozicijskog sortiranja mogao je barem djelomično postojati i kod konturita na što upućuju i svi mogući prelazi između konturita, sitnozrnatih turbidita i hemipelagita.

Tipove sitnozrnatih naslaga ne karakteriziraju toliko posebni tipovi bušača koliko intenzitet bioturbacija. Tako su hemipelagiti gotovo u pravilu potpuno višestruko bioturbirani različitim tipovima bušača. Muljni konturiti su također bioturbirani kroz cijelu svoju debljinu ali su u većini slučajeva barem djelomično sačuvane lamine i ostale karakteristike, dok kod pješčanih konturita gotovo da tragova bušača nema. Kod sitnozrnatih turbidita intenzivnija bioturbacija je vezana za gornje dijelove sekvencija.

Pješčani i pješčano-šljunčani konturiti vjerojatno su taloženi na padini ili višim dijelovima lepeze, relativno blizu podmorskog kanjona ili kanala, dok su muljni konturiti taloženi na donjem dijelu padine ili lepeze, ili čak na dnu bazena.

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