original scientific paper UDK 551.781(262.3 Piranski z.)

STRATIGRAPHY AND SEDIMENTOLOGY OF THE PIRAN FLYSCH AREA (SLOVENIA)

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ABSTRACT

Eocene deep-sea sediments cover an area of about 400 km² in the Flysch Area of Piran in Istria. Marlstones with Globigerina *are followed by a flysch series of more than 500 m in thickness. The flysch is devided into four units based on the occurrence of intercalated limestone turbidites. Globigerinal marlstone belongs to the combined Nannoplankton Zone NP 15/16, Flysch Units 1 to 4 to NP 16, of the Paleogene.*

Basin plain turbidites and trace fossils of the Paleodictyon *subfacies (Seilacher, 1977) indicate deposition in a deep-sea environment. Individual turbidites can be traced over several kilometres. The flysch comprises marlstone beds, siliciclastic, pure carbonate, and sandy carbonate turbidites.*

Turbidity currents that delivered siliciclastic turbidites moved parallel to the WNW-ESE striking axis of the basin, whereas carbonate turbidites were delivered from a carbonate platform in SSW.

Key words: stratigraphy, sedimentology, Flysch, Piran, Slovenia
Ključne besede: stratigrafija, sedimentologija, fliš, Piran, Slovenija

INTRODUCTION

The Flysch Area of Piran borders on the Čičarija-Plateau in the east, the Buje-Anticline in the south and its the Adriatic Sea in the northwest. At its eastern margin, Paleocene and Eocene limestones of the Čičarija-Plateau are thrust southwest onto Eocene flysch. The contact of the flysch to the Paleogene and Cretaceous limestones of the Buje-Anticline is flexural due to the uplift of the anticline (Pleničar *et al.*, 1969).

The oldest sediments in the flysch basin are limestones with *Nummulites* and *Alveolina* in Izola. They are of Middle to Upper Cuisian to Lower Lutetian age (Pavlovec, 1985). These shallow water limestones are overlain by marly, glauconite bearing limestones which grade into globigerinal marlstones and flysch, thus indicating the deepening of the basin. In this text the deep-sea sediments are emphasized.

The biostratigraphy of the Flysch area of Piran was investigated by Piccoli & Proto-Decima (1969) and Pavšič (1981), who examined the planktonic foraminifers and calcareous nannoplankton respectively. In the autumn of 1994 we took samples of the flysch, which was previously mapped and investigated sedimentologically (Peckmann, 1995).

Samples ST 1 to ST 15 were taken of the globigerinal marlstone to the 4th. Flysch unit (Fig. 2). We sampled freshly broken marlstones. Over 35 species of calcareous nannoplakton were determined. The frequency of the poorly preserved fossils is low. In all examined samples both *in situ* and reworked fossils occur. Reworked nannofossils originate from the Cretaceous, Paleocene and Lower Eocene strata. Especially, nannoliths of the genus *Discoaster* are poorly preserved, partly dissolved and overgrown.

All samples were examined and photographed with a Leitz Photo Microscope. They are not suitable for detailed studies under the SEM.

Most of the field work was carried out in the mapping area (see Fig. 1). Thickness of the described Flysch Units varies significantly. The column shown in Fig. 2 is located in the central part of the mapping area. The Lower and the Middle Limestone Turbidite can be traced throughout most of the flysch basin.

THE GLOBIGERINAL MARLSTONE

The globigerinal marlstone crops out in a quarry east of Izola and in coastal cliffs west of Izola. The grey coloured marlstone shows no bedding and breaks into polygonal pieces. In places where globigerinal marlstones are replaced by flysch, some thin siltstone beds occur.

In the quarry of the old brickwork east of Izola we took the sample ST 10, southwest of Izola we sampled ST 9. In these samples we determined 24 species of calcareous nannoplankton (Fig. 4). Among these, only the following species are important for stratigraphy:
Nannotetrina cristata (Martini)
Dictyococcites bisectus (Hay, Mohler et Wade)
Reticulofenestra dictyoda (Deflandre)
Discoaster nodifer (Bramlette et Riedel)
Discoaster saipanensis Bramlette et Riedel

These species, to the exclusion of *Discoaster nodifer*, have already been reported in Pavšič (1981). This nannofossil is very rare and poorly preserved. *Reticulofenestra dictyoda* is common. Because of its poor preservation, it is hardly possible to discriminate it from *Reticulofenestra placomorpha*.

According to the determined species we conclude that the globigerinal marlstone belongs to the combined biozone NP15/16.

Stratigraphical distribution of *Discoaster nodifer* ranges from NP 15 to NP 17, with its first permanent occurrence in biozone NP 17 (Perch-Nielsen, 1985). Proto-Decima *et al.* (1975) state that *D. nodifer* appeared at the end of biozone NP 15.

THE FLYSCH UNITS

Common features of the Flysch Units

All Flysch Units consist of interbedded sandstones and marlstones. The ratio of marlstone to sandstone bed thickness changes as does the average thickness of the beds, whereas lithology and sedimentary structures do not change significantly throughout the sediment column. The sandstone beds are siliciclastic turbidites. Most marlstone beds were partly deposited by turbidity currents, but most of their material was deposited by background sedimentation in a hemipelagic setting. Individual beds can be traced over great distances.

Detrital components of the sandstones are quartz and carbonate at about equal frequency, with slight variations. Glauconite grains are frequent and are smaller on the average than quartz grains. Felspars and micas are rare. The most common heavy minerals are pyrite and garnets. The matrix of the well sorted sandstones is carbonatic. No visible porosity has been preserved. Occasional joints are filled with coarse carbonate cements. The unweathered sandstone is grey, weathered brownish, indicating the oxidation of the originally reduced iron.

The siliciclastic turbidite beds are usually graded, with sharp bases and occasional flute casts. Amalgamation can be found, cross bedding and other sedimentary structures are rare. Only beds that are some decimetres thick show cross bedding and lamination. Dewatering structures are common in thicker beds. Convolute bedding is often asymmetrical, indicating a depositional slope (see Discussion). Dish structures are rare.

A lineation parallel to the axis of the basin due to compressional stress is developed on the lower bedding planes of many sandstone beds.

Plant debris are frequent especially in the lower part of the 1st. Flysch Unit (Plate 1, Fig. 1). Some siliciclastic turbidites have layers of plant debris at the bases and at the tops. These layers are continuous in outcrop. The plant debris, which contain many wood fragments, are terrigenic.

Most common trace fossil is *Taphrehelminthopsis* of the *Scolicia* Typ. These fossils are preserved on the lower bedding plane of siliciclastic turbidites and in marlstone beds. The winding burrows with two parallel sediment strings are about 4 cm in diameter. The Scolicia Typ was attributed to gastropods (Seilacher, 1962) and to echinoids (Smith & Crimes, 1983). The *Taphrehelminthopsis* burrows are preserved as postdepositional and predepositional traces (in sense of Seilacher, 1962). Postdepositional traces are exposed on lower bedding planes of siliciclastic turbidites and in marlstones. They are preserved in three-dimensional shape in cross section. Below thin and thick bedded sandstones trace fossils occur as casts of preexisting burrows filled by the sediment of the turbidity current (positive hypo-relief in sense of Seilacher, 1964). In cross section only the lower side of the burrow has been preserved. The predepositional trace fossils *Taphrehelminthopsis* are much more common than postdepositional traces.

The regular nets of *Paleodictyon* are made of hexagonal meshes and vertical outlets. Preferentially, the net is preserved (Uchman, 1995). *Paleodictyon* is exposed on the lower bedding planes of sandstone beds. The diameter of a single hexagon varies between 0.2 and 7 cm (Pavlovec, 1980). In the Flysch Basin of Piran the hexa-

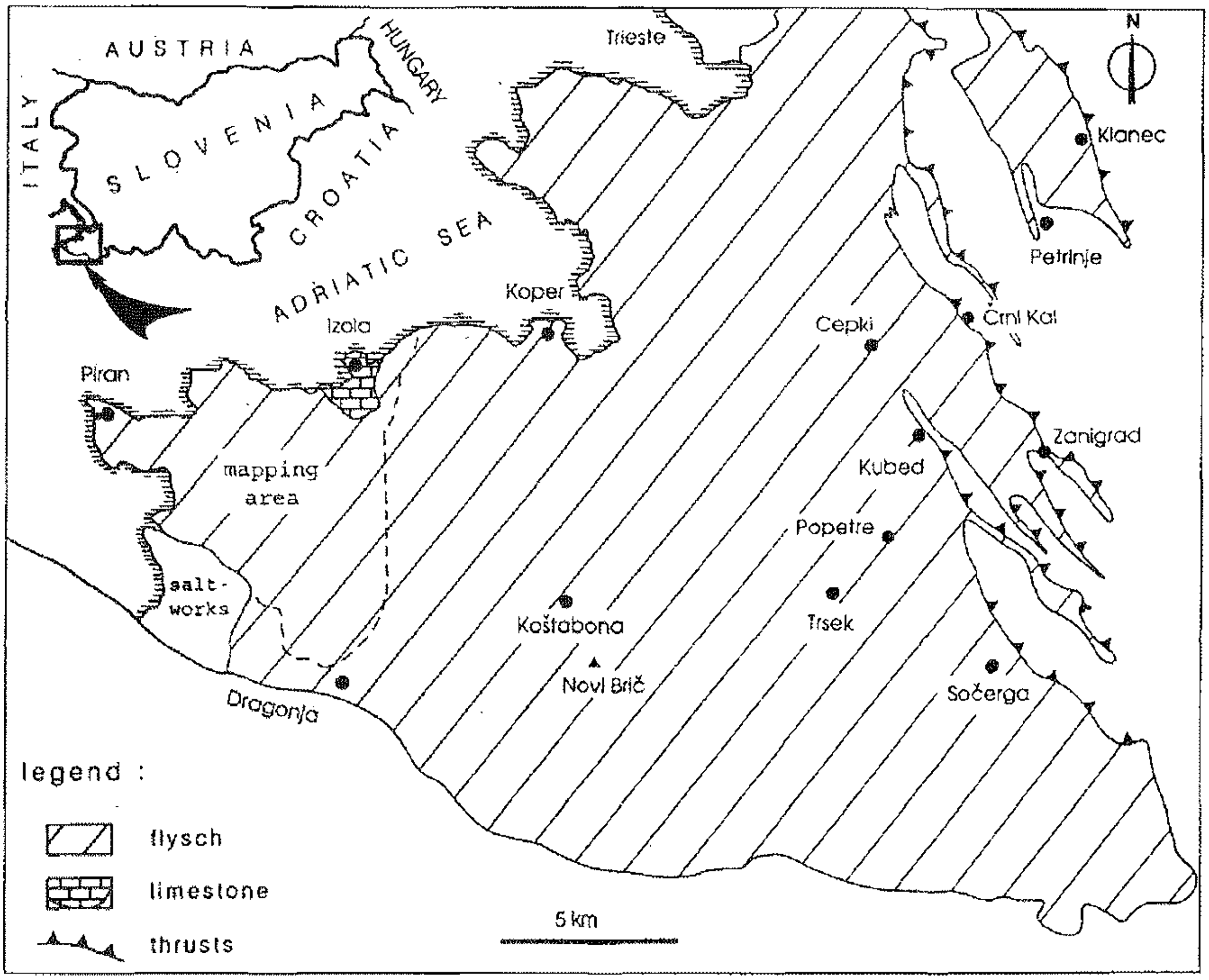

Fig. 1: Flysch Area of Piran; geological margins after Pleničar et al. (1969).
Sl. 1: Piransko flišno območje; geološke meje po Pleničarju in sodelavcih (1969).

gons are elongated parallel to the axis of the basin (see Discussion). *Paleodictyon* is exclusively predepositional.

The sharply bounded burrows of *Granularia* are intersecting flute casts, providing clear evidence for the postdepositional nature of *Granularia*.

In the 1st Flysch Unit a single specimen of *Glockeria alata* (Seilacher, 1977) was found. The trace has a diameter of 40 cm. Several burrows, 1 cm in diameter, are directed from one centre to the periphery. *Zoophycos* was found as a single specimen in the 2nd Flysch Unit. It is a three-dimensional spreite structure with helicoidal elements (Ekdale, 1977; Uchman, 1995).

The 1st Flysch Unit

The 1st Flysch Unit is 175 m thick. It consists of marlstone and sandstone beds and some intercalated sandy carbonate turbidites. In the basal part of the 1st Flysch Unit the ratio of marlstone to sandstone bed thickness is much higher east rather than west of Izola (Fig. 3, Sections a and b). East of Izola most marlstone beds range in thickness from 16 to 64 cm, while west of Izola most marlstone beds range from 4 to 32 cm. In the intermediate part of the Unit sandstone beds are reduced in bed thickness (Fig. 3, Section c). There the ratio of marlstone to sandstone of 6:1 is higher than anywhere else in the flysch.

Samples ST 5, ST 6, ST 8 and ST 11 come from the lower part of the 1st Flysch Unit. We found 27 species of calcareous nannoplankton including the following species, significant for biostratigraphy:

Discoaster nodifer (Bramlette et Riedel)
Discoaster saipanensis (Bramlette et Riedel)
Reticulofenestra umbilica (Levin)
Cribrocentrum coenurum (Reinhardt)
Dictyococcites bisectus (Hay, Mohler et Wade)

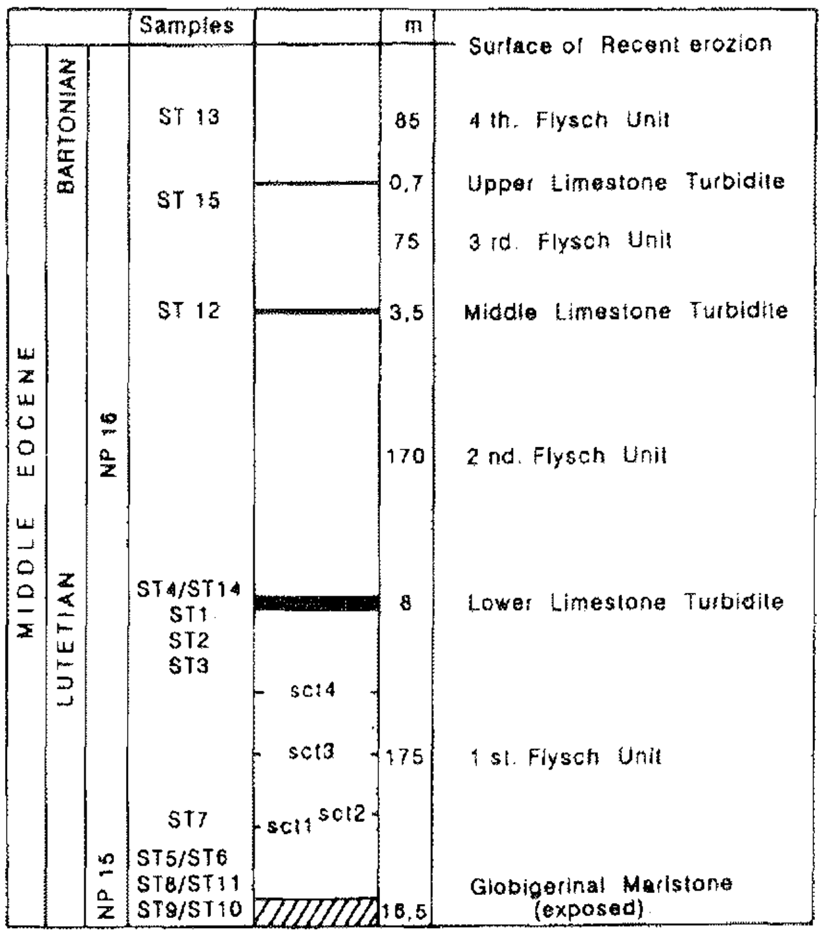

Fig. 2: Stratigraphic column of the flysch in the central part of the mapping area including the sandy carbonate turbidites sct 1 to sct 4.
Sl. 2: Stratigrafski stolpec fliša v osrednjem delu kartiranega območja, vključno s karbonatnim turbiditom (profil 1 do profil 4).

With the beginning of flysch sedimentation *Reticulofenestra umbilica, Reticulofenestra dictyoda* and *Cribrocentrum coenurum* appear. *R. umbilica* and *C. coenurum* have a similar stratigraphical range from NP 16 to NP 23 (Perch-Nielsen, 1985). Because of their poor state, it is very difficult to distinguish these two species.

The first occurrence of *Dictyococcites bisectus* is controversial. According to Perch-Nielsen (1985) *D. bisectus* appears at the base of NP 17 (p. 504) or at the biozone NP 16 (p. 431). Proto-Decima *et al.* (1975) state that it first occurred in biozone NP 16.

In the samples of the younger marlstones of the 1st Flysch Unit ST 7, ST 3, ST 2 and ST 1 we found 21 species of calcareous nannoplankton (Fig. 4). All these nannofossils are characteristic of biozone NP 16.

The 2nd Flysch Unit

The 2nd Flysch Unit is 170 m thick in the centre of the mapping area and slightly less in the southeast. Marlstone beds are reduced in thickness in comparison to the 1st Flysch Unit (Fig. 10, Section d). The 1.3:1 ratio between marlstone and sandstone is at its lowest value in the whole flysch succession. Amalgamated sandstone beds are frequent. Assuming a constant sedimentation rate for the hemipelagic marls, siliciclastic turbidites are more frequent in time compared with the 1st Flysch Unit (see Discussion).

The 3rd Flysch Unit

The thickness of the 3rd Flysch Unit is reduced from 90 m near Piran to 50 m in the southeast of the mapping area. The Unit has a similar ratio of marlstone to sandstone bed thickness as the 2nd Flysch Unit.

Sample ST 12 is of the marlstone cap of the Middle Limestone Turbidite. In sample ST 15 we determined 14 species of calcareous nannoplankton, including the following species:

Cribrocentrum reticulatum (Gartner et Smith)
Dictyococcites bisectus (Hay, Mohler et Wade)
Reticulofenestra umbilica (Levin)
Discoaster saipanensis Bramlette et Riedel
Discoaster nodifer (Bramlette et Riedel)

According to the frequent occurrence of *Cribrocentrum reticulatum,* this unit belongs to the upper part of biozone NP 16 or to biozone NP 17. Clear evidence of the affiliation to NP 17 is missing.

The 4th Flysch Unit

The 4th Flysch Unit forms the tops of the highest hills in the mapping area. Younger sediments are eroded. Today 85 m of the 4th. Flysch Unit are exposed. In the western part of the Flysch Area there is only one small outcrop in this Unit (Fig. 3, Section e). The ratio of marlstone to sandstone is 2:1.

Sample ST 13 contains the same stratigraphically relevant nannofossils as the 3rd Flysch Unit:

Cribrocentrum reticulatum (Gartner et Smith)
Dictyococcites biesctus (Hay, Mohler et Wade)
Reticulofenestra umbilica (Levin)
Discoaster saipanensis Bramlette et Riedel
Discoaster nodifer (Bramlette et Riedel)

We assigned it to the upper part of biozone NP 16.

SANDY CARBONATE TURBIDITES

Sandy carbonate turbidites differ from siliciclastic and pure limestone turbidites. This type of turbidite occurs in the 1st. Flysch Unit, but it is missing in the other Units. The four sandy carbonate turbidites (sct1-sct4) are prominent beds, wich are more resistent to weathering than siliciclastic turbidites.

The bed sct1 consists of carbonate detritus and a minor portion of quartz detritus. It is 33 cm thick. Compounds are not rounded and very well sorted. sct1 has no marlstone cap in contrast to sct3 and sct4. From base to top a graded zone is followed by lamination, cross bedding and finally by a structureless zone.

Bed sct2 is 50 cm thick. It is one bed deposited by three turbidity currents. This is documented by thin marlstone interbeds. The quartz content is higher compared to sct1.

The layer sct3 has a 81 cm thick sandy limestone bed and a marlstone cap of 34 cm. The hemipelagic marlstones differ from the marlstones sedimentated by a turbidity current of the sandy carbonate type. The turbidite marlstones are much harder, brighter and have a higher carbonate content. They break into polygonal pieces and show no bedding planes. The sandy limestone bed is 81 cm thick. It is divided vertically in three zones: laminated base, cross bedded center and laminated top.

The 12 cm thick limestone bed of sct4 is capped by 40 cm marlstone (Plate 2, Fig 3). The limestone bed consists mainly of detrital carbonate. Quartz grains are enriched in layers. Glaukonite grains are frequent. Components are not rounded. Sorting is good, no porosity is visible.

LIMESTONE TURBIDITES

Limestone Turbidites are most spectacular beds in the Flysch Basin of Piran. In coastal cliffs, the Lower and the Middle Limestone Turbidite are well detectable from great distance.

The Lower Limestone Turbidite

The Lower Limestone Turbidite consists of a limestone bed and a marlstone cap. Its maximal thickness is exposed in coastal cliffs, where the limestone bed is 3.58 to 3.75 m and the marlstone cap 4,05 m thick. South of the mapping area the thickness of the limestone bed is reduced to 1.7 m.

Limestone is made of various biogenic detritus. Foraminifera of the genera *Nummulites* and *Discocyclina* and the coralline red algae *Lithothamnium* are the most frequent components. Nummulites refer to the species *Nummulites millecaput* after Pavlovec (1963). In Limestone Turbidites the microspheric forms dominate. Foraminifera of the genus *Gypsina,* cheilostomate bryozons, the red algae *Mesophyllum,* fragments of brachiopod shells and echinoids and small snail conchs were found in Limestone Turbidites, too. Clasts make about 10% of the rock volume. Partly they show a high diagenetic grade. The upper part of the limestone bed, where miliolid foraminifera dominate, contains small fragments of *Nummulites* and *Discocyclina.*

The Lower Limestone Turbidite has no matrix and no visible porosity. Pressure solution is very intense. Stylolites are "circumidenic" and their form is "peaked low amplitude" to "irregular" (after Logan & Semeniuk, 1976). The intensity of pressure solution increases with grain size. Cements are developed in proloculi and partly in the median chambers layer of *Nummulites.* The cavities are filled with blocky spar and partly with ferroan calcite. Fringing cements are rare. In proloculi geopetal cements and micrites can be found. The geopetals show different orientations and indicate a filling of the cavities before resedimentation. Most of the limestone bed of the Lower Limestone Turbidite is rudstone, while its uppermost part is grainstone. Sorting in horizontal section is good and increases upwards. The components consist of calcite. Glauconite grains are quite frequent, too. Marlstone chips, eroded hemipelagic marls, can be found in the lower part of the bed.

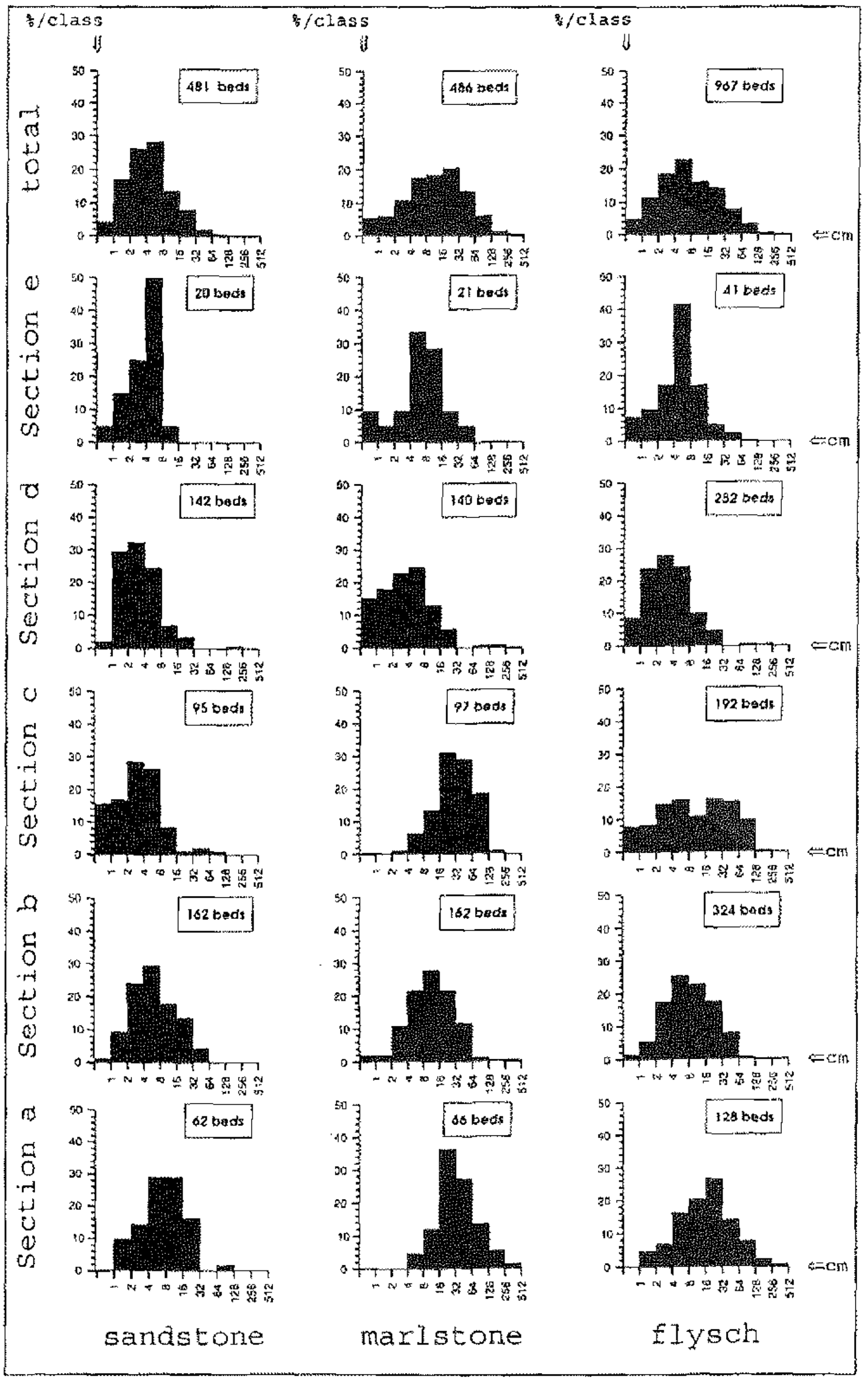

Fig. 3: Frequency distribution of bed thickness; Section a: 1st Flysch Unit (basal) east of Izola, Section b: 1st Flysch Unit (basal) west of Izola, Section c: 1st Flysch Unit (intermediate), Section d: 2nd Flysch Unit, Section e: 4th Flysch Unit.

Sl. 3: Frekvenčna porazdelitev debeline plasti; profil a: prva flišna enota (bazalni del) vzhodno od Izole, profil b: prva flišna enota (bazalni del) zahodno od Izole, profil c: prva flišna enota (vmesni del), sekcija d: druga flišna enota, profil e: četrta flišna enota.

Species / Samples → ST/	9	10	11	8	5	6	7	3	2	1	4	14	12	15	13
Coccolithus pelagicus	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Cyclicargolithus floridanus	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Discoaster bisectus	+	+	+			+	+	+	+	+	+	+	+	+	+
Fasciculithus tympaniformis	+	+	+	+				+		+		+	+	+	+
Ericsonia formosa	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Braarudosphaera bigelowi					+	+		+	+		+	+	+	+	+
Chiasmolithus grandis	+	+	+	+	+	+	+		+			+			
Discoaster barbadiensis	+				+	+		+	+	+	+		+		
Ericsonia cava	+	+	+		+	+	+	+	+		+	+	+	+	+
Discoaster lodoensis									+				+		
Discoaster deflandrei		+	+		+	+	+		+				+		
Discoaster binodosus	+	+	+		+	+		+	+		+		+		
Coccolithus eopelagicus	+	+	+		+	+			+					+	
Thoracosphaera sp.									+			+			
Transversopontis pulcheroides													+	+	
Pontosphaera plana	+	+	+		+		+	+	+		+				+
Helicosphaera seminulum						+		+	+		+				
Lanternithus minutus		+	+	+	+	+	+	+	+		+		+		
Sphenolithus radians	+	+	+	+	+		+						+		+
Sphenolithus obtusus						+									+
Cribrocentrum coenurum		+	+		+	+	+		+						
Prinsius bisulcus	+			+		+							+		
Pemma rotundum													+		
Cribrocentrum reticulatum												+	+	+	+
Transversopontis obliquipos													+		
Zygrhablithus bijugatus	+	+	+	+	+	+	+	+	+		+	+	+	+	
Nannotetrina cristata			+		+	+									
Discoaster germanicus													+		
Heliolithus kleinpellii							+								
Reticulofenestra umbilica			+	+	+	+	+	+	+	+	+	+	+	+	+
Reticulofenestra dictyoda	+	+		+	+	+	+	+	+		+	+	+	+	+
Dictyococcites scrippsae													+	+	+
Discoaster distinctus	+	+		+		+									
Discoaster nodifer	+		+	+		+							+	+	+
Discoaster saipanensis	+			+		+	+						+	+	+
Micrantholithus sp.												+			
Toweius eminens			+												
Discoaster elegans							+						+		
Discoaster keupperi							+								
Discoaster aster									+						
Discoaster diastypus						+									
Reticulofenestra hampdenensis														+	
Toweius callosus															+
Helicosphaaera lophota													+		
Neococcolithes dubius													+		

Fig. 4: Distribution of calcareous nannoplankton in the samples of Piran Flysch Area.
Sl. 4: Razporeditev kalcitnega nanoplanktona v vzorcih piranskega flišnega območja.

Inverse grading of the basal part changes into normal grading. Foraminifera and other planar elements are imbricated. Near the top of the bed a zone of basal inverse grading overlies a laminated zone. The amalgamated limestone bed was deposited by two turbidity currents. The second current followed directly after the first one.

The marlstone cap was deposited from the tails of the turbidity currents. It is harder and brighter than the hemipelagic marlstones, shows no bedding and breaks into polygonal pieces.

Samples ST 4 and ST 14 are of the marlstone cap of the Lower Limestone Turbidite. They contain the following relevant nannoflora:

Discoaster nodifer (Bramlette et Riedel)
Discoaster saipanensis Bramlette et Riedel
Reticulofenestra umbilica (Levin)
Cribrocentrum coenurum (Reinhardt)
Cribrocentrum reticulatum (Gartner et Smith)

Of special interest is *Cribocentrum reticulatum*. Perch-Nielsen (1985) attributes its first occurence to the upper part of biozone NP 16 before the first constant occurrence of *Discoaster nodifer* and also before the occurrence of *Reticulofenestra umbilica*. We assigned the Lower Limestone Turbidite to the upper part of biozone NP 16.

PLATES - TABLE

Plate 1 - Tabla 1

Fig. 1: Plant debris on the lower bedding plane of a thick bedded siliciclastic turbidite, 1st Flysch Unit.
Fig. 2: *Taphrehelminthopsis* ***on the lower bedding plane of a siliciclastic turbidite.***
Sl. 1: Ostanki rastlin na spodnji strani plasti debelo plastnatega silikoklastičnega turbidita. Prva flišna enota.
Sl. 2: *Taphrehelminthopsis* ***na spodnji strani plasti kresilikoklastičnega turbiditnega peščenjaka.***

Plate 2 - Tabla 2

Fig. 1: Middle Limestone Turbidite separating 2nd and 3rd Flysch Units.
Fig. 2: 1st. Flysch Unit, interbedding of sandstones and marlstones.
Fig. 3: Sandy carbonate turbidite sct 4.
Sl. 1: Apnenčev turbidit, ki loči drugo in tretjo flišno enoto.
Sl. 2: Prva flišna enota; menjavanje peščenjaka in laporja.
Sl. 3: Peščen karbonatni turbidit, profil 4.

Plate 3 - Tabla 3

Fig.(Sl.)
1, 2 Discoaster nodifer (Bramlette et Riedel), ST/6
3 D. nodifer (Bramlette et Riedel), ST/12
4 D. nodifer (Bramlette et Riedel), ST/13
5 Discoaster keupperi Stradner, ST/7
6, 7 Discoaster saipanensis Bramlette et Riedel, ST/12
8 Discoaster germanicus Martini, ST/12
9 Discoaster aster Bramlette et Riedel, ST/2
10, 12 Discoaster binodosus, Martini ST/6
13 Discoaster diastypus Bramlette et Sullivan, ST/6
14 Discoaster elegans Bramlette et Sullivan, ST/12
15, 16 Heliolithus kleinpellii Sullivan, ST/7
All under ordinary light. All 2000 X enlarged.
Vse pod presevno svetlobo, 2000-kratna povečava.

Plate 4 - Tabla 4

Fig. (Sl.)
1-6 Reticulofenestra umbilica (Levin), 1, 3, 4, 5 ST/2, 2 ST/7, 6 ST/17
7-9 Dictyococcites bisectus (Hay, Mohler et Wade), 7,8 ST/13, 9 ST/17
10 Reticulofenestra hampdenensis Edwards, ST/13
11 Toweius callosus Perch-Nielsen, ST/13
12 Cyclicargolithus floridanus (Roth et Hay), ST/6
13 Sphenolithus radians Deflandre, ST/11
14 Ericsonia formosa (Kamptner), ST/2
15 Helicosphaera lophota Bramlette et Sullivan, ST/12
Fig. 4. under ordinary light. All others between crossed nicols. All 2000 X enlarged.
Sl. 4. pod presevno svetlobo. Druge pod navzkrižnimi nikoli, vse 2000-kratna povečava.

Plate 5 - Tabla 5

Fig. (Sl.)
1-3 Chiasmolithus grandis (Bramlette et Riedel), 1,3 ST/11, 2 ST/6
4, 7, 8 Coccolithus pelagicus (Wallich), 4 ST/12, 7 ST/3, 8 ST/11
5, 6 Cribrocentrum reticulatum (Gartner et Smith), 5 ST/14, 6 ST/12
9 Braarudosphaera bigelowi (Gran et Braarud), ST/15
10, 11 Pontosphaera plana (Bramlette et Sullivan) 10 ST/11, 11 ST/9
12 Neococcolithes dubius (Deflandre), ST/12
13, 14 Neotetrina sp., ST/6
15 Zygrhablithus bijugatus (Deflnadre), ST/9
16 Lanternithus minutus Stradner, ST/2
Fig. 3, 8, 11, 12, 13 under ordinary light. All others between crossed nicols. All 2000 enlarged.
Slike 3, 8, 11, 12 in 13 pod presevno svetlobo, druge pod navzkrižnimi nikoli. Vse 2000-krat povečano.

1

2

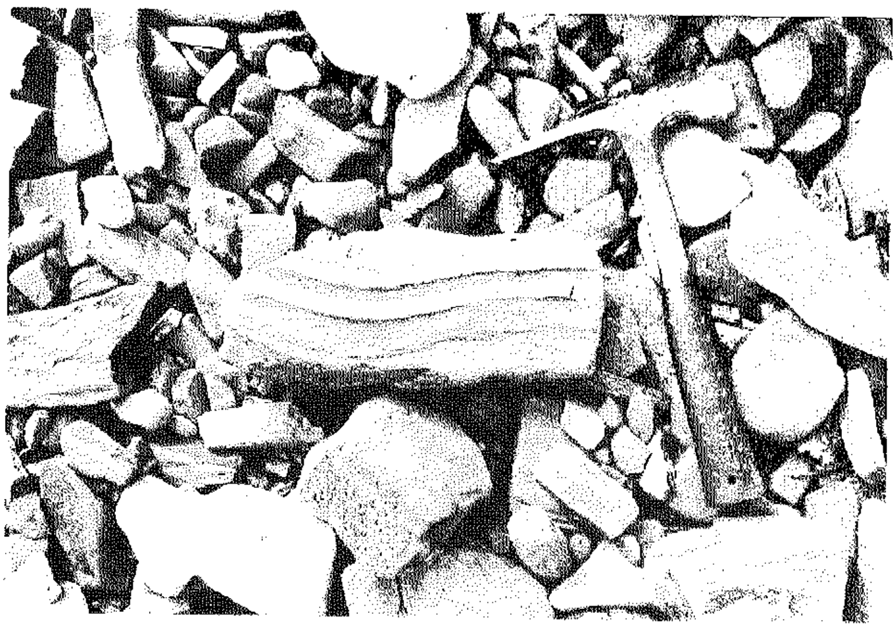

Plate 1 - Tabla 1

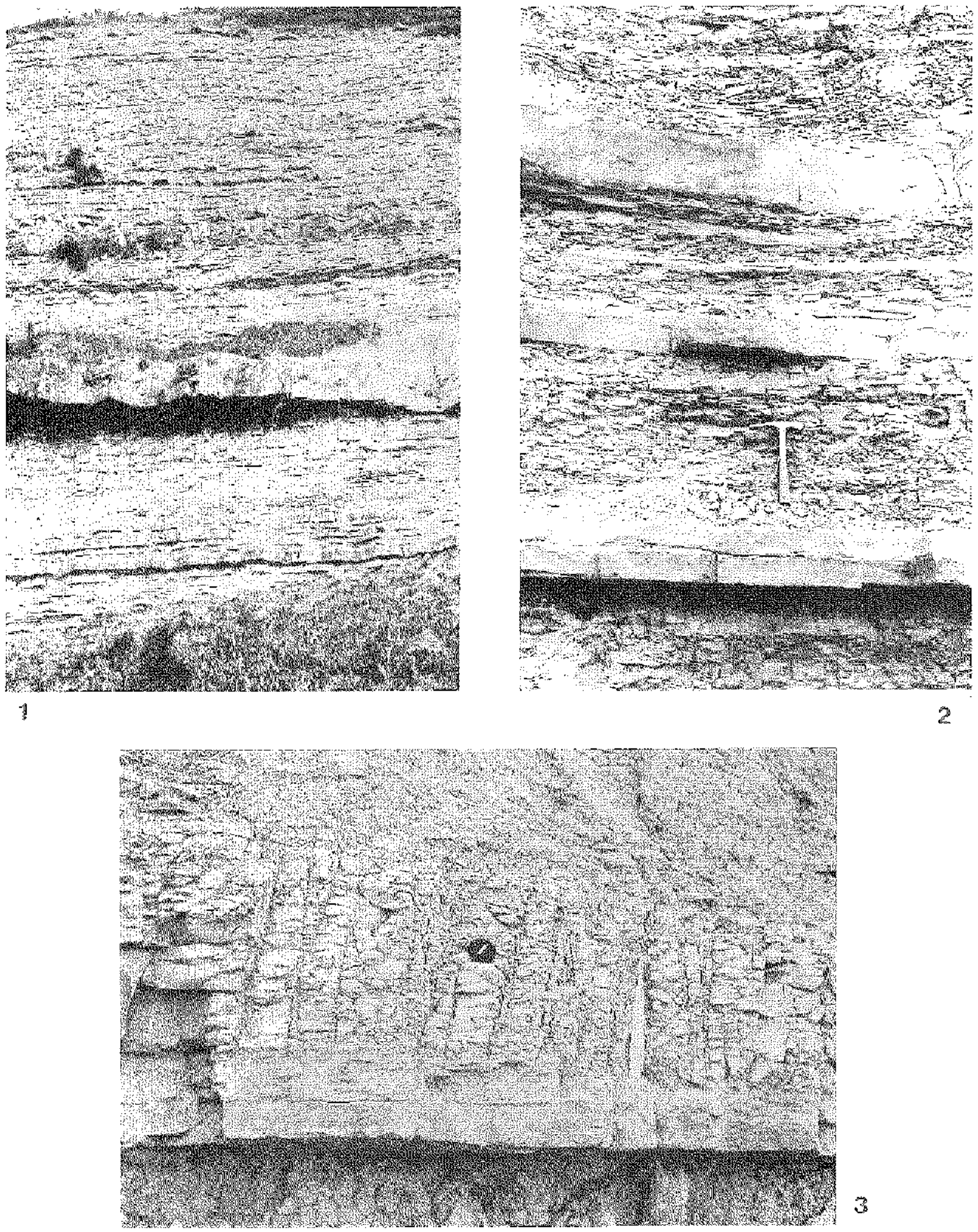

Plate 2 - Tabla 2

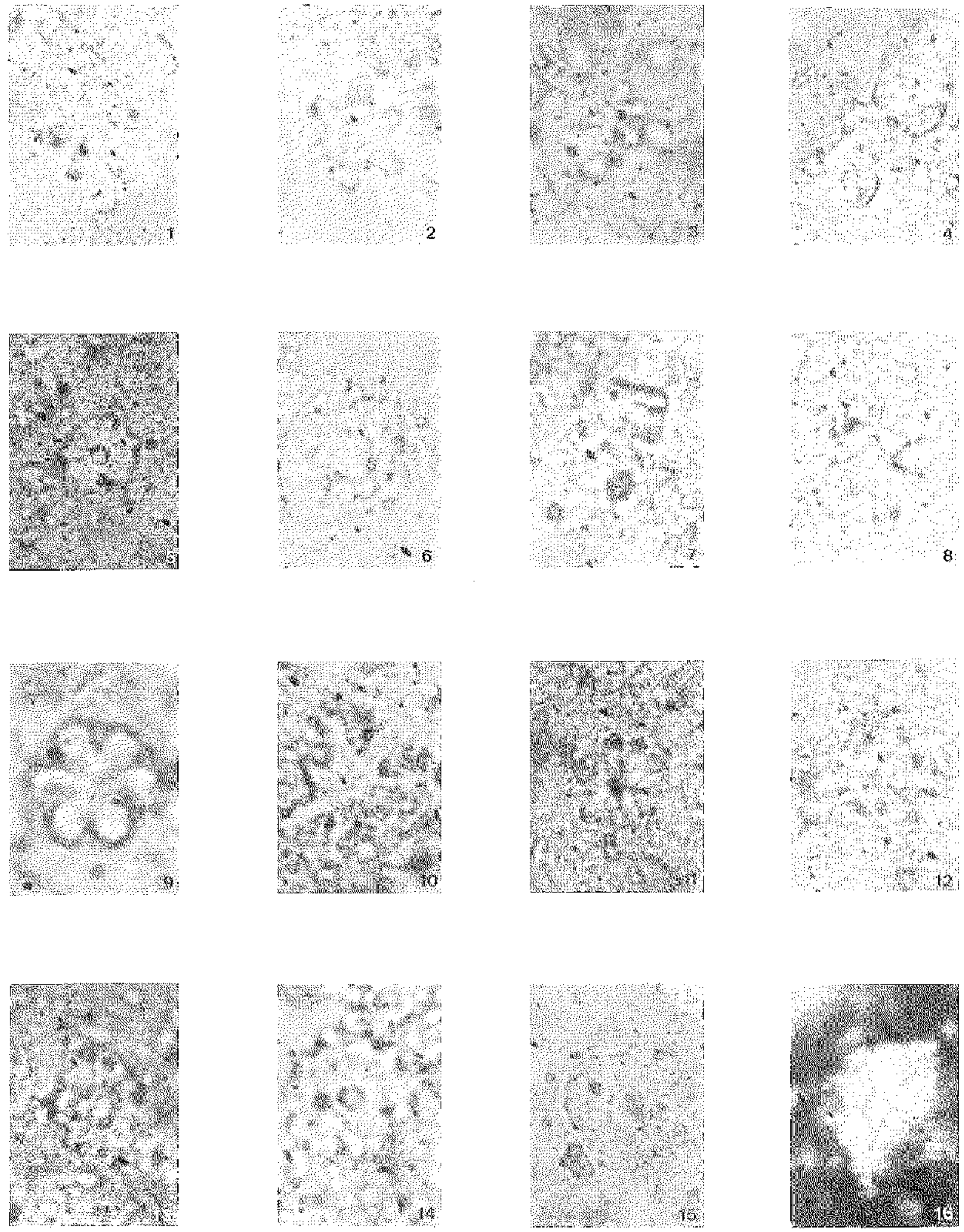

Plate 3 - Tabla 3

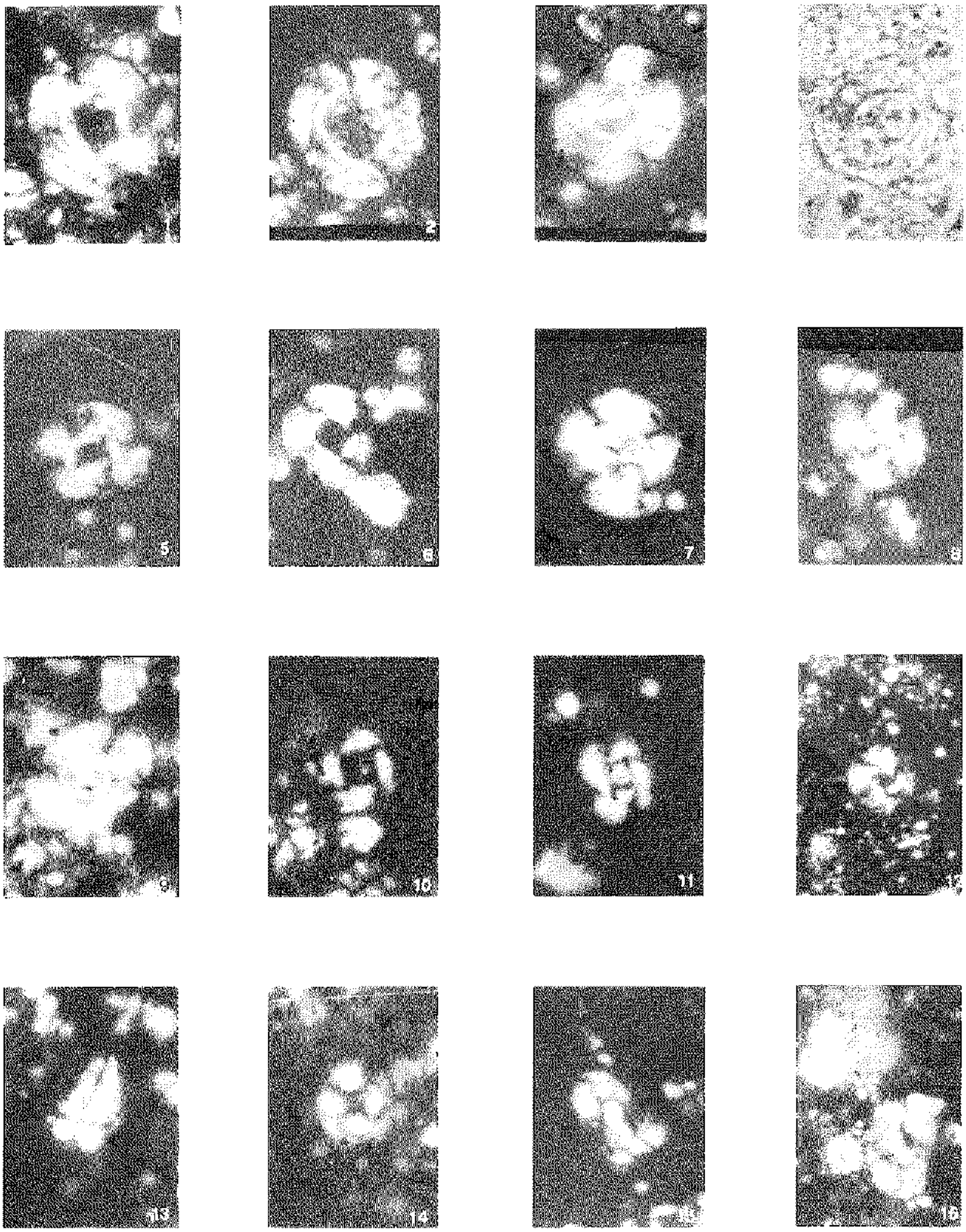

Plate 4 - Tabla 4

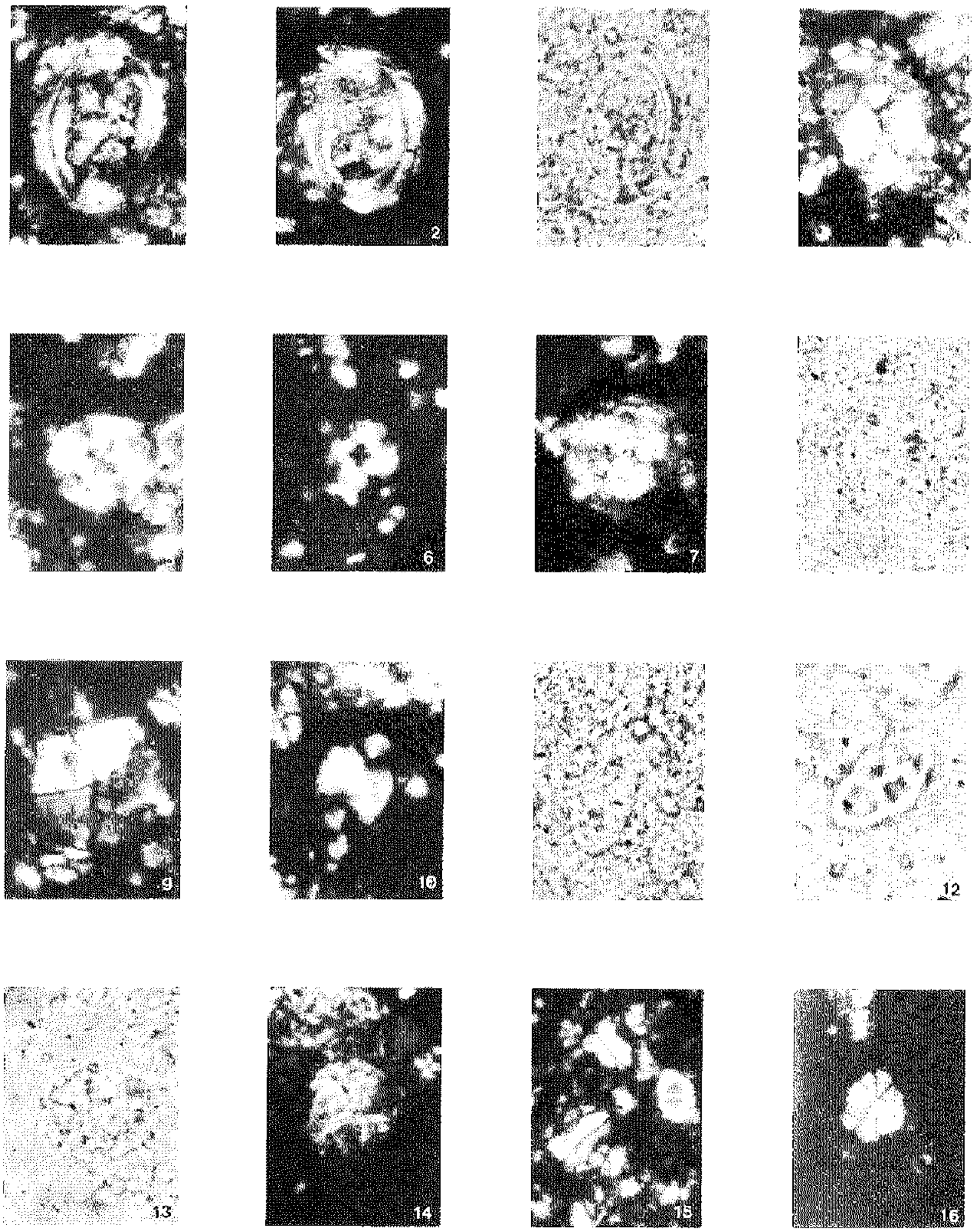

Plate 5 - Tabla 5

The Middle Limestone Turbidite

The Middle Limestone Turbidite is similar to the Lower Limestone Turbidite. It is made of the same components, shows the same sedimentological features and is amalgamated, too. The maximal thickness is 1.65 m for the limestone bed and 2.03 m for the marlstone cap. The Middle Limestone Turbidite is well exposed in most parts of the basin. We estimate its rock volume at about 1 km^3.

Sample ST 12 was taken of the marlstone cap of the Middle Limestone Turbidite. According to the frequent occurrence of *Cribocentrum reticulatum,* we believe that this layer belongs to the upper part of biozone NP 16.

The Upper Limestone Turbidite

The Upper Limestone Turbidite has no marlstone cap. Its thickness decreases from 1.3 m in the south to 0.4 m in the north of the mapping area. It consists of the same components as the other Limestone Turbidites, though clasts are less frequent. Pressure solution is equally intense (see Discussion). Grading is less obvious because of good sorting throughout the bed. The grain size is smaller in comparison to the older Limestone Turbidites. A rudstone at the basis grades into a grainstone. As a consequence of its narrow grain size spectrum, the Upper Limestone Turbidite shows intense cross bedding, which is missing in other Limestone Turbidites (cf. Engel, 1974).

DISCUSSION

Turbidites in association with trace fossils clearly indicate the deep-sea environment during flysch sedimentation. The trace fossils belong to the Paleodictyon subfacies of the *Nereites* facies in sense of Seilacher (1977) or to the *Zoophycos-Nereites*-association in sense of Collinson & Thompson (1989). During flysch sedimentation the water depth ranged of some hundred metres. Gohrbandt *et al.* (1960) suggested 700-1200 m based on the association of foraminifera and a depth of several hundred metres based on the association of ostracods.

Assuming a water-depth of several hundred metres, a strong subsidence in the basin is needed to explain a succession of several hundred metres of flysch. Today more than 500 m of deep-sea sediments are exposed in vertical succession. The intense pressure solution in the Upper Lime Turbidite indicates that it was covered by a much thicker sediment-column than the 85 m that are preserved of the 4th Flysch Unit.

The axis of the Eocene basin extended in WNW-ESE direction. This can be seen from the lineation on lower bedding planes of sandstone beds, from the inclination of originally vertical elements caused by sedimentary creep, from the orientation of the long axis of elongated *Paleodictyon* hexagons and from the asymmetry of convolute bedding.

Turbidity currents of the siliciclastic turbidites moved parallel to the axis of the basin, in the 1st. Flysch Unit from ESE to WNW. In the uppermost part of this Unit the direction was reversed, and from then on remained from WNW to ESE. With this change in current directions the ratio of marlstone to sandstone bed thicknesses decreased. Turbidity currents of the Limestone Turbidites were directed to NNE, which is evident from the dipping of the imbrication of foraminifera and other planar elements. Their source area was the rim of a carbonate platform in the SSW.

CONCLUSIONS

Sedimentology

The Piran Flysch shows the characteristics of basin plain sediments in sense of Ricci Lucchi & Valmori (1980). It is a regular, repetitive interbedding of hemipelagites with turbidites. The ratio of marlstone to sandstone bed thickness changes irregulary from one section to another (see Fig. 3). Obvious trends like thickening- or coarsening-upward sequences are missing. Beds do not wedge out and can be traced over long distances. The turbidity currents moved parallel to the axis of the basin. They experienced a reversal in current direction.

The Piran Flysch corresponds to Type I System in sense of Mutti (1985), which develops in the proximity of an uplifting orogen at times of low sealevel. The Eocene was a period of global sealevel lowstand (Heller & Dickinson, 1985). The turbidites were deposited by highly efficient turbidity currents carrying their load far into the Basin (cf. Mutti, 1985).

Biostratigraphy

Biostratigraphers began to investigate the flysch between Trieste and Piran by microfossils in 1969. The work of Piccoli & Proto-Decima (1969) deals with planktonic foraminifera in the area of Slovensko Primorje. The main purpose of their paper was to determine the age of flysch sediments. In the area between Trieste and Piran they reported four plankton biozones: the oldest biozone, *Globorotalia aragonensis* (now *Morozovella aragonensis,* P8), containing planktonic foraminifers near Trieste, biozone *Hantkenina aragonensis* (now *Hantkenina nuttalli,* P10) in Milje peninsula, biozone *Globigerapis kugleri* (now *Globigerinatheka s. subconglobata,* P11) between Črni Kal, Rižana and Dekani, and biozones P11 and *Globorotalia lehneri* (now *Morozovella lehneri,* P12) between Koper and Piran.

Pavšič (1981) studied nannofossils of different strata in Slovensko Primorje. He reported biozone *Discoaster lodoensis* (NP 13) at Ankaran, biozone *Discoaster sublodoensis* from the surroundings of Dekani and biozone *Nanotetrina fulgens*, which corresponds to the long ranging biozone NP15 - NP16, form the globigerinal marlstone in the quarry of the old brickwork at Izola. According to Pavšič (1981) the flysch sequence between Izola and Piran is equivalent to biozone NP 16. Comparing plankton and nannoplankton biozones P11, corresponds to NP15 and P12 to NP16.

The limestone with nummulitins and alveolinas at Izola grades into marly limestones with glauconite, which are overlain by the globigerinal marlstone. Pavlovec (1985) divided the limestone at Izola in four parts: a transition from Middle to Upper Cuisian, Upper Cuisian, Uppermost Cuisian and Lower Lutetian, corresponding to the biozone *Nummulites gallensis*. Biozone *N. gallensis* corresponds to the standard nannoplankton biozone *Discoaster sublodoensis* (NP 14) (Kapellos & Schaub, 1973; Serra-Kiel & Hottinger, 1995).

The globigerinal marlstone belongs to the combined biozone NP 15/16. The Flysch Units 1 to 4 are assigned to NP 16 on the basis of the following species: *Discoaster saipanensis, Reticulofenestra umbilica* and *Cribocentrum reticulatum*. *Cribocentrum reticulatum* is characteristic for the upper part of NP16. In the southern parts of the Piran Flysch Basin even younger sediments crop out (Pleničar *et al.*, 1969). So the existence of younger flysch, belonging to NP17, could be expected.

ACKNOWLEDGEMENTS

Jörn Peckmann benefited from the advice and helpful criticism of the manuscript by Prof. Dieter Meischner, Göttingen.

POVZETEK

Eocenski globokomorski sedimenti piranskega flišnega območja se razprostirajo na površini okrog 400 km^2. Globigerinskemu laporju, ki leži nad alveolinsko-numulitnim apnencem pri Izoli, sledi flišno zaporedje, debelo več kot 500 metrov. Fliš je bil razdeljen na štiri enote glede na število vmesnih apnenčevih turbiditov. Globigerinski lapor pripada meji nanoplanktonskih biocon NP 15/16, vse druge flišne enote pa nanoplanktonski paleogenski bioconi NP 16.

Bazenski turbiditi in fosilni sledovi Paleodictyon *podfaciesa (Seilacher, 1977) kažejo na globokomorsko okolje. Posamezni turbiditi si lahko sledijo na več kilometrov. Fliš sestoji iz laporjev, silikoklastitov, čistih karbonatov in peščenih karbonatnih turbiditov.*

Turbiditni tokovi, ki so prinašali silikoklastične turbidite, so tekli v smeri ZSZ-VJV, medtem ko so karbonatni turbiditi dobivali material iz karbonatne platforme iz smeri JJZ.

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