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## TRACE FOSSILS FROM THE BRKINI FLYSCH (EOCENE), SOUTH-WESTERN SLOVENIA

### TRACCE FOSSILI DEL FLYSCH EOCENICO DELLA REGIONE DI BRKINI, SLOVENIA SUD-OCCIDENTALE

**Abstract** - Fifteen trace fossil taxa have been recognised in the mostly sandy Eocene flysch of the Brkini region in the SW Slovenia. The ichnoassemblage is atypical of other Paleogene flysch deposits, because it is less diverse and dominated by abundant *Ophiomorpha*. Graphoglyptids (e.g., *Paleodictyon*, *Megagraption*) are relatively rare. This ichnoassemblage is a good example of the newly distinguished *Ophiomorpha rudis* ichnosubfacies within the classical deep-sea *Nereites* ichnofacies. This ichnosubfacies is typical of channel and proximal lobe facies, and is relatively shallower than the other ichnosubfacies. It is probable that it indicates relatively shallower deep-sea environment in the upper (proximal) part of depositional system. *Ophiomorpha* was produced by crustaceans that produced deep burrow systems and fed on buried plant detritus that was matured by microbes after hundreds or thousands of years, maybe in disoxic conditions. Large amounts of plant detritus, sandy substrates and high rate of sedimentation favoured trace makers of this trace fossil. High-energy flows in the depositional environment destroyed muddy substrates and their typically abundant ichnofauna and reduced preservational potential. These factors strongly controlled the composition of the ichnoassemblage.

**Key words:** Trace fossils, Flysch, Eocene, Slovenia.

**Riassunto breve** - Vengono descritti quindici taxa relativi a tracce fossili riconosciute in depositi prevalentemente arenacei del flysch affiorante nella regione di Brkini, Slovenia sud-occidentale. L'associazione icnologica è alquanto atipica rispetto agli altri depositi di flysch paleogenici del Subalpino orientale, in quanto poco diversificata e dominata da abbondanti *Ophiomorpha*. I grafogliptidi (ad esempio: *Paleodictyon*, *Megagraption*) sono relativamente rari. Questa associazione icnologica rappresenta un buon esempio della subichnofacies *Ophiomorpha rudis*, recentemente riconosciuta all'interno della classica ichnofacies a *Nereites*, tipica di ambiente marino profondo. La subichnofacies in questione è tipica di porzioni prossimali canalizzate di lobo di conoide sottomarina ed è quindi relativamente meno profonda rispetto alle altre subichnofacies di questo tipo di ambiente (conoide sottomarina). Probabilmente essa indica un ambiente sottomarino relativamente meno profondo, ubicato nella porzione superiore (prossimale) del sistema deposizionale in oggetto. *Ophiomorpha* è stata prodotta da crostacei che hanno scavato profondi sistemi di tane cibandosi di detrito vegetale sepolto, trasformato nel corso di centinaia o migliaia di anni da microbi che, presumibilmente, hanno operato in condizioni di scarsa ossigenazione al fondo. Grandi quantità di detrito vegetale, substrati sabbiosi e alti tassi di

*sedimentazione hanno favorito le condizioni di vita degli organismi responsabili di queste tracce fossili. Flussi ad elevata energia attivi in questo ambiente avrebbero asportato i substrati fangosi e distrutto la loro tipica, abbondante ichnofauna o perlomeno limitato la loro potenziale conservazione. Questi fattori hanno fortemente controllato la composizione delle associazioni icnologiche.*

**Parole chiave:** *Tracce fossili, Flysch, Eocene, Slovenia.*

## Introduction

Flysch deposits display a great diversity of trace fossils, which associations belong generally to the *Nereites* ichnofacies (e.g., SEILACHER, 1967; FREY & SEILACHER, 1980), but which are not uniform. Trace fossil associations of particular flysch units can display large differences, which are caused by many palaeoenvironmental, evolutionary and preservational factors (e.g., TUNIS & UCHMAN, 1996a; UCHMAN, 1999; 2001).

The flysch deposits of the Brkini region (SW Slovenia) accumulated in a small intraplateau basin. A dominance of *Ophiomorpha* is their striking ichnological feature. This trace fossil is here much more abundant than in coeval flysch deposits of the Istria Peninsula (TUNIS & UCHMAN, 1996b). Description and interpretation of trace fossils from the Brkini flysch is the main aim of this paper. These deposits have been never ichnologically investigated.

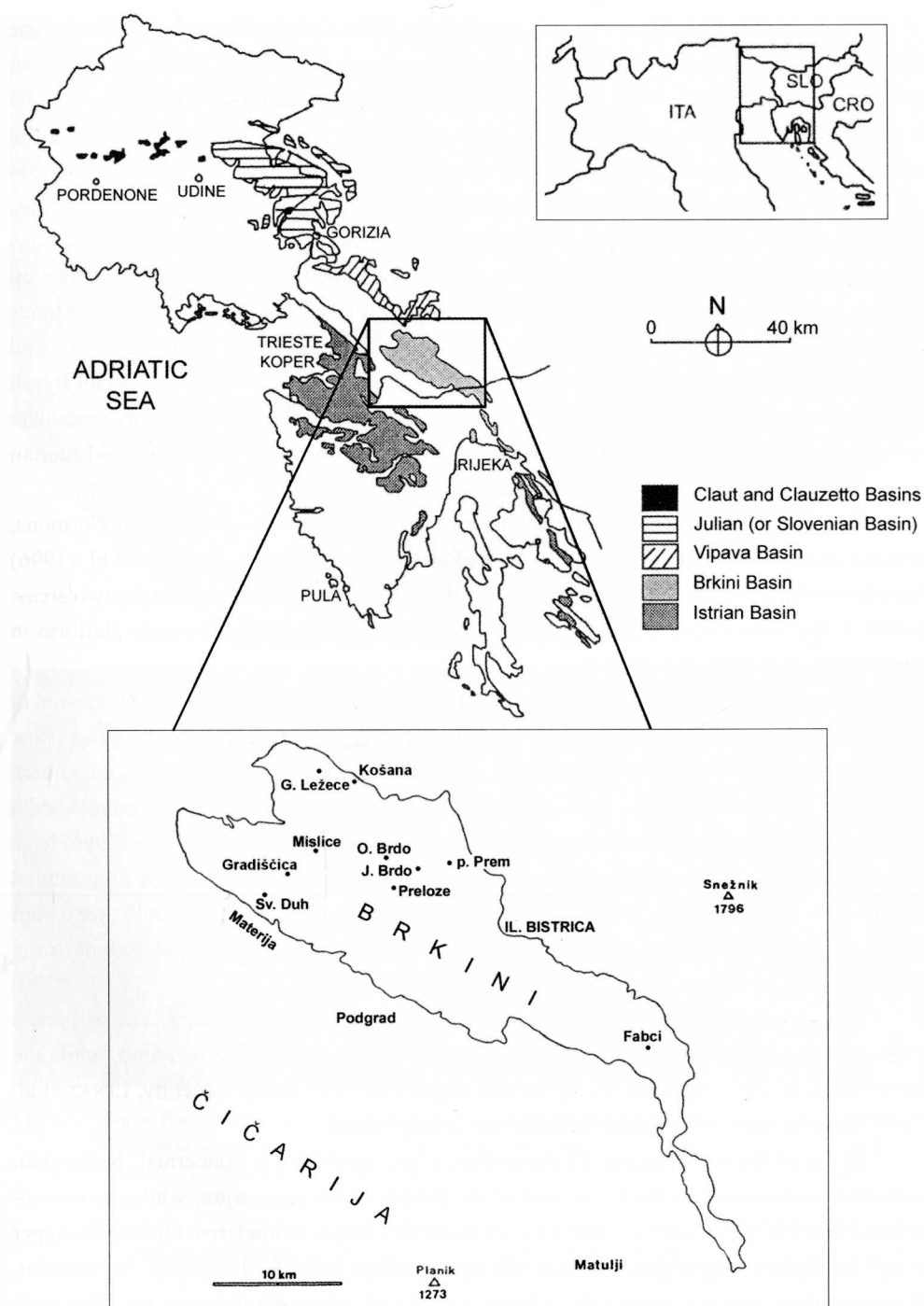
Some of the illustrated specimens are housed in the Institute of Geological Sciences of the Jagiellonian University in Krakow (acronym: 167P). Data on sedimentology and general geology were provided by the first author (G.T.), while the ichnological work was made by the second author (A.U.).

## Geological setting and sampling locations

The Brkini plateau shows, in general, a synclinal structure and it belongs to the Rjeka synclinorium sensu lato (SIKIC & PLENICAR, 1975). To the NE it borders with the thrust Cretaceous succession of Mt. Snežnik while, on the southern border, it passes into the wide karstified Materija plane. The core of the syncline is represented by flysch deposits. At present, due to the numerous faults and folds and, mostly, to the lack of methodical, advanced stratigraphic investigations, no continuous composite section has been described. The estimated thickness of the Brkini clastic deposits is about 1000 m (SIKIC & PLENICAR, 1975) but this datum is not certain.

Fig. 1 - Location map of the examined sections in the Brkini region.

- Carta indice con ubicazione delle sezioni esaminate nella regione di Brkini.



The time span of the Brkini section embraces the lower Eocene pro parte - middle Eocene pro parte. PAVLOVEC et al. (1991) described the basal part of the Brkini flysch close to Kosana, Sv. Trojca and Leskovec, where a 78 m thick carbonate megabreccia unit directly overlies the lower Eocene Alveolina-Nummulites limestones. This part has been assigned to the nannoplankton biozone NP13. TUNIS & VENTURINI (1996) noticed that the succession continues with thin-bedded fine-grained turbidites and graded calcarenite-marlstone intercalations. Successively, the ratio of marlstone to sandstone bed thickness decreases and intercalations of medium- to thick-bedded and medium- to coarse-grained sandstones start. Further up section, matrix-supported conglomerates are rather common as well as coarse sandstones and conglomerates with a large amount of chert and quartz pebbles. Fine sandstones and siltstones and silty clayey marls, probably representing molassic facies, top the Brkini flysch succession. So, a gradual lithological shift from prevailing carbonate and sandy carbonate rocks to predominant siliciclastic lithologies occurred during the late Ypresian-Lutetian deposition of the flysch in the Brkini basin.

This succession shows strong similarities with that of the coeval flysch di Cormons, situated about 30-40 km NW of the Brkini region. As a matter of fact, BONAZZI et al. (1996) hypothesized a palaeogeographic continuity of the flysch occurrences between the two areas; however, the Brkini basin is located more inward inside the Adriatic carbonate platform in comparison with the Cormons area.

The carbonate detritus was delivered from a carbonate platform, presumably located in SSE, while a peculiar characteristic of the Brkini flysch is represented by the palaeoflow measurements of the siliciclastic turbidites. The most numerous data to assess the source area of the siliciclastic detritus were provided by OREHEK (1970; 1991) which established a prevailing northwestward palaeotransport direction. However, TUNIS & VENTURINI (1996) have measured also southeast trending palaeocurrent directions. So, both directions are longitudinal in respect to the strike of the Brkini basin, but they are just opposite. Unfortunately, we do not know, in most of the cases, the exact stratigraphic position of the deposits where the measurements have been carried out.

The detrital components of the sandstones of the Brkini flysch are quartz and carbonate in about equal quantity (OREHEK, 1970). Micas and feldspars are rather common, while the most common heavy minerals are pyrite and garnet (OREHEK, 1970). Recently, LENAZ et al. (2001) have recognized cr-spinel, ilmenite and orthopyroxene.

As far as the environment of deposition of the turbidites is concerned, basin-plain turbidites predominate in the lower part of the Brkini flysch succession, while the coarse-grained facies of the sandstones and the conglomerates which characterize the middle-upper part of the section suggest that these deposits were proximal to the feeder system. In particular, the easternmost outcrops seem to be related to sand-rich lobes of a deep-sea fan. However,

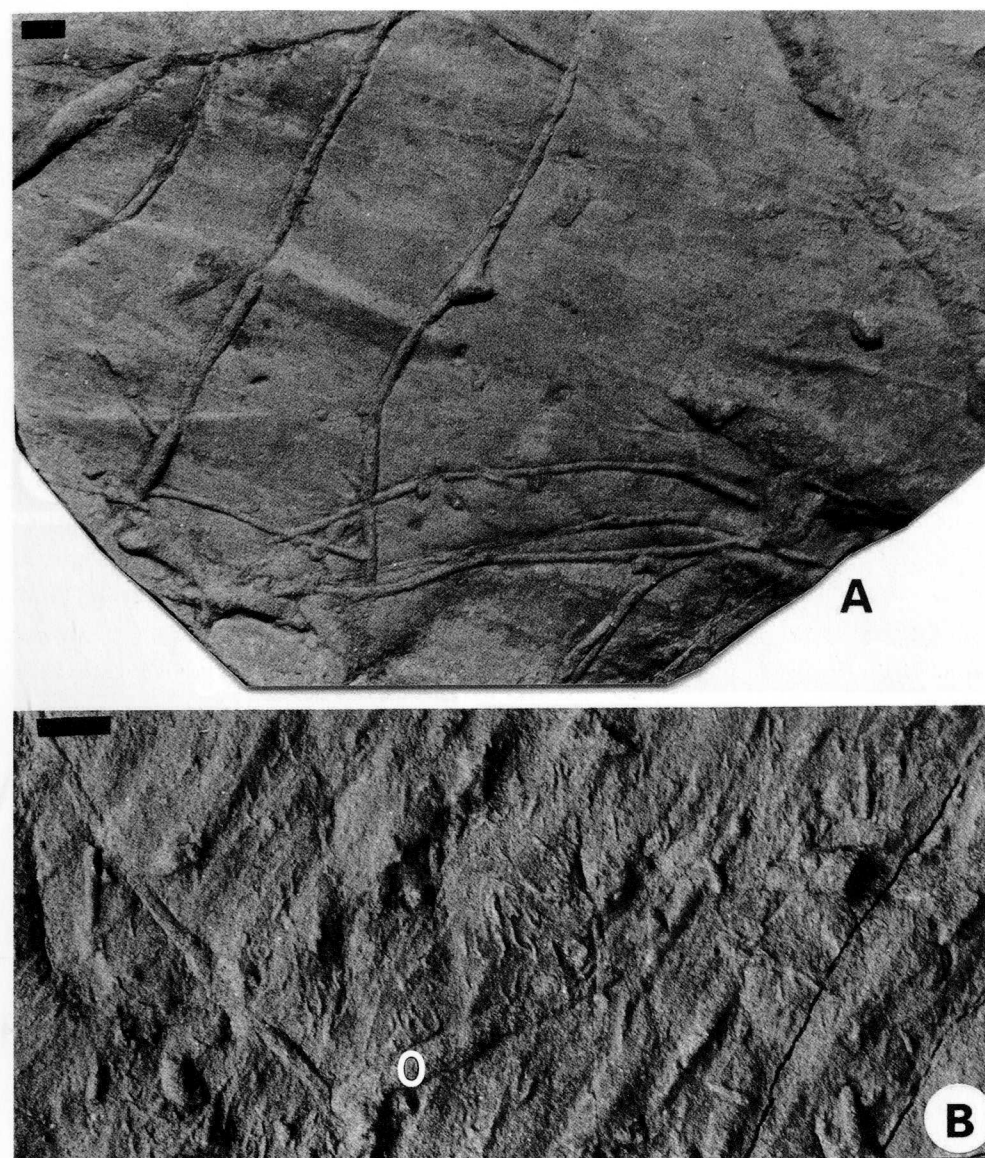
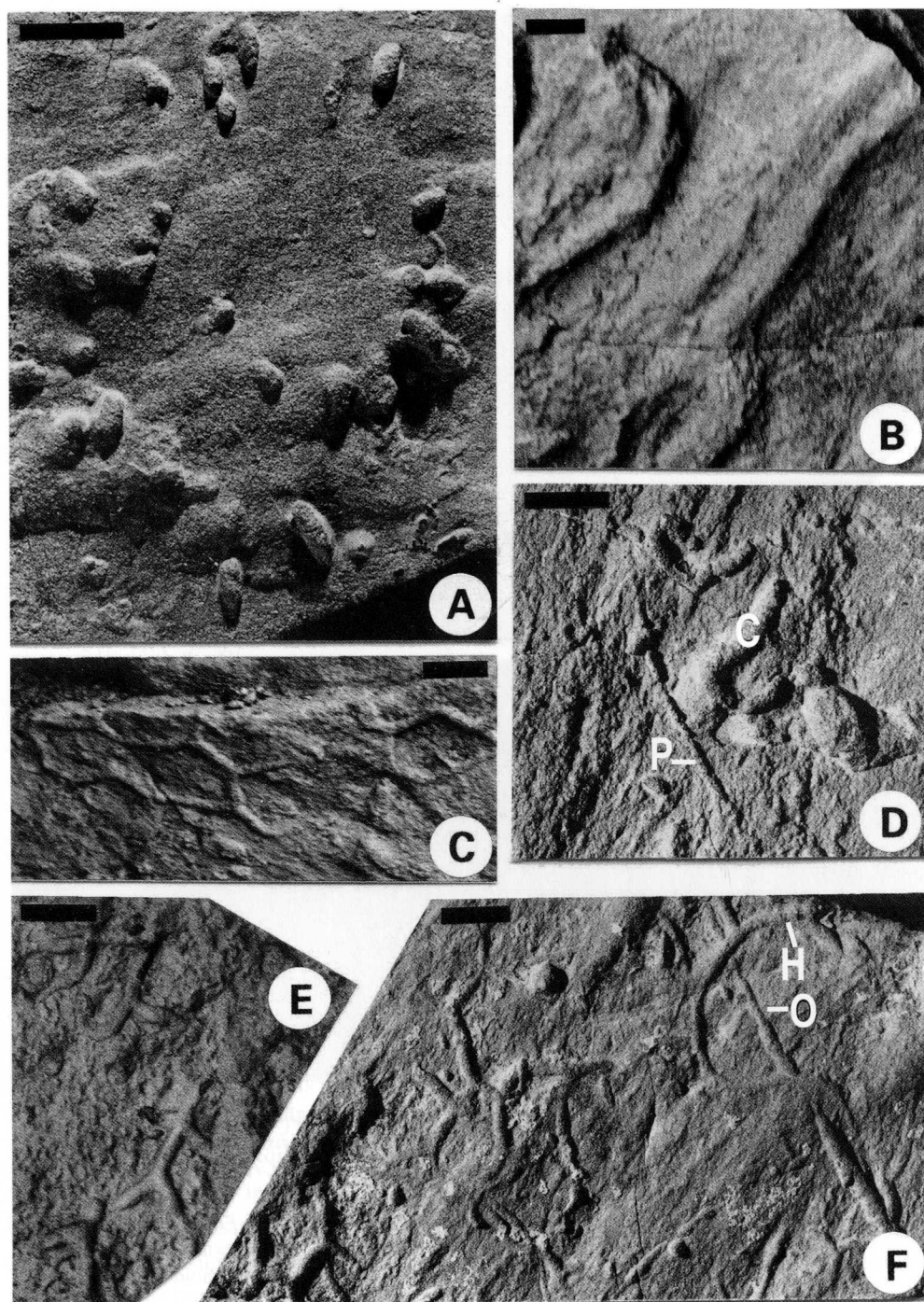


Fig. 2 - Trace fossils on soles of turbiditic sandstone beds from the Brkini Flysch at Fabci. A. *Ophiomorpha annulata* (KSIAŻKIEWICZ) and *Ophiomorpha rudis* (KSIAŻKIEWICZ) (upper right corner). B. *Ophiomorpha annulata* (KSIAŻKIEWICZ) (O) and ?*Urohelminthoida* isp. (at the centre). Field photographs. Scale bars = 1 cm.

- Controimpronte di tracce fossili alla base di strati arenacei presso Fabci (Flysch di Brkini). A. *Ophiomorpha annulata* (KSIAŻKIEWICZ) e *Ophiomorpha rudis* (KSIAŻKIEWICZ) (lato superiore destro). B. *Ophiomorpha annulata* (KSIAŻKIEWICZ) (O) e ?*Urohelminthoida* isp. (al centro). Foto di affioramento. Scala di riferimento = cm 1.





due to the absence both of northern and eastern marginal parts of the Brkini flysch basin that are not preserved owing to the tectonic detachments, we do not know the characteristics of the terrigenous material dispersal system.

The ichnological observations have been made in ten localities, selected for different stratigraphic positions and for good exposures (fig. 1).

Investigations have been carried out on ten short sections outcropping near Fabci, Nova Vas (close to Fabci), Janežovo Brdo, Ostrožno Brdo, Gorne Ležee, potok Prem, Prelože, Misliče, Gradišnica and Svety Duh (fig. 1). The Misliče, Gorne Ležee, potok Prem and Gradišnica-Svety Duh sections are represented by marlstone and sandstone beds and some intercalated sandy carbonate turbidites. The ratio of marlstone to sandstone bed-thickness is usually higher than 1, the lithology and the sedimentary structures do not change significantly throughout the sections.

The siliciclastic turbidite beds are usually graded with sharp bases and occasional flute casts. Cross bedding and other sedimentary structures are rare, only beds thicker than 20-30 cm show cross bedding and laminations (Gradišnica-Svety Duh sections).

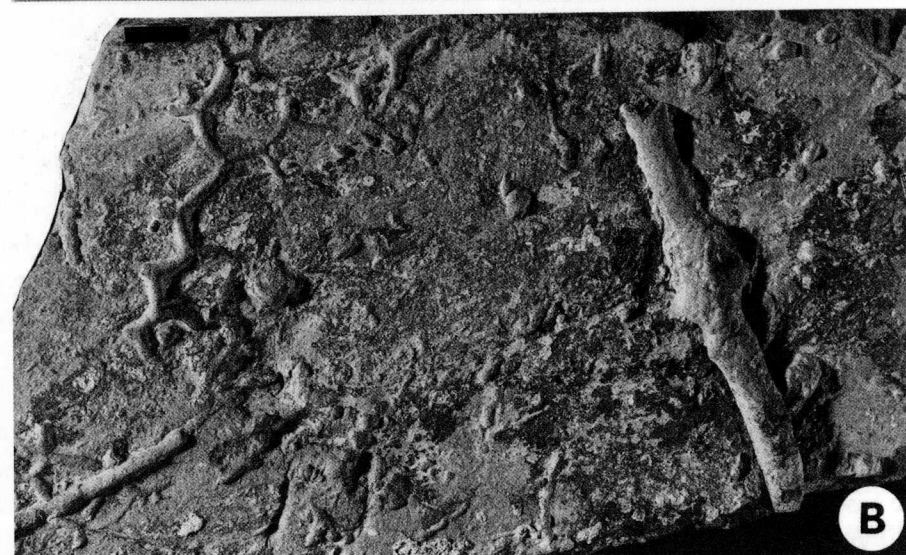
Janežovo Brdo is the most complete section of the Brkini region. A distinct feature of the lower part of this section is the presence of thick, matrix-supported conglomerate beds, while further up-section thick-bedded and coarse-grained sandstones prevail over the sandstone and marlstone intercalations.

Abundance of sandstones and conglomerates characterizes the two short sections at Prelože and Ostrožno Brdo.

The sections close to Nova Vas and Fabci are characterized by medium-grained thin- to thick-bedded turbidites, which display truncated bases and uncommon complete Bouma sequences. Plant debris occurs frequently especially at the base of turbidites, and rarely both at the base and at the top. Anyway, more or less abundant plant debris characterizes the middle-upper part of the Brkini flysch succession.

Fig. 3 - Other trace fossils on soles of turbiditic sandstone beds from the Brkini Flysch. A. *Lorenzina* isp., 167P9, Ostrožno Brdo. B. *Scolicia strozzii*, Janežovo Brdo. C. *Paleodictyon arvense* BARBIER, Janežovo Brdo. D. *Planolites* isp. (P) and *Cosmorhaphie* isp., 167P7, Janežovo Brdo. E. *Protapaleodictyon* isp., Fabci. F. *Paleodictyon goetzingeri* VIALOV & GOLEV (lower left corner), *Helminthopsis* isp. (H) and *Ophiomorpha annulata* (KŚIAŻKIEWICZ) (O), 167P5, Janežovo Brdo. B, C, E - field photographs. Scale bars = 1 cm.

- *Altre tracce fossili alla base di arenarie torbiditiche del Flysch di Brkini*. A. *Lorenzina* isp., 167P9, Ostrožno Brdo. B. *Scolicia strozzii*, Janežovo Brdo. C. *Paleodictyon arvense* BARBIER, Janežovo Brdo. D. *Planolites* isp. (P) e *Cosmorhaphie* isp., 167P7, Janežovo Brdo. E. *Protapaleodictyon* isp., Fabci. F. *Paleodictyon goetzingeri* VIALOV & GOLEV (lato inferiore sinistro). *Helminthopsis* isp. (H) e *Ophiomorpha annulata* (KŚIAŻKIEWICZ) (O), 167P5, Janežovo Brdo. B, C, E - Foto di affioramento. Scala di riferimento = cm 1.



## Systematic description of trace fossils

### Simple and branched structures

*Ophiomorpha annulata* (KSIAŹKIEWICZ, 1977) (figs. 2A, B, 3F, 4A, B, 5B) is an exichnial, hypichnial or rarely epichnial, straight to slightly winding, horizontal, rarely oblique to vertical, cylindrical, branched walled trace fossil preserved in full-relief, 2.5-5 mm in diameter. It is filled mostly with sandstone. In flysch deposits this trace fossil rarely displays a wall covered with small oval knobs, which are characteristic of the ichnogenus *Ophiomorpha* (UCHMAN, 1995). The horizontal parts are concentrated mostly along the bedding surfaces. *O. annulata* is produced probably by small crustaceans.

*Ophiomorpha rudis* (KSIAŹKIEWICZ, 1977) (figs. 4B, 5A, B) is preserved as horizontal, oblique to vertical cylindrical, walled or unwalled, sand-filled, branched tunnels, 9-22 mm in diameter. Commonly, they penetrate horizontally along bedding surfaces. The exterior part of tunnels is smooth or displays indistinct, irregular sandy granules. *O. rudis* penetrates through at least a few turbidites, of which the total thickness can exceed 1 m. It is produced probably by crustaceans (UCHMAN, 2001).

?*Planolites* isp. (fig. 3D) is preserved as simple hypichnial straight or slightly curved strings, which are about 1.0 mm wide. For discussion of *Planolites* see PEMBERTON & FREY (1982) and KEIGHLEY & PICKERILL (1995).

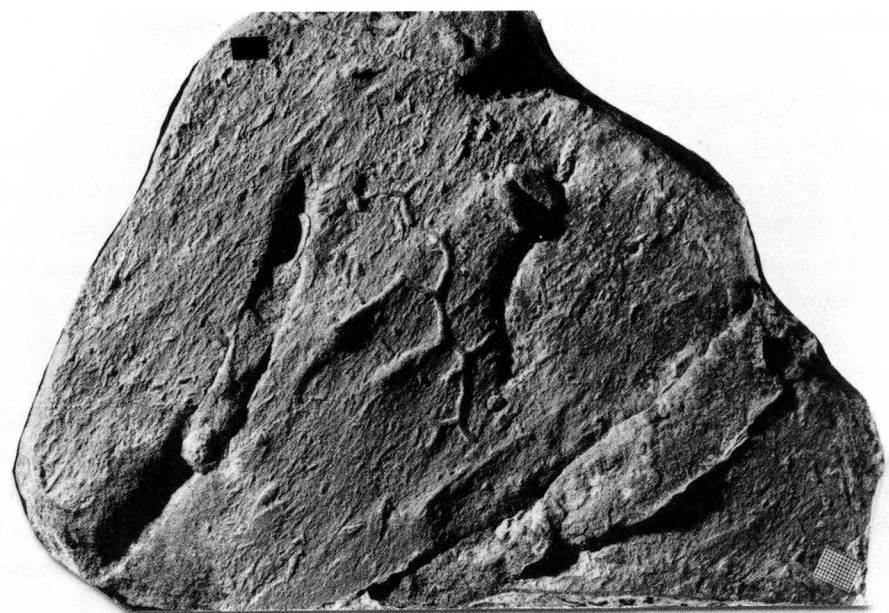
### Radial structures

*Lorenzinia* isp. (fig. 3A) is composed of hypichnial simple ridges and knobs, which are radially arranged in a wreath around central flat area. The ridges are as much as 6 mm wide and 1.5 mm high. The wreath is maximally about 50 mm wide. The knobs and ridges are irregularly distributed in the wreath. For discussion of *Lorenzinia* see UCHMAN (1998).

Fig. 4 - Graphoglyptid and other trace fossils on soles of turbiditic sandstone beds from the Brkini Flysch at Svety Duh. A. *Paleodictyon maximum* (EICHWALD) and *Ophiomorpha annulata* (KSIAŹKIEWICZ) (right side), 167P3. B. *Paleodictyon arvense* BARBIER, *Ophiomorpha annulata* (KSIAŹKIEWICZ) (lower left corner) and *Ophiomorpha rudis* (KSIAŹKIEWICZ) (right side), 167P1. C. *Megagraption submontanum* (AZPEITIA MOROS) 167P6. Scale bars = 1 cm.

- *Grafoglyptidi ed altre tracce fossili alla base di arenarie torbiditiche presso Svety Duh (Flysch di Brkini)*. A. *Paleodictyon maximum* (EICHWALD) e *Ophiomorpha annulata* (KSIAŹKIEWICZ) (lato destro), 167P3. B. *Paleodictyon arvense* BARBIER, *Ophiomorpha annulata* (KSIAŹKIEWICZ) (lato inferiore sinistro) e *Ophiomorpha rudis* (KSIAŹKIEWICZ) (lato destro), 167P1. C. *Megagraption submontanum* (AZPEITIA MOROS), 167P6. Scala di riferimento = cm 1.





A



B

### *Spreite structures*

*Phycosiphon incertum* FISCHER-OOSTER, 1858 is observed in horizontal polished slabs as curved endichnial lobes, 2 mm wide and up to 20 mm long, encircled by a marginal tunnel, which is 0.7-1.0 mm wide. In vertical cross-sections it occurs as patches of dark, elongated spots, about 1 mm in diameter, surrounded by a light mantle. More information about *Phycosiphon* can be found in WETZEL & BROMLEY (1994).

*Zoophycos* isp. is a planar spreite structure, at least 5 cm across, composed of spreite laminae and a thin marginal tunnel.

### *Winding and meandering structures*

?*Cosmorhapha* isp. (fig. 3D) is a fragment of a hypichnial meandering semicircular string, about 2 mm wide, preserved in semi-relief. The meanders are at least 17 mm deep, and their amplitude attains about 15 mm.

?*Helminthopsis* isp. (fig. 3F) is a hypichnial, loosely meandering semicircular ridge, about 2.0 mm wide, preserved in semi-relief.

*Scolicia strozzii* (SAVI & MENEGHINI, 1850) (fig. 3B) is a hypichnial, low, smooth bilobate ridge, about 15 m wide, with a central wide, gently sloped furrow. It is preserved in semi-relief.

### *Branched winding and meandering structures*

*Protopaleodictyon* isp. (fig. 3E) is a hypichnial meandering string with branches. It is about 2 mm wide, and preserved in semi-relief.

?*Urohelminthoida* isp. (fig. 2B) is a hypichnial, poorly preserved delicate meandering string with indistinct protrusions at the end of the meanders. The meanders are deep and narrow. The string is less than 1 mm wide, and the meanders are about 10 mm deep.

Fig. 5 - Graphoglyptid and non-graphoglyptid trace fossils on soles of turbiditic sandstone beds from the Brkini Flysch. A. *Paleodictyon goetzingeri* VIALOV & GOLEV and *Ophiomorpha rudis* (KSIAZKIEWICZ) (thick cylinders), 167P4, Svety Duh. B. *Paleodictyon goetzingeri* VIALOV & GOLEV, *Ophiomorpha annulata* (KSIAZKIEWICZ) (thinner ridges) and *Ophiomorpha rudis* (KSIAZKIEWICZ) (thick ridges), Fabci, field photograph. Scale bars = 1 cm.

- *Tracce fossili di grafoglitidi e no alla base di arenarie torbiditiche del Flysch di Brkini. A. Paleodictyon goetzingeri* VIALOV & GOLEV e *Ophiomorpha rudis* (KSIAZKIEWICZ) (*spessi cilindri*) 167P4, Svety Duh. B. *Paleodictyon goetzingeri* VIALOV & GOLEV, *Ophiomorpha annulata* (KSIAZKIEWICZ) (*creste sottili*) e *Ophiomorpha rudis* (KSIAZKIEWICZ) (*creste spesse*) Fabci, foto di affioramento. Scala di riferimento = cm 1.

### Net structures

*Megagraption submontanum* (AZPEITIA MOROS, 1933) (fig. 4C) is hypichnial, incompletely preserved irregular net, composed of a winding semicircular string. Meshes of the net are at least 30 mm wide, and the string is about 2.0 mm wide.

*Paleodictyon arvense* BARBIER, 1956 (figs. 3D, 4B) is a hypichnial hexagonal net composed of a convex semicircular string preserved in semi-relief. Meshes of the net are maximally 13-19 mm wide, and the string is about 1.5-1.7 mm wide.

*Paleodictyon maximum* (EICHWALD, 1868) (fig. 4A) is a hypichnial hexagonal net composed of a convex semicircular string preserved in semi-relief. Meshes of the net are maximally 9-13 mm wide, and the string is about 1.6-1.8 mm wide.

*Paleodictyon goetzingeri* VIALOV & GOLEV, 1965 (figs. 3F, 5A, B) is a hypichnial hexagonal net composed of a convex semicircular string preserved in semi-relief. Meshes of the net are maximally 16-22 mm wide, and the string is about 1.4-1.5 mm wide.

### Discussion

Distribution of the trace fossils is shown in table I. The ichnoassemblage is distinctly dominated by *Ophiomorpha annulata* and *Ophiomorpha rudis*, which occur very frequently and frequently in all the studied outcrops. The other trace fossils are rare or very rare. *Helminthopsis* isp. occurs in 4 of 10 outcrops and *Phycosiphon incertum* in 3 of 10 outcrops. The remaining ichnotaxa were found only in one or two outcrops. Most of the trace fossils have been observed on the bedding surfaces. *Ophiomorpha* was seen also on differently oriented parting surfaces.

The ichnoassemblage is atypical of other Paleogene flysch deposits, including those from the Julian Pre-Alps (TUNIS & UCHMAN, 1992; 1996a), Istria (TUNIS & UCHMAN, 1996b) or the Carnian Pre-Alps (TUNIS & UCHMAN, 1998). The latter are much more diverse, with less abundant *Ophiomorpha*, and more common graphoglyptids (e.g., *Paleodictyon*, *Helminthorhapha*, *Cosmorhapha*). Their ichnoassemblages are typical of the deep-sea *Nereites* ichnofacies (SEILACHER, 1967), especially of the *Paleodictyon* ichnosubfacies, which occurs mostly in "normal" sandy flysch deposits (SEILACHER, 1974). The Brkini Flysch ichnoassociation is typical of the *Ophiomorpha rudis* ichnosubfacies, which was distinguished by UCHMAN (2001). It occurs mainly in thick-bedded flysch, mostly of the channel and proximal lobe facies. The lithology of the studied outcrops suggests facies of this type. It is probable, that the *Ophiomorpha rudis* ichnosubfacies has a bathymetric meaning, i.e. it indicates a relatively shallower deep-sea environment in the upper (proximal) part of the depositional system, in comparison to the other ichnosubfacies of the *Nereites* ichnofacies.

Composition of the studied ichnoassemblage was influenced by several ecological and

Ichnotaxa	Outcrops									
	1	2	3	4	5	6	7	8	9	10
<i>Ophiomorpha annulata</i>	A	A	A	A	A	A	A	A	A	A
<i>Ophiomorpha rudis</i>	C	C	C	C	C	C	C	C	C	C
? <i>Planolites</i> isp.			R							
<i>Phycosiphon incertum</i>						VR		VR		VR
<i>Zoophycos</i> isp.	VR									
<i>Lorenzina</i> isp.				VR						
? <i>Cosmorhapha</i> isp.			VR							
? <i>Helminthopsis</i> isp.			VR				VR		VR	VR
<i>Scolicia strozzii</i>			R							
<i>Protopaleodictyon</i> isp.	VR									
? <i>Urohelminthoida</i> isp.	VR									
<i>Megagraption submontanum</i>			VR							VR
<i>Paleodictyon arvense</i>			VR							VR
<i>Paleodictyon goetzingeri</i>	VR		?VR							VR
<i>Paleodictyon maximum</i>										VR

Tabl. I - Occurrence of trace fossils in the flysch of the Brkini area. Abundance: VR - very rare; R - rare; C - frequent; A - very frequent. Outcrops: 1 - Fabci; 2 - Nova Vas; 3 - Janežovo Brdo; 4 - Ostrožno Brdo; 5 - Gorne Ležee; 6 - potok Prem; 7 - Prelože; 8 - Misliče; 9 - Gradišnica; 10 - Svety Duh.

- Presenza di tracce fossili nel flysch dell'area di Brkini. Abbondanza: VR - molto raro; R - raro; C - frequente; A - molto frequente. Sezioni: 1 - Fabci; 2 - Nova Vas; 3 - Janežovo Brdo; 4 - Ostrožno Brdo; 5 - Gorne Ležee; 6 - potok Prem; 7 - Prelože; 8 - Misliče; 9 - Gradišnica; 10 - Svety Duh.

taphonomic factors. The probable crustacean trace makers of *Ophiomorpha* penetrated deeply (even more than 1 m) into the sandy sediment, most probably to find buried plant detritus that was matured by microbes for hundreds or thousands of years, maybe in disoxic conditions. The crustaceans were able to pump oxygenated water into the open burrow system. Their burrows are most dense in the upper part of turbiditic or fluxoturbiditic beds, where the plant detritus is most abundant. In this part of the beds the burrows form horizontal mazes joined by rare vertical to oblique shafts passing up through the overlying sandstone beds. Therefore, the domination of sandstones and high content of plant detritus in the sediments favoured the *Ophiomorpha* trace makers.

High energy flows in channels and proximal lobes caused common erosion that was commonly stronger than the delicate scouring in the thin- or thick-bedded flysch. This reduced the preservational potential of graphoglyptids, which require delicate scouring and casting (e.g., SEILACHER, 1977). The strong erosion removed also the muddy substrate that is typical for graphoglyptids and for most other predepositional flysch trace fossils (KERN, 1980). All

these phenomena can explain the low contribution of graphoglyptids and the unusual abundance of *Ophiomorpha* in the Brkini Flysch.

## Conclusion

The ichnoassemblage of the Brkini Flysch, dominated by *Ophiomorpha annulata* and *Ophiomorpha rudis*, is typical of the *Ophiomorpha rudis* ichnosubfacies of the Nereites ichnofacies. This ichnosubfacies indicates probably the shallower part of the deep-sea depositional system.

The ichnoassemblage was influenced by deep burial of plant organic detritus, which favoured deeply burrowing *Ophiomorpha* crustacean tracemakers.

Deeperosion during deposition of thick beds, especially the muddy substrate, reduced occurrence of graphoglyptids.

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