GEOLOGICA CARPATHICA, AUGUST 2006, 57, 4, 279–294

Sedimentology, paleoichnology and sequence stratigraphy of a Karpatian sandy facies (Salgótarján Lignite Formation, N Hungary)

ÁRPÁD DÁVID[1], ZOLTÁN PÜSPÖKI[2], PÉTER KÓNYA[3], LÁSZLÓ VINCZE[2], MIKLÓS KOZÁK[2] and RICHARD W. McINTOSH[2]

[1]Károly Eszterházy College, Department of Geography, Leanyka út 6, 3300 Eger, Hungary; davida@ektf.hu
[2]Debrecen University, Department of Mineralogy and Geology, Egyetem square 1, 4032 Debrecen, Hungary
[3]Geological Institute of Hungary, Stefánia út. 14, 1143 Budapest, Hungary

(Manuscript received January 24, 2005; accepted in revised form December 8, 2005)

Abstract: Detailed sedimentological and paleoichnological investigations were done on the sandy facies of the sequence stratigraphically well researched coal-bearing sediment series (Salgótarján Lignite Formation) in the East Borsod Basin (Northern Hungary) to provide data for paleoenvironmental reconstruction. Collection and identification of bioerosional and bioturbational reworked trace fossils were carried out within 9 stratigraphic levels of the outcrops representing 5 parasequences from the 25 of the entire series and reaching about 26 m in vertical extension. 11 sedimentological units were dissected; 11 ichnogenera and 25 ichnospecies were identified and documented in the series. Regarding the sedimentological data, the dominant facies zone of the sedimentation was the shoreface, mainly its upper and middle, sometimes its lower part, while at the lower and/or uppermost parts of the parasequences some formations of fore- and backshore and even lagoonal materials as well as open marine (offshore) sediments can appear. 4 ichnofacies, namely the *Entobia*, *Skolithos*, *Cruziana* and *Glossifungites* were determined and described by paleoichnological and sedimentological terms. Regarding these results in the framework of the sequence stratigraphic model, it can be concluded that in the researched series the *Entobia* ichnofacies is related to the transgressive bars below the flooding surfaces of the subsequent parasequence, *Skolithos* and *Glossifungites* ichnofacies are related to the foreshore, upper and middle shoreface of the prograding parts of the parasequences while the *Cruziana* ichnofacies is related to the lower shoreface of the prograding parts of the aggrading parasequences.

Key words: Karpatian, Hungary, sequence stratigraphy, paleoichnology.

Introduction and aims

In the last 5 years the sequence stratigraphic analysis of the 200–400 m thick coal-bearing Miocene Karpatian series in Northern Hungary (Salgótarján Lignite Formation) was carried out, one of the essential requirements of which was the adequate description of its facies. The former paleoecological reconstructions of the series (e.g. Báldi 1973; Bohn-Havas 1985; Korecz-Laky 1985) focused mainly on the silty facies of lagoons and shallow marine environments. In order to describe the bio- and lithofacies characteristics of the sandy facies poor in fossils, sedimentological and paleoichnological investigations were made.

Sedimentological and paleoichnological investigations have been performed on well exposed outcrops along the about 60 m high walls of a sand pit, which represents an important part of the whole series and was interpreted in detail in the course of sequence-stratigraphic research (Fig. 1).

The aims of this paper are:

— to identify the existing ichnofacies on the basis of a joint documentation of the sedimentological and paleoichnological data, and

— to determine the relationship between sequence stratigraphic position and the contained ichnofacies of the analysed sedimentary units giving their paleoenvironmental status.

Stratigraphic background

The Salgótarján Lignite Formation was formed during the Karpatian Stage of the Miocene as a siliciclastic series of the TB2.2 (Haq et al. 1988) or Bur-4 (Vakarcs et al. 1998) eustatic transgression with lagoonal (oligohaline) and shallow marine (polyhaline) silty intercalations and with coal seams in the oligohaline facies (Püspöki 2002) (Fig. 2).

The series has a cyclic appearance, and as a result of sequence stratigraphic analysis we could detect 25 parasequences in the whole series. On the basis of the spatial shifting of sedimentary circumstances, six important transgressions and subsequent progradations can be separated (Püspöki 2001) (Fig. 3). The series can be interpreted as a transgressive and early highstand systems tract of one eustatic 3rd-order sequence. Within this sequence, four 4th-order cycles can be separated, three of which have tectonic determination. The parasequences are 5th-order cycles generated by the precession fluctuations. The series has an aggrading character from the upper part of the 11th

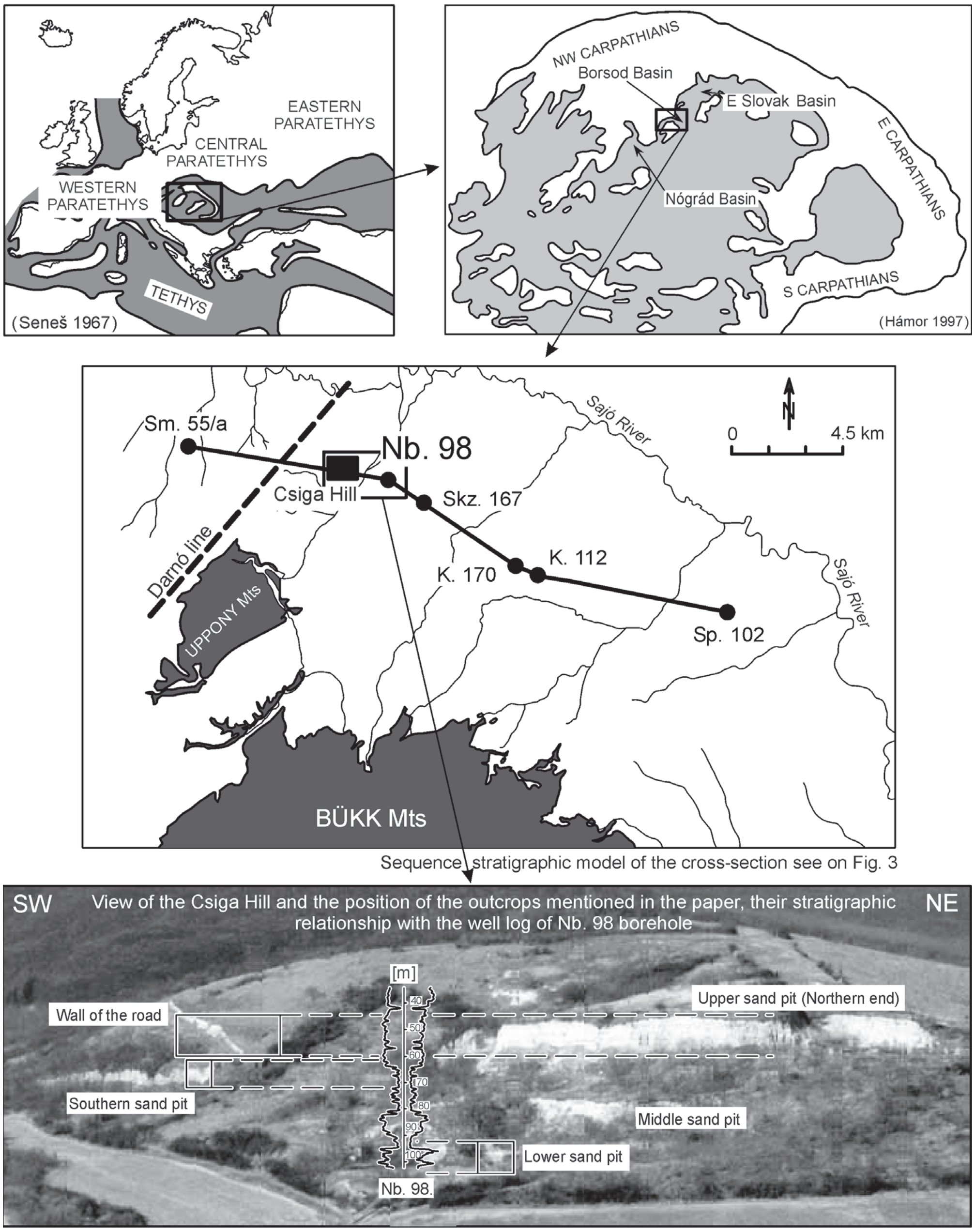


Fig. 1. Paleogeograpy and geographical position of Csiga Hill (Bánhorváti).

parasequence to that of the 16th. The important influence of small scale eustatic oscillations refers to the elevated marginal position of the sub-basin and to a relatively intensive sedimentation, which can lead to the thickening of the 5th-order cycles and to the occurrence of the oscillating character. The coal beam V was formed by a retrogradational period while the others (IV–I) were formed by progradational events, which is evidenced both by the facies pattern of the enclosing sediment series and the geometry of the coal beams like duplication, small horizontal extension in the case of coal beam V (Püspöki 2001).

The series of the Csiga-Hill is exposed in four sand pits and in a nearby road-cut (Fig. 1). The lithological column correlated with the well log of the borehole Nb 98 and the results of the material research are shown in Fig. 4. It is well observable that the exposed series represents the 8th, 11th and 12th parasequences of the series. Unfortunately the middle sand pit representing the 9th and 10th parasequences of the series, because of its poor conservation, is not accessible now.

Methods

Sedimentological investigations were made partly in the field with documentation of the stratification, and partly in the laboratory as the determination of grain size distribution and the measurement of the carbonate content.

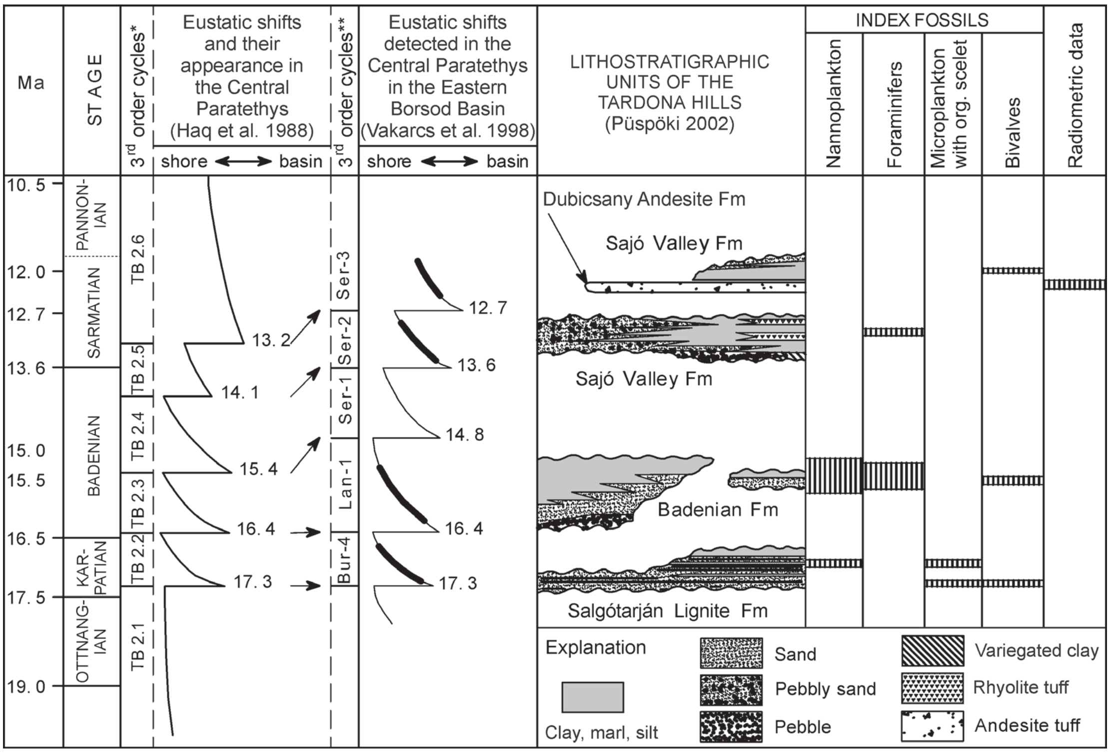


Fig. 2. Stratigraphic position of the Salgótarján Lignite Formation according to the eustatic shifts of the Central Paratethys.

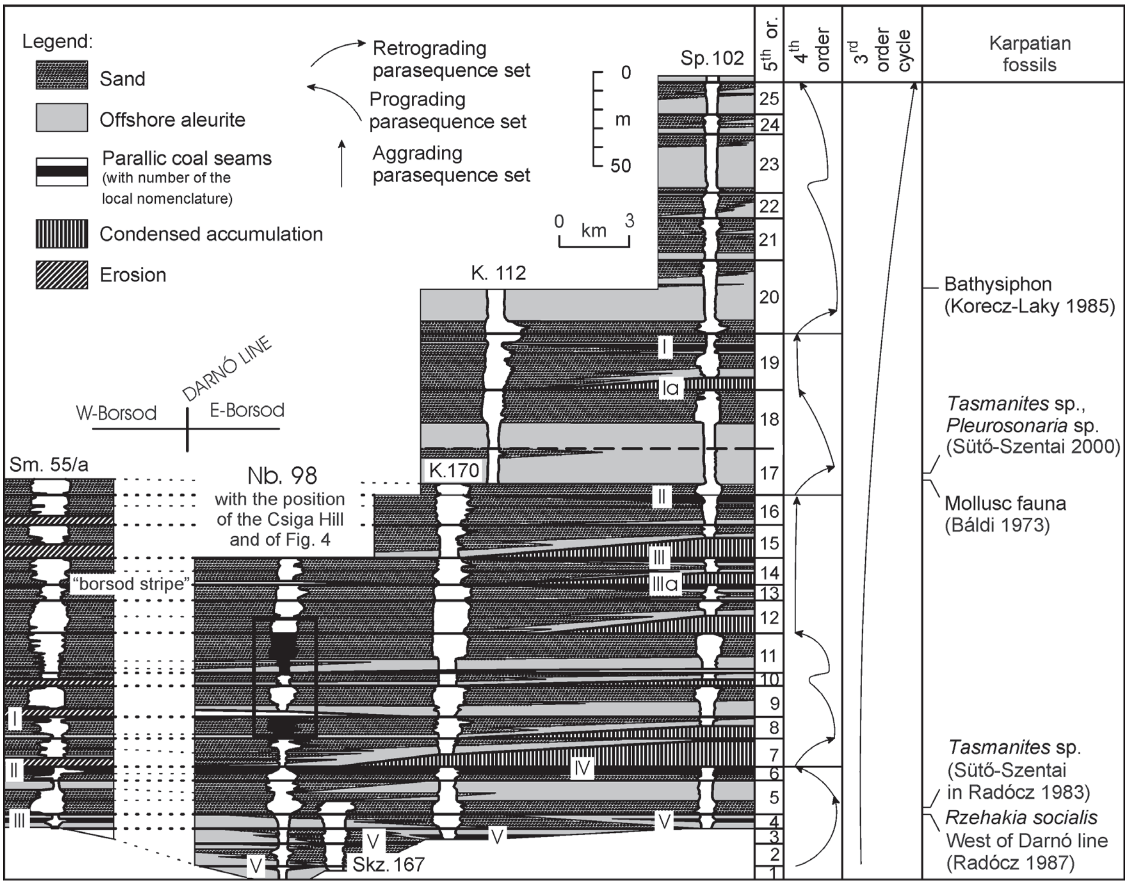


Fig. 3. Sequence stratigraphic model of the Karpatian coal-bearing sediment series in the East Borsod Basin (for the strike of the cross-section see Fig. 1).

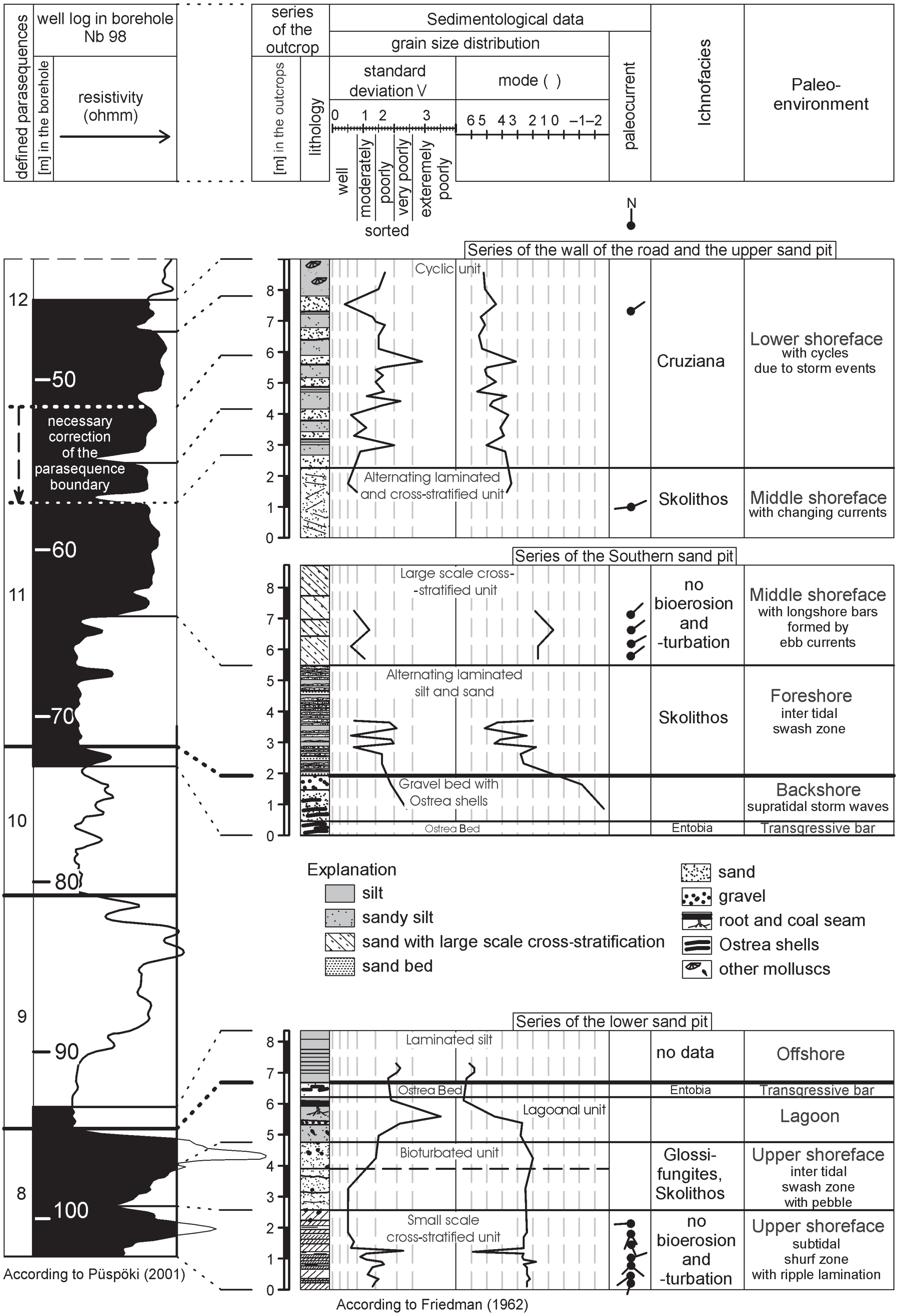


Fig. 4. Sedimentological and ichnological summary of the material research.

Investigations of bioerosion were made on the material of an *Ostrea* shell Bed by collection of bulk sample of more than 200 *Ostrea* valves. The preservation of the collected material was relatively poor (fragmented) and only a certain portion was represented by complete *Ostrea* valves, dominantly right, subdominantly left ones. Traces of bioerosion were observed by stereomicroscope, identification of them was made using ichnotaxonomical data by Seilacher (1953, 1969), Boekschoten (1966, 1970), Bromley (1970, 1992), Tasch (1973), Warme (1975), Bromley & D'Alessandro (1983, 1984), Kelly & Bromley (1984), Boucot (1990), Bromley & Martinell (1991), De Gibert et al. (1998), Farinati & Zavala (2002). To recognize the inner structure of the ichnospecies, epoxy casts were made with ARALDIT AY 103 and HARTER HY 956 components (Golubic et al. 1970). The preparation was carried out at the laboratory of Károly Eszterházy College, Department of Geography, Eger.

Observation of the bioturbation was carried out by large scale (cm, dm, inch) mapping and in situ photo documentation of the outcrops in the sand pits. The identifications of the ichnospecies were made on photos, considering the ichnotaxonomical data by Seilacher (1953, 1967), Crimes & Harper (1970), Ekdale et al. (1984), Bromley (1990), Bottjer & Doser (1992), Curran (1992), Ekdale (1992), Maples & West (1992), de Gibert & Martinell (1995, 1999), Nielsen et al. (1996), Nara (1997, 2002). The ichnofabric index (ii) has been determined by using the classification of Droser and Bottjer (Droser & Bottjer 1986).

Results

Sedimentological description of the series

The following description of the *sedimentary units* (Fig. 4) is focused on the well preserved parts of the series suitable for detailed analysis.

Series of the lower sand pit

Small scale cross-stratified unit: The thickness is 2.4 m. Moderately well sorted ($\sigma = 0.64–1.67$) fine sand (mode = 0.18 mm) and sandy fine pebbles with small scale ripple lamination, and with some clayey silt along the bed surfaces. Bioerosion cannot be seen, bioturbation is very rare (ii 2).

Bioturbated unit: The thickness is 2.2 m. Moderately sorted ($\sigma = 1.14$) and poorly bedded sand, gravelly sand. Bioerosion is lacking, bioturbation is strong (ii 3–4).

Lagoonal unit: The thickness is 1.3 m. Various beds of poorly sorted silty sand, lagoonal clay, and clayey brown coal. The overlying formation is a poorly preserved *Ostrea* Bed with clayey matrix. Bioerosion can be seen on the material of the *Ostrea* Bed (sponge and worm borings).

Ostrea Bed (poorly preserved): The thickness is 25–30 cm. The *Ostrea* valves are mainly right ones, their size is not more than 15 cm and lay on each other with their convex side upwards, without any matrix. Bioturbation cannot be seen, bioerosion is strong. The inner sides of the valves are also bioturbated.

Laminated silt: Silty clay containing an association of brackish foraminifers, the dominant species of which are *Rotalia beccarii* and *Nonion granosum*.

Series of the Southern sand pit

Ostrea Bed (well preserved): The thickness is 30–50 cm. The *Ostrea* valves are mainly left ones, their size is not more than 15 cm and lay on each other with their convex side upwards, without any matrix. Bioturbation cannot be seen, bioerosion is strong.

Gravel bed with Ostrea valves: The thickness is 1.4 m. Moderately sorted fine- and medium-sized gravel, gravelly sand with slight bedding. Resedimented *Ostrea* valves and driftwood fragments can also be seen. Both bioerosion and bioturbation are characteristic.

Alternating laminated silt and sand: The thickness is 3.6 m. Intercalations of thin layers of clayey silt and moderately sorted ($\sigma = 1.074$) medium-sized sand (mode = 0.142–0.277 mm). Bioerosion is missing, but bioturbation is characteristic.

Large scale cross-stratified unit: The thickness is 4 m. Moderately sorted ($\sigma = 0.919$) medium-sized sand (mode = 0.262–0.605 mm) with large scale cross-bedding and with thin silt intercalations along the cross-laminae. The thickness of beds is about 0.5 m. Bioerosion and bioturbation cannot be seen.

Series of the wall of the road and the upper sand pit

Alternating laminated and cross-stratified unit: Moderately well sorted $\sigma = 0.684$) fine sand (mode = 0.074–0.095 mm). The cross-bedding is variable in direction with varying angles, and is locally replaced by laminar structures, sometimes with intercalations of clasts with clayey-silty matrix (storm deposits). Bioerosion is missing, bioturbation is significant.

Cyclic unit: This has a thickness of more than 10 m. Rhythmic intercalations of moderately sorted sand (mode = 0.042–0.114 mm, $\sigma = 1.13$) and poorly sorted clayey sandy silt (mode = 0.01–0.04, $\sigma = 1.63$). The surfaces of the cycles are eroded. Bioerosion is missing, however bioturbation is intensive. *Ophiomorpha* is the dominant ichnogenus. It indicates lower shoreface within which the material from the middle and upper shoreface had also been transported during storms.

Trace fossil description

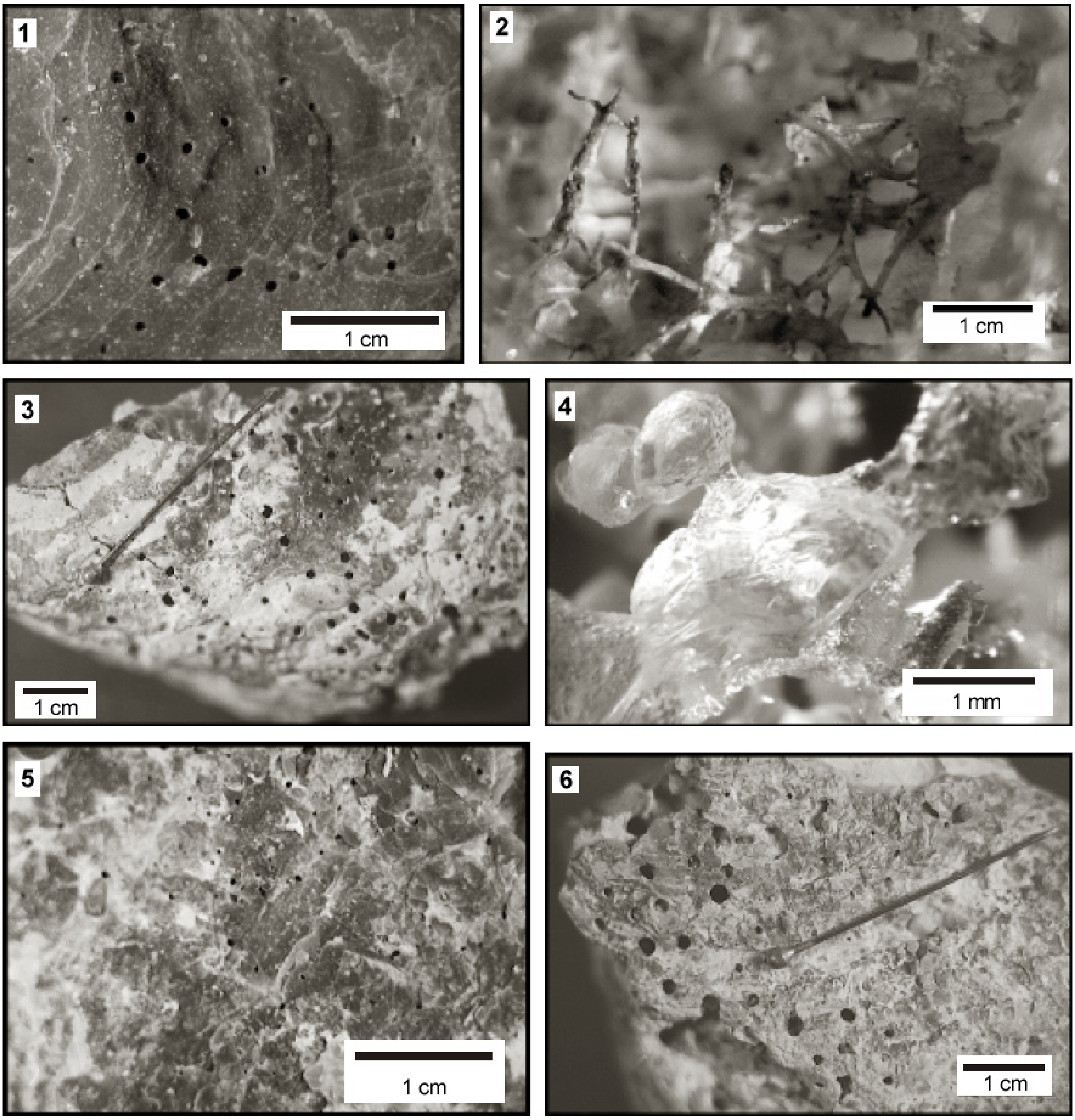
Inventory Numbers are related to the collection at the Department of Geography Károly Eszterházy College, Eger.

Bioerosion

Ichnogenus *Entobia* Bronn, 1838

Entobia cateniformis Bromley et D'Alessandro, 1984

(Fig. 5.1,2)



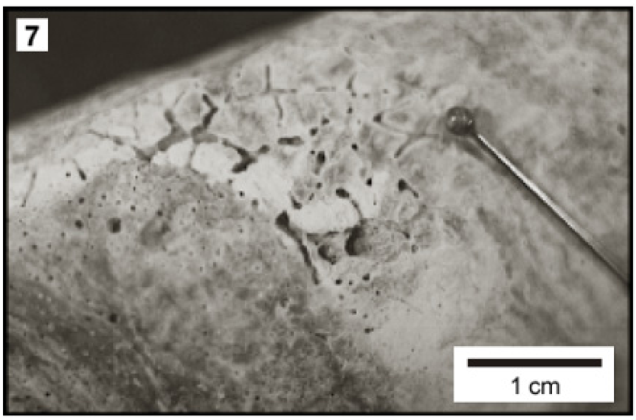


Fig. 5. Trace fossils from the Csiga Hill sand pit. Bioerosion: **1** — *Entobia cateniformis* Bromley et D'Alessandro, 1984 in right valve of *Ostrea* sp. Collected at Csiga Hill middle sand pit. **2** — Epoxy cast of *Entobia cateniformis* Bromley et D'Alessandro, 1984, exploratory threads, growth phase A. Collected at Csiga Hill middle sand pit. **3** — *Entobia geometrica* Bromley et D'Alessandro, 1984 in right valve of *Ostrea* sp. Collected at Csiga Hill middle sand pit. **4** — Epoxy cast *Entobia geometrica* Bromley et D'Alessandro, 1984, growth phase C. Collected at Csiga Hill middle sand pit. **5** — *Entobia megastoma* Fischer, 1868 in right valve of *Ostrea* sp. Collected at Csiga Hill middle sand pit. **6** — *Entobia paradoxa* Fischer, 1868 in right valve of *Ostrea* sp. Collected at Csiga Hill middle sand pit. **7** — *Entobia ovula* Bromley et D'Alessandro, 1984 in right valve of *Ostrea* sp. Collected at Csiga Hill middle sand pit.

Substrate: poorly preserved *Ostrea* valves from the *Ostrea* Bed of the pit. The borings are stenomorphic. The stenomorph character is indicated by the small diameter of the apertures and the length of their canal. The chambers are not as elongated as in the case of the idiomorphic forms. Only the B growing phase occurred in the examined material. Collecting site: *Ostrea Bed of the Southern sand pit*. Inv. Nos. E 25, E 28, E 75.

Entobia geometrica Bromley et D'Alessandro, 1984
(Fig. 5.3,4)

Substrate: poorly preserved *Ostrea* valves from the *Ostrea* Bed of the pit. The forms are stenomorphic. This is indicated by the relatively small diameter of the apertures, by the shape of the apertural channels, by the small diameter of the chambers and by the small number of the canal connecting the chambers. Collecting site: *Ostrea Bed of the Southern sand pit*. Inv. Nos. E 23, E 54.

Entobia laquea Bromley et D'Alessandro, 1984

Substrate: poorly preserved *Ostrea* valves from the *Ostrea* Bed of the pit. Stenomorphic forms. Regarding the shape of the chambers the spherical, slightly flattened forms are dominant. The sizes of the apertures and chambers are different from those of idiomorphic forms. Collecting site: *Ostrea Bed of the Southern sand pit*. Inv. Nos. E 65.

Entobia megastoma (Fischer, 1868)
(Fig. 5.5)

Substrate: poorly preserved *Ostrea* valves from the *Ostrea* Bed of the pit. Stenomorphic form. It is proved by the number of the canals and by the lack of connection between them. The diameters of the apertures also differ from those of the idiomorphic forms. Collecting site: *Ostrea Bed of the Southern sand pit*. Inv. Nos. E 27, E 30, E 32, E 70.

Entobia paradoxa (Fischer, 1868)
(Fig. 5.6)

Substrate: also an *Ostrea* valve from the *Ostrea* Bed of the pit. The apertures are relatively small; their diameter is between 0.4 and 0.8 mm. Their shape is rounded. Apertural canals are short. All of these canals are connected with a chamber. The chambers form a one-level net and are arranged more or less parallel to the surface of the substrate. The sponge colony reached growing phase B. The shape of the chambers is potato-like, elongated, amoeboid. Occurrence of thin apophyses is general. Collecting site: *Ostrea Bed of the Southern sand pit*. Inv. Nos. E 24.

Entobia ovula Bromley et D'Alessandro, 1984
(Fig. 5.7)

Substrate: poorly preserved *Ostrea* valves from the *Ostrea* Bed of the pit. It is a camerate entobian with rounded or oval apertures. The chambers are situated in large numbers and are arranged close to each other. The chambers are connected with extremely short canals. Characteristic is the development of small barrel-like chambers. The exploratory threads are slightly developed. Collecting site: *Ostrea Bed of the Southern sand pit*. Inv. Nos. E 41, E 42.

Entobia isp. indet.

Substrate: poorly preserved *Ostrea* valve from the *Ostrea* Bed of the pit. The character of the substratum inhibited the development of the idiomorphic form of the bioerosion for this reason these cannot be identified at ichnospecies level. Collecting site: *Ostrea Bed of the Southern sand pit*. Inv. Nos. E 26.

Ichnogenus *Caulostrepsis* Clarke, 1908
Caulostrepsis taeniola Clarke, 1908
(Fig. 6.1)

Substrate: poorly preserved *Ostrea* valves from the *Ostrea* Bed of the pit. The apertures are usually eight-shaped. The gallery is cylindrical. Lengths vary between 3 mm and 7 mm. Smaller individuals are tongue-shaped over the whole length, while the longer ones become thinner at the vicinity of the aperture than at the distal end. In most cases the structure lies within a plane. The surface is smooth. Collecting site: *Ostrea Bed of the Southern sand pit*. Inv. Nos. E 29, E 31, E 58, E 65, E 70.

Ichnogenus *Maeandropolydora* Voigt, 1965
Maeandropolydora decipiens Voigt, 1965
(Fig. 6.2)

Substrate: five *Ostrea* valves. Apertures are rounded. The irregularly winding galleries are split. Width is between 0.8 and 1.1 mm. Length is around 1.5 cm. The most characteristic feature of the ichnospecies are the pouches that can be recognized clearly. Collecting site: *Ostrea Bed of the Southern sand pit*. Inv. Nos. Bh 6, Bh 47, Bh 54, Bh 101, Bh 171.

Maeandropolydora sulcans Voigt, 1965
(Fig. 6.3)

Substrate: seven *Ostrea* valves collected from the *Ostrea* shelly Bed of the outcrop. The diameter of the long, cylindrical galleries is between 0.8 and 1.2 mm. They extend winding irregularly and forming loops of various sizes, which turn back and contact with themselves. The galleries in the *Ostrea* valves in most instances imitate the changes in the surface of the substrate. Collecting site: *Ostrea Bed of the Southern sand pit*. Inv. Nos. Bh 15, Bh 18, Bh 35, Bh 149, Bh 204, Bh 205, Bh 700.

Maeandropolydora elegans Bromley et D'Alessandro, 1984 (Fig. 6.4)

Substrate: eleven *Ostrea* valves collected from the *Ostrea* shelly Bed of the outcrop. The tubes usually ex-

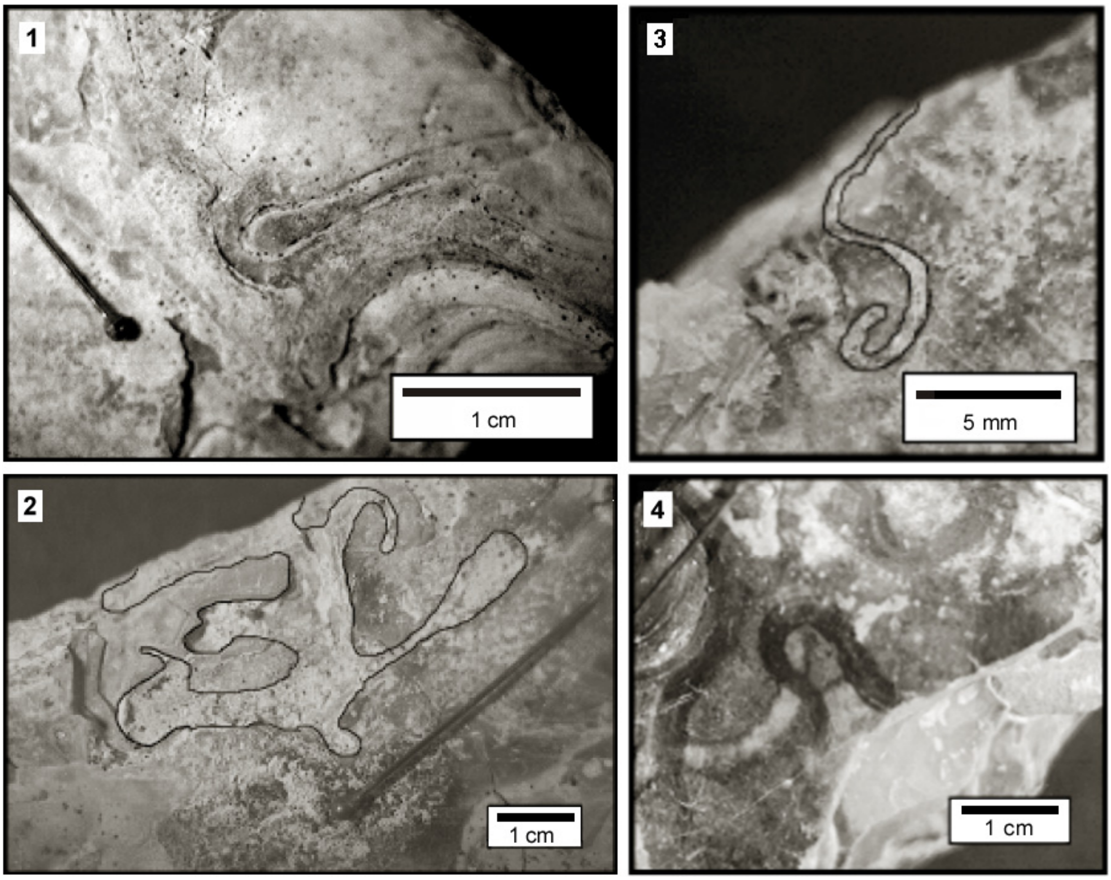


Fig. 6. Trace fossils from the Csiga Hill sand pit. Bioerosion: **1** — *Caulostrepsis taeniola* Clarke, 1908 in inner side of left valve of *Ostrea* sp. Collected at Csiga Hill middle sand pit. **2** — *Maeandropolydora decipiens* Voigt, 1965 in outer side of right valve of *Ostrea* sp. Collected at Csiga Hill middle sand pit. **3** — *Maeandropolydora sulcans* Voigt, 1965 in outer side of right valve of *Ostrea* sp. Collected at Csiga Hill middle sand pit. **4** — *Maeandropolydora elegans* Bromley et D'Alessandro, 1983 in inner side of right valve of *Ostrea* sp. Collected at Csiga Hill middle sand pit.

tend over relatively great distances in pairs parallel with each other. Irregular winding in different directions is characteristic. Collecting site: *Ostrea Bed of the Southern sand pit*. Inv. Nos. Bh 80, Bh 95, Bh 111, Bh 140, Bh 141, Bh 142, Bh 145, Bh 334, Bh 544, Bh 601, Bh 804.

Ichnogenus *Gastrochaenolites* Leymeriere, 1842
Gastrochaenolites lapidicus Kelly et Bromley, 1984
(Fig. 7.1)

This is an elongated oval dwelling structure with smooth surfaces. The cross-section is rounded all along the tube except the immediate surroundings of the aperture and at the base of the erosion where it may be oval. The biggest diameter of a boring can be observed in the equatorial region of the chamber. Collecting site: *Ostrea Bed of the Southern sand pit*. Inv. Nos. E 29.

Gastrochaenolites cluniformis Kelly et Bromley, 1984
(Fig. 7.2)

This boring has a smooth surface. Along the main chamber extend a primary incision opposite to which a less developed secondary incision can also be observed at the other side. The aperture and the neck are rounded or oval, the base is cut in two. Collecting site: *Ostrea Bed of the Southern sand pit*. Inv. Nos. E 70.

Gastrochaenolites torpedo Kelly et Bromley, 1984
(Fig. 7.3)

Substrate: two *Ostrea* valves. This is an elongated smooth boring. The maximum diameter can be observed in its middle part. The base is oval. The neck is compressed but the aperture itself is oval nearly eight-shaped. Collecting site: *Ostrea Bed of the Southern sand pit*. Inv. Nos. Bh 800, Bh 805.

Gastrochaenolites turbinatus Kelly et Bromley, 1984
(Fig. 7.4)

Substrate: a single *Ostrea* valve. This is a cone-shaped boring with smooth walls. Its widest part can be observed near the rounded base. The cross-section is rounded all along the boring. Collecting site: *Ostrea Bed of the Southern sand pit*. Inv. No. Bh 310.

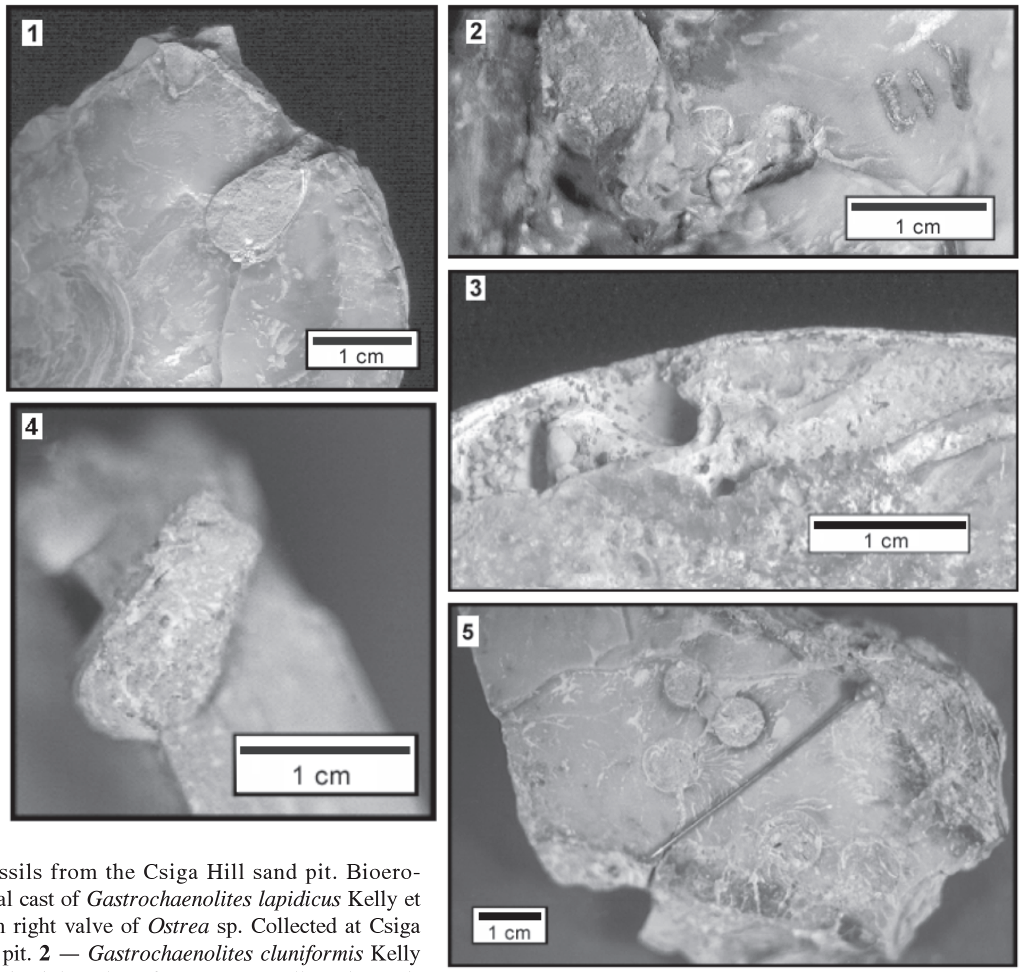


Fig. 7. Trace fossils from the Csiga Hill sand pit. Bioerosion: **1** — Natural cast of *Gastrochaenolites lapidicus* Kelly et Bromley, 1984 in right valve of *Ostrea* sp. Collected at Csiga Hill middle sand pit. **2** — *Gastrochaenolites cluniformis* Kelly et Bromley, 1984 in right valve of *Ostrea* sp. Collected at Csiga Hill middle sand pit. **3** — *Gastrochaenolites torpedo* Kelly et Bromley, 1984 in right valve of *Ostrea* sp. Collected at Csiga Hill middle sand pit. **4** — Natural cast of *Gastrochaenolites turbinatus* Kelly et Bromley, 1984 in right valve of *Ostrea* sp. Collected at Csiga Hill middle sand pit. **5** — Cross-section of *Gastrochaenolites* isp. indet. in right valve of *Ostrea* sp. Collected at Csiga Hill middle sand pit.

Gastrochaenolites isp. indet.
(Fig. 7.5)

These are strongly eroded, poorly preserved borings. Only a small part of the chambers can be observed. In most cases even the species characteristics of the basal part cannot be recognized. Collecting site: *Ostrea Bed of the Southern sand pit*. Inv. Nos. Bh 141, Bh 157, Bh 164.

Ichnogenus *Teredolites* Leymeriere, 1842
Teredolites longissimus Kelly et Bromley, 1984
(Fig. 8.1)

The tubes are straight or slightly winding. They appear in more consecutive levels as horizontal tube systems lying parallel to each other and to the surface of the substratum, which is formed by a drift wood fragment. The ichnospecies appears in the lower level of the southern pit in the *Ostrea* valve bearing gravel bed in an embedded one meter long driftwood fragment. The diameter of the tubes is between 5 and 12 mm. Collecting site: *Gravel bed with Ostrea valves* (Southern sand pit).

Ichnogenus *Centrichnus* Bromley et Martinell, 1991
Centrichnus concentricus Bromley et Martinell, 1991

(Fig. 8.2)

Substrate: eight *Ostrea* valves collected from the *Ostrea* shelly Bed of the outcrop. This etching scar is a rounded hollow surrounded by a flat margin slightly eroded into the substratum. The outline of the margin is oval, scalloped and frequently ornamented by concentric rings. Collecting site: *Ostrea Bed of the Southern sand pit*. Inv. Nos. Bh 59, Bh 104, Bh 124, Bh 125, Bh 126, Bh 401, Bh 402, Bh 403.

Bioturbation

Collecting sites are determined by the stratigraphic nomenclature given in the sedimentological description of the series and on Fig. 4.

Ichnogenus *Skolithos* Haldeman, 1840
Skolithos linearis Haldeman, 1840
(Fig. 9.1,2)

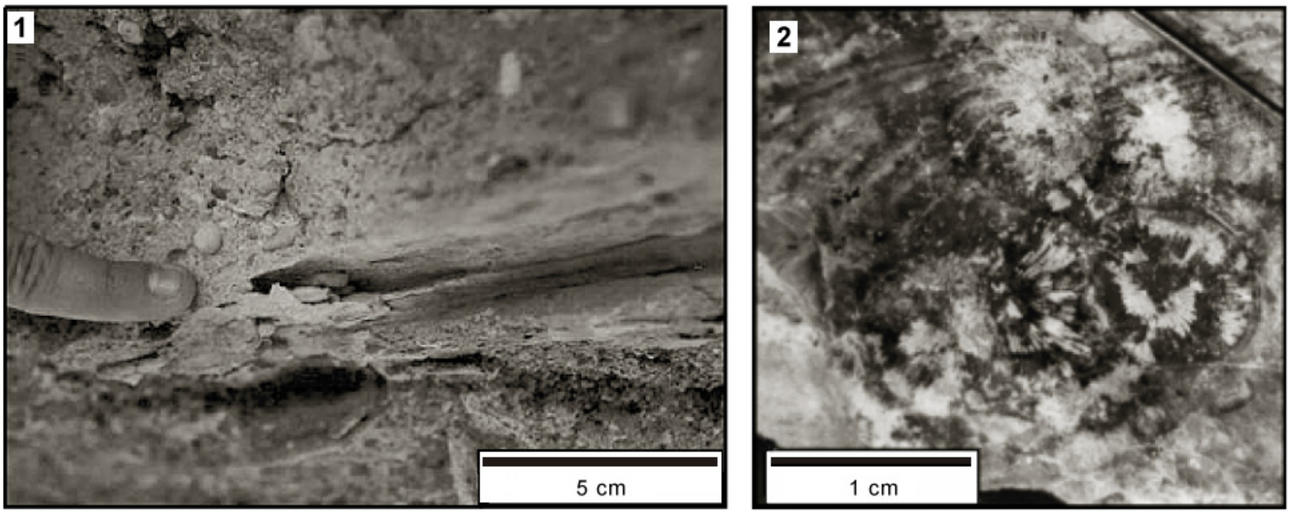


Fig. 8. Trace fossils from the Csiga Hill sand pit. Bioerosion: **1** — Natural cast of *Teredolites longissimus* in a drift wood fragment. Csiga Hill, southern sand pit. **2** — *Centrichnus concentricus* Bromley et Martinell, 1991 on the right valve of *Ostrea* sp. Collected at Csiga Hill middle sand pit.

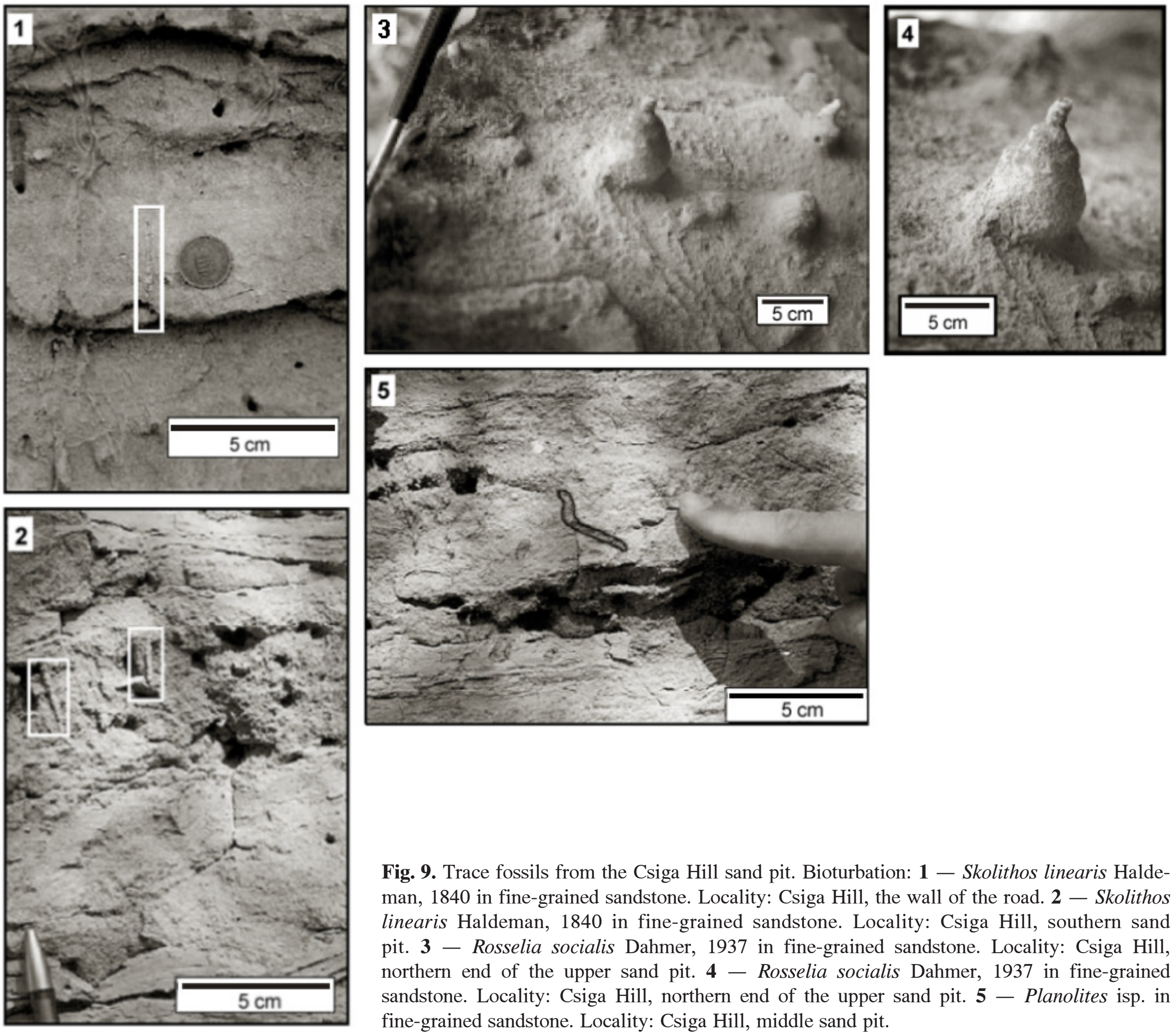


Fig. 9. Trace fossils from the Csiga Hill sand pit. Bioturbation: **1** — *Skolithos linearis* Haldeman, 1840 in fine-grained sandstone. Locality: Csiga Hill, the wall of the road. **2** — *Skolithos linearis* Haldeman, 1840 in fine-grained sandstone. Locality: Csiga Hill, southern sand pit. **3** — *Rosselia socialis* Dahmer, 1937 in fine-grained sandstone. Locality: Csiga Hill, northern end of the upper sand pit. **4** — *Rosselia socialis* Dahmer, 1937 in fine-grained sandstone. Locality: Csiga Hill, northern end of the upper sand pit. **5** — *Planolites* isp. in fine-grained sandstone. Locality: Csiga Hill, middle sand pit.

Skolithos linearis is a simple straight burrow with much larger length than width. The burrow is always perpendicular to the surface of the layer. Its diameter is not more than a few mm. In the outcrop it appears in great numbers in the laminated sand-mud series. Collecting site: *Alternating laminated silt and sand* (Southern sand pit), *alternating laminated and cross-stratified unit* of the wall of the road.

Ichnogenus *Rosselia* Dahmer, 1937
Rosselia socialis Dahmer, 1937
(Fig. 9.3,4)

A cone-shaped cave with a vertical tube in the substratum the depth of which is several centimeters. It has a central, usually vertical tube surrounded by structures containing concentric laminae. The shape of these structures can vary from bulbous to cone-shaped. The tube narrows with depth. The dwelling place was formed by the sessile animal moving upward in the cave simultaneously with sedimentation. Diameter may be 2–10 cm, length can reach 50 cm. In horizontal cross-section the central sandy tubes appear surrounded by concentric clayey laminae. Collecting site: *Alternating laminated and cross-stratified unit* of the upper sand pit (Northern end).

Ichnogenus *Planolites* Nicholson, 1873
Planolites isp.
(Fig. 9.5)

Irregularly sinuous slightly inclined unbranched burrow; 0.8–1.1 cm in diameter. It is preserved in full relief at the locality. The ichnotaxon also occurs in the gravel layer of the lower sand pit and at the thin bedded clayey-sandy profile of the middle sand pit of the southern part of the exposure. Collecting site: *Gravel bed with Ostrea valves*, *alternating laminated silt and sand* (Southern sand pit).

Ichnogenus *Ophiomorpha* Lundgren, 1891
Ophiomorpha nodosa Lundgren, 1891
(Fig. 10.1,2)

Apertures were not observable in the bedding planes of the pit since they are narrow and lack encrusting nodules so the chance of fossilization is rather small. The apertures usually extend in vertical shafts but fossil examples of this cannot be observed either. However, great numbers of simple, T- or Y-shaped branching tubes can be seen in both cross- and in longitudinal section. Collecting site: upper bed in the *bioturbated unit of the lower sand pit*, *alternating laminated and cross-stratified unit* of the upper sand pit (Northern end).

Ophiomorpha isp.
(Fig. 10.3–5)

The traces cannot be determined on ichnospecies level because the apertures are not exposed in the examined beds. However the vertical shafts can be observed in the lower part of the southern pit in the sandy pebble and can be seen in great numbers in the laminated sand-mud series. These shafts are only a few cm in length and the connected tubes are missing. Since the beds are rather thin the organisms were not be able to form a branching tube system in the deeper parts. In thicker beds vertical cavities also appear. In the laminated sandy-muddy series of the pit the ichnospecies can be observed frequently together with *Skolithos linearis*. Collecting site: *Alternating laminated silt and sand* (Southern sand pit).

Ichnogenus *Thalassinoides* Ehrenberg, 1944
Thalassinoides suevicus (Rieth, 1932)
(Fig. 11.1)

This trace fossil is a burrow network with smooth walls. The apertures extend into vertical shafts. These shafts are connected by horizontal or inclined tubes. Between the shafts and tubes or between the tubes there are Y- (120°) or T- (90°) shaped connections. Y-shaped connections are the most characteristic for the ichnospecies. The branching and anastomosing tubes form a labyrinth in one or more planes while the numerous connected shafts and tubes form a three-dimensional net. Labyrinths are more frequent than nets. Apertures and connecting vertical shafts are not visible in the outcrop but the Y-shaped branching points and the inclining orientation of the tubes can be observed well. Collecting site in the outcrop: *Alternating laminated silt and sand* (Southern sand pit).

Thalassinoides isp. (Fig. 11.2–6)

Cross-sections with irregular shape can also be observed. These might have been dwelling places and were formed by repeated usage. It is not common that the tubes intersect in the same plane. However, both vertical cavities and connecting tubes can appear in deeper beds. It is well observable in the figure that at the dual Y-shape branching point a horizontal tube also appears. It also can be found that an inclined tube turns back and then spreads horizontally. The small ramifications ("appendices") are common in both the vertical and horizontal tubes. Sometimes the tubes are arched at the cavity system of the trace fossil. Collecting site: lower bed in the *bioturbated unit of the lower sand pit*, *alternating laminated silt and sand* (Southern sand pit).

The ichnofacies

In the following we list the ichnofacies identified describing the enclosing lithofacies, determining the enclosing sedimentary unit, giving the list of ichnotaxa and a short description of the bioerosion or bioturbation.

Entobia Ichnofacies (sensu Bromley & Asgaard 1993)

Lithofacies: Strongly cemented *Ostrea* shelly Bed containing variable but mostly only a small amount of

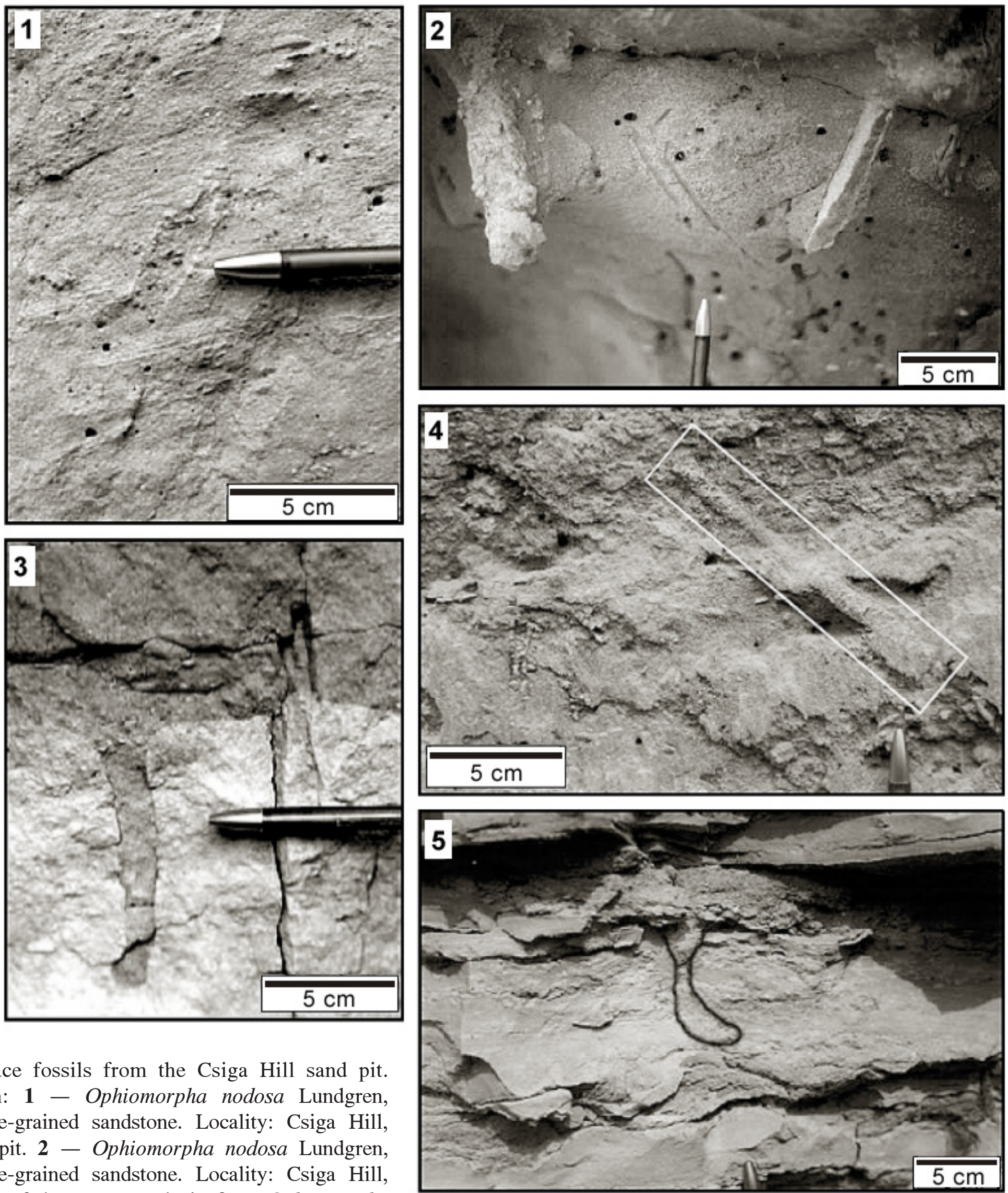


Fig. 10. Trace fossils from the Csiga Hill sand pit. Bioturbation: **1** — *Ophiomorpha nodosa* Lundgren, 1891 in fine-grained sandstone. Locality: Csiga Hill, lower sand pit. **2** — *Ophiomorpha nodosa* Lundgren, 1891 in fine-grained sandstone. Locality: Csiga Hill, northern end of the upper sand pit. **3** — *Ophiomorpha* isp. in an eroded bed surface. Locality: Csiga Hill, northern end of the upper sand pit. **4** — *Ophiomorpha* isp. in fine-grained sandstone. Locality: Csiga Hill, northern end of the upper sand pit. **5** — *Ophiomorpha* isp. in clayey sandstone. Locality: Csiga Hill, southern sand pit.

matrix. The *Ostrea* valves are reworked and strongly fragmented, with upwardly convex orientation. The majority (59.5 %) of the shell remnants are left valves.

Position: The *Ostrea* Bed of the southern sand pit.

Ichnotaxa: *Entobia cateniformis*, *Entobia geometrica*, *Entobia laquea*, *Entobia megastoma*, *Entobia paradoxa*, *Entobia ovula*, *Entobia* isp. indet., *Caulostrepsis taeniola*, *Maeandropolydora decipiens*, *Maeandropolydora sulcans*, *Maeandropolydora elegans*, *Gastrochaenolites lapidicus*, *Gastrochaenolites cluniformis*, *Gastrochaenolites torpedo*, *Gastrochaenolites turbinatus*, *Gastrochaenolites* isp. indet., *Centrichnus concentricus*.

The series is a good example for *Entobia* ichnofacies (Bromley & Asgaard 1993).

Bioerosion: The *Ostrea* valves are moderately bioeroded. The shallow borings occur maily in the surface of the valves. The diversity of the bioerosional traces is great. The traces are well preserved, but in the case of common presence of several ichnogenera identification of the ichnospecies was difficult.

Skolithos Ichnofacies (sensu Seilacher 1967; Pemberton et al. 1992)

Lithofacies: Poorly bedded and poorly sorted pebbly sand. The bed surfaces are strongly eroded by bioturbation.

Changing series of clayey silt and silty sand. The thickness of the bed is 1–10 cm, the bed surfaces are undulat-

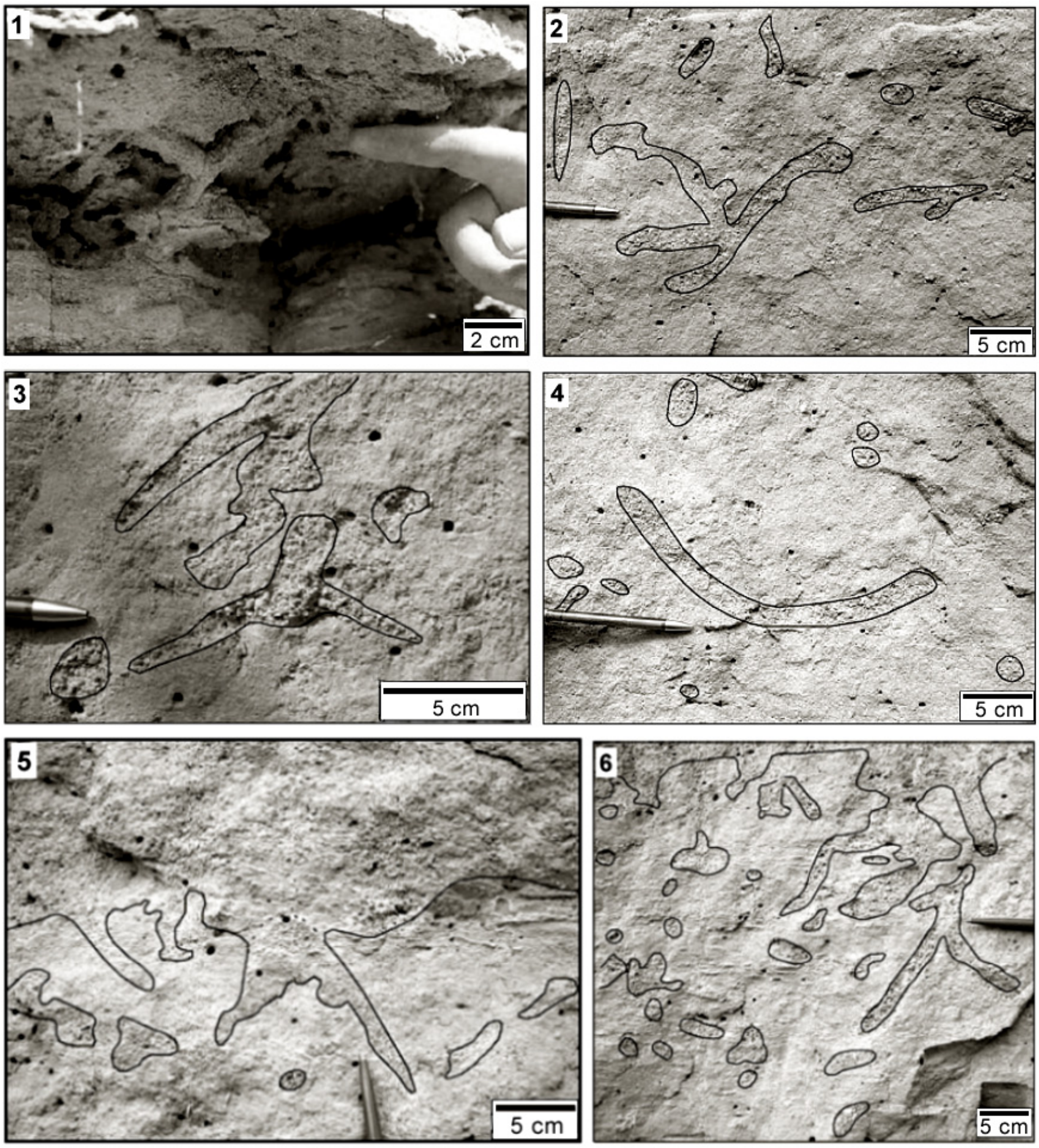


Fig. 11. Trace fossils from the Csiga Hill sand pit. Bioturbation: **1** — *Thalassinoides suevicus* Rieth, 1932 in clayey sandstone. Locality: Csiga Hill, southern sand pit. **2** — *Thalassinoides* isp. in sandstone. Locality: Csiga Hill, lower sand pit. **3** — *Thalassinoides* isp. in sandstone. Locality: Csiga Hill, lower sand pit. **4** — *Thalassinoides* isp. in sandstone. Locality: Csiga Hill lower sand pit. **5** — *Thalassinoides* isp. in sandstone. Locality: Csiga Hill lower sand pit. **6** — *Thalassinoides* isp. in sandstone. Locality: Csiga Hill lower sand pit.

ing. The sand is moderately sorted, sometimes it may be reworked even by wind under dry conditions.

Position: The *bioturbated unit* of the lower sand pit, the *alternating laminated silt and sand* in the southern sand pit, *alternating laminated and cross-stratified unit* in the wall of the road.

Ichnotaxa: *Ophiomorpha* isp., *Skolithos linearis.*

Bioturbation: The rate of bioturbation is high, while its diversity is low (ii 3–4). The different ichnospecies occur together. The complex evolution of the burrows of *Ophiomorpha* isp. and *Planolites* isp. was inhibited by thin character of the enclosing beds. The preservation of the burrows is worse so they could be identified only at ichnogenus level. Because of the relatively strong paleocurrents the bed surfaces were commonly erosionally decreased, so the entrance of the burrows could not be preserved. The lumens of the burrows formed in the pebbly sand are filled with the finer material of the overlying strata.

Cruziana Ichnofacies (sensu Seilacher 1967;
Pemberton et al. 1992)

Lithofacies: Moderately sorted, cross-layered or laminated fine sand. Bed surfaces are frequently eroded, locally with small clasts of clayey silt material along the bed surfaces (storm deposits).

Position: *Cyclic unit* in the upper sand pit.

Ichnotaxa: *Planolites* isp., *Rosselia socialis.*

Bioturbation: *Planolites* isp. is relatively rare and because of its poor preservation it cannot be identified at ichnospecies level. *Rosselia socialis* is relatively common in the given strata and because of its good preservation the morphological characteristics (vertical shafts, cone like structures) are clearly observable, but having been prepared by natural erosional processes the vertical tubes connecting the cone like caves can easily be destroyed (ii 3).

Glossifungites Ichnofacies (sensu Seilacher 1967; Pemberton et al. 1992)

Lithofacies: Slightly stratified, poorly sorted sand with strongly bioturbated bed surfaces, occasionally with convolute forms.

Position: *Bioturbated unit* in the lower sand pit.

Ichnotaxa: *Thalassinoides suevicus, Thalassinoides* isp.

Bioturbation: The burrows form a complex net in the exposed strata. The preservation is very good, the morphological characteristics (T- and Y-form junctions) are clearly observable, so the ichnospecies can be easily identified (ii 4). The lumens of the burrows are filled with pebbly sand of the overlying bed.

Discussion — Sequence stratigraphic position and paleoenvironments of the sedimentary units and the enclosed ichnofacies

In the paleoenvironmental evaluation of the outcrop we had to consider, that a parasequence follows Walter's law, while at the boundary of parasequences a gap in the facies can appear. From this point of view, referring to the generalized model and facies zones of a siliciclastic shallow marine shore zone (Fig. 12) the sediment series of the Csiga Hill can be interpreted well mostly in good accordance with the sequence stratigraphic model of the series sometimes giving additional data on undecided questions. In the order of the stratigraphic position we can reconstruct the following paleoenvironments (Fig. 4):

— The *lower sand pit* represents the upper prograding part of parasequence 8, and the flooding surface of parasequence 9. An upper shoreface is represented by the *lower small scale cross-stratified unit* without significant bioturbation and by the *bioturbated unit*, where the identified ichnofacies are *Glossifungites* and *Skolithos*. The end of progradation is represented by the appearance of the coal-bearing *lagoonal unit*, while along and above the flooding surface of the next parasequence the *Ostrea Bed* of the transgressive bar with sponge borings and the *laminated silt* of the offshore environments with foraminifers was accumulated.

— The Southern sand pit represents the uppermost beds of parasequence 10 and the flooding surface and earlier part of parasequence 11. The *Ostrea Bed* with a well preserved *Entobia* ichnofaces represents a transgressive bar while the *gravel bed with Ostrea valves* with driftwood fragments with *Teredolites longissimus* specimens is the material of a short-term gravelly back shore paleoenvironment. The flooding surface of parasequence 11 starts with the *alternating laminated silt and sand* with well preserved *Skolithos* and *Cruziana* ichnofacies representing the intertidal swash zone of a foreshore with a depth of about 4 m. The upper part of the Southern sand pit with the *large scale cross-stratified unit* and without any bioturbation represents the upper part of parasequence 11 reflecting longshore bars of the middle shoreface.

— From the upper part of parasequence 11 to parasequence 16 the series has an aggrading character (Fig. 3) where significant facies shifting cannot be detected in the zone of the Csiga Hill, so the dissection of the parasequences is uncertain and instead of the trend like shifting of facies from offshore to backshore, a permanent existence of the shoreface with slight change from the upper to the lower part can be observed. The first stage of this is the above mentioned longshore bar series of the Southern sand pit. The next stage is the *alternating laminated and cross-stratified unit* of the wall of the road and of the upper sand pit with *Cruziana* and *Skolithos* ichnofacies which also reflect a middle shoreface. The latter is followed by the *cyclic unit* containing *Ophiomorpha* specimens, which represents the appearance of the lower part of the shoreface with cycles reflecting storm events within the flooding period of parasequence 12. Considering the last statement the parasequence boundary between parasequences 11 and 12 needs some correction

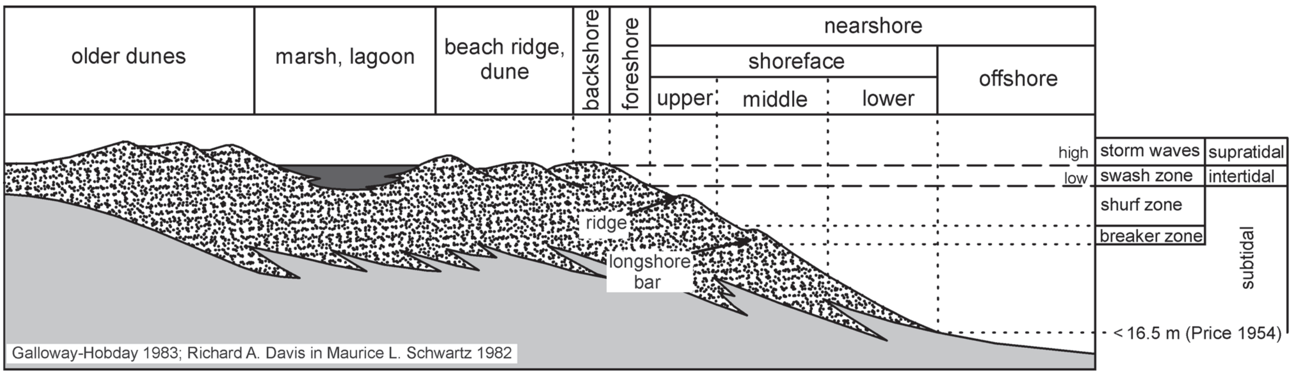


Fig. 12. Facies zones and paleoenvironments of a siliciclastic shallow marine shore zone.

from the depth of 51.6 m to 57.2 m in the borehole Nb 98 (see on Fig. 4).

Conclusions

Entobia, *Skolithos*, *Cruziana* and *Glossifungites* ichnofacies were determined and described by the lithofacies, ichnotaxa and by the characteristics of the bioerosion and bioturbation.

Regarding the sedimentological data, the dominant facies zone of the sedimentation was the shoreface, mainly its upper and middle, sometimes its lower part, while at the lower and/or uppermost parts of the parasequences some formations of fore- and backshore and even the lagoonal materials can appear just as sediments of open marine (offshore) sediments.

Compiling the sedimentological and ichnofacies data with the sequence stratigraphic model we can state that in the researched Karpatian series (Fig. 4):

— *Entobia Ichnofacies* is related to the transgressive bars below the flooding surfaces of the subsequent parasequence;

— *Skolithos* and *Glossifungites Ichnofacies* are related to the foreshore, upper and middle shoreface of the prograding parts of the parasequences;

— *Cruziana Ichnofacies* is related to the lower shoreface of the prograding parts of aggrading parasequences.

With the necessary correction of the boundary between the 11^{th} and 12^{th} parasequences, the research gives a good example for drawing a conclusion on sequence stratigraphic boundaries defined in well logs in accordance with paleoichnological and sedimentological data.

Acknowledgments: We extend our special thanks to Richard G. Bromley (Copenhagen) for his critical comments and improvement of the English text. Special thanks to Jordi M. de Gibert (Barcelona), Jozef Michalík (Bratislava) and Radek Mikuláš (Prague) who were the official reviewers of the manuscript.

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