VERSITA

Trace fossils from the Lower Muschelkalk of Raciborowice Górne (North Sudetic Synclinorium, SW Poland) and their palaeoenvironmental interpretation

ALINA CHRZĄSTEK

Institute of Geological Sciences, Wrocław University, Maksa Borna 9, PL-50-204 Wrocław, Poland.
E-mail: alina.chrzastek@ing.uni.wroc.pl

ABSTRACT:

Chrząstek, A. 2013. Trace fossils from the Lower Muschelkalk of Raciborowice Górne (North Sudetic Synclinorium, SW Poland) and their palaeoenvironmental interpretation. *Acta Geologica Polonica*, **63** (3), 315–353. Warszawa.

The following trace fossils have been recognised in the Lower Muschelkalk of Raciborowice Górne (North Sudetic Synclinorium, SW Poland): *Archaeonassa fossulata, Balanoglossites triadicus,* ?*Gastrochaenolites* isp., *Lockeia* isp., *Palaeophycus tubularis, Palaeophycus* isp., ?*Planolites beverleyensis, P. montanus, Planolites* isp.*,* ?*Protovirgularia* isp., *Rhizocorallium commune* var. *auriforme, R. commune* var. *irregulare, R. jenense, Skolithos linearis, Thalassinoides suevicus* and *Trypanites weisei*. Coprolites and an unidentified trace fossil A are also described. The trace fossils allow the discrimination of five ichnoassociations in the Raciborowice Górne section: (IA 1) *Rhizocorallium-Pholeus*, (IA 2) *Rhizocorallium-Palaeophycus*, (IA 3) *Thalassinoides*, (IA 4) *Trypanites-Balanoglossites* and (IA 5) *Planolites-Palaeophycus*. The Lower Muschelkalk succession was deposited on a shallow carbonate ramp affected by frequent storms. Deposition commenced with sedimentation in a restricted lagoon on the inner ramp with a short episode of sabkha formation. It continued on the middle and outer ramp and then on a skeletal shoal of the outer ramp and in an open basin. Ichnoassociation IA 5 is related to a maximum transgression that commenced with the deposition of the *Spiriferina* Bed and which probably marked the opening of the Silesian-Moravian Gate. The basin underwent two shallowing episodes, as evidenced by ichnoassociations IA 3–IA 4, resulting in the formation of hardgrounds. Bathymetric changes in the Raciborowice Górne section correspond well with a general transgressive trend in the Germanic Basin.

Key words: Sudetes; North Sudetic Synclinorium; Lower Muschelkalk; Trace fossils; Ichnoassociations; Carbonate ramp; Palaeoenvironment.

INTRODUCTION

The analysis of trace fossils has been proved to be a useful and informative approach in palaeoenvironmental reconstructions, facies analysis, biostratigraphy and sequence stratigraphy (e.g. Seilacher 1967, 2007; Bromley 1996; Brenchley and Harper 1998; McIlroy 2004a; Bromley *et al*. 2007; Miller 2007; Bu-

atois and Mángano 2011; Knaust and Bromley 2012). In contrast to those of the Jurassic and Cretaceous, the Triassic trace fossils are generally poorly documented. However, a few reports on the Middle Triassic carbonate successions of Germany (e.g. Knaust 1998, 2007a, b; 2008, 2013; Knaust *et al*. 2012), southern Spain and Italy (Sardinia) (Rodríguez-Tovar *et al*. 2007; Rodríguez-Tovar and Pérez-Valera 2008; Knaust and Costamagna 2012; Pérez-López and Pérez-Valera 2012) were published recently.

In Poland, Middle Triassic trace fossils from Upper Silesia were studied by Szulc (1990a, b; 2000) and Kowal-Linka and Bodzioch (2011), and by Jaglarz and Uchman (2010) from the Tatra Mts. A few reports deal with trace fossils from the Lower Muschelkalk of the North Sudetic Synclinorium, SW Poland (Szulc 1991a; Chrząstek 2002, 2004, 2007, 2008b; Chrząstek and Wojewoda 2011). This paper presents the results of ichnological studies from the latter area, giving the first detailed description of trace fossils from the Lower Muschelkalk. The ichnoassociations recognised are used to characterise the sedimentary environment; sedimentation rate, environment energy, salinity, oxygenation level and substrate consistency.

METHODS

The studied material comes from the Raciborowice Górne quarry. The photographic documentation was done in the quarry and laboratory.

The approximate percentage of bedding planes covered by burrows is referred to as the bedding-plane bioturbation index (bi) (after Taylor and Goldring 1993). Cuttings perpendicular to bedding planes were used to analyse the ichnofabric index (ii) (after Droser and Bottjer 1986 and Bottjer and Droser 1991). The sediment type, ichnofabric and bioturbation indices, are determined for each of the ichnoassociations.

Ichnoassociation denotes "a group of trace fossils that occur consistently in one subfacies or lithology within an environmental zone. It comprises all trace fossils within an environmental zone and commonly consists of several ichnoassemblages" (according to Narrbone 1984). *Ichnocoenosis* is understood as "a trace fossil assemblage derived from the work of a single endobenthic community" (according to Bromley 1996).

The specimens described are housed in the collection of the Geological Museum of the University of Wrocław (MGUWr-5410s-5449s).

GEOLOGICAL SETTING

Palaeogeographically, the sequences of the North Sudetic Synclinorium, SW Poland, formed the North Sudetic Basin, which was part of the Triassic Germanic Basin. From the Late Olenekian to the Ladinian, the Germanic Basin was a semi-closed marine basin, separated from the open Tethys to the south by the Vindelician-Bohemian Massif (Szulc 2000, 2007a, b; Szulc *et al*. 2009). Communication between the Tethys and the Germanic Basin was realised through the Silesian-Moravian Gate and the East-Carpathian Gate and, since the Ladinian, also through the Western Gate. The Germanic Basin was subdivided into various carbonate platforms and ramps (Knaust 2007a).

The North Sudetic Synclinorium, running WNW–ESE, is bordered by the Fore-Sudetic Block on the northeast, the Karkonosze-Izera crystalline massif on the southwest and the Kaczawa Metamorphic Complex to the east (Text-fig. 1). In the eastern part it is divided into synclines and grabens. Its basement is built of Eocambrian–Lower Carboniferous rocks (Baranowski *et al*. 1990; Kryza *et al*. 2007), and the synclinorium itself is composed of Pennsylvanian to Cenozoic deposits (Baranowski *et al*. 1990; Chrząstek 2002, 2004). The folding and faulting leading to the formation of the synclinorium took place in the Palaeogene (Żelaźniewicz and Aleksandrowski 2008).

The Triassic rocks crop out in the northern and southern margins of the synclinorium, while in the central part they are overlain by a thick sequence of younger deposits. They belong to the Radłówek (Lower–Middle Buntsandstein) and Raciborowice formations (Röt–Lower Muschelkalk) (Milewicz 1985). The former is composed of an up to 700 m thick terrigenous continental sequence (Chrząstek 2002; Śliwiński *et al*. 2003; Chrząstek *et al*. 2004; Chrząstek and Wojewoda 2011); the latter is built of marine sediments. The Röt is represented by an up to 140 m thick marly, marly-calcareous and marly-dolomitic sequence with subordinate gypsum, anhydrite and clastic rocks (Chrząstek 2002). The Lower Muschelkalk consists of an up to 160-m-thick carbonate succession, exposed in the Grodziec and Leszczyna synclines in the northern and eastern part of the synclinorium respectively (Chrząstek 1995, 2002). The most complete succession is exposed in the quarry in the village of Raciborowice Górne (Grodziec Syncline); the Lower Muschelkalk crops out fragmentarily in the village of Jerzmanice (Leszczyna Syncline). Younger, Middle and Late Triassic deposits are known only from boreholes (Leśniak 1978; Chrząstek 2002).
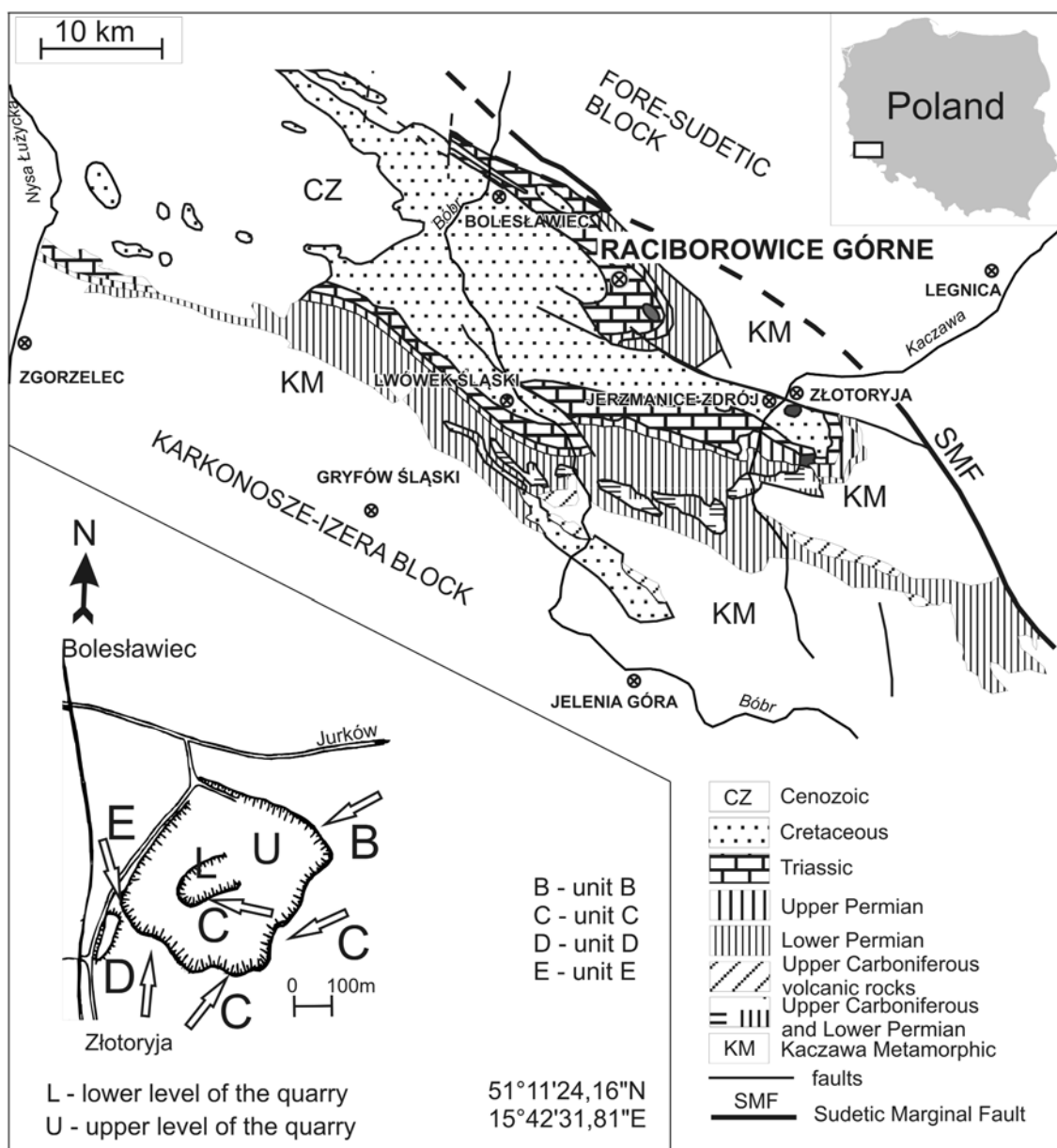
Text-fig. 1. Geological map of the North Sudetic Basin Synclinorium, modified after Sawicki and Teisseyre (1978). Insert: Schematic plan of the Raciborowice Górne quarry.

Places where individual units (B to E) are exposed are marked

LOWER MUSCHELKALK OF THE RACIBOROWICE GÓRNE SECTION

The village of Raciborowice Górne is located southeast of the town of Bolesławiec (Text-fig. 1). An almost complete succession of the Lower Muschelkalk is exposed here, except its uppermost part.
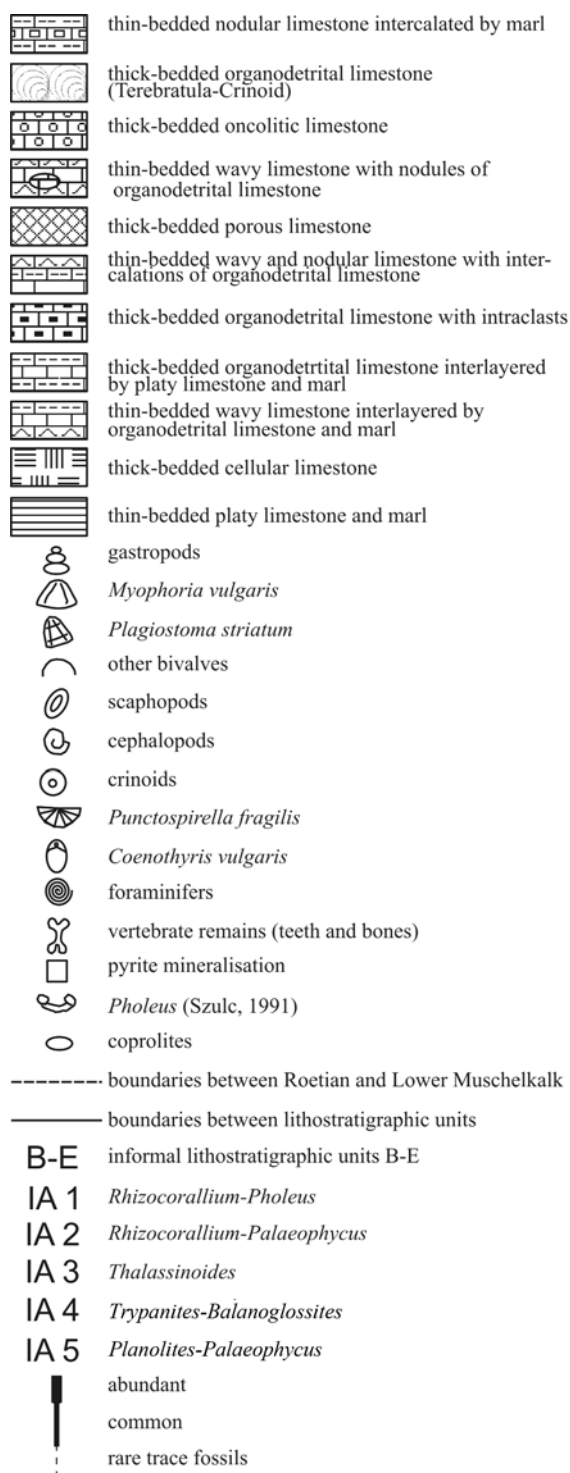
Lithology and fossil assemblages provide a basis for an informal lithostratigraphic subdivision of these deposits into units B–E (Chrząstek 2002). Unit A crops out only in Jerzmanice Górne (Chrząstek 1995).

The lowermost part of the Raciborowice Górne succession is represented by the about 15 m thick unit B, exposed in the northeastern part of the quarry (Text-figs 1, 2). It starts with a 1.8 m thick unfossiliferous unit, composed of thin-bedded platy limestone with marly intercalations (Text-fig. 2). The unit is overlain by thick-bedded organodetrital limestone with abundant detritus of crinoids, mainly *Dadocrinus* sp. and subdominant *Holocrinus acutangulus* Meyer (Hagdorn and Głuchowski 1993; Chrząstek 2002). The topmost part of unit B is composed of a distinctive cellu-
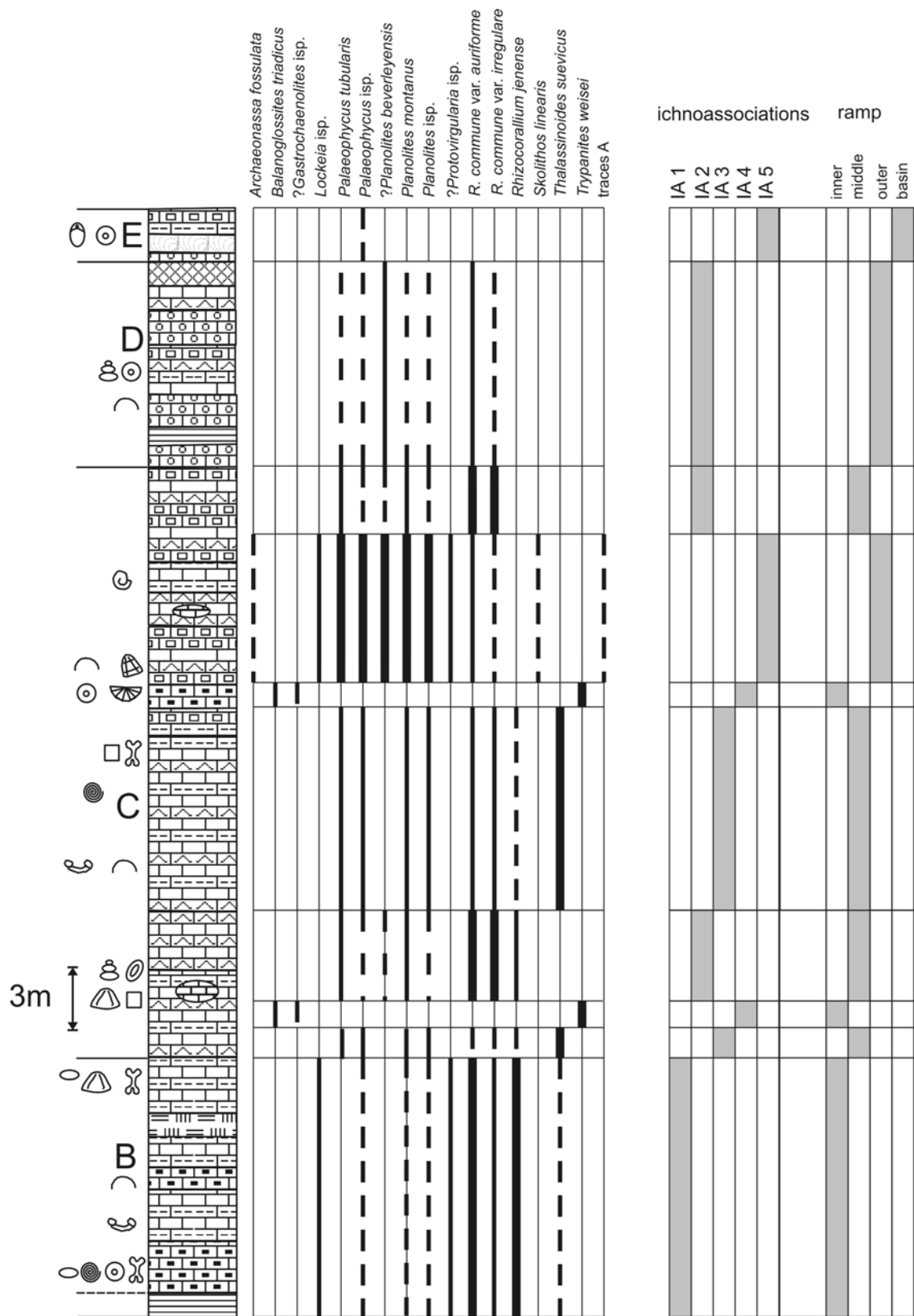
Text-fig. 2. Succession of the Lower Muschelkalk ichnoassociations in Raciborowice Górne, North Sudetic Basin Synclinorium

lar limestone and thick-bedded organodetrital limestone, intercalated by thin-bedded platy limestone and marl. These beds contain bivalves (mainly *Myophoria vulgaris* Schlotheim, *Hoernesia socialis* Schlotheim, *Pecten* cf. *laevigatus* and *Entolium discites* Schlotheim), gastropods and vertebrate remains:

	thin-bedded nodular limestone intercalated by marl
	thick-bedded organodetrital limestone (Terebratula-Crinoid)
	thick-bedded oncolitic limestone
	thin-bedded wavy limestone with nodules of organodetrital limestone
	thick-bedded porous limestone
	thin-bedded wavy and nodular limestone with intercalations of organodetrital limestone
	thick-bedded organodetrital limestone with intraclasts
	thick-bedded organodetrtital limestone interlayered by platy limestone and marl
	thin-bedded wavy limestone interlayered by organodetrital limestone and marl
	thick-bedded cellular limestone
	thin-bedded platy limestone and marl
	gastropods
	Myophoria vulgaris
	Plagiostoma striatum
	other bivalves
	scaphopods
	cephalopods
	crinoids
	Punctospirella fragilis
	Coenothyris vulgaris
	foraminifers
	vertebrate remains (teeth and bones)
	pyrite mineralisation
	Pholeus (Szulc, 1991)
	coprolites
- - - - - - - -	boundaries between Roetian and Lower Muschelkalk
————	boundaries between lithostratigraphic units
B-E	informal lithostratigraphic units B-E
IA 1	*Rhizocorallium-Pholeus*
IA 2	*Rhizocorallium-Palaeophycus*
IA 3	*Thalassinoides*
IA 4	*Trypanites-Balanoglossites*
IA 5	*Planolites-Palaeophycus*
	abundant
	common
	rare trace fossils

Nothosaurus cf. *mirabilis*, *Acrodus lateralis* Agassiz, *Palaeobates angustissimus* Agassiz (Chrząstek and Niedźwiedzki 1998; Chrząstek 2002, 2008a; Chrząstek and Wojewoda 2011).

Szulc (1991a) placed the Röt/Lower Muschelkalk boundary at the top of unit B, whereas Głuchowski and Salamon (2005), who interpreted the deposition of the crinoid-rich limestone of this unit as the beginning of the Lower Muschelkalk (cf. Assmann 1944), put this boundary within unit B (immediately above the 1.8 thick basal part of the unit). The latter interpretation is followed herein.

The upper part of the succession, exposed in the northeastern wall of the quarry, belongs to the basal part of unit C. It is composed of thin-bedded platy and marly limestone and marl with intercalations of thick-bedded organodetrital limestone. The younger strata are exposed in the northeastern, eastern and southern walls of the lower quarry level and in the eastern wall of the upper level (Text-figs 1, 2). They are represented by thick-bedded organodetrital limestone, thin-bedded platy, wavy and nodular limestone and marl. The wavy and nodular limestones start to dominate in the uppermost part of unit C. Two hardgrounds are present within the unit. The lower one forms a continuous horizon and the upper one occurs as dark blue limestone intraclasts within the *Spiriferina* Bed. Numerous bivalves (e.g. *Mytilus* sp., *Gervilleia* sp., *Pleuromya musculoides* Schlotheim and *Plagiostoma striatum* Schlotheim) and gastropods were described from unit C (Chrząstek 2002). The total thickness of unit C reaches c. 50 m.

The up to 40 cm thick *Spiriferina* and Bone Beds constitute distinctive correlation horizons. The *Spriferina* Bed is built of organodetrital limestone with intraclasts and is rich in crinoids, mainly *Holocrinus acutangulus* Meyer, ?*Encrinus* + *Chelocrinus* sp. (Chrząstek 2002), as well as *Eckicrinus radiatus* Schauroth (Głuchowski and Salamon 2005) and the echinoid *Triadotiaris grandaeva* Alberti (Salamon *et al*. 2003). Niedźwiedzki *et al*. (2011) found whole cups of the crinoid *Encrinus aculeatus* Meyer. The eponymous taxon *Punctospirella* (= *Spiriferina*) *fragilis* Schlotheim is restricted to this bed [*Spiriferina* Bed of Chrząstek (2002) (following Holdefleis 1915); *Punctospirella* Bed of Głuchowski and Salamon (2005) and of Niedźwiedzki *et al*. (2011)]. The bed also contains numerous trace fossils. The cephalopods *Balatonites ottonis* Buch and *Germanonautilus* sp. were described from a limestone horizon slightly above the *Spiriferina* Bed (Chrząstek 2002; Treter 2003). The Bone Bed contains a rich assemblage of vertebrate remains: chondrichthyan (*Acrodus lateralis* Agassiz, *Palaeobates angustissimus* Agassiz) and

osteichthyan teeth and scales (*Birgeria* sp., *Gyrolepis* sp.), as well as reptile teeth (Nothosauridae or Cymathosauridae) (Chrząstek 2008a).

The overlying 18 m thick unit D is exposed in the southern wall of the quarry (Text-figs 1, 2). The unit consists of thick-bedded oncolitic and porous organodetrital limestone with inliers of thin-bedded platy, wavy and nodular limestone and marl. The body fossils are dominated by the bivalves *Enantiostreon difformae* Schlotheim (?=*Umbrostrea cristadifformis* Schlotheim; see discussion in Márquez-Aliaga *et al*. 2005; Hautmann 2006; Malchus 2008) and *Plagiostoma striatum* Schlotheim, gastropods and the crinoids *Holocrinus dubius* Goldfuss, ?*Encrinus* + *Chelocrinus* sp. (Chrząstek 2002; Głuchowski and Salamon 2005).

Unit E forms the topmost 3.5 m thick part of the Lower Muschelkalk and crops out in small fragments in the southwestern quarry wall (Text-figs 1, 2). It is composed of thick-bedded organodetrital limestone, especially rich in the crinoids *Holocrinus dubius* Goldfuss, ?*Encrinus* + *Chelocrinus* sp., and the brachiopod *Coenothyris vulgaris* Schlotheim, with intercalations of thin-bedded wavy and nodular limestone and marl.

The correlation of the Lower Muschelkalk succession between the North Sudetic Basin and its equivalents from the Opole Trough, as suggested by Głuchowski and Salamon (2005), is accepted here. Consequently, unit B is regarded as an equivalent of the Lower Gogolin Beds and the lower part of the Upper Gogolin Beds, whereas unit C corresponds to the remaining part of the Upper Gogolin Beds and the lower part of the Górażdże Beds. Unit D may correlate with the top part of the Górażdże Beds and unit E with the Terebratula Beds (=Dziewkowice Formation).

Leśniak (1978), based on boreholes from the Raciborowice Górne neighbourhood, subdivided the Lower Muschelkalk into a series of lithostratigraphic units (VII–XIV). He suggested that the uperrmost part of his complexes XIII and XIV may be equivalents of the Karchowice Beds and of the lower part of the Middle Muschelkalk from the Opole region.

DESCRIPTION OF TRACE FOSSILS

The ichnotaxa recognized in the Lower Muschelkalk of Raciborowice Górne (Text-fig. 2) are described below in alphabetic order.

***Archaeonassa fossulata* Fenton and Fenton, 1937** (Pl. 1, Fig. 1). These are simple, unbranched burrows, elongated, straight or meandering with narrow ridges; circular or V-shaped in cross-section, 0.3–0.45 cm in diameter, 3–4 cm (up to 12 cm) in length. They occur as epirelief with no ornamentation on bedding planes of the platy limestone of unit C, above the *Spiriferina* Bed (Text-fig. 2).

Knaust (2007a) described *A. fossulata* as a gastropod burrow (fodinichnion). Mángano *et al*. (2005), Carmona *et al*. (2006) and Sarkar *et al*. (2009) interpreted it as a grazing trace (pascichnion) produced by arthropods, annelids and molluscs. Baucon and Felletti (2013b) related *Archaeonassa* to the locomotion behaviour of gastropods, independently of their feeding strategy.

Archaeonassa was described from lakes, deltas and shallow seas (Knaust 2007a, Buatois and Mángano 2002, 2009; Sarkar *et al*. 2009; Hofmann *et al*. 2012; Mángano *et al*. 2013).

It is known mainly from the Palaeozoic (e.g., Cambrian; Mángano *et al*. 2005; Pazos *et al*. 2007; Marenco and Bottjer 2008); younger examples are rare. Buatois and Mángano (2011), Hoffman *et al*. (2012) and Mángano *et al*. (2012) reported *Archaeonassa fossulata* from the Ediacaran. Known from the Muschelkalk of Thuringia, Germany (Knaust 2007a), and from the Middle Eocene–Early Miocene of Argentina (Carmona *et al*. 2006). Baucon and Felletti (2013b) described *Archaeonassa* from the Holocene of Italy.

***Balanoglossites triadicus* Mägdefrau, 1932** (Pl. 1. Figs 2–5). Preserved as U-shaped burrows or borings, with burrow diameters ranging between 0.3 cm and 1.7 cm, 1.0–1.5 cm on average. U-shaped galleries are preserved very seldom, usually only a part of a burrow is available (Pl. 1, Figs 2–3). Sometimes, *B. triadicus* appears on bedding planes as circular or elliptical tunnel openings that continue as a subsurface system, occasionally with irregular, blind branching (see also Knaust 2007a, 2008). They penetrate the substrate as deep as 6 cm. The whole system is passively filled with ochre-coloured dolomite (see Bertling 1999 and Knaust 2007a, 2008). The walls are generally unlined. In some cases, when only part of a burrow is preserved, it can easily be mistaken for *Thalassinoides* (e.g., Pl. 1, Fig. 5) (see Jaglarz and Uchman 2010; Knaust 2012). It co-occurs with *Trypanites weisei* in dark intraclasts in the *Spiriferina* Bed (Text-fig. 2).

B. triadicus is interpreted as a combined feeding and dwelling structure (fodinichnion/domichnion) (Knaust and Costamagna 2012) produced by enteropneusts, e.g. worms (polychaetes), sipunculans and even crustaceans (Mägdefrau 1932; Kaźmierczak and Pszczółkowski 1969; Kennedy 1975; Knaust *et al*.

1999; Knaust 2007a, 2008). According to Knaust (2008, 2010a), sipunculans (peanut worms) and polychaetes (eunicid-like polychaetes) are more probable tracemakers, as enteropneusts (acorn worms) are not typical bioeroders (see also Jaglarz and Uchman 2010). This ichnotaxon involves burrow system at the transition between firmgrounds and hardgrounds (Knaust and Costamagna 2012) and is a common component of the *Glossifungites* and *Trypanites* ichnofacies (Knaust 2008). *B. triadicus* appears not only as burrows but also as borings (Knaust 2008, 2010b; Desai and Saklani 2012). Recently, MacEachern *et al*. (2012) and Knaust *et al*. (2012) suggested that it characterizes mainly the *Glossifungites* ichnofacies. *B. triadicus* is common in carbonates of very shallow to intertidal marine environments (Knaust 1998; 2007a, 2008; Knaust *et al*. 2012; Pérez-López and Pérez-Valera 2012).

Known from the Phanerozoic (Kaźmierczak and Pszczółkowski 1969; Goldring and Kaźmierczak 1974; Palmer 1978; Dronov *et al*. 2002; Carmona *et al*. 2008; Hoffman and Uchman 2008; Hoffman *et al*. 2009); especially common in the Triassic (Szulc 1990a, b, 2000; Knaust 2007a, 2008; Jaglarz and Uchman 2010; Knaust and Costamagna 2012).

?*Gastrochaenolites* isp. (Pl. 1, Fig. 6). These are oval, elongated borings with a straight, curved or irregular axis, corresponding to *Gastrochaenolites* isp. of Kelly and Bromley (1984). Their length varies from 1.3 to 1.5 cm, and they are 0.4 to 0.9 cm wide, in the widest part, becoming narrower in the neck-like upper part. It co-occurs with *Trypanites weisei* in limestone intraclasts of the *Spiriferina* Bed (Text-fig. 2).

Gastrochaenolites isp. is regarded a dwelling trace (domichnion), produced by suspension-feeding bivalves (Kelly and Bromley 1984; Farinati 2007; Knaust 2007a; Buatois and Encinas 2011; Knaust and Costamagna 2012) and sipunculan worms (Malpas *et al*. 2005). Mytilidae (*Lithophaga lithophaga*) and Gastrochaenidae (*Gastrochaena dubia*) are suggested as their potential producers in modern environments (Warme 1975; Wilson and Palmer 1998; Wilson and Taylor 2001; Donovan and Hensley 2006; Perry and Smithers 2006; Wilson *et al*. 2008; Buatois and Mángano 2011; Gibert *et al*. 2012). Because the same behaviour, without significant differences in morphology, is represented in bivalve dwelling structures in both hard and firm substrates, *Gastrochaenolites* applies both to borings and burrows (Ekdale and Bromley 2001a; Donovan 2002; Mikuláš *et al*. 2003; Bertling *et al*. 2006; Carmona *et al*. 2007; MacEachern *et al*. 2007b; Knaust 2008; Dronov 2010). *Gastrochaenolites* belongs to the *Glossifungites* and *Try-

panites ichnofacies (MacEachern *et al*. 2007a, 2012; Knaust *et al*. 2012).

Gastrochaenolites is a generally shallow water trace fossil (Bromley and Asgaard 1993; Farinati and Zavala 2002; Cachão *et al*. 2009; Santos *et al*. 2010) although Bassi *et al*. (2011) reported this ichnogenus from a deep water reef setting. Recently, Santos *et al*. (2011) described this ichnospecies even from basalts.

Known from the Early Ordovician to the Cenozoic (Kelly and Bromley 1984; Pleydell and Jones 1988; Benner *et al*. 2004; Gibert *et al*. 2004, 2012; Knaust 2007a).

***Lockeia* isp.** (Pl. 1, Figs 7–8). These are small (2.5–3.0 mm wide and 4.0–7.0 mm long), elongated burrows, usually almond-shaped, seldom triangular or heart-shaped, generally elliptical in cross section. It occurs in unit B and above the *Spiriferina* Bed (Text-fig. 2). *Lockeia* is usually interpreted as a resting trace (cubichnion) of bivalves (Häntzschel 1975; Maples and Suttner 1990; Radley and Barker 1998; Ekdale and Bromley 2001b; Knaust and Costamagna 2012; Alonso-Muruaga *et al.* 2013; Mikuláš *et al.* 2013; Zonneveld and Gingras 2013), however, its function as a domicile and escape trace have also been suggested (Archer and Maples 1984; Gibert and Ekdale 2002; Buatois *et al*. 2005; Buatois *et al.* 2005; Mángano *et al*. 2005; Knaust 2007a; Melchor *et al.* 2012a; Rindsberg 2012)). According to Uchman *et al*. (2011) *Lockeia* should be restricted to resting trace cubichnia.

Although *Lockeia* is produced mainly by bivalves, small forms have been attributed to ostracods or conchostracans (Pollard 1981; Goldring *et al*. 2005; Chen *et al*. 2012; Melchor *et al*. 2012a).

It belongs to the *Psilonichnus* ichnofacies (MacEachern *et al*. 2012) and *Cruziana* ichnofacies (MacEachern *et al*. 2007a; Buatois and Mángano 2011). Among potential producers are protobranch bivalves (Seilacher and Seilacher 1994; Mángano *et al*. 1998; Bradshaw 2010), crustaceans (ostracods), unionid and corbiculid bivalves, as well as viviparid gastropods (Radley *et al*. 1998; Goldring *et al*. 2005; Lawfield and Pickerill 2006; Fernández *et al*. 2010; Kane 2010).

Lockeia is present in both marine (from marginal-marine to the deep-sea) and freshwater settings (Radley *et al*. 1998; Goldring *et al*. 2005; Hofmann *et al*. 2011; Melchor *et al*. 2012a, b).

Known from the ?Late Cambrian/Early Ordovician (Fillion and Pickerill 1990; Uchman *et al*. 2004a; Uchman and Gaździcki 2006) through to the Pleistocene (Hofmann *et al*. 2011). Kim (1994) reported *Lockeia* from the Precambrian.

***Palaeophycus tubularis*, Hall 1847** (Pl. 2, Figs 1–2, 8–9; Pl. 3, Figs 1–2). These are thin, straight and horizontal burrows, rarely curved and branched, with distinct, smooth and unornamented walls. They are often long with the fill similar to the host rock, slightly elliptical in planar section, 2.0–5.0 mm in diameter, 1.5–4.7 cm in length. Found mainly in unit C, especially above the *Spiriferina* Bed (Text-fig. 2).

Palaeophycus is regarded as dwelling burrow (domichnion) of suspension-feeders or predators (Pemberton and Frey 1982). Rodríguez-Tovar *et al*. (2010) suggested fodinichnion/domichnion, while Gouramanis *et al*. (2003) and Chen *et al*. (2012) suggested repichnion or domichnion. The trace was produced by various organisms: worms (polychaetes), worm-like animals (Pickerill *et al*. 1984; Keighley and Pickerill 1995; Gillette *et al*. 2003; Mikuláš 2006; Mikuláš and Martínek 2006), arthropods (Zonneveld *et al*. 2010; Chen *et al*. 2012), sipunculids and enteropneusts (Loughlin and Hillier 2010), crustaceans and insects (in freshwater environments) (Buatois and Mángano 2002; Kim *et al*. 2002; Bradshaw 2010). It characterizes the *Skolithos* and *Cruziana* ichnofacies (MacEachern *et al*. 2007a, 2012). *Palaeophycus* is an eurybathic trace fossil and appears both in shallow and deep marine environments, though it is common in nearshore settings (Pemberton *et al*. 2001; Buatois and Mángano 2011).

It is known from the Proterozoic (Ediacaran) to the Holocene (Häntzschel 1975, Pemberton and Frey 1982; Gradziński and Uchman 1994; Kim 1994; Kumpulainen *et al*. 2006; Avanzini *et al*. 2011).

***Palaeophycus* isp.** (Pl. 3, Fig. 3). These are mostly straight or slightly undulating, horizontal burrows, unbranched and distinctly lined, usually 2.0–9.0 mm in diameter, 3.5–4.7 cm long, with maximum length up to 15 cm. Generally *Palaeophycus* isp. are elliptical in planar section, with smooth walls and with the fill identical to the host rock (see Pemberton and Frey 1982). It occurs throughout the Raciborowice Górne succession together with *Planolites montanus* and is particularly abundant above the *Spiriferina* Bed (Text-fig. 2).

The tracemakers were predaceous or suspension-feeders (Pemberton and Frey 1982) usually polychaete annelids (sipunculids), enteropneusts and arthropods (Häntzschel 1975; Keighley and Pickerill 1995; Gibert and Ekdale 2002; Loughlin and Hillier 2010; Hofmann *et al*. 2011); Bradshaw (2010) also reported bivalves and gastropods. In non-marine environments crustaceans and insects are considered as *Palaeophycus* producers (Kim 1994; Kim *et al*. 2002; Chen *et al*.

2012). It is interpreted as a domichnion (Pemberton and Frey 1982). Virtasalo *et al*. (2011) and Lauridsen *et al*. (2011) interpreted *Palaeophycus* as a feeding trace, combination deposit and dwelling (fodinichnion). Schlirf (2003) interpreted this ichnotaxon as domichnion/?fodinichnion.

It is common in the *Cruziana* and *Skolithos* ichnofacies (Frey and Seilacher 1980; Frey *et al*. 1990; MacEachern *et al*. 2007a, 2012). It occurs in intertidal-subtidal shallow carbonates (Narrbone 1984).

Palaeophycus is known from the Late Proterozoic (Ediacaran) to the Holocene (Pemberton and Frey 1982; McCann and Pickerill 1988; Hofmann *et al*. 2011; Chen *et al*. 2013).

?*Palaeophycus* isp. (Pl. 2, Figs 1–4, 6–8; Pl. 3, Fig. 4). These are 1.1 to 1.7 cm large, oval or elliptical "heaps" on bedding planes that continue as tunnels within the rocks (Pl. 2, Figs 6–8). A closer documentation is impossible because of the lack of diagnostic details. The presence of a distinct wall and a fill the same as the host rock, visible in cross-section (Pl. 2, Figs 6–7), suggests assignment of these traces to *Palaeophycus* (for more detail see Pemberton and Frey 1982). It occurs in unit C, above the *Spiriferina* Bed.

The tracemakers were polychaete annelids and arthropods (Häntzschel 1975; Pickerill *et al*. 1984; Keighley and Pickerill 1995). *Palaeophycus* is interpreted as a dwelling burrow (domichnion) of suspension-feeders or predators (Pemberton and Frey 1982). It is a facies-crossing ichnotaxon and occurs in the *Skolithos*, *Cruziana* and *Glossifungites* ichnofacies (Pemberton *et al*. 2001; MacEachern *et al*. 2012).

Palaeophycus is known from the Late Proterozoic (Ediacaran) to the Holocene (Pemberton and Frey 1982; McCann and Pickerill 1988; Uchman *et al*. 2005).

?*Planolites beverleyensis* Billings, 1862 (Pl. 3, Figs 5–7). These are relatively large (7.0–8.0 mm in diameter and 3.5–7.0 cm long), smooth, straight or undulating burrows, strongly flattened and unbranched or exceptionally branched, horizontal or slightly oblique to bedding planes. Lithology of the burrow fill differs from the host rock. It occurs above the *Spiriferina* Bed in units C and in unit D (Text-fig. 2).

?*P. beverleyensis* is interpreted as a pascichnion (Bromley 1996, Heinberg and Birkelund 1984; Rodríguez-Tovar and Uchman 2004, 2006; 2010; Bressan and Palma 2009; Pervesler *et al*. 2011) and less commonly as fodinichnia of deposit feeders (Kim 1994; Mángano *et al*. 2005; Loughlin and Hillier 2010; Mikuláš *et al*. 2012; Rindsberg 2012).

Its tracemakers are worms (polychaetes), larval insects, as well as arthropods (?crustaceans) or molluscs (Pemberton and Frey 1982; Kim *et al*. 2002; Knaust 2007a; Singh *et al*. 2008; Rodríguez-Tovar and Uchman 2010; Chen *et al*. 2011, 2012).

It characterizes the *Psilonichnus*, *Cruziana* and *Zoophycos* ichnofacies (MacEachern *et al*. 2012). *Planolites* is an eurybathic trace fossil characteristic mainly of shallow and deep subtidal settings (Buatois and Mángano 2011; Angulo and Buatois 2012; Knaust *et al*. 2012).

The trace is known from the Ediacaran to the Holocene (McCann and Pickerill 1988; Uchman *et al*. 2005; MacNaughton 2007; Peng *et al*. 2012).

***Planolites montanus* Richter, 1937** (Pl. 3, Fig. 8; Pl. 4, Fig. 1; Pl. 5, Fig. 8). These are curved burrows, slightly undulating, rarely straight and usually branched irregularly, with elliptical or circular cross-section, with diameter 3.0–5.0 mm and length 5–15 cm. They are usually horizontal and follow bedding planes often crosscutting each other in various directions. Sometimes they penetrate the strata obliquely. The fill is different from the host rock. It occurs throughout the Lower Muschelkalk sequence studied except unit E (Text-fig. 2), and is particularly abundant above the *Spiriferina* Bed in the upper part of unit C (Text-fig. 2).

Planolites is interpreted as a pascichnion produced by various organisms, mostly polychaetes (Pemberton and Frey 1982; Keighley and Pickerill 1995); Knaust (2007a) has suggested bivalves or other molluscs as potential tracemakers. Large specimens of *Planolites* are interpreted as produced by isopod crustaceans (Virtasalo *et al*. 2011). In lacustrine sediments, they may be produced by insect larvae (Gradziński and Uchman 1994; Kim *et al*. 2002; Gillette *et al*. 2003; Singh *et al*. 2008), arthropods and annelids (oligochaetes) (Rodríguez-Tovar and Uchman 2010).

Although *Planolites* has been documented from all marine and continental environments (Rodríguez-Tovar and Uchman 2004; Hofmann *et al*. 2011; Phillips *et al*. 2011; Uchman and Kumpulainen 2011), it is common in shallow marine settings (Bann and Fielding 2004; Bressan and Palma 2009; Sarkar *et al*. 2009; Leszczyński 2010; Buatois and Mángano 2011).

The trace is known since the latest Neoproterozoic (McCann and Pickerill 1988; Erdoğan *et al*. 2004; Rodríguez-Tovar and Uchman 2004).

***Planolites* isp.** (Pl. 6, Fig. 4). These are unlined or rarely lined, horizontal to oblique burrows, straightly to gently curved, smooth and unwalled, 3.5–5.5 mm in diameter and 5.5–7 cm in length. Their fill differs in lithology from the host rock. The cross-section is elliptical or circular. They appear in units B, C and D (Text-fig. 2).

Planolites isp. is interpreted as pascichnia of deposit-feeders (Alpert 1975; Fürsich 1998; Tchoumatchenco and Uchman 1999; Schlirf 2003; Knaust 2010b; Monaco *et al*. 2012). It may be produced by e.g. worms, arthropods, molluscs, insects (e.g. Gradziński and Uchman 1994; Keighley and Pickerill 1995; Bromley 1996; Uchman 1998; Buatois and Mángano 2002; Knaust 2007a), or infaunal holothuroids (Chen *et al*. 2011).

It appears in the *Cruziana* ichnofacies (Frey and Seilacher 1980; MacEachern *et al*. 2007a). In shallow-marine carbonates, it occurs in the shallow subtidal and more commonly in the deep subtidal (middle-outer ramp settings) (Olóriz and Rodríguez-Tovar 2002; Buatois and Mángano 2011; Knaust *et al*. 2012).

Planolites ranges from the Proterozoic to the Holocene (Häntzschel 1975; Hofmann *et al*. 2011).

?*Protovirgularia* isp. (Pl. 1, Figs 7–8; Pl. 4, Fig. 2). It occurs on bedding planes as horizontal, straight or slightly curved, branched traces, 1.5–4.5 cm long and 2.0–5.0 mm in diameter. Their cross-section is trapezoidal or subtriangular (Pl. 4, Fig. 2). They are smooth and mostly unornamented, which may indicate transition to *Planolites*; the lack of clear chevron-like ornamentation may be caused by a less resistant substrate. It occurs in unit B and above the *Spiriferina* Bed of unit C (Text-fig. 2).

Protovirgularia isp. represents movement trails (repichnia) of protobranch bivalves (nuculacean and tellinacean) or scaphopods (Seilacher and Seilacher 1994; Ekdale and Bromley 2001b; Worsley and Mørk 2001; Uchman *et al*. 2004b, 2011; Kim *et al*. 2005; Knaust 2007a; Carmona *et al*. 2010). Sometimes, they are linked to the locomotion-feeding (pascichnia) activity of protobranch bivalves and arthropods (Mángano *et al*. 2005; Uchman *et al*. 2005; Zonneveld *et al*. 2010; Knaust and Costamagna 2012). Uchman *et al*. (2011) suggested that *Protovirgularia* should be restricted to repichnia.

Bradshaw (2010) suggests nuculid bivalve (*Notonucula*) as a producer. Radley *et al*. (1998) and Goldring *et al*. (2005) and interpreted it as an escape structures from a *Lockeia*-like resting burrow. Annelids, arthropods, crabs, dragonfly larvae were also proposed as its possible producers (Han and Pickerill 1994; Metz 2002, 2009; Kim *et al*. 2005; Gaillard and Racheboeuf 2006; Fernández *et al*. 2010). It is known from the *Cruziana* ichnofacies (MacEachern *et al*. 2007a, 2012).

Protovirgularia is common in both the Lower and the Upper Muschelkalk, where it is preserved as burrows within softground sediment (Knaust 2007a). Substrate consistency played a significant role in the taphonomic history of *Protovirgularia* judging by the sharpness (Mángano *et al*. 1998; Buatois and Mángano 2013) and the presence/absence of chevron ornament. It is common in shallow seas (Han and Pickerill 1994), but also occurs in deep seas (Nara and Ikari 2011).

It ranges from the Ordovician (Arenig) to Recent (Häntzschel 1975; Fillion and Pickerill 1990; Uchman 1998; Chen *et al*. 2011).

Rhizocorallium commune Schmid, 1876

***Rhizocorallium commune* var. *auriforme* Hall, 1843** (Pl. 4, Figs 3-4; Pl. 5, Fig. 8; Pl. 6, Fig. 3). They are straight, short, U-shaped and mainly horizontal or subhorizontal burrows, with very rare branching. In some cases clear spreiten structure is seen. They are 6 to 12 cm long, with the diameter of individual tubes from 1 to 2 cm, and the width of a U-shaped structure (tongue-shaped) between 5.5 and 6.5 cm. Based on their small size they are referred to *R. commune* var. *auriforme* (see discussion in Knaust 2013). It is known from the whole succession studied and is particularly common in unit B and in the lower and upper part of unit C (Text-fig. 2).

According to Knaust (2010c), *R. commune* contains actively produced spreiten and faecal pellets. It is interpreted as fodinichnia (Knaust 2008, 2013; Knaust and Costamagna 2012). Their tracemakers are deposit feeders worms (polychaetes) and worm-like animals (Fürsich 1974; Knaust 2007a, 2013; Knaust and Costamagna 2012; Knaust *et al*. 2012); Fürsich (1974), Pickerill *et al*. (1984) and Schlirf (2003) suggested crustaceans, probably shrimps (Seilacher 1967; Wincierz 1973). Knaust (2013) suggested deposit- and suspension-feeders, mainly polychaetes, as the tracemakers of *R. commune* var. *auriforme*. These are softground to stiffground burrows and occur in the *Cruziana* ichnofacies (Knaust 2010c, 2013).

Rhizocorallium is common in Mesozoic shallow-marine carbonate and siliciclastic deposits (Pemberton *et al*. 2001, 2012; Knaust *et al*. 2012; Rodríguez-Tovar *et al*. 2012). *R. commune* var. *auriforme* occurs in middle-outer ramp settings, as well as in lagoons and tidal flats and, in the Cenozoic, forms similar to *R. commune* also occur in deep-marine deposits (Knaust 2013).

It is abundant in the Röt and Muschelkalk (Knaust 2007a; 2013). Recently, Knaust *et al*. (2012) and Knaust (2013) regarded *Rhizocorallium commune* as

a senior synonym of *R. irregulare* and suggested its occurrence from the Early Cambrian to the Holocene.

***Rhizocorallium commune* var. *irregulare* Mayer, 1954** (Pl. 4, Figs 5–8; Pl. 5, Figs 1–7). These are large, long, undulating and seldom branched, horizontal U-shaped spreiten structures with parallel limbs. The tubes are elliptical in vertical section, their diameters range from 1.0 to 2.0 cm, width from 5.0 to 9.0 cm and length from 15 to 24 cm. It occurs in units B and D, and in the lower and upper parts of unit C. It is particularly common above the *Spiriferina* Bed, on the lower level of the quarry, where it forms clusters on bedding planes (Pl. 4, Fig. 8; Pl. 5, Figs 1–2).

R. irregulare (= *R. commune* var. *irregulare*) was interpreted as fodinichnia or domichnia of deposit-feeders (Fürsich 1974, 1975, 1998; Głuszek 1998; Worsley and Mørk 2001; Rodríguez-Tovar and Pérez-Valera 2008; Allington-Jones *et al*. 2010), possibly of crustaceans or worm-like animals (Schlirf 2003; Knaust 2007a). Recently (Knaust 2013) interpreted *R. commune* var. *irregulare* as a fodinichnion and suggested deposit- and suspension-feeeders as the tracemakers.

Rhizocorallium is most common in shallow marine deposits (Hofmann *et al*. 2011) but is reported from various settings including deep marine (Uchman 1991; Lukeneder *et al*. 2012; Knaust 2013) and non-marine (Fürsich and Mayr 1981); known from the Cambrian to the Miocene. *R. commune* var. *irregulare* dominates in intertidal and shallow subtidal environments (Knaust 2013).

R. commune var. *irregulare* is common in the Lower and Upper Muschelkalk (Knaust 2007a, 2013; Rodríguez-Tovar and Pérez-Valera 2008).

***Rhizocorallium jenense* Zenker, 1836** (Pl. 6, Figs 1–2). These are straight, short, subhorizontal to subvertical, U-shaped structures with parallel to sub-parallel limbs, without branchings. Spreiten are not always well developed. It is oblique to the bedding plane and rarely horizontal. It is 5.0–6.5 cm wide, 9.0–10 cm long and has tube diameters of 1.0–2.0 cm. It is common in unit B and becomes sporadic in unit C (Text-fig. 2).

R. jenense is a passive burrow with net-like scratches (Knaust personal communication) and is interpreted as a domichnion of suspension-feeders (Knaust 2007a, 2013; Singh *et al*. 2008; Loughlin and Hillier 2010). Schlirf (2011) interpreted *R jenense* as a composite structure of deposit- and suspension-feeding organisms. Głuszek (1998) suggested a gardening model as a good explanation of its ethology. Their

tracemakers can be arthropods (crustaceans), worm-like animals, annelids, or even insect larvae (mayfly larvae) (Fürsich and Mayr 1981; Schlirf 2003, 2011; Knaust 2007a; Rodríguez-Tovar and Pérez-Valera 2008; Knaust *et al*. 2012). According to Knaust (2013), in marine settings its tracemakers are polychaetes, whereas in fluvial deposits they are probably crus-taceans and mayflies. It is a firmground burrow be-longing to the *Glossifungites* ichnofacies and lacks faecal pellets (Knaust 2010c). It is typical of firm-grounds and is most typical of the *Glossifungites* ich-nofacies. *R. jenense* is a junior synonim of this ichno-facies (see Uchman *et al*. 2000; Knaust *et al*. 2012).

R. jenense has been documented from various en-vironments, usually related to unstable sedimentary conditions, from foreshore to deep water settings (Für-sich 1975; Uchman 1991; Knaust 1998; Worsley and Mørk 2001). According to Knaust (2013) it occurs from upper intertidal to supratidal and in fluvial set-tings; in the latter since the Miocene.

It is common in the Upper Buntsandstein (Röt), Lower Muschelkalk (Knaust 2007a) and Eocene (Uch-man and Gaździcki 2006). According to Knaust *et al*. (2012) *R. jenense* (sensu stricto) characterizes Triassic and youger deposits. It is particularly widespread in the Jurassic (Rodríguez-Tovar *et al*. 2012).

***Skolithos linearis* Haldeman, 1840** (Pl. 6, Fig. 4). These are straight or slightly curved, vertical and un-branched separate burrows, cylindrical or sub-cylin-drical in planar section, with structureless fill, smooth walls and no prominent lining. The burrows are 1.0 mm in diameter and 3.0 mm long. It occurs only above the *Spiriferina Bed* in unit C (Text-fig. 2).

Skolithos is a dwelling burrow (domichnion) of suspension-feeding annelids (polychaete), sipuncu-lans, phoronids, crustaceans (Alpert 1974; Miller and Knox 1985; Gouramanis *et al*. 2003; Bressan and Palma 2009; Desjardins *et al*. 2010; Hofmann *et al*. 2012; Knaust 2012; Baucon and Felletti 2013a). It is interpreted as fodinichnia or equilibrichnia of deposit feeders (Kim *et al*. 2002, Davies *et al*. 2009; Lough-lin and Hillier 2010). Zonneveld *et al*. (2012) pro-posed fish, worms, insects and anemones as the po-tential tracemakers of both *Skolithos* and *Mono-craterion*. In non-marine settings *Skolithos* may be produced even by insects: midge larvae, tiger beetle, arachnids, ants or plants (Alpert 1974; Häntzschel 1975; Pemberton *et al*. 1984; Bjerstedt 1988; Pem-berton and Jones 1988; Gillette *et al*. 2003; Schlirf and Uchman 2005; Morrisey *et al*. 2006, 2012; Singh *et al*. 2008; Knaust 2012). According to Bradshaw (2010) modern *Skolithos* is produced by polychaete worms

(*Onuphis microcephala*) and wormlike phoronids (*Phoronopsis viridis*).

*Skolitho*s is mainly recognized in shallow-water en-vironments (Curran 1985; Droser and Bottjer 1989; Fillion and Pickerill 1990; Droser 1991; Singh *et a*l. 2008) but also rarely in non-marine environments (Schlirf and Uchman 2005; Netto 2007) and deep seas (Buatois and Mángano 2011).

Skolithos occurs from the Neoproterozoic (Upper Vendian) to Recent (Häntzschel 1975; Fillion and Pickerill 1990; Erdoğan *et al*. 2004; Uchman *et al*. 2004a; Schlirf and Uchman 2005; Landing *et al.* 2013). *Skolithos linearis* was described from the Ordovician (Fillion and Pickerill 1984).

***Thalassinoides suevicus* Rieth, 1932** (Pl. 6, Figs 5–7). These are open Y-shaped and smoothly walled burrows, branched at an angle of 50–80º. The bur-rows are usually more or less horizontal and often el-liptical in cross-section. The fill is rather structureless and similar to the host rock. Labyrinth-like intercon-nected structures and T-shaped branches were not observed. Tube diameters vary from 0.5 to 3 cm. They are 3.0–5.0 cm wide and up to 9.0 cm long. *T. suevicus* was identified only in the bottom and cen-tral parts (above the Bone Bed) of the beds of unit C (Text-fig. 2). One specimen was found in unit B (Pl. 6, Fig. 8)

Thalassinoides are fodinichnial (Heinberg and Birkelund 1984, Bromley 1996; Knaust and Costam-agna 2012), domichnial (Bromley and Ekdale 1984, Myrow 1995; Miller 2001), or agrichnial (Ekdale and Bromley 2003) structures. Most authors suggested domichnial/fodinichnial (Häntzschel 1975; Kamola 1984; Miller and Knox 1985; Rodríguez-Tovar *et al*. 2009a, b; 2011a, b, c; Jaglarz and Uchman 2010; Monaco *et al*. 2012).

Deposit-feeders are suggested as the tracemakers (Gibert and Martinell 1998; Kędzierski and Uchman 2001; Ekdale and Bromley 2003). Kim *et al*. (2002) suggested ?suspension-feeders. Decapod crustaceans, probably thalassinid shrimps or shrimp-like organ-isms (McCarthy 1979; Sheehan and Schiefelbein 1984; Ekdale and Bromley 2003; Pervesler and Uchman 2009; Chen *et al*. 2011); lobsters, crabs (Frey *et al*. 1984; Myrow 1995; Bromley 1996; Gingras *et al*. 2002; Rossetti and Netto 2006; Carvalho *et al*. 2007) are suggested as the producers of *T. suevicus*. Ceri-anthid sea anemones, balanoglossan enteropneusts, acorn worms and fish (Myrow 1995; Bromley 1996; Kim *et al*. 2002; Pruss and Bottjer 2004; Chen *et al*. 2011, 2012) are also proposed. Bromley and Ekdale (1984) interpret *Thalassinoides* as structures left on a

shelf by big arthropods. *Thalassinoides* in Palaeozoic strata might have been constructed by trilobites, other arthropods, enteropneust worms, ancestors of decapods or unidentified organisms (Gouramanis *et al.* 2003; Cherns *et al.* 2006; Gibert *et al.* 2011; Knaust *et al.* 2012). In non-marine environments the most likely producers are decapod crustaceans and crayfish (Kim *et al.* 2002).

 T. suevicus is a facies-crossing form most typical of shallow-marine environments, frequently related to an oxygenated environment (Savrda 1991; Pemberton *et al.* 2001, 2012; Rodriguez-Tovar and Uchman 2004; Singh *et al.* 2008; Hoffman *et al.* 2011; Phillips *et al.* 2011) and less frequently occurring in deep marine settings (Uchman 1995, 1998; Cummings and Hodgson 2011). *Thalassinoides* form in firmground and/or hardgrounds (Myrow 1995) as part of the *Glossifungites* ichnofacies (Pemberton and Frey 1985), whereas *Thalassinoides* in softgrounds belongs to the *Cruziana* ichnofacies (MacEachern *et al.* 2007a, 2012).

This ichnogenus has been observed as a boring in some cases (Eisawi *et al.* 2011). Recent *Thalassinoides*, in modern shallow marine and freshwater environments, were interpreted as traces of crustaceans, mainly shrimps or crabs: *Callichirus* (*Callianassa*), *Mecochirus rapax*, *Glyphea*, *Neotrypaea*, *Alpheus* (Narrbone 1984; Myrow 1995; Nesbitt and Campbell 2002; Jank *et al.* 2006; Carvalho *et al.* 2007; Hembree *et al.* 2011).

Thalassinoides occurs from the Cambrian (Miller and Byers 1984; Mikuláš 2000; Gibert *et al.* 2011; Hofmann *et al.* 2011) to the Holocene (Sheehan and Schiefelbein 1984; McCann and Pickerill 1988). It becomes abundant in the Ordovician (Myrow 1995; Ekdale and Bromley 2003; Pruss and Bottjer 2004; Jin *et al.* 2011; Phillips *et al.* 2011). *T. suevicus* occurs predominantly in the Lower Muschelkalk (Knaust *et al.* 2012).

***Trypanites weisei* Mägdefrau, 1932** (Pl. 7, Figs 1–8) It is a straight, vertical or oblique unbranched boring terminating in a single opening. The length of the borings range from 0.2 to 3.1cm (1.2–1.8 cm on average) and the diameter reaches 1.0 mm. The borings are passively filled with dolomitic sediment, as described by Bertling (1999). *Trypanites weisei* was observed at two horizons. It occurs within organodetrital limestone in the lower part and in the *Spiriferina* Bed in the upper part of unit C (Text-fig. 2).

Polychaetes, sipunculans and barnacles are the most typical tracemakers of *Trypanites weisei* (Pickerill *et al.* 1984; Knaust 2007a; Checconi *et al.* 2010; Gibert *et al.* 2011; Bassi *et al.* 2013).

This ichnogenus characterizes the *Trypanites* ichnofacies (Seilacher 1967; MacEachern *et al.* 2007a, 2012). In carbonate deposits it forms borings in hardgrounds and is most typical of the inner ramp (Ekdale and Bromley 1984; Ghibaudo *et al.* 1996; Knaust 1998, 2007a, 2008, 2010a; Žítt and Mikuláš 2006; Knaust *et al.* 2012).

Trypanites weisei is known from the Ordovician (Palmer 1978) to the Neogene (Pleydell and Jones 1988; Benner *et al.* 2004; Blissett and Pickerill 2007). Johnson *et al.* (2010) suggest that *Trypanites* is the oldest known macroboring, recording it from the Early Cambrian. Ekdale and Bromley (2001a) and Vinn (2004) also reported *Trypanites* from the Cambrian. *Trypanites weisei* is common in some horizons of the Lower Muschelkalk of Thuringia (Knaust 1998, 2007a). This ichnotaxon was describrd by Fillion and Pickerill (1984) and Pickerill *et al.* (1984) from the Ordovician**.**

Unidentified traces A (Pl. 2, Fig. 5). These are 0.5–1.1 cm large oval traces on the bottom surface of a bedding plane. They are straight or slightly oblique smooth-walled burrows, sometimes thinner at one end. Their morphology resembles the outlets of vertical burrows (?*Palaeophycus*) but, since they were not observed in polished slabs, it is difficult to identify them unambiguously. The trace was found together with *Palaeophycus tubularis* and?*Palaeophycus* isp. above the *Spiriferina* Bed of unit C (Text-fig. 2).

Coprolites. Vertebrate coprolites, elongated and well rounded, 1.5–2.5 cm long and 0.5–1.0 cm wide, occur in the organodetrital limestone (Chrząstek 2008a) in the lower and upper parts of unit B (Text-fig. 2).

TRACE FOSSIL ASSOCIATIONS AND THEIR SEDIMENTARY ENVIRONMENT

The following ichnoassociations (IA) were distinguished in the Raciborowice Górne section: *Rhizocorallium–Pholeus* (IA 1)*, Rhizocorallium–Palaeophycus* (IA 2), *Thalassinoides* (IA 3), *Trypanites–Balanoglossites* (IA 4) and *Planolites–Palaeophycus* (IA 5) (Text-fig. 3)*.*
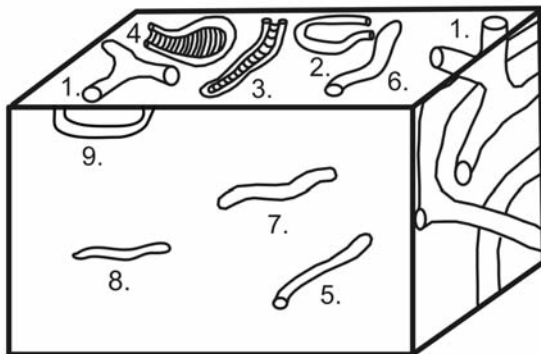
Rhizocorallium-Pholeus Ichnoassociation (IA 1)

Characteristics: IA 1 comprises very abundant *Rhizocorallium jenense* as well as *R. commune* var. *auriforme*; *R. commune* var. *irregulare*, *Lockeia* isp. and *Protovirgularia* isp. are common, whereas *Palaeo-*
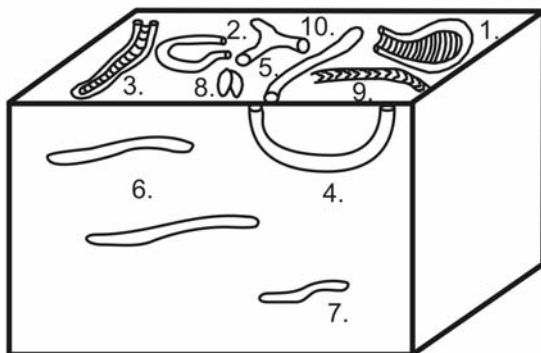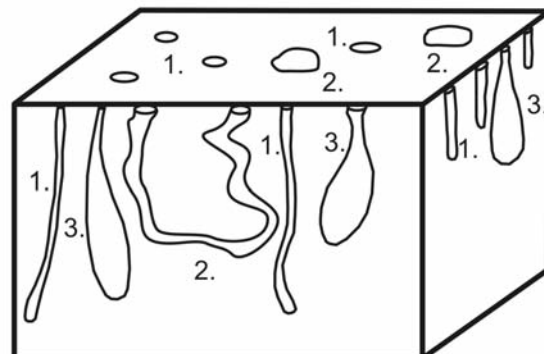
Text-fig. 3a. Ichnoassociation IA1 -
Rhizocorallium-Pholeus. 1. *Rhizocorallium
jenense*, 2. *R. commune* var. *auriforme*, 3. *R.
commune* var. *irregulare*, 4. *Pholeus* isp., 5.
Palaeophycus isp., 6. *Planolites montanus*, 7.
Planolites isp., 8. *Lockeia* isp., 9.
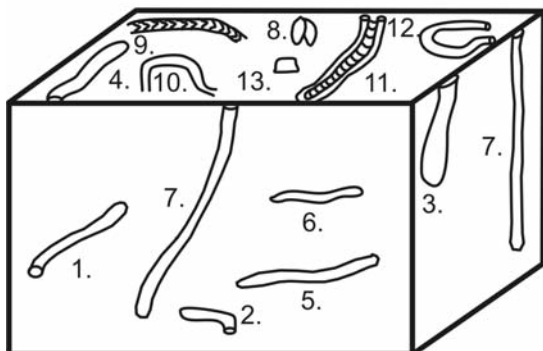*Protovirgularia* isp., 10. *Thalassinoides suevicus*
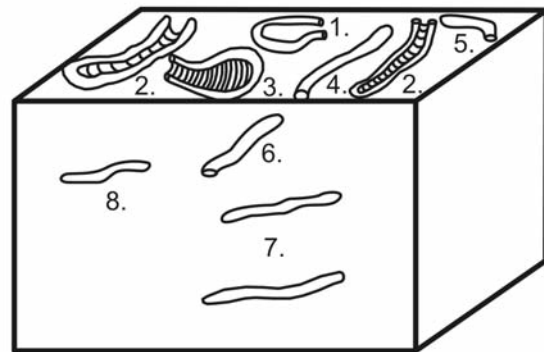
Text-fig. 3b. Ichnoassociation IA2 -
Rhizocorallium-Palaeophycus
1. *Rhizocorallium commune* var. *auriforme*, 2.
R. commune var. *irregulare*, 3. *R. jenense*, 4.
Palaeophycus tubularis, 5. *Palaeophycus* isp., 6.
?*Planolites beverleyensis*, 7. *Planolites
montanus*, 8. *Planolites* isp.

Text-fig. 3c. Ichnoassociation IA3 -
Thalassinoides
1. *Thalassinoides suevicus*, 2. *Rhizocorallium
commune* var. *auriforme*, 3. *R. commune* var.
irregulare, 4. *R. jenense*, 5. *Palaeophycus
tubularis*, 6. *Palaeophycus* isp., 7. *Planolites
montanus*, 8. *Planolites* isp., 9. *Pholeus* isp.

Text-fig. 3d. Ichnoassociation IA4 -
Trypanites-Balanoglossites
1. *Trypanites weisei*, 2. *Balanoglossites
triadicus*, 3. ?*Gastrochaenolites* isp.

Text-fig. 3e. Ichnoassociation IA5 -
Planolites-Palaeophycus, 1. *Palaeophycus
tubularis*, 2. *Palaeophycus* isp., 3.
?*Palaeophycus* isp., 4. ?*Planolites
beverleyensis*, 5. *Planolites montanus*, 6.
Planolites isp., 7. *Skolithos linearis*, 8. *Lockeia*
isp., 9. ?*Protovirgularia* isp. 10. *Archaeonassa
fossulata*, 11. *Rhizocorallium commune* var.
irregulare, 12. *Rhizocorallium commune* var.
auriforme, 13. traces A

Text-fig. 3. Ichnoassociations in the Lower Muschelkalk of the North Sudetic Basin Synclinorium

phycus isp., *Planolites montanus* and *Planolites* isp. are rare. *Pholeus* isp. was reported by Szulc (1991a; 2000, fig. 22/E). *Thalassinoides suevicus*, strongly washed-out and preserved as hyporelief, is known from a single specimen (Pl. 6, Fig. 8). IA 1 also contains vertebrate coprolites (Text-figs 2, 3a).

IA 1 occurs in sparsely-slightly (see Taylor and Goldring 1993) bioturbated sediments (ii=1–2; bi=1–2) of unit B (Text-fig. 2); in thick-bedded organodetrital limestone, rich in crinoids (*Dadocrinus* sp.) and vertebrate remains, in the lower part of the unit, and in thick-bedded organodetrital limestones, with abundant bivalves (*Myophoria vulgaris*) and vertebrate remains, in the upper part. Between the bioclastic beds occur platy marly limestones, dolomitic in places, with *Lockeia* isp., *Protovirgulari*a isp., *T. suevicus*, *R. commune* var. *auriforme*, *R. commune* var. *irregulare* and *R. jenense*, overlain by fine-grained, yellow-orange evaporitic dolomites (cellular, brecciated and crystalline – Chrząstek 2002) with sulphate pseudomorphs, devoid of trace fossils.

Ethologically, IA1 is dominated by domichnia or domichnia/fodinichnia (*Palaeophycus* isp., *Pholeus* isp., *T. suevicus*, *R. jenense*) and fodinichnia (*R. commune* var. *auriforme*, *R. commune* var. *irregulare*). Repichnia (?*Protovirgularia* isp.) and cubichnia (*Lockeia* isp.) are also common, whereas pascichnia (*Planolites montanus*, *Planolites* isp.) are rare.

Sedimentary environment: The trace fossils of IA 1 can be divided into a softground suite, belonging to the *Cruziana* ichnofacies (*Protovirgularia* isp., *Lockeia* isp., *R. commune* var. *auriforme*, *R. commune* var. *irregulare*, *Palaeophycus*, *P. montanus*, *Planolites* isp., *T. suevicus*), and a firmground suite of the *Glossifungites* ichnofacies (*R. jenense*) (MacEachern *et al*. 2007a, 2012; Buatois and Mángano 2011). The *Cruziana* ichnofacies (Seilacher 1967; Frey and Seilacher 1980; Frey *et al*. 1990; MacEachern *et al*. 2007a, 2012) is the most common among carbonate systems (Knaust *et al*. 2012). It occurs in shallow-marine environments between the fair-weather- and the storm-wave base, commonly in moderate to low energy conditions (especially the distal part of a carbonate ramp). The *Cruziana* ichnofacies is replaced in a proximal direction by the *Glossifungites* ichnofacies, which develops in semi-consolidated substrates (firmgrounds) (cf. Knaust and Costamagna 2012). The *Glossifungites* ichnofacies (Seilacher 1967; and Frey and Seilacher 1980; Pemberton and Frey 1985; Pemberton *et al*. 2001, 2004; MacEachern *et al*. 2007a, 2012; Buatois and Mángano 2011) can occur in various environments but most commonly in shallow sub-

tidal to supratidal settings (Buatois and Mángano 2011).

According to the "Conceptual model of a carbonate ramp with characteristic depositional environments" (Knaust *et al*. 2012) the *Cruziana* ichnofacies is typical of lagoon and mid- and outer ramp settings, while the *Glossifungites* ichnofacies occurs in lagoon and tidal flats.

In the Lower Muschelkalk succession, the low-energy background sedimentation (marlstone-limestone) is interrupted by high-energy event deposits (bioclastic, intraclastic beds), recognized as storm-related tempestites (Aigner 1984; Knaust 2007a), and most probably partly as tsunamites (Knaust *et al*. 2012; Pérez-López ans Pérez-Valera 2012). In the Raciborowice Górne section, the bioclastic beds occur mainly in the lower and upper parts of unit B, and are separated by marly and dolomitic limestones. The latter deposits contain omission surfaces (firmgrounds), bioturbated mainly by *R. jenense*. The softground suite, characterizing the *Cruziana* ichnofacies, is represented by ?*Protovirgularia* isp., *Lockeia* isp., *R. commune* var. *auriforme*, *R. commune* var. *irregulare*, *P. montanus*, *Planolites* isp. and *Palaeophycus* isp. In some cases, *R. jenense* occurs in bivalve (*Myophoria*) and gastropod beds, frequently crosscutting shell concentrations (Pl. 6, Fig. 2). *R. jenense* from the *Glossifungites* ichnofacies is related mostly to sea-level changes or to omission surfaces and storm-generated sediments (Rodríguez-Tovar *et al*. 2007). In Raciborowice Górne, *R. jenense* occurs in high-energy, storm bioclastic beds.

R. jenense is often related to storm deposits (Worsley and Mørk 2001; Rodríguez-Tovar *et al*. 2007; Rodríguez-Tovar and Pérez-Valera 2008; Knaust *et al*. 2012) or its appearance is connected with transgressive surfaces (Szulc 1990b; Uchman *et al*. 2000; Singh *et al*. 2008; Rodríguez-Tovar *et al*. 2012; Knaust 2013). The type of *R. jenense* occurs in great abundance at the base of a bioclastic limestone that marks the beginning of the Muschelkalk transgression (Knaust 2007a, 2010c). It is abundant in the nearshore zone (foreshore, shoreface) and becomes less common in shallower and more offshore settings (Fürsich and Mayr 1981; Worsley and Mørk 2001; Mørk and Bromley 2008; Singh *et al*. 2008).

Although most of the trace fossils in unit B are facies-crossing ichnotaxa, some of them (*Lockeia*, *Protovirgularia*, *Thalassinoides*, *Planolites*) are regarded as shallow marine forms, especially in carbonate settings (see: Buatois and Mángano 2011; Knaust *et al*. 2012). In the Germanic Muschelkalk, *R. jenense*, *Lockeia*, *Pholeus* and *T. suevicus* characterize inner and

middle ramp settings, whereas *Protovirgularia* and *R. commune* may occur in inner, middle and outer ramp settings (Knaust 1998; Knaust *et al*. 2012). In the carbonate ramp deposits, *Planolites* occurs in shallow and deep subtidal deposits (Buatois and Mángano 2011). *Thalassinoides* and *Planolites* are known from marginal- to shallow-marine deposits (tidal flat-upper offshore) (Angulo and Buatois 2012) and *Thalassinoides* has been related to organisms that live in intertidal to shallow-subtidal settings and lagoons (Jank *et al*. 2006). The assemblage of *R. irregulare* (=*R. commune*), *Palaeophycus tubularis*, *Planolites* isp., *Lockeia* isp. and *Protovirgularia* isp. was described from tidal flat deposits (Mángano and Buatois 2004; Desjardins *et al*. 2012).

Pholeus seems to be restricted to the nearshore marine environments (intertidal, lagoon, shallow subtidal) (Knaust 1998, 2002). The *Pholeus-Thalassinoides* ichnofabric characterizes the topmost parts of shallowing-upward cycles in the German Muschelkalk (Knaust 1998, 2002). Ruffel and Wach (1998) also reported *Thalassinoides* from the top of coarsening-up cycles. Knaust *et al*. (2012) described *T. suevicus* and *R. commune* from dolomitic, marly limestone with features of subaerial exposure (tidal flats, inner ramp). According to Szulc (1990b) the *Pholeus* assemblage is characteristic of transgressive deposits. *R. commune* var. *auriforme* and *R. commune* var. *irregulare* are common in lagoons and tidal flats of the inner ramp and in shallow subtidal settings (Knaust *et al*. 2012; Knaust 2013).

Lockeia and *Protovirgularia* have been recorded in both marine and freshwater settings (Hofmann *et al*. 2011; Melchor *et al*. 2012a), and are usually ascribed to shallow environments (Kim 1994; Uchman *et al*. 2004a; Goldring *et al*. 2005). The occurrence of *Protovirgularia* in deltaic tide-dominated marginal-marine deposits (Carmona *et al*. 2009, 2010) suggests that its producers, protobranch bivalves, were tolerant of fluctuations in salinity and oxygenation. An assemblage of *Protovirgularia*, *Lockeia*, *T. suevicus*, and *R. commune* was reported from a lagoon with slightly higher salinity from the Triassic of Sardinia (Knaust and Costamagna 2012), and *Planolites*, *Protovirgularia*, *Thalassinoides*, and *Rhizocorallium* were reported from the hypersaline part of the carbonate ramp of the Tatra Mts, Poland (Jaglarz and Uchman 2010). Dense populations of *Lockeia* (nursery populations) and *Protovirgularia* are known from intertidal deposits of abnormal salinity from the Triassic of the Betic Cordillera, Spain (Rodríguez-Tovar and Pérez-Valera 2013).

During deposition of unit B the salinity fluctuated. This is evidenced, on the one hand, by the presence of organisms that live under normal salinity (e.g., crinoids) in the lower part of the unit and, on the other hand, by the presence of sulphate pseudomorphs within the cellular limestone in the middle and upper parts of the unit, recognized as sabkha-type deposits (Szulc 1991a, Chrząstek 2002). Similar deposits are known from the time-equivalent deposits of Upper Silesia (Bodzioch and Kwiatkowski 1992; Kaim 1997).

In the dolomitic marly limestone and marly limestone in the middle part of the succession, *Lockeia* and *Protovirgularia* are common, whereas *T. suevicus* is rare (only one specimen found). Also abundant is *R. commune* var. *auriforme*; *R. commune* var. *irregulare* is less common. The occurrence of protobranch bivalve traces (*Lockeia*, *Protovirgularia*) in this part of the section may be explained by their high salinity tolerance of these bivalves. However, these trace fossils are also common in environments with normal salinity.

Sedimentological study of IA 1 host rocks showed that they were probably deposited in a shallow environment (inner ramp). This is also evidenced by the presence of bioclastic beds that are typical of the uppermost part of shallowing-upward cycles (Knaust 1998; Pérez-Valera and Pérez-López 2008; Knaust *et al*. 2012) and of dolomitic cellular limestone that characterizes sabkha deposits (Wilson 1975; Tucker and Wright 1990). The dolomitic limestone from the middle part of unit B points to a low energy tidal flats environment or to a shallow subtidal-lagoon (see Knaust *et al*. 2012). The occurrence of coprolites and vertebrate remains in the bioclastic beds also suggests a very shallow environment. The bioclastic beds are interpreted as shoals on the inner ramp (Kowal-Linka and Bodzioch 2011; Knaust *et al*. 2012). The assemblage of trace fossils is typical of the inner ramp (lagoon, tidal flats). *R. commune* (*R. commune* var. *auriforme*; *R. commune* var. *irregulare*), *R. jenense*, *T. suevicus*, *Protovirgularia* isp., *Pholeus* isp., found in this part of the Raciborowice Górne section, were also reported from the equivalent deposits of the German Muschelkalk (Knaust *et al*. 2012; Knaust 2013). According to these authors, *R. commune* and *T. suevicus* characterize tidal environments in the Germanic Basin (Thuringia, Germany), *Protovirgularia* shallow subtidal settings, and *R. jenense* supratidal to upper intertidal settings.

To sum up, the macrofossils, trace fossils, and character of host sediments, suggest a restricted lagoon on the inner ramp as the sedimentary environment of IA 1. The bioclastic beds are interpreted as shoals on the inner ramp and some of the dolomitic limestone might have been deposited in a tidal flat setting. This

interpretation is similar to the one proposed by Szulc (1991a) for this part of the section studied. The equivalent deposits from Upper Silesia were deposited in a similar environment (Szulc 1990a, b; Kowal-Linka and Bodzioch 2011). The environment during the deposition of unit B containing IA1 was well-oxygenated, as evidenced by the presence of *T. suevicus*, *R. jenense*, *R. commune* var. *auriforme* and *R. commune* var. *irregulare*. The salinity was normal in the bioclastic beds and increased during deposition of the part of unit B represented by cellular dolomitic limestones.

Rhizocorallium-Palaeophycus Ichnoassociation (IA 2)

Characteristics: IA 2 comprises abundant *Rhizocorallium commune* var. *irregulare* and *R. commune* var. *auriforme* and less common *R. jenense*, ?*Planolites beverleyensis*, *Palaeophycus tubularis* and *Planolites montanus* (Text-fig. 3b). *Palaeophycus* isp. and ?*Planolites* isp. are rare.

IA 2 occurs in two intervals in unit C, within thin-bedded, platy, wavy and marly limestones, slightly-moderately bioturbated bioturbated (ii=1–3; bi=2–3), and in unit D. In the upper interval of unit C, it is characterised by a mass occurrence of *R. commune* var. *irregulare* and *R. commune* var. *auriforme* (Text-fig.2). IA 2 is dominated by domichnia (*Palaeophycus tubularis, Palaeophycus* isp., *R. jenense*) and fodinichnia (*R. commune* var. *auriforme*, *R. commune* var. *irregulare*). Pascichnia, represented by *P. montanus* and ?*Planolites beverleyensis*, are less common.

Sedimentary environment: The ichnotaxa of IA 2 belong mainly to the *Cruziana* ichnofacies and are known from a wide range of shallow marine environments.

Rhizocorallium characterizes shallow-marine depositional systems (Archer 1984; Knaust 2010c; Hofmann *et al*. 2011); intertidal to subtidal settings. In siliciclastic and mixed carbonate-siliciclastic deposits it occur mostly from the middle to lower shoreface to offshore settings (Pemberton *et al*. 2001; 2012; Buatois and Mángano 2011; Mata and Bottjer 2011). In carbonate deposits, *R. commune* is typical of subtidal environments, mainly lagoon, outer ramp and intertidal mud flat (Knaust 2010c). It dominates in the middle-outer ramp settings, whereas *R. jenense* occurs in the inner-middle ramp settings (Knaust 1998, 2010c, 2013; Knaust *et al*. 2012).

Rhizocorallium usually indicates normal marine conditions (Fraiser and Bottjer 2009; Gingras *et al*. 2011). It is also a useful indicator of water energy level, substrate consistency and organic matter distribution (Rodríguez-Tovar and Pérez-Valera 2008). *R. jenense* is related to unstable sedimentary environments and high energy regimes, whereas *R. commune* is characteristic of quieter, low energy environments, either deep offshore or shallow lagoonal (Rodríguez-Tovar and Pérez-Valera 2008). The presence of *R. commune* (*R. commune* var. *auriforme*, *R. commune* var. *irregulare*) probably reflects inter-storm phases (softgrounds–stiffgrounds of the *Cruziana* ichnofacies), while *R. jenense* reveals colonization during storm phases (firmgrounds, *Glossifungites* ichnofacies) (Knaust 2010c, 2013). *R. irregulare* (= *R. commune*) is known from storm-influenced ramp environments, representing calm background conditions (between-storms deposits) with low sedimentation rates (Fürsich 1998; Rodríguez-Tovar and Pérez-Valera 2008). The dominance of *R. jenense* reflects a high concentration of nutrients in the water column, probably related to storm events (Rodríguez-Tovar and Pérez-Valera 2008), whereas producers of *R. commune* need organic-rich sediment (deposit-feeding mode of life). The dominance of *R. commune* var. *auriforme* and *R. commune* var. *irregulare* and the rarity of *R. jenense* in the platy and wavy limestones and marly limestones within IA 2, could be explained by colonization mostly during comparatively quieter intervals under lower energy conditions, probably between storm phases. *R. jenense,* although rare in this ichnoassociation, is known from higher-energy storm-related environments.

In siliciclastic and mixed carbonate-siliciclastic deposits *Planolites* and *Palaeophycus* usually occur from the middle-lower shoreface to lower offshore settings (Pemberton *et al*. 2001, 2012; Malpas *et al*. 2005; Buatois and Mángano 2011; Mata and Bottjer 2011). In carbonate ramp deposits *P. montanus* characterizes middle-outer ramp settings (Knaust *et al*. 2012).

Rhizocorallium commune var. *auriforme*, *R. commune* var. *irregulare*, *P. montanus*, ?*P. beverleyensis*, *Planolites* isp., and *Palaeophycus* isp. were produced during a relatively quiet inter-storm regime (pre- and post-omission depositional suite; Bromley 1975; Buatois and Mángano 2011). This assemblage is a typical example of the *Cruziana* ichnofacies, produced shortly after or before tempestite deposition. The moderately diverse, omission suite represents relatively calm background conditions with low rates or breaks in sedimentation, and is characterized by *Rhizocorallium jenense* (*Glossifungites* ichnofacies). Changes in the occurrence frequency of IA 2 trace fossils may also imply changes in water oxygenation. Although, apart from well-oxygenated environments, *R. irregulare* (=*R. commune*) may also occur in dysoxic conditions

(Wignall 1991; Knaust 2004, 2007b, 2013), the mass abundance of *R. commune* var. *irregulare* and *R. commune* var. *irregulae* in the uppermost part of unit C can be explained by a well-oxygenated environment during colonization by the tracemakers. The relationship between *Rhizocorallium* and well-oxygenated environments is often reported (Martin 2004; Gingras *et al.* 2011; Kotlarczyk and Uchman 2012; Olivero 2012). *Rhizocorallium* usually indicates normal marine conditions; it is rare in brackish or hypersaline settings (MacEachern and Gingras 2007; Knaust 2013). IA 2 thus suggests a well-oxygenated, normal salinity environment. The occurrence of IA 2 in the platy, wavy and marly limestons points to the middle-outer ramp. Such deposits are typical of the middle to lower parts of the shallowing-upward cycles in the German Muschelkalk (Knaust 1998; Knaust *et al.* 2012). According to the latter authors, although *R. commune* can appear in inner ramp setings (tidal flats, lagoons), it is most typical in middle-outer ramp settings, whereas *Planolites* occurs commonly in the outer ramp and becomes less common in the middle ramp. Knaust *et al.* (2012) and Knaust (2013) reported *R. commune* var. *irregulare* from the Germanic Basin (Germany) mostly from lagoons, tidal flats and the shallow subtidal of the inner and middle ramp. *R. commune* var. *auriforme* is typical of lagoons, middle-outer ramp and basin, where it usually co-occurs with *Planolites montanus* and *Protovirgularia* isp. (Knaust 2013). In Raciborowice Górne, *R. commune* var. *irregulare* is common in the middle ramp, whereas *R. commune* var. *auriforme* dominates the middle-outer ramp.

Thalassinoides Ichnoassociation (IA 3)

Characteristics: *Thalassinoides suevicus* is the most characteristic constituent of IA 3. It is accompanied by *R. commune* var. *auriforme*, *R. commune* var. *irregulare*, *R. jenense*, *Planolites* isp. and *Palaeophycus* isp. (Text-fig. 3c). *Planolites montanus* and *Palaeophycus tubularis* are less common. IA 3 also contains *Pholeus* isp. (Szulc 1991a).

IA 3 occurs in platy and wavy limestones, sparsely-slightly bioturbated bioturbated (ii=1–2; bi=1–2), in the lower part of unit C and reappears below the *Spiriferina* Bed in unit C (Text-fig. 2). This part of the succession displays moderate ichnodiversity. In the lower interval *T. suevicus* is accompanied mainly by *Rhizocorallium*, and by *Planolites* and *Palaeophycus* in the upper interval.

T. suevicus appears repeatedly over pyrite-mineralized strata; above layers rich in gastropods, the bivalve *Myophoria vulgaris* Schlotheim and scaphopods

(Text-fig. 2), and above dark limestones with abundant fish teeth (Chrząstek and Niedźwiedzki 1998; Chrząstek 2002, 2008a). The latter contains *Planolites* isp. (Text-fig. 2).

From the ethological point of view IA 3 is dominated by domichnia or domichnia/fodinichnia (*T. suevicus*, *Pa. tubularis*, *Palaeophycus* isp., *R. jenense*) and fodinichnia (*R. commune* var. *auriforme*, *R. commune* var. *irregulare*). Pascichnia (*P. montanus*, *Planolites* isp.) are less common.

Sedimentary environment: *T. suevicus* (abundant); *P. montanus*, *Planolites* isp., *Pa. tubularis*, *Palaeophycus* isp., *R. commune* var. *auriforme*, *R. commune* var. *irregulare* (common) and *R. jenense* (rare) are part of the *Cruziana* ichnofacies (sensu Seilacher 1967).

T. suevicus is most typical of shallow-marine deposits of the *Cruziana* ichnofacies (McCann and Pickerill 1988; Rodríguez-Tovar and Uchman 2004, 2010; Rodríguez-Tovar and Pérez-Valera 2008; Singh *et al.* 2008; Jaglarz and Uchman 2010; Hofmann *et al.* 2011). In siliciclastic deposits, *Thalassinoides* is indicative of lower shoreface-offshore settings (Pemberton *et al.* 2001; 2012; Uchman and Krenmayr 2004; Buatois and Mángano 2011; Chrząstek 2013; La Croix *et al.* 2013). It is also reported from the inner-middle carbonate ramp (Knaust 1998; Knaust *et al.* 2012), and mostly from shallow carbonate deposits (Monaco and Giannetti 2002; Jach 2005; Waite *et al.* 2008, 2013; Vlahovic *et al.* 2011; Wiedl *et al.* 2012, 2013). *Thalassinoides* was described from the upper part of the shallowing upward cycle (Knaust 1998; Pérez-Valera and Pérez-López 2008; Knaust *et al.* 2012; Pérez-López and Pérez-Valera 2012).

Although *Thalassinoides* may be treated as eurybathic (Sheehan and Schiefelbein 1984; McCann and Pickerill 1988; Knaust 1998, 2002), its palaeoenvironmental distribution depends more on substrate character than on bathymetry. It is a good indicator of firmgrounds, stiffground (softgrounds) and hardgrounds (Myrow 1995; MacEachern and Burton 2000; Savrda *et al.* 2001; Malpas *et al.* 2005; MacEachern *et al.* 2007b; Knaust 2009; Pearson *et al.* 2012). It is usually found in oxygenated substrates (Ekdale and Bromley 1984; Pruss and Bottjer 2004; Rodríguez-Tovar and Uchman 2004, 2010; Giannetti and McCann 2010). Thus, the presence of *Thalassinoides* is considered as a reliable indicator of well-oxygenated conditions (Savrda and Bottjer 1986; Ekdale and Mason 1988; Savrda 2007; Boyer and Droser 2011; Buatois and Mángano 2011; Hofmann *et al.* 2011).

Changes in the lithological and palaeontological record, as well as local pyrite mineralization, clearly

indicate differences in water oxygenation during the sedimentation of deposits with IA 3. The Bone Bed with *Planolites* (middle part of unit C) was deposited in a relatively oxygen-poor environment as evidenced by pyrite mineralisation and the colour of the strata (Leszczyński 1991; Chrząstek and Niedźwiedzki 1998; Wetzel and Uchman 1998b; Chrząstek 2002). Low oxygenation might have been caused by decomposition of fish remains (Chrząstek 2008a). The Bone Bed is overlain by strata containing *Thalassinoides*, indicating better water oxygenation. However, it should be noted that, in contrast to the makers of *Thalassinoides* and *Rhizocorallium*, the *Planolites* producers have no direct access to sea water and use oxygen from the deposit (Wetzel and Uchman 1997, 1998a, 2001; Głuszek 1998; Uchman 2004). Thus the environment with *Planolites* makers was not necessarily completely anoxic. A similar succession is observed in the lower part of unit C, where the pyrite-mineralized beds with gastropods and bivalves precede the strata with *Thalassinoides* (Text-fig. 2).

A similar replacement of *Planolites* by *Thalassinoides* caused by increasing water oxygenation was reported by numerous authors (e.g. Szulc 2000).

No apparent changes in water salinity occurred during the deposition of beds with IA 3, as evidenced by both the macrofaunal assemblages (Chrząstek 2002) and the trace fossils, especially *T. suevicus* and of *R. commune* var. *auriforme*, *R. commune* var. *irregulare* and *R. jenense*, which are characteristic of normal marine conditions.

IA 3 occurs in two intervals of the Raciborowice Górne section, always preceding the hardground-related IA 4. Thus, the presence of *Thalassinoides* signals the beginning of regressive trends in the Lower Muschelkalk basin. A similar situation was observed in regression-related deposits of other sedimentary basins (Szulc 1990b). The occurrence of *Thalassinoides* at the transition from a quiet water (middle shelf micritic firmgrounds) setting to higher energy, more nearshore settings (intertidal) is commonly reported (e.g., Pruss and Bottjer 2004). *T. suevicus* occurring in platy limestones is typical of middle ramp settings and usually occurs in the upper part of shallowing-upward cycles (Knaust 1998, 2002; Pérez-Valera and Pérez-López 2008; Knaust *et al*. 2012). In the Raciborowice Górne section IA 3 appear twice, always preceeding IA 4 characterising hardground horizons (Text-fig. 2).

All IA 3 traces are common in the middle ramp setting (compare Knaust 1998; Knaust *et al*. 2012). Based on ichnological analysis, the formation of IA 3 in Raciborowice Górne took place in the middle ramp en-

vironment. The environment during sedimentation of IA 3 host rocks was fully marine and well-oxygenated, as evidenced by *Thalassinoides* and *Rhizocorallium*, ichnotaxa that are typically found in shallow marine environments (Hofmann *et al*. 2011).

Trypanites-Balanoglossites Ichnoassociation (IA 4)

Characteristics: IA 4 is dominated by *Trypanites weisei* (abundant), accompanied by *Balanoglossites triadicus* (common) and ?*Gastrochaenolites* isp. (rare) (Text-fig. 3d). It appears within the *Trypanites*-bearing micritic limestone (hardgrounds), in the lower part of unit C, and in the *Spriferina* Bed (Text-fig. 2; Pl. 7, Figs 1–8). The micritic limestones that contain borings are slightly to moderately bioeroded (ii=2–3; bi=2–3). Ethologically, IA 4 is dominated by domichnia (*Tr. weisei*, ?*Gastrochaenolites* isp.) and fodinichnia/domichnia (*B. triadicus*).

Sedimentary environment: The trace fossils of IA 4 represent the *Trypanites* ichnofacies (*Tr. weisei*, ?*Gastrochaenolites* isp.) that characterizes hardgrounds and the *Glossifungites* ichnofacies (*B. triadicus*) typical of firmgrounds (Pemberton *et al*. 2001; MacEachern *et al*. 2007a, 2012; Buatois and Mángano 2011).

The *Trypanites* ichnofacies was originally introduced by Frey and Seilacher (1980), and subsequently revised by Bromley and Asgaard (1993); Pemberton *et al*. (2001); MacEachern *et al*. (2007a, 2012); and Buatois and Mángano (2011). Buatois and Encinas (2011) subdivided the *Glossifungites* ichnofacies into an archetypical expression in carbonate substrates and a depauperate expression in non-carbonate metamorphic igneous rocks. Bromley and Asgaard (1993) established the *Entobia* subichnofacies within *Trypanites* ichnofacies that contained *Gastrochaenolites*, but recently MacEachern *et al*. (2007a, 2012) and Buatois and Mángano (2011) suggested that it is equivalent to the *Trypanites* ichnofacies.

The *Trypanites* ichnofacies develops in fully lithified substrates such as hardgrounds, reefs, rocky coasts and beachrock, as well as shells and bones (Pemberton *et al*. 2001; Buatois and Mángano 2011). The *Trypanites* ichnofacies is directly associated with different types of unconformities, either omission or erosive surfaces.

The *Trypanites* ichnofacies commonly intergrades with the *Glossifungites* ichnofacies (Pemberton *et al*. 2001; Knaust *et al*. 2012); the *Trypanites* suite crosscuts the *Glossifungites* suites, reflecting progressive cementation of the original substrate. In IA 4, ?*Gastrochaenolites* and *Tr. weisei* are regarded mainly as

borings in hard substrates, whereas *B. triadicus* is interpreted as firmground burrows. In Raciborowice Górne the trace fossils of IA 4 are associated mainly with hardground horizons (Seilacher 1967; Knaust 2004, 2010b; Bertling *et al*. 2006).

Firmgrounds with *B. triadicus* (*Glossifungites* ichnofacies) grade progressively into hardgrounds with *Tr. weisei* and ?*Gastrochaenolites* isp. (*Trypanites* ichnofacies). *Balanoglossites* sometimes co-occurs with *Trypanites*, suggesting its occurrence in hardground substrates (Pl. 1, Figs 2, 5). The co-occurrence may also be explained by the transition of the firm substrate with *B. triadicus* into a hardground, bioeroded later by *Tr. weisei* producers.

Trypanites is more typical of the inner shelf than the outer shelf and also occurs on intertidal flats and in lagoons (Fürsich 1975; Pickerill *et al*. 1984; Frey *et al*. 1990). Its development depends more on the substrate consistency than on bathymetry (Frey and Seilacher 1980). *Trypanites* and *B. triadicus* usually characterize very shallow, well-aerated hard substrates (Szulc 1990b; Knaust 2007a, 2008; Johnson *et al*. 2010; Vinn and Wilson 2010). *Trypanites* appears in abundance down to a depth of c. 30 m, in low energy environments (Bassi *et al*. 2011).

B. triadicus is common in shallow marine carbonate platforms and may also occur in peritidal (marginal-marine) environments (Knaust *et al*. 2012; Pérez-López and Pérez-Valera 2012). Knaust (1998) and Knaust *et al*. (2012) reported *Trypanites* and *Balanoglossites* from inner ramp settings.

Gastrochaenolites is indicative of very shallow marine environments, intertidal–upper subtidal (Bromley and Asgaard 1993; Ekdale and Bromley 2001a; Wilson *et al*. 2005; Carmona *et al*. 2007; Checconi *et al*. 2010; Bover-Arnal *et al*. 2011; Caracuel *et al*. 2011; Belaústegui *et al*. 2012). Malpas *et al*. (2005) regard this ichnogenus to be limited to waters of no more than a few metres deep. In the Mediterranean and Caribbean, *Lithophaga lithophaga*, the modern tracemaker of *Gastrochaenolites*, is restricted to 0-10 m (Farinati 2007; Santos *et al*. 2010) and is most common in very shallow waters (1–2 m) with a low sedimentation rate.

IA 4 first appears in the lower part of unit C within the deposits interpreted either as a hardground or as an intraclast horizon. It reappears within hardground intraclasts in the *Spiriferina* Bed (Pl. 1, Figs 2–6; Pl. 7, Figs 1–8).

Formation of a hardground is related to a fall in sea level (e.g., Bromley and Asgaard 1993; Ghibaudo *et al*. 1996; MacEachern *et al*. 2007b; Cachão *et al*. 2009; Santos *et al*. 2010). The *Glossifungites* ichnofacies has been recognized at the base of regressive deposits (Buatois *et al*. 2002). *Balanoglossites* and *Trypanites* were reported from the top of shallowing-upward cycles (Knaust 1998; Bertling 1999; Knaust *et al*. 2012). In Raciborowice Górne, the *Trypanites-Balanoglossites* ichnoassociation follows the *Thalassinoides* ichnofacies which marks the beginning of a regression.

The formation of a hardground may be followed by a relatively fast rise in sea level, leading to the deposition of marly limestone which usually represents a deeper environment – outer ramp (e.g., Pérez-López and Pérez-Valera 2012). Such a scenario probably took place in the Raciborowice Górne succession; the hardground is followed by the *Spiriferina* Bed, with the first occurrence of *Punctospirella fragilis* Schlotheim, encrinids and, in the overlying limestone bed, the cephalopods *Balatonites ottonis* Buch and *Germanonautilus* sp., suggesting the connection of the North Sudetic Basin with Tethys due to transgression.

Planolites-Palaeophycus Ichnoassociation (IA 5)

Characteristics: IA 5 comprises mainly *Palaeophycus tubularis*, *Palaeophycus* isp., ?*Palaeophycus* isp., *Planolites montanus,* ?*P. beverleyensis* and *Planolites* isp.; *Lockeia* isp., ?*Protovirgularia* isp. and *Rhizocorallium commune* var. *auriforme* are less common (Text-fig. 3 e). *Archaeonassa fossulata*, *Skolithos linearis*, *R. commune* var. *irregulare* and the unidentified traces A are rare.

IA 5 occurs in thin-bedded nodular and wavy limestone, sparsely-highly bioturbated (ii=1–5; bi=1–4), in the upper part of unit C, immediately above the *Spiriferina* Bed (Text-fig. 2). *Palaeophycus* isp. was also observed in the uppermost part of unit E (Text-fig. 2); suggesting that IA 5 may also be present in this unit. In I A5 a wide spectrum of ethological types occurs, e.g. domichnia (*Pa. tubularis*, *Palaeophycus* isp., *Skolithos linearis*), fodinichnia (*R. commune* var. *auriforme*, *R. commune* var. *irregulare*), cubichnia (*Lockeia* isp.), repichnia (?*Protovirgularia* isp.), pascichnia (*P. beverleyensis*, *P. montanus*, *Planolites* isp.), and pascichnia/fodinichnia (*A. fossulata*).

Sedimentary environment: *Archaeonassa*, *Lockeia*, *Skolithos* and *Protovirgularia* are usually interpreted as characteristic of shallow environments, from nearshore to lower offshore (Uchman *et al*. 2004a; Bradshaw 2010; Cabrera and Olivero 2011; Nagel *et al*. 2013; Olivero and Cabrera 2013) but they also appear in deep-sea settings (Uchman 2004; Poursoltani *et al*. 2007; Wetzel *et al*. 2007; Zhang *et al*. 2008; Nara and Ikari 2011; Uchman and Rattazzi 2011; Greene *et al*. 2012). They are also known from marginal-marine and freshwater settings (McIlroy 2004b; 2007; Carmona *et*

al. 2009; Buatois and Mángano 2011; Gingras *et al.* 2011; Melchor *et al.* 2012b; Scott *et al.* 2012). *Archaeonassa* was described mainly from marginal- and shallow-marine deposits (Buckman 1994; Knaust 2007a; Buatois and Mángano 2009; Sarkar *et al.* 2009; Mángano *et al.* 2013). According to Buckman (1994) it is a useful environmental indicator typical of intertidal and shallow seas.

Skolithos is recognized mainly in shallow-water environments (Fillion and Pickerill 1990; Singh *et al.* 2008; Pearson *et al.* 2013; Rossetti *et al.* 2013). It is typical of foreshore-shoreface subenvironments of the *Skolithos* ichnofacies but can also occurs in upper offshore environments (Pemberton *et al.* 2001, 2012; MacEachern *et al.* 2007a, 2012; Baucon and Felletti 2013a; Mayoral *et al.* 2013). In carbonate deposits it is mostly characteristic of the inner ramp (Knaust *et al.* 2012).

Lockeia is commonly interpreted as a shallow-marine trace fossil (Pollard 1981; Kim 1994; Uchman *et al.* 2004a; Buatois and Mángano 2011; Fernández and Pazos 2013). In carbonate deposits *Lockeia* and *Protovirgularia* characterize inner-outer ramp deposits (Knaust 2007a, Knaust *et al.* 2012).

Rhizocorallium characterizes medium-energy, marginal-marine and shallow-marine environments (Worsley and Mørk 2001; Buatois *et al.* 2002; Bann and Fielding 2004; Sarkar *et al.* 2009; Hofmann *et al.* 2011) and is usually attributed to periodic oxygenation events (Mørk and Bromley 2008; Gingras *et al.* 2011).

Abundant *Planolites* and *Palaeophycus* have been recorded in storm-influenced, middle-lower shoreface to lower offshore deposits (Uchman and Tchoumatchenco 2003; Bann and Fielding 2004; Sarkar *et al.* 2009; Bressan and and Palma 2009; Leszczyński 2010). *Palaeophycus*-producers prefer low-moderate energy environments (Seilacher 1967; Gillette *et al.* 2003; MacEachern *et al.* 2007a; Mohseni *et al.* 2011), dominating in offshore environments (Angulo and Buatois 2012; Mayoral *et al.* 2013).

All of the ichnotaxa of IA 5 are common in shoreface, offshore environments (Pemberton *et al.* 2001, 2012; Bann *et al.* 2004; Malpas *et al.* 2005; Buatois and Mángano 2011; Mata and Bottjer 2011). They are typical of normal salinity but also occur in hypersaline conditions and in short episodes of oxygen depletion (McCann and Pickerill 1988; Gillette *et al.* 2003; McIlroy 2004b; Jaglarz and Uchman 2010).

In carbonate ramp deposits the *Planolites-Palaeophycus* assemblage is most typical of outer ramp deposits and usually appears in nodular limestone representing the lower part of shallowing-upward cycles (Knaust 1998). *R. commune*, especially *R. commune* var. *auriforme*, and *Protovirgularia* are also abundant

in outer ramp settings (Knaust *et al.* 2012). Buatois and Mángano (2011) described *Planolites* and *Rhizocorallium* from deep-subtidal carbonate deposits.

Consequently, based on trace fossils, it can be assumed that IA 5 records the deepest environments in the Raciborowice Górne section. This is also confirmed by the appearance of the cephalopods *Balatonites ottonis* Buch and *Germanonautilus* sp. (Chrząstek 2002; Treter 2003) in the limestone above the *Spiriferina* Bed (Text-fig. 2).

IA 5 formed during two transgressive maxima (outer ramp in the upper part of unit C; and open sea in unit E), separated by the shallowing event recorded by IA 2 (uppermost part of unit C and unit D). A deep, low energy environment during sedimentation of the upper part of unit C is reflected by its high ichnofabric index (ii up to 5). The taxonomic composition of the macrofossils, especially the occurrence of ammonites, nautiloids and crinoids, indicates stenohalic conditions (Chrząstek 2002). Although abundant *Planolites* and *Palaeophycus* may suggest low water oxygenation (Szulc 1990b; Knaust *et al.* 1999), the high bioturbation index for IA 5 (bi up to 4) suggests well-oxygenated environments (for details see Savrda 1995). The abundance of *Planolites* as an indication of well-oxygenated bottom waters in shallow-marine settings, and its low abundance as a result of a lowered oxygen level, was also suggested by Phillips *et al.* (2011). *Planolites* from well-oxygenated settings was also described by Wilson *et al.* (2005), Giannetti and McCann (2010), Gingras *et al.* (2011) and Hofmann *et al.* (2011). Consequently, it may be suggested that IA 5 might indicate fully oxic bottom conditions in the North Sudetic Muschelkalk Basin (Table 1).

PALAEOGEOGRAPHY

From the Olenekian to the Anisian the communication between the North Sudetic Basin and the Tethys Ocean was restricted to two marine gateways, the East Carpathian and the Silesian-Moravian. Neither trace fossils nor macrofossils offer a sufficient basis to conclude which of the two was dominant during the sedimentation of the lower part of the Lower Muschelkalk in Raciborowice Górne (Chrząstek 2008a). In the Late Olenekian and the Early Anisian (*sensu* Nawrocki and Szulc 2000), faunal migration most probably took place through both of the gateways (Szulc 2000; Niedźwiedzki and Salamon 2002). In the Pelsonian it was restricted to the Silesian-Moravian Gate (Hagdorn 1991; Hagdorn *et al.* 1998; Narkiewicz and Szulc 2004), which offered a convenient connection between

Upper part of table (Thuringia / Germany)

Chronostratigraphy Bachman et al. 2009; Szurlies 2007; Ogg 2012		Knaust 1998, 2007a; Knaust et al. 2012	Thuringia
Lower Muschelkalk (Anisian) — Pelsonian		Planolites, Teichichnus	Upper Wellenkalk
		Planolites, Teichichnus	Terebratula Bed
Bithynian		Palaeophycus, Pholeus, Planolites, Thalassinoides	Middle Wellenkalk
			Oolith Bed
		Balanoglossites, Pholeus, Rhizocorallium, Thalassinoides, Trypanites, Gastrochaenolites, Lockeia, Protovirgularia, Archaeonassa, Skolithos, Planolites	Lower Wellenkalk
Röt			Röt

Lower part of table (North-Sudetic Basin / Opole Region)

Chrząstek 2002, this paper; Szulc 1991a	North-Sudetic Basin	Bodzioch 1991a, b; 1997; Szulc and Głuchowski 1991; Kowal-Linka 2008; Szulc 1990a, b, 1991b, 2000, 2007b	Opole Region, Upper Silesia	Chronostratigraphy Nawrocki and Szulc 2000
Palaeophycus	Unit E	Alcyonidiopsis, Arenicolites, Balanoglossites, Cliona, Palaeophycus, Planolites, Rhizocorallium, Teichichnus, Trypanites	Dziewkowice Formation (Terebratula Beds)	Pelsonian (Anisian, Lower Muschelkalk)
Palaeophycus, Planolites, Rhizocorallium	Unit D	Balanoglossites, Palaeophycus, Planolites, Trypanites	Goraźdże Beds	
Archaeonassa, Balanoglossites, ?Gastrochaenolites, Palaeophycus, Pholeus, ?Protovirgularia, Planolites, Rhizocorallium, Skolithos, Thalassinoides, Trypanites, traces A	Unit C	Chondrites, Palaeophycus, Pholeus, Planolites, Rhizocorallium	Upper Gogolin Beds	Bithynian / Aegean
Lockeia, Palaeophycus, Pholeus, Planolites, ?Protovirgularia, Rhizocorallium, Thalassinoides, coprolites	Unit B	Palaeophycus, Pholeus, Planolites, Rhizocorallium, Thalassinoides, Teichichnus	Lower Gogolin Beds	Spathian (Olenekian)

Table 1. Correlation of the ichnoassociations from the North Sudetic Basin Synclinorium with their equivalents from other areas (Opole region, Thuringia). Lithostratigraphic correlation of the Lower Muschelkalk from Opole Silesia with Thuringian equivalents after Kędzierski (2002), Szulc (2007b) and Szurlies (2007). Lithostratigraphic divisions of the Lower Muschelkalk from the North Sudetic Basin after Chrząstek (2002), the Opole region after Assmann (1944) and Thuringia after Wendland (1980). The boundary between Röt and Lower Muschelkalk in the North Sudetic Synclinorium after Głuchowski and Salamon (2005). The base of the Anisian (base of Röt Formation of Germany) according to Ogg (2012)

local sub-basins (North Sudetic, Opole and Upper Silesia) and the Tethys Ocean (Kędzierski and Szulc 1996; Chrząstek 2002, 2008a). In the Raciborowice Górne succession, the opening of this gateway is marked by the appearance of the brachiopod *Punctospirella fragilis* together with numerous crinoids and typical Tethyan conodonts in the *Spiriferina* Bed and, in the overlying limestone, of the cephalopods *Balatonites ottonis* and *Germanonautilus* sp. (Hagdorn and Głuchowski 1993; Kędzierski and Szulc 1996; Chrząstek 2002, 2004, 2008a; Treter 2003). The Pelsonian age of the *Spiriferina* Bed is confirmed by the presence of *Eckicrinus radiatus* (Głuchowski and Salamon 2005).

After the deposition of the *Spiriferina* Bed, the Sudetic Basin started to deepen, as evidenced not only by the macrofauna (brachiopods, cephalopods) but also by the trace fossils. The upper part of unit C in Raciborowice Górne is dominated by IA 5, which records the deepest environment in the whole succession.

COMPARATIVE REMARKS

Most of the trace fossils recognized in the Raciborowice Górne section are also known from time-equivalent deposits in other areas of the Triassic Germanic Basin. Based on trace fossils, the North Sudetic succession is most similar to the successions known from Thuringia, Germany (compare Knaust 1998; Knaust 2007a, Knaust *et al.* 2012). The observation that *R. jenense* is common in unit B and appears sporadically in unit C, of the Raciborowice Górne section, where *R. commune* dominates, is in agreement with *R. jenense* appearing in the Röt and the lower part of the Lower Muschelkalk successions in Germany. Similarly, *R. commune* becomes abundant in the upper part of the German Lower Muschelkalk. The sequence from Raciborowice Górne differs from the German Muchelkalk in having *Trypanites weisei*, *Balanoglossites triadicus* and *Gastrochaenolites* only in the upper part of the succession (Unit C). In its lower part, in unit B, these trace fossils are absent. Compared to their occurrences in the German Muschelkalk, *Palaeophycus* is more abundant in Raciborowice Górne, whereas *Pholeus* isp. and *Archaeonassa fossulata* are less common (see Table 1).

The Raciborowice Górne succession is also ichnologically similar to the succession known from the Opole Region of Poland (see the reference list in Table 1). One of the main differences is the higher diversity of the trace fossil assemblage in the North Sudetic Basin. Moreover, in the North Sudetic Basin, *Trypanites*, *Balanoglossites* and *Thalassinoides* are common in the lower part of the succession and are absent from its upper part, which is opposite to their occurrence pattern in the Opole succession, where they are sporadic in the lower part and common in the upper part, in the *Terebratula* Beds (=Dziewkowice Formation) (see Table 1) (Szulc 2007b; Kowal-Linka 2008). Another difference is a decrease in the abundance of *Rhizocorallium* in the uppermost part of the Upper Gogolin Beds of the Opole region (Szulc 1993; Niedźwiedzki 1999), and its mass abundance in the equivalent beds of the North Sudetic Basin (Pl. 4, Figs 7–8; Pl. 5, Figs 1–2).

The correlation of ichnotaxonomic composition between time-equivalent sediments from other sub-basins in southern Europe also does not show significant differences. From the Anisian-Keuper of Sardinia, Italy, Knaust and Costamagna (2012) reported a very similar assemblage, composed of: *Protovirgularia*, *Lockeia*, *Rhizocorallium commune*, *Planolites montanus*, *Balanoglossites triadicus*, *Thalassinoides suevicus* and *Gastrochaenolites*. Very similar assemblages were also reported from the Middle Triassic carbonate platform of the Betic Cordillera in southern Spain, with *Thalassinoides*, *Rhizocorallium*, *Planolite*s, *Balanoglossites*, *Trypanites*, *Lockeia* and *Protovirgularia* (Pérez-López 2001; Rodríguez-Tovar *et al.* 2007; Pérez-Valera and Pérez-López 2008; Rodríguez-Tovar and Pérez-Valera 2008, 2013; Pérez-López and Pérez-Valera 2012).

SUMMARY AND CONCLUSIONS

A moderately diverse trace fossil assemblage was found in the Lower Muschelkalk of Raciborowice Górne. The assemblage includes different ethological groups: fodinichnia (*Rhizocorallium commune* var. *auriforme*, *R. commune* var. *irregulare*), domichnia or domichnia/fodinichnia (*Rhizocorallium jenense*, *Pholeus*, *Palaeophycus tubularis*, *Palaeophycus isp.*, *Skolithos linearis*, *Thalassinoides suevicus*, *Balanoglossites triadicus*, *?Gastrochaenolites* isp., *Trypanites weisei*), pascichnia (*?Planolites beverleyensis*, *Pl. montanus*, *Planolites* isp.), repichnia (*?Protovirgularia* isp.) and cubichnia (*Lockeia* isp.).

The most abundant are *R. commune* var. *auriforme*, *R. commune* var. *irregulare*, *R. jenense*, *Trypanites weisei* and *Palaeophycus tubularis*. *Lockeia*, *Protovirgularia*, *Thalassinoides suevicus*, *Planolites montanus*, *Planolites beverleyensis* and *Balanoglossites triadicus* are common, whereas *Archaeonassa fossulata*, *Gastrochaenolites* isp., *Pholeus* isp. and *Skolithos linearis* are rare.

The trace fossil assemblage characterizes the *Cruziana*, *Glossifungites* and *Trypanites* ichnofacies. The assemblage can be divided into a softground suite typical of the *Cruziana* ichnofacies (?*Planolites beverleyensis*, *P. montanus*, *Planolites* isp., *Palaeophycus tubularis*, *Palaeophycus* isp., ?*Protovirgularia* isp., *Lockeia* isp., *Rhizocorallium commune* var. *auriforme*, *R. commune* var. *irregulare*, *Archaeonassa fossulata*, *Pholeus* isp.), a firmground suite that characterizes the *Glossifungites* ichnofacies (*Rhizocorallium jenense*, *Balanoglossites triadicus*) and a hardground suite typified by the *Trypanites* ichnofacies (*Trypanites weisei*, *Balanoglossites triadicus*, ?*Gastrochaenolites* isp.).

Lower Muschelkalk deposits of the Raciborowice Górne quarry are interpreted as storm-originated deposits (tempestites), deposited on a homoclinal carbonate ramp. The background sedimentation, characterized by the *Cruziana* ichnofacies, was interrupted by high-energy events related to storms, which formed the bioclastic beds (bivalves, crinoids, gastropods, vertebrate remains). The *Glossifungites* and *Trypanites* ichnofacies are related to omission surfaces – the periods of non-deposition or erosion, formation of firm- and hardgrounds.

Five ichnoassociations of trace fossils were distinguished in the succession studied: *Rhizocorallium-Pholeus* (IA 1); *Rhizocorallium-Palaeophycus* (IA 2), *Thalassinoides* (IA 3), *Trypanites-Balanoglossites* (IA 4); *Planolites-Palaeophycus* (IA 5).

Based on ichnological analysis, IA 1 (*Rhizocorallium-Pholeus*) and IA 4 (*Trypanites-Balanoglossites*) are related to intertidal/lagoonal environments on the inner ramp, IA 2 (*Rhizocorallium-Palaeophycus*) to the middle-outer ramp, and IA3 (*Thalassinoides*) to the middle ramp setting. IA 5 (*Planolites-Palaeophycus*) indicates the deepest environment, in the outer ramp setting to open basin.

The recognised ichnoassociations show repetitive patterns of vertical occurrence in the succession: (Text-fig. 2). IA 1 occurs in unit B, IA 2 occurs twice in unit C and reappears in unit D; IA 3, as well as IA 4, also occur twice in unit C (Text-fig. 2). Ichnoassociation IA 5 appears in the upper part of unit C and in unit E.

Two episodes of shallowing are recorded by IA 4 related to the formation of hardground horizons (lower part of unit C and the *Spiriferina* Bed). Shallower, high-energy environments are also marked by the oncolitic limestone of unit D and the sabkha deposits of unit B.

Ichnological, as well as lithological and palaeontological records of the Lower Muschelkalk, evidence progressive deepening of the basin. This process commenced with the beginning of sedimentation of unit B

(ichnoassociation IA 1) in the environment of a restricted lagoon on the inner ramp, partly tidal flats, with a short episode of sabkha formation. It is recorded by the low content of trace fossils, and by the presence of bone remains, coprolites and horizons of cellular limestone. The sedimentation of unit C took place in the deeper environments of the middle (ichnoassociations IA 2 and 3) and outer ramp (ichnoassociation IA 5). The deepening reached a maximum during the deposition of the upper part of unit C and the whole of unit E (from the outer ramp to open sea). The deepest environment was recorded by ichnoassociation IA 5. The abundance of *Planolites* and *Palaeophycus* in the upper part of unit C is typical of a transgression peak. The maximum transgression recorded in the Raciborowice Górne section started with the deposition of the *Spiriferina* Bed and may be related to the opening of the Silesian-Moravian marine gateway at the beginning of the Pelsonian (Hagdorn and Głuchowski 1993; Kędzierski and Szulc 1996; Chrząstek 2002, 2008a; Głuchowski and Salamon 2005).

The highest values of ichnofabric index (ii) and bioturbation index (up to 4 – highly bioturbated), that reflect low energy of water and great depth, were noted for the nodular and marly limestone of ichnoassociation IA 5 (ii 1–5; bi 1–4). The deposits of ichnoassociations IA 4 (ii 2–3; bi 2–3) and IA 2 (ii 1–3; bi 2–3) are moderately bioturbated/bioeroded, whereas ichnoassociations I A1 and IA 3 are sparsely to slightly bioturbated (ii 1–2; bi 1–2).

Similar trends of bathymetric changes, with regressive-transgressive cycles, were documented by the Thuringian trace fossil record (Knaust 1998). According to Szulc (1993, 2000), the assemblage of trace fossils in the upper part of the Opole Lower Muschelkalk (*Terebratula* Beds-Dziewkowice Formation) also shows maximum deepening of the basin. Thus, it may be assumed that the sedimentation of the Lower Muschelkalk in the North Sudetic Basin took place at the same time as the Germanic Basin was consequently deepening.

An assemblage of trace fossils may also be an indicator of water oxygenation level. Short episodes of oxygen deficit were recorded by sulphide mineralisation in the lower part of unit C. A rich trace fossil assemblage of ichnoassociation IA 5, followed by a mass-occurrence of *Rhizocorallium* (*R. commune* var. *auriforme*, *R. commune* var. *irregulare*) in the uppermost part of unit C, suggest fully oxic conditions. The environment during deposition of the Lower Muschelkalk in the North Sudetic Basin was of normal salinity, which increased only in the middle-upper part of unit B (cellular dolomitic limestone - sabkha deposits)

Correlation of the ichnoassociations from the Lower Muschelkalk in the North Sudetic Synclinorium with equivalent assemblages from the Opole region, Poland, as well as from Thuringia, Germany, showed no significant differences in the succession of environments. In terms of the abundance of ichnotaxa and their stratigraphic succession in the Lower Muschelkalk, the trace fossil associations from Raciborowice Górne correspond best with their Thuringian counterparts (Table 1**).**

Acknowledgements

REFERENCES

Aigner, T. 1984. Fossil-Lagerstätten Nr. 59: Dynamic stratigraphy of epicontinental carbonates, Upper Muschelkalk (M. Triassic), South-German Basin. *Neues Jahrbuch für Geologie und Palaontologie, Abhandlungen*, **169**, 127–159.

Allington-Jones, Braddy, S.J. and Trueman, C.N. 2010. Palaeoenvironmental implications of the ichnology and geochemistry of the Westbury Formation (Rhaetian), Westbury-On-Severn, South-West England. *Palaeontology*, **53**, 491–506.

Alonso-Muruaga, P.J., Buatois, L.A. and Limarino, C.O. 2013. Ichnology of the Late Carboniferous Hoyada Verde Formation of western Argentina: exploring postglacial shallow-marine ecosystems of Gondwana. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **369**, 228–238.

Alpert, S.P. 1974. Systematic review of the genus *Skolithos*. *Journal of Paleontology*, **48**, 661–669.

Alpert, S.P. 1975. *Planolites* and *Skolithos* from the Upper Precambrian-Lower Cambrian White-Inyo Mountains, California. *Journal of Paleontology*, **49**, 509–521.

Angulo, S. and Buatois, L.A. 2012. Ichnology of a Late Devonian-Early Carboniferous low-energy seaway: The Bakken Formation of subsurface Saskatchewan, Canada: Assessing paleoenvironmental controls and biotic responses. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **315–316**, 46–60.

Archer, A.W. 1984. Preservational control of trace-fossil assemblages: Middle Mississippian Carbonates of South-Central Indiana. *Journal of Paleontology*, **58**, 285–297.

Archer, A.W. and Maples, C.G. 1984. Trace-fossil distribution across a marine-to-nonmarine gradient in the Pennsylvanian of Southwerstern Indiana. *Journal of Paleontology*, **58**, 448–466.

Assmann, P. 1944. Die Stratigraphie der oberschlesischen Trias. Teil II: Der Muschelkalk. *Abhandlungen des Reichsamts für Bodenforschung*, *Neue Folge,* **208**, 1–124, Berlin.

Avanzini, M., Contard, P., Ronchi, A. and Santi, G. 2011. Ichnosystematics of the lower Permian invertebrate traces from the Collio and Mt. Luco Basins (North Italy). *Ichnos*, **18**, 95–113.

Bachmann, G.H., Hauschke, N. and Kozur, H.W. 2009. Buntsandstein Cyclicity and Conchostracan Biostratigraphy of the Halle (Saale) Area, Central Germany. In: G.H. Bachman, N. Hauschke and H.W. Kozur (Eds), 6th International Field Workshop on the Triassic of Germany, September 12-13, 2009. Martin-Luther-Universität Halle-Wittenberg Institut für Geowissenschaften, pp. 1–30. Halle.

Bann, K.L. and Fielding, C.R. 2004. An integrated ichnological and sedimentological comparison of non-deltaic shoreface and subaqueous delta deposits in Permian reservoir units of Australia. In: D. McIlroy (Ed.), The application of ichnology to palaeoenvironmental and stratigraphic analysis. *Geological Society Special Publication*, **228**, 273–310.

Bann, K.L., Fielding, C.R., MacEachern, J.A. and Tye, S.C. 2004. Differentiation of estuarine and offshore marine deposits using integrated ichnology and sedimentology: Permian Pebbley Beach Formation, Sydney Basin, Australia. In: D. McIlroy (Ed.), The application of ichnology to palaeoenvironmental and stratigraphic analysis. *Geological Society Special Publication*, **228**, 179–211.

Baranowski, Z., Haydukiewicz, A., Kryza, R., Lorenc, S., Muszyński, A., Solecki, A. and Urbanek, Z. 1990. Outline of the geology of the Góry Kaczawskie (Sudetes, Poland). *Neues Jahrbuch für Geologie und Pälaontologie, Abhandlungen*, **179**, 223–257.

Bassi, D., Humblet, M. and Iryu, Y. 2011. Recent ichnocoenosis in deep water macroids, Ryukyu Islands, Japan. *Palaios*, **26**, 232–238.

Bassi, D., Iryu, Y., Braga, J.C., Takayanagi, H. and Tsuji, Y. 2013. Bathymetric distribution of ichnocoenoses from

recent subtropical algal nodules off Fraser Island, eastern Australia. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **369**, 58–66

Baucon, A. and Felletti, F. 2013a. The IchnoGIS method: Network science and geostatistics ichnology. Theory and application (Grado lagoon, Italy). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **375**, 85–111.

Baucon, A. and Felletti, F. 2013b. Neoichnology of a barrier-island system: the Mula di Muggia (Grado lagoon, Italy). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **375**, 112-124.

Belaústegui, Z., Gibert, J.M. de, Domènech, R., Muñiz, F. and Martinell, J. 2012. Clavate borings in a Miocene cetacean skeleton from Tarragona (NE Spain) and the fossil record of marine bone bioerosion. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **323–325**, 68–74.

Benner, J.S., Ekdale, A.A. and Gibert, J.M. de 2004. Macro-borings (*Gastrochaenolites*) in Lower Ordovician hard-grounds of Utah: sedimentologic, paleoecologic and evolutionary implications. *Palaios*, **19**, 543–550.

Bertling, M. 1999. Taphonomy of trace fossils at omission surfaces (Middle Triassic, East Germany). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **149,** 27–40.

Bertling, M., Braddy, S.J., Bromley, R.G., Demathieu, G.R., Genise, J., Mikuláš, R., Nielsen, J.K., Nielsen, K.S.S., Rindsberg, A.K., Schlirf, M. and Uchman, A. 2006. Names for trace fossils: a uniform approach. *Lethaia*, **39,** 265–286.

Billings, E. 1862. New species of fossils from different parts of the Lower, Middle and Upper Silurian rocks of Canada. In: Palaeozoic Fossils, volume I (1861-1865). Geological Survey of Canada, Dawson Brothers, 96–168, Montreal.

Bjerstedt, T.W. 1988. Trace fossils from the Early Mississippian Price Delta, southeast West Virginia. *Journal of Paleontology*, **62**, 506–519.

Blissett, D.J. and Pickerill, R.K. 2007. Systematic ichnology of microborings from the Cenozoic White Limestone Group, Jamaica, West India. *Scripta Geologica*, **134**, 77–108.

Bodzioch, A. 1991a. The Röt/Muschelkalk boundary. In: H. Hagdorn, T.D. Simon and J. Szulc (Eds), Muschelkalk. A Field Guide, pp. 63–64. Goldschneck-Verlag; Stuttgart.

Bodzioch, A. 1991b. Stop B14, Tarnów Opolski (Poland, Upper Silesia). In: H. Hagdorn, T. D. Simon and J. Szulc (Eds), Muschelkalk. A Field Guide, pp. 69–71. Goldschneck-Verlag; Stuttgart.

Bodzioch, A. 1997. Formacja karchowicka: definicja i stratygrafia. Uniwersytet Adama Mickiewicza w Poznaniu. *Geologos,* **2**, 165–199.

Bodzioch, A. and Kwiatkowski, S. 1992. Sedimentation and early diagenesis of the Cavernous Limestone (Roth) of Gogolin, Silesian-Kraków Region, Poland. *Annales Societatis Geologorum Poloniae, Journal of the Polish Geological Society*, **62**, 223–242.

Bottjer, D.J. and Droser, M.L. 1991. Ichnofabric and basin analysis. *Palaios*, **6**, 199–205.

Bover-Arnal, T., Jaramillo-Vogel, D., Showani, A. and Strasser, A. 2011. Late Eocene transgressive sedimentation in the western Swiss Alps: Records of autochthonous and quasi-autochthonous biofacies on a karstic rocky shore. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **312**, 24–39.

Boyer, D.L. and Droser, M.L. 2011. A combined trace-and body-fossil approach reveals high-resolution record of oxygen fluctuations in Devonian seas. *Palaios*, **26**, 500–508.

Bradshaw, M.A. 2010. Devonian trace fossils of the Horlick Formation, Ohio Range, Antarctica: Systematic description and palaeoenvironmental interpretation. *Ichnos*, **17**, 58–114.

Brenchley, P.J. and Harper, D.A.T. 1998. Palaeoecology. Ecosystems, environments and evolution. Chapter. V. Trace fossils, pp. 148–178, Chapman and Hall; Oxford.

Bressan, G.S. and Palma, R.M., 2009. Trace fossils from the Lower-Middle Jurassic Bardas Blances Formation, Neuquén Basin, Mendoza Province, Argentina. *Acta Geologica Polonica,* **59**, 201–220.

Bromley, R.G. 1975. Trace fossils at omission surfaces. In: R.W. Frey (Ed.), The Study of Trace Fossils, A Synthesis of Principles, Problems, and Procedures in Ichnology, pp. 399–428.

Bromley, R.G. 1996. Trace Fossils. Biology, Taphonomy and Applications, pp. 1–347. Chapman and Hall; London.

Bromley, R.G. and Asgaard, U. 1993. Two bioerosion ichnofacies produced by early and late burial associated with sea-level change. *Geologische Rundschau*, **82**, 276–280.

Bromley, R.G. and Ekdale, A.A. 1984. Trace fossil preservation in flint in the European chalk. *Journal of Paleontology*, **58**, 298–311.

Bromley, R.G., Buatois, L.A., Mángano, G., Genise, J.F. and Melchor, R.N. 2007. Sediment-Organism Interactions: A Multifaceted Ichnology. *SEPM Special Publication*, **88**, 1–393.

Buatois, L.A. and Encinas, A. 2011. Ichnology, sequence stratigraphy and depositional evolution of an Upper Cretaceous rocky shoreline in central Chile: Bioerosion structures in a transgressed metamorphic basement. *Cretaceous Research*, **32**, 203–212.

Buatois, L.A. and Mángano, M.G. 2002. Trace fossils from Carboniferous floodplain deposits in western Argentina: implications for ichnofacies models of continental environments. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **183**, 71–86.

Buatois, L. A. and Mángano, M. G. 2009. Applications of ichnology in lacustrine sequence stratigraphy: Potential and limitations. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **272,** 127–142.

Buatois, L. and Mángano, M.G. 2011. Ichnology, Organism-

Substrate Interactions in Space and Time, pp. 1–358. Cambridge University Press; Cambridge.

Buatois, L. and Mángano 2013. Ichnodiversity and ichnodisparity: significance and caveats. *Lethaia*, **46**, 281–292.

Buatois, L.A., Gingras, M.K., MacEachern, J., Mángano, M.G., Zonnveld, J.P., Pemberton, S.G., Netto, R.G. and Martin, A. 2005. Colonization of brakish-water systems through time: evidence from the trace-fossil record. *Palaios*, **20**, 321–347.

Buatois, L.A., Mángano, M.G., Alissa, A. and Carr, T.R. 2002. Sequence stratigraphic and sedimentologic significance of biogenic structures from a late Paleozoic marginal-to open-marine reservoir, Morrow Sandstone, subsurface of southwest Kansas, USA. *Sedimentary Geology*, **152**, 99–132.

Buckman, J.O. 1994. *Archaeonassa* Fenton and Fenton 1937 revisited. *Ichnos*, **3**, 185–192.

Cabrera, M.I.L. and Olivero, E.B. 2011. An Eocene articulated Polyplacophora (Mollusca) from the La Meseta Formation, Antarctica and the stratigraphy of the fossil-bearing strata. *Journal of Paleontology*, **85**, 970–976.

Cachão, M., Silva, C.M. da, Santos, A., Domènech, R., Martinell, J. and Mayoral, E. 2009. The bioeroded megasurface of Oura (algarve, south Portugal): implications for the Neogene stratigraphy and tectonic evolution of southwest Iberia. *Facies*, **55**, 213–225.

Caracuel, J.E., Corbi, H., Giannetti, A., Monaco, P., Soria, J.M., Tent-Manclús, J.E. and Yébenes, A. 2011. Paleoenvironmental changes during the Late Miocene (Messinian)-Pl transition (Bajo Segura Basin, southeastern Spain): Sedimentological and ichnological evidence. *Palaios*, **26**, 754–766.

Carmona, N. B., Buatois, L. A., Mángano, M. G. and Bromley, R. G. 2008. Ichnology of the Lower Miocene Chenque Formation, Patagonia, Argentina: animal-substrate interactions and the Modern Evolutionary Fauna. *Ameghiniana*, **45**, 93–112.

Carmona, N.B., Buatois, L.A., Ponce, J.J. and Mángano, M.G. 2009. Ichnology and sedimentology of a tide-influenced delta, Lower Miocene Chenque Formation, Patagonia, Argentina: Trace-fossil distribution and response to environmental stresses. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **273**, 75–86.

Carmona, N.B., Mángano, M.G., Buatois, L.A. and Ponce, J.J. 2007. Bivalve trace fossils in an early Miocene discontinuity surface in Patagonia, Argentina: Burrowing behaviour and implications for ichnotaxonomy at the firmground-hardground divide. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **255**, 329–341.

Carmona, N.B., Mángano, M.G., Buatois, L.A. and Ponce, J.J. 2010. Taphonomy and paleoecology of the bivalve trace fossil *Protovirgularia* in deltaic heterolithic facies of the Miocene Chenque Formation Patagonia, Argentina. *Journal of Paleontology*, **84**, 730–738.

Carmona, N.B., Ponce, J. J., and Mángano, M. G. 2006. Variability of the *Glossifungites* ichnofacies at the boundary between the Sarmiento Formation (middle Eocene – early Miocene) and Chenque Formation (early Miocene) in San Jorge Gulf, Chubut, Argentina. *Ameghiniana*, **43**, 413–425.

Carvalho, C.N., Viegas, P.A. and Cachão, M. 2007. *Thalassinoides* and its producer: populations of *Mecochirus* buried within their burrow systems, Boca do Chapim Formation (Lower Cretaceous), Portugal. *Palaios*, **22**, 104–109.

Checconi, A., Bassi, D., Carannante G. and Monaco, P. 2010. Re-deposited rhodoliths in the Middle Miocene hemipelagic deposits of Vitulano (Southern Apennines, Italy): coralline assemblage characterization and related trace fossils. *Sedimentary Geology*, **225**, 50–66.

Chen, Z.-Q., Fraiser, M.L. and Bolton, C. 2012. Early Triassic trace fossils from Gondwana Interior Sea: implications for ecosystem recovery following the end-Permian mass extinction in south high-latitude regon. *Gondwana Research*, **22**, 238–255.

Chen, Z-Q., Tong, J. and Fraiser, M.L. 2011. Trace fossil evidence for restoration of marine ecosystems following the end-Permian mass extinction in the Lower Yangtze region, South China. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **299**, 449–474.

Chen, Z., Zhou, C., Meyer, M., Xiang, K., Schiffbauer, J.D., Yuan, X. and Xiao, S. 2013. Trace fossil evidence for Ediacaran bilaterian animals with complex behaviors. *Precambrian Research*, **224**, 690–701.

Cherns, L., Wheeley, J.R. and Karis. L. 2006. Tunneling trilobites: habitual infaunalism in an Ordovician carbonate floor. *Geology*, **34**, 657–660.

Chrząstek, A. 1995. The Muschelkalk from Jerzmanice Zdrój. *Acta Universitatis Wratislaviensis No 1607, Prace Geologiczno – Mineralogiczne*, **64,** 61–79. [In Polish with English summary]

Chrząstek, A. 2002. Stratigraphy and sedimentation conditions of Röt and Lower Muschelkalk of the North Sudetic Basin. *Acta Universitatis Wratislaviensis No 2383, Prace Geologiczno – Mineralogiczne*, **73**, 1–112. [In Polish with English summary]

Chrząstek, A. 2004. Twarde dno w dolnym wapieniu muszlowym w Raciborowicach Górnych (niecka północnosudecka). In: J. Muszer (Ed.), XIX Konferencja Paleobiologów i Biostratygrafów PTG, "Zapis paleontologiczny jako wskaźnik środowisk" (16–18.09), pp. 6–17. Wrocław.

Chrząstek, A. 2007. Ichnoasocjacje dolnego wapienia muszlowego niecki północnosudeckiej. In: A. Żylińska (Ed.), Granice Paleontologii. XX Konferencja Naukowa Paleobiologów i Biostratygrafów PTG, Św. Katarzyna pod Łysicą, 10-13.09, pp. 43–45. Warszawa.

Chrząstek, A. 2008a. Vertebrate remains from the Lower Muschelkalk of Raciborowice Górne (North-Sudetic

Basin, SW Poland). *Geological Quarterly*, **52**, 225–238.

Chrząstek, A. 2008b. Trace fossils from the Lower Muschelkalk of the North-Sudetic Basin (SW Poland). In: A. Uchman (Ed.), Abstract Book and the Intra-Congress Field Trip Guidebook. The Second International Congress on Ichnology, Kraków, Poland, 29.08–08.09, p. 27, Kraków.

Chrząstek, A. 2013. Middle Turonian trace fossils from the Bystrzyca and Długopole sandstones in the Nysa Kłodzka Graben (Sudety Mountains, SW Poland). *Geological Quarterly*, **57**, 443–466.

Chrząstek, A. and Niedźwiedzki, R. 1998. Vertebrates of the Roetian and Lower Muschelkalk In Silesia. *Acta Universitatis Wratislaviensis, No 2004, Prace Geologiczno – Mineralogiczne*, **64**, 69–81. [In Polish with English summary]

Chrząstek, A. and Wojewoda, J. 2011. Mesozoic of South-Western Poland (The North Sudetic Synclinorium). In: A. Żelaźniewicz, J. Wojewoda and W. Ciężkowski (Eds), Mezozoik i Kenozik Dolnego Śląska, Zjazd PTG, WIND, pp. 1–10. Wrocław. [In Polish, with English summary]

Chrząstek, A., Kosarewicz, U. and Raczyński P. 2004. Cechsztyn i trias w niecce północnosudeckiej. In: J. Muszer (Ed.), Zapis paleontologiczny jako wskaźnik paleośrodowisk. XIX Konferencja Naukowa Paleobiologów i Biostratygrafów PTG poświęcona 300-leciu Uniwersytetu Wrocławskiego, 16–18.09, pp. 108–112, Wrocław. [In Polish]

Cummings, J.P. and Hodgson, D.M. 2011. Assessing controls on the distribution of ichnotaxa in submarine fan environments, the Basque Basin, Northern Spain. *Sedimentary Geology*, **239**, 162–187.

Curran, H.A. 1985. The trace fossil assemblage of a Cretaceous nearshore environment: Englishtown Formation of Delaware, U.S.A. In: H.A. Curran (Ed.), Biogenic structures: their use in interpreting depositional environments, *SEPM Special Publication*, **35**, 261–276.

Davies, N.S., Herringshaw, L.G. and Raine, R.J. 2009. Controls on trace fossil diversity in an Early Cambrian epeiric sea: new perspectives from northwest Scotland. *Lethaia*, **42**, 17–30.

Desai, B.G. and Saklani, R.D. 2012. Significance of the trace fossil *Balanoglossites* Mägdefrau, 1932 from the Lower Cretaceous Guneri member (Bhuj formation) of the Guneri dome, Kachchh, India. *Swiss Journal of Palaeontology*, **131**, 255–263.

Desjardins, P.R., Mángano, M.G., Buatois, L.A. and Pratt, B.R. 2010. *Skolithos* pipe rock and associated ichnofabrics from the southern Rocky Mountains, Canada: colonization trends and environmental controls in an early Cambrian sand-sheet complex. *Lethaia*, **43**, 507–528.

Desjardins, P.R., Buatois, L.A. and Mángano, M.G. 2012. Tidal flats and subtidal sand bodies. In: D. Knaust and R.G. Bromley (Eds), Trace fossils as indicators of sedimentary environments, *Developments in Sedimentology*, **64**, 529–561.

Donovan, S.K. 2002. A new ichnospecies of *Gastrochaenolites* Leymerie from the Pleistocene Port Morant Formation of southeast Jamaica and the taphonomy of calcareous linings in clavate borings. *Ichnos*, **9**, 61–66.

Donovan, S.K. and Hensley, C. 2006. *Gastrochaenolites* Leymerie in the Cenozoic of the Antillean Region. *Ichnos*, **13**, 11–19.

Dronov, A., V., Mikuláš, R. and Logvinova, M. 2002. Trace fossils and ichnofabrics across the Volkhov depositional sequence (Ordovician, Arenigian of St. Petersburg Region, Russia). *Journal of the Czech Geological Society*, **47**, 133–146.

Dronov, A.V. 2010. Morphological variations of vertical borings and burrows from the Ordovician of East Baltic: ichnotaxonomical implications. In: A.V. Dronov (Ed.), IV Workshop on Ichnotaxonomy. Abstracts. June 21–26, pp. 31–32. Moscow – St.-Petersburg.

Droser, M.L. 1991. Ichnofabric of the Paleozoic *Skolithos* Ichnofacies and the Nature and Distribution of *Skolithos* piperock. *Palaios*, **6**, 316–325.

Droser, M.L. and Bottjer, D.J. 1986. A semiquantitative classification of ichnofabric. *Journal of Sedimentary Petrology*, **56**, 558–569.

Droser, M.L. and Bottjer, D.J. 1989. Ichnofabric of sandstones deposited in high-energy nearshore environment: measurement and utilization. *Palaios*, **4**, 598–604.

Eisawi, A.A.M., Babikir, I. A.A. and Salih, K.A. O. 2011. Paleoecological significance of newly discovered trace fossils near the Gedaref town, eastern Sudan. *Journal of African Earth Sciences*, **61**, 233–237.

Ekdale, A.A. and Bromley, R.G. 1984. Comparative ichnology of shelf-sea and deep-sea chalk. *Journal of Paleontology*, **58**, 322–332.

Ekdale, A.A. and Bromley, R.G. 2001a. Bioerosional innovation for living in carbonate hardgrounds in the Early Ordovician of Sweden. *Lethaia*, **34**, 1–12.

Ekdale, A.A. and Bromley, R.G. 2001b. A day and a night in the life of a cleft-foot clam: *Protovirgularia-Lockeia-Lophoctenium*. *Lethaia*, **34**, 119–124.

Ekdale, A.A. and Bromley, R.G. 2003. Paleoethologic interpretation of complex *Thalassinoides* in shallow-marine limestones, Lower Ordovician, southern Sweden. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **192**, 221–227.

Ekdale, A.A. and Mason, T.R. 1988. Characteristic trace-fossil associations in oxygen-poor sedimentary environments. *Palaios*, **16**, 721–723.

Erdoğan, B., Uchman, A., Güngör, T. and Özgül, N. 2004. Litostratigraphy of the Lower Cambrian metaclastics and their age based on trace fossils in the Sandikli region, southwestern Turkey. *Geobios*, **37**, 346–360.

Farinati, E.A. 2007. Trace fossils in firm sediment and skele-

tal substrates, Miocene to Pliocene, Patagonia, Argentina. In: R.G. Bromley, L.A. Buatois, G. Mángano, J.F. Genise and R.N. Melchor (Eds), Sediment-organisms interactions: A multifaceted ichnology. *SEPM Special Publication*, **88**, 279–285.

Farinati, E. and Zavala, C. 2002. Trace fossils on shelly substrate. An example from the Miocene of Patagonia, Argentina. *Acta Geologica Hispanica*, **37**, 29–36.

Fenton, C.L. and Fenton, M.A. 1937. *Archaeonassa*, Cambrian snail trails and burrows. *American Midland Naturalist*, **18**, 454–456.

Fernández, D.E. and Pazos, P.J. 2013. Xiphosurid trackways in a Lower Cretaceous tidal flat in Patagonia: Palaeoecological implications and the involvement of microbial mats in trace-fossil preservation. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **375**, 16–29.

Fernández, D.E., Pazos, J.P. and Aguirre-Urreta, M.B. 2010. *Protovirgularia dichotoma-Protovirgularia rugosa*: An Example of a Compound Trace Fossil from the Lower Cretaceous (Agrio Formation) of the Neuquén Basin, Argentina. *Ichnos,* **17**, 40–47.

Fillion, D. and Pickerill, R.K. 1984. Systematic ichnology of the Middle Ordovician Trenton Group St. Lawrence Lowland, eastern Canada. *Maritime Sediments and Atlantic Geology*, **20**, 1–41.

Fillion, D. and Pickerill, R.K. 1990. Ichnology of the Upper Cambrian? to Lower Ordovician Bell Island and Wabana groups of eastern Newfoundland, Canada. *Palaeontographica Canadiana*, **7**, 1–119.

Fraiser, M.L. and Bottjer, D.J. 2009. Opportunistic behavior of invertebrate marine tracemakers during the Early Triassic aftermath of the end-Permian mass extinction. *Australian Journal of Earth Sciences*, **56**, 841–857.

Frey, R.W. and Seilacher, A. 1980. Uniformity in marine invertebrate ichnology. *Lethaia*, **13**, 183–207.

Frey, R.W., Curran, A. and Pemberton, S.G. 1984. Tracemaking activities of crabs and their environmental significance: the ichnogenus *Psilonichnus*. *Journal of Paleontology*, **58**, 333–350.

Frey, R.W., Pemberton, S.G. and Saunders, T.D.A. 1990. Ichnofacies and bathymetry: a passive relationship. *Journal of Paleontology*, **64**, 155–158.

Fürsich, F.T. 1974. Ichnogenus *Rhizocorallium*. *Paläontologische Zeitschrift*, **48**, 16–28.

Fürsich, F.T. 1975. Trace fossils as environmental indicators in the Corallian of England and Normandy. *Lethaia*, **8**, 151–172.

Fürsich, F.T. 1998. Environmental Distribution of Trace Fossils in the Jurassic of Kachchh (Western India). *Facies*, **39**, 243–272.

Fürsich, F.T. and Mayr, H. 1981. Non-marine *Rhizocorallium* (trace fossil) from the Upper Freshwater Molasse (Upper Miocene) of southern Germany. *Neues Jahrbuch für Geologie und Paläontologie*, *Monatshefte*, **6**, 321–333.

Gaillard, Ch. and Racheboeuf, P.R. 2006. Trace fossils from nearshore to offshore environments: Lower Devonian of Bolivia. *Journal of Paleontology*, **80**, 1205–1226.

Ghibaudo, G., Grandesso, P., Massari, F. and Uchman, A. 1996. Use of trace fossils in delineating sequence stratigraphic surfaces (Tertiary Venetian Basin, northeastern Italy). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **120**, 261–279.

Giannetti, A. and McCann, T. 2010. The Upper Paleocene of the Zumaya section (northern Spain): review of the ichnological content and preliminary palaeoecological interpretation. *Ichnos*, **17**, 137–161.

Gibert, J.M. de and Ekdale, A.A. 2002. Ichnology of a restricted epicontinental sea, Arapien Shale, Middle Jurassic, Utah, USA. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **183**, 275–286.

Gibert J.M. de and Martinell J., 1998. Ichnofabric analysis of the Pliocene marine sediments of the Var Basin (Nice, SE France). *Geobios*, **31**, 271–281.

Gibert, J. M. de, Domènech, R. and Martinell, J. 2004. An ethological framework for animal bioerosion trace fossils upon mineral substrates with proposal of a new class, fixichnia. *Lethaia*, **37**, 429–437.

Gibert, J.M. de, Domènech, R. and Martinell, J. 2012. Rocky shorelines. In: D. Knaust and R.G. Bromley (Eds), Trace fossils as indicators of sedimentary environments, *Developments in Sedimentology*, **64**, 441–462.

Gibert, J. M. de, Ramos, E. and Marzo, M. 2011. Trace fossils and depositional environments in the Hawaz Formation, Middle Ordovician, western Libya. *Journal of African Earth Sciences*, **60**, 28–37.

Gillette, L., Pemberton, S.G. and Sarjeant W.A.S., 2003. A Late Triassic invertebrate ichnofauna from Ghost Ranch, New Mexico. *Ichnos*, **10**, 141–151.

Gingras, M.K., MacEachern, J.A. and Dashtgard, S.E. 2011. Process ichnology and the elucidation of physic-chemical stress. *Sedimentary Geology*, **237**, 115–134.

Gingras, M.K., Räsänen, M. and Ranzi, A. 2002. The significance of bioturbated inclined heterolithic stratification in the southern part of the Miocene Solimoes Formation, Rio Acre, Amazonia Brazil. *Palaios*, **17**, 591–601.

Głuchowski, E. and Salamon, M. 2005. The Lower Muschelkalk crinoids from Raciborowice, North-Sudetic Basin, SW Poland. *Geological Quarterly*, **49**, 83–92.

Głuszek, A. 1998. Trace fossils from Late Carboniferous storm deposits, Upper Silesia Coal Basin, Poland. *Acta Palaeontologica Polonica*, **43**, 517–546.

Goldring, R. and Kaźmierczak, J. 1974. Ecological succession in intraformational hardground formation. *Palaeontology*, **17**, 949–962.

Goldring, R., Pollard, J.E. and Radley, J.D. 2005. Trace fossils and pseudofossils from the Wealden strata (non-ma-

rine Lower Cretaceous) of southern England. *Cretaceous Research*, **26**, 665–685.

Gouramanis, C., Webb, J.A. and Warren, A.A. 2003. Fluviodeltaic sedimentology and ichnology of part of the Silurian Grampians Group, western Victoria. *Australian Journal of Earth Sciences*, **50**, 811–825.

Gradziński, R. and Uchman, A. 1994. Trace fossils from interdune deposits-an example from the Lower Triassic aeolian Tumlin Sandstone, central Poland. *Palaeogeography, Palaeoclimatolology, Palaeoecology*, **108**, 121–138.

Greene, T.J., Gingras, M.K., Gordon, G.S. and McKeel, D.R. 2012. The significance of deep-water cryptic bioturbation in slope-channel massive sand deposits of the lower Rio Dell Formation, Eel River basin, California. *Marine and Petroleum Geology*, **29**, 152–174.

Hagdorn, H.D. 1991. The Muschelkalk in Germany – An Introduction. In: H. Hagdorn, T. Simon and J. Szulc (Eds), Muschelkalk. A Field Guide, pp. 7–21. Goldschneck-Verlag Werner K. Weidert Korb; Stuttgart.

Hagdorn, H.D. and Głuchowski, E. 1993. Palaeobiogeography and Stratigraphy of Muschelkalk Echinoderms (Crinoidea, Echinoidea) in Upper Silesia. In: H. Hagdorn and A. Seilacher (Eds), Muschelkalk Schöntaler Symposium 1991. Sonderbände der Gesellschaft für Natur-Kunde Württemberg, 2, pp. 165–176. Goldschneck; Stuttgart.

Hagdorn, H., Horn, M. and Simon, T. 1998. Muschelkalk. In: G.H. Backmann, G. Borg, H. Haubold, H. Heinisch, C. Lempp, H. Polmann and P. Wycisk (Eds), Epicontinental Triassic International Symposium Halle 1998 – Excursions. *Hallesches Jahrbuch für Geowissenschaften, Reihe B: Geologie, Paläontologie, Mineralogie, Beiheft*, **6**, 35–44.

Haldeman, S.S., 1840. Supplement to number of "A monograph of the Limniades, and other fresh water univalve shells of North America", containing descriptions of apparently new animal in different classes, and the names and characters of the subgenera in *Paludina* and *Anculosa*. Philadelphia, p. 3.

Hall, J. 1843. Geology of New-York. Part 4. Comprising the Survey of the Fourth Geological District, 525 pp. Carroll and Cook; Albany.

Hall, J. 1847. Paleontology of New York. Volume 1.C, 1 – 362. Van Benthuysen; Albany.

Hautmann, M. 2006. Shell morphology and phylogenetic origin of oysters. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **240**, 668–671.

Han, Y. and Pickerill, R.K. 1994. Taxonomic reassessment of *Protovirgularia* M'Coy 1850 with new examples from the Paleozoic of New Brunswick, eastern Canada. *Ichnos*, **3**, 203–212.

Häntzschel, W. 1975. Trace fossils and problematica. In: C. Teichert (Ed.), Treatise on Invertebrate Paleontology, Part W, Miscellanea Supplement I, 1–269, Geological Society of America, Boulder-Colorado and University of Kansas; Lawrence-Kansas.

Heinberg C. and Birkelund, T. 1984. Trace-fossil assemblages and basin evolution of the Vardekloft Formation (Middle Jurassic, Central East Greenland). *Journal of Paleontology*, **58**, 362–397.

Hembree, D.I., Nadon, G.C. and King, M.R. 2011. Large complex burrow systems from freshwater deposits of the Monongahela Group (Virgilian), Southeast Ohio, USA, *Palaeogeography, Palaeoclimatology, Palaeoecology*, **300**, 128–137.

Hoffman, M. and Uchman, A. 2008. Stop 2. Dębnik – the new quarry – Devonian (Frasnian) limestones. In: A. Uchman (Ed.), The intra-congress field trip guidebook. The Second International Congress on Ichnology, ICHNIA 2008, pp. 144–152. Kraków.

Hofmann, R., Goudemand, N., Wasmer, M. and Bucher, H. 2011. New trace fossil evidence for an early recovery signal in the aftermath of the end-Permian mass extinction. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **310**, 216–226.

Hofmann, R., Mángano, M.G., Elicki, O. and Shinaq, R. 2012. Paleoecologic and biostratigraphuc significance of trace fossils from shallow- to marginal-marine environments from the Middle Cambrian (Stage 5) of Jordan. *Journal of Paleontology*, **86**, 931–955.

Hoffmann, M., Paszkowski, M., Uchman, A. and Szulc, J. 2009. Facies succession and its controls on the Upper Devonian-Lower Carboniferous carbonate platform on the Kraków Upland. In: G. Haczewski (Ed.), Abstracts and field guide. 6th International Field Workshop on the Triassic of Germany, 12-13.09. Martin-Luther-Universität Halle-Wittenberg Institut für Geowissenschaften, pp. 49–65, Halle.

Holdefleis, G. 1915. Das Triasvorkommen von Gross-Hartmannsdorf in Niederschlesien. Zweiundneunzigster Jahres-Bericht der Schlesischen Gesellschaft für vaterländische Cultur, Band **I**, VI Abteilung, Breslau, 1–23.

Jach, R. 2005. Storm-dominated deposition of the Lower Jurassic crinoidal limestones in the Krížna unit, Western Tatra Mountains, Poland. *Facies*, **50**, 561-572.

Jaglarz, P. and Uchman, A. 2010. A hypersaline ichnoassemblage from the middle Triassic carbonate ramp of the Tatricum domain in the Tatra Mountains, Southern Poland. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **292**, 71–81.

Jank, M., Wetzel, A. and Meyer, C.A. 2006. Late Jurassic sea-level fluctuations in NW Switzerland (Late Oxfordian to Late Kimmeridgian): closing the gap between the Boreal and Tethyan realm in Western Europe. *Facies*, **52**, 487–519.

Jin, J., Harper, D.A.T., Rasmussen, J.A. and Sheehan, P.M. 2011. Late Ordovician massive-bedded *Thalassinoides* ichnofacies along the palaeoequator of Laurentia. *Palaeo-*

geography, Palaeoclimatology, Palaeoecology, **367–368**, 73–88.

Johnson, M.E., Wilson, M.A. and Medden, J.A. 2010. Borings in Quartzite Surf Boulders from the Upper Cambrian Basal Deadwood Formation, Black Hills of South Dakota. *Ichnos*, **17**, 48–55.

Kaim, A. 1997. Brachiopod-bivalve assemblages of the Middle Triassic Terebratula Beds, Upper Silesia, Poland. *Acta Palaeontologica Polonica*, **42**, 333–359.

Kamola, D.L. 1984. Trace fossils from marginal-marine facies of the Spring Canyon Member, Blackhaw Formation (Upper Cretaceous), East-Central Utah. *Journal of Paleontology*, **58**, 529–541.

Kane, I.A. 2010. Turbulence, displacement, death and worms: a day in the life of a fluvial Carboniferous bivalve. *Lethaia*, **43**, 381–395.

Kaźmierczak, J. and Pszczółkowski, A. 1969. Synsedimentary discontinuities in the Lower Kimeridgian of the Holy Cross Mountains. *Acta Geologica Polonica*, **18**, 587–612.

Keighley, D.G. and Pickerill, R.K. 1995. Commentary: the ichnotaxa *Palaeophycus* and *Planolites*, historical perspective and recommendations. *Ichnos*, **3**, 301–309.

Kelly, S.R.A. and Bromley, R.G. 1984. Ichnological nomenclature of clavate borings. *Palaeontology*, **27**, 793–807.

Kennedy, W.J. 1975. Trace fossils in carbonate rocks. In: R.W. Frey (Ed.), The study of trace fossils, A synthesis of principles, problems, and procedures in ichnology, 377–398.

Kędzierski, J. 2002. Sequenzstratigraphie des Unteren Muschelkalks im ostlichen Teil des Germanischen Beckens (Deutschland, Polen). *Hallesches Jahrbuch für Geowissenschaften, Reihe B: Geologie., Paläontologie, Mineralogie*, **16**, 1–52.

Kędzierski M. and Uchman A., 2001. Ichnofabric of the Upper Cretaceous marlstones in the Opole region, southern Poland. *Acta Geologica Polonica*, **51**, 81–91.

Kędzierski, J. and Szulc, J. 1996. Anisian conodonts of the Lower Silesia and their significance for reconstruction of the Muschelkalk transgression in the eastern part of the Germanic Basin. In: J. Dzik (Ed.), 6th European Conodont Symposium. Abstracts. Institute of Paleobiology PAN, p. 28. Warszawa.

Kim J.-Y. 1994. A unique occurrence of *Lockeia* from the Yeongheung Formation (Middle Ordovician), Yeongwed, Korea. *Ichnos*, **3**, 219–225.

Kim, J.-Y., Keighley, D.G., Pickerill, R.K., Hwang, W. and Kim, K.-S. 2005. Trace fossils from marginal lacustrine deposits of the Cretaceous Jinju Formation, southern coast of Korea. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **218**, 105–124.

Kim, J.-Y., Kim, K.-S. and Pickerill, R.K. 2002. Cretaceous nonmarine trace fossils from the Hasandong and Jinju For-

mations of the Namhae Area, Kyongsangnamdo, southeast Korea. *Ichnos*, **9**, 41–60.

Knaust, D. 1998. Trace fossils and ichnofabric on the Lower Muschelkalk carbonate ramp (Triassic) of Germany: tool for high-resolution sequence stratigraphy. *Geologische Rundschau*, **87**, 21–31.

Knaust, D. 2002. Ichnogenus *Pholeus* Fiege, 1944, revisited. *Journal of Paleontology*, **76**, 882–891.

Knaust, D. 2004. The oldest Mesozoic nearshore *Zoophycos*: evidence from the German Triassic. *Lethaia*, **37**, 297–306.

Knaust, D. 2007a. Invertebrate trace fossils and ichnodiversity in shallow-marine carbonates of the German Middle Triassic (Muschelkalk). In: R.G. Bromley, L., Buatois, G. Mángano, J.F. Genise and R.N. Melchor (Eds), Sediment-Organism Interactions: A Multifaceted Ichnology. *SEPM Special Publication*, **88**, 221–238.

Knaust, D. 2007b. Meiobenthic Trace Fossils as Keys to the Taphonomic History of Shallow-Marine Epicontinental Carbonates (Chapter 31). In: W. Miller, III (Ed.), Trace Fossils Concepts, Problems, Prospects. Geology Department Humboldt State University Arcata, CA, USA, Elsevier, 502–517.

Knaust, D. 2008. *Balanoglossites* Mägdefrau, 1932 from the Middle Triassic of Germany: part of a complex trace fossil probably produced by burrowing and boring polychaetes. *Paläontologische Zeitschrift*, **82**, 347–372.

Knaust, D. 2009. Characterisation of a Campanian deep-sea fan system in the Norwegian Sea by means of ichnofabrics. *Marine and Petroleum Geology*, **26**, 1199–1211.

Knaust, D. 2010a. Remarkably preserved benthic organisms and their traces from a Middle Triassic (Muschelkalk) mud flat. *Lethaia*, **43**, 344–356.

Knaust, D. 2010b. The end-Permian mass extinction and its aftermath on an equatorial carbonate platform; insights from ichnology. *Terra Nova*, **22**, 195–202.

Knaust, D. 2010c. Why ichnotaxonomy is so important: *Rhizocorallium* and its value for facies reconstruction. In: A.V. Dronov (Ed.), IV International Workshop on Ichnotaxonomy, Abstracts, June 21-26, Abstracts, pp. 33–35. Moscov – St.-Petersburg.

Knaust, D. 2012. Trace-fossil systematics. In: D.Knaust and R.G. Bromley (Eds), Trace fossils as indicators of sedimentary environments, *Developments in Sedimentology*, **64**, 79–101.

Knaust, D. 2013. The ichnogenus *Rhizocorallium*: classification, trace makers, palaeoenvironments and evolution. *Earth Science Reviews*, **126**, 1–47.

Knaust, D. and Bromley, R.G. 2012. Trace fossils as indicators of sedimentary environments. *Developments in Sedimentology* (series editor: A.J. van Loon), **64**, 1–924. Elsevier.

Knaust, D. and Costamagna, L.G. 2012. Ichnology and sedi-

mentology of the Triassic carbonates of North-west Sardinia, Italy. *Sedimentology*, **59**, 1190-1207.

Knaust, D., Curran, H.A. and Dronov, A.V. 2012. Shallow-marine carbonates. In: D.Knaust and R.G. Bromley (Eds), Trace fossils as indicators of sedimentary environments, *Developments in Sedimentology*, **64**, 705–750.

Knaust, D., Szulc, J. and Uchman, A. 1999. Spurenfossilien in der Germanischen Trias und deren Bedeutung. In: N. Hauschke and V. Wilde (Eds), Trias – Eine ganz andere Welt. Mitteleuropa im frühen Erdmittelalter, pp. 229–238. Dr. Friedrich Pfeil; München.

Kotlarczyk, J. and Uchman, A. 2012. Integrated ichnology and ichthyology of the Oligocene Menilite Formation, Skole and Subsilesian nappes, Polish Carpathians: a proxy to oxygenation history. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **331–332**, 104–118.

Kowal-Linka, M. 2008. Formalization of the lithostratigraphy of the Gogolin Formation (Middle Triassic) in the Opole (Silesia) region. *Geologos*, **14**, 125–161. [In Polish with English summary]

Kowal-Linka, M. and Bodzioch, A. 2011. Sedimentological implications of an unusual form of the trace fossil *Rhizocorallium* from the Lower Muschelkalk (Middle Triassic), S. Poland. *Facies*, **57**, 695–703.

Kryza, R., Zalasiewicz, J., Mazur, S., Aleksandrowski, P., Sergeev, S. and Larionov, A. 2007. Precambrian crustal contribution to the Variscan accretionary prism of the Kaczawa Mountains (Sudetes, SW Poland): evidence from SHRIMP dating of detrital zircons. International Journal of the Earth Science, *Geologische Rundschau*, **96**, 1153–1162.

Kumpulainen, R.A., Uchman, A., Woldehaimanot, B., Kreuser, T. and Ghirmay, S. 2006. Trace fossil evidence from the Adigrant Sandstone for an Ordovician glaciation in Eritrea, NE Africa. *Journal of African Earth Sciences*, **45**, 408–420.

La Croix, A.D., Gingras, M.K., Pemberton, S.G., Mendoza, C.A., MacEachern, J.A. and Lemiski, R.T. 2013. Biogenically enhanced reservoir properties in the Medicine Hat gas field, Alberta, Canada. *Marine and Petroleum Geology*, **43**, 464–477.

Landing, E., Geyer, G., Brasier, M.D. and Bowring, S.A. 2013. Cambrian Evolutionary Radiation: Context, correlation, and chronostratigraphy – Overcoming deficiences of the first appearance datum (FAD) concept. *Earth-Science Reviews*, **123**, 133–172.

Lauridsen, B.W., Surlyk, F. And Bromley, R,G. 2011. Trace fossils of a cyclic chalk-marl succession; the Upper Maastrichtian Rordal Member, Denmark. *Cretaceous Research*, **32**, 194–202.

Lawfield, A.M.W. and Pickerill, R.K. 2006. A novel contemporary fluvial ichnocoenose: unionid bivalves and the *Scoyenia-Mermia* ichnofacies transition. *Palaios*, **21**, 391–396.

Leszczyński, S. 1991. Oxygen-related controls on predepositional ichnofacies in turbidites, Guipúzcoan flysch (Albian–Lower Eocene), northern Spain. *Palaios*, **6**, 271–280.

Leszczyński, S. 2010. Coniacian-?Santonian paralic sedimentation in the Rakowice Małe area of the North Sudetic Basin, SW Poland: Sedimentary facies, ichnological record and palaeogeographical reconstruction of an evolving marine embayment. *Annales Societatis Geologorum Poloniae*, **80**, 1–24.

Leśniak, T. 1978. Lithostratigraphical profile of Bunter Sandstone and Muschelkalk deposits in the North-Sudetic Depression. *Zeszyty Naukowe AGH, Geologia*, **4**, 5–26. [In Polish with English summary]

Loughlin, N.J.D. and Hillier, R.D. 2010. Early Cambrian *Teichichnus*-dominated ichnofabrics and palaeoenvironmental analysis of the Caerfai Group, Southwest Wales, UK. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **297**, 239–251.

Lukeneder, A., Uchman, A., Gaillard, C. and Olivero, D. 2012. The late Barremian *Halimedides* horizon of the Dolomites (Southern Alps, Italy). *Cretaceous Research*, **35**, 199–207.

MacEachern, J.A. and Burton, J.A. 2000. Firmground *Zoophycos* in the Lower Cretaceous Viking Formation, Alberta: A distal expression of the *Glossifungites* ichnofacies. *Palaios*, **15**, 387–398.

MacEachern, J. A. and Gingras, M. K. 2007. Recognition of brackish-water trace-fossil suites in the Cretaceous Western Interior Seaway of Alberta, Canada. In: R.G. Bromley, L.A. Buatois, G. Mángano, J.F. Genise and R.N. Melchor (Eds), Sediment-organisms interactions: A multifaceted ichnology. *SEPM Special Publication*, **88**, 149–193.

MacEachern, J.A., Bann, K.L., Gingras, M.K., Zonneveld, J.-P., Dashtgard, S.E. and Pemberton, S.G. 2012. The ichnofacies paradigm. In: D.Knaust and R.G. Bromley (Eds), Trace fossils as indicators of sedimentary environments. *Developments in Sedimentology*, **64**, 103–138.

MacEachern, J.A., Pemberton, S.G., Gingras, M.K. and Bann, K.L. 2007a. The Ichnofacies Paradigm: A Fifty-Year Retrospective. In: W. Miller, III (Ed.), Trace Fossils. Concepts, Problems, Prospects, 52–77. Elsevier.

MacEachern, J.A. Pemberton, S., Gingras, M., Bann, K. and Dafoe, L.T. 2007b. Uses of Trace Fossils in Genetic Stratigraphy. In: W. Miller, III (Ed.), Trace Fossils. Concepts, Problems, Prospects, 110–113. Elsevier.

MacNaughton, R.B. 2007. The application of trace fossils to biostratigraphy. In: W. Miller, III (Ed.), Trace fossils. Concepts, Problems, Prospects, 135–148. Elsevier.

Malchus, N. 2008. Problems concerning early oyster evolution; A reply to Márquez-Aliaga and Hautmann. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **258**, 130–134.

Malpas, J.A., Gawthorpe, J.E., Pollard, J.E. and Sharp, J.R. 2005. Ichnofabric analysis of the shallow marine Nukhul Formation (Miocene), Suez Rift, Egypt: implications for depositional processes and sequence stratigraphic evolution. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **215**, 239–264.

Mángano, M.G. and Buatois, L. 2004. Ichnology of Carboniferous tide-influenced environments and tidal flat variability in the North American Midcontinent. *SEPM Special Publication*, **228**, 157–178.

Mángano, M.G., Buatois, L.A. and Guinea F.M. 2005. Ichnology of the Alfarcito Member (Santa Rosita Formation) of northwestern Argentina: animal-substrate interactions in a Lower Paleozoic wave-domianted shallow sea. *Ameghiniana*, **42**, 641–668.

Mángano, M.G., Buatois, L. and MacNaughton, R.B. 2012. Ichnostratigraphy. In: D.Knaust and R.G. Bromley (Eds), Trace fossils as indicators of sedimentary environments, *Developments in Sedimentology*, **64**, 195–212.

Mángano, M.G., Buatois, L., West, R.R. and Maples, CH.G. 1998. Contrasting behavioral and feeding strategies recorded by tidal-flat bivalve trace fossils from the Upper Carboniferous of Eastern Kansas. *Palaios*, **13**, 335–351.

Mángano, M.G., Buatois, L.A., Hofmann, R., Elicki, O. and Shinaq, R. 2013. Exploring the aftermath of the Cambrian explosion: the evolutionary significance of marginal- to shallow-marine ichnofaunas of Jordan. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **374**, 1–15.

Maples, CH.G. and Suttner, L.J. 1990. Trace fossils and marine –nonmarine cyclicity in the Fountain Formation (Pennsylvanian: Morrowan/Atokan) near Manitou Springs, Colorado. *Journal of Paleontology*, **64**, 859–880.

Marenco, K.N. and Bottjer, D.J. 2008. The importance of *Planolites* in the Cambrian substrate revolution. *Palaeogeographgy, Palaeoclimatology, Palaeoecology*, **258**, 189–199.

Márquez-Aliaga, A., Jiménez-Jiménez, A.P., Checa, A.G. and Hagdorn, H. 2005. Early oysters and their supposed Permian ancestors. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **229**, 127–136.

Martin, K.D. 2004. A re-evaluation of the between trace fossils and dysoxia. In: D. McIlroy (Ed.), The application of ichnology to palaeoenvironmental and stratigraphic analysis. *Geological Society Special Publication*, **228**, 141–156.

Mata, S.A. and Bottjer, D.J. 2011. Origin of Lower Triassic microbialites in mixed carbonate-siliciclastic successions: Ichnology, applied stratigraphy, and the end-Permian mass extinction. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **300**, 158–178.

Mayer, G. 1954. Ein neues *Rhizocorallium* aus dem Mittleren Hauptmuschelkalk von Bruchsal. *Beiträge zur Naturkundlichen Forschung in Sudwestdeutschland*, **13,** 80–83.

Mayoral, E., Ledesma-Vazgues, J., Baarli, B.G., Santos, A., Ramalho, R., Cachão, M., Silva, C.M. da and Johnson, M.E. 2013. Ichnology in oceanic islabds; cuse studies from the Cape Verde Archipelago. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **381–382**, 47–66.

Mägdefrau, K. 1932. Über einige Bohrgänge aus dem Unteren Muschelkalk von Jena. *Paläontologische Zeitschrift*, **14**, 150–160.

McCann, T. And Pickerill, R.K. 1988. Flysch trace fossils from the Cretaceous Kodiak Formation of Alaska. *Journal of Paleontology*, **62**, 330–348.

McCarthy, B. 1979. Trace fossils from a Permian shoreface - foreshore environment, Eastern Australia. *Journal of Paleontology*, **53**, 345–366.

McIlroy, D. 2004a. The application of ichnology to palaeoenvironmental and stratigraphic analysis. *Geological Society Special Publication*, **228**, 1–490.

McIlroy, D. 2004b. Ichnofabrics and sedimentary facies of a tide-dominated delta: Jurassic Ile Formation of Kristin Field, Haltenbanken, offshore Mid-Norway. In: D. McIlroy (Ed.), The application of ichnology to palaeoenvironmental and stratigraphic analysis. *Geological Society Special Publication*, **228**, 237–272.

McIlroy, D. 2007. Ichnology of a macrotidal tide-dominated deltaic depositional system: Lajas Formation, Neuquén Province, Argentina. In: R.G. Bromley, L.A. Buatois, G. Mángano, J.F. Genise and R.N. Melchor (Eds), Sediment-organisms interactions: A multifaceted ichnology. *SEPM Special Publication*, **88**, 195–211.

Melchor, R.N., Cardonatto, M.C. and Visconti G. 2012a. Palaeoenvironmental and palaeoecological significance of flamingo-like footprints in shallow-lacustrine rocks: An example from the Oligocene-Miocene Vinchina Formation, Argentina. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **315–316**, 181–198.

Melchor, R.N., Genise, J.F., Buatois, L.A. and Umazano, A.M. 2012b. Fluvial environments. In: D. Knaust and R.G. Bromley (Eds), Trace fossils as indicators of sedimentary environments, *Developments in Sedimentology*, **64**, 329–378.

Metz, R. 2002. Nonmarine Cretaceous *Protovirgularia*: possible dragonfly larva tracemaker. Short communication. *Ichnos*, **9**, 75–76.

Metz, R. 2009. Trace fossils from the Mahantango Formation (Upper Middle Devonian) Pike County, Pennsylvania. *Bulletin of the New Jersey Academy of Science*, **54**, 9–17.

Mikuláš, R. 2000. Trace fossils from the Cambrian of the Barandian area. *Czech Geological Survey, Special Paper*s, **12**, 1–29.

Mikuláš, R. 2006. Ichnofabric and substrate consistency in Upper Turonian carbonates of the Bohemian Cretaceous Basin (Czech Republic). *Geologia Carpathica,* **57**, 79–90.

Mikuláš, R. and Martínek, K. 2006. Ichnology of the non-ma-

rine deposits of the Boskovice Basin (Carboniferous-Permian, Czech Republic). *Bulletin of Geosciences,* **81**, 81–91.

Mikuláš, R., Fatka, O. and Szabad M. 2012. Paleoecologic implications of ichnofossils associated with slightly skeletonized body fossils, Middle Cambrian of the Barrandian Area, Czech Republic. *Ichnos*, **19**, 199–210.

Mikuláš, R., Meškis, S., Ivanov, A., Lukševičs, E., Zupiņš, I, Stinkulis, G., 2013. A rich ichnofossil assemblage from the Frasnian (Upper Devonian) deposits at Andoma Hill, Onega Lake, Russia. *Bulletin of Geosciences*, **88**, 389–400.

Mikuláš, R., Žítt, J. and Nekovařík, C. 2003. The ichnogenus *Gastrochaenolites* and its tracemakers from firmgrounds of the Bohemian Cretaceous Basin (Czech Republic). *Ichnos*, **10**, 15–23.

Milewicz, J. 1985. Propozycja formalnego podziału stratygraficznego utworów wypełniajacych depresję północnosudecką. *Przegląd Geologiczny*, **33**, 385–390.

Miller W., III, 2001. *Thalassinoides-Phycodes* compound burrow systems in Paleocene deep-water limestone, Southern Alps of Italy. *Palaeogeography, Palaeoclimatology, Palaeecology*, **170**, 149–156.

Miller, W., III, 2007. Trace fossils. Concepts, problems, prospects. Elsevier Sciences Geology Department Humboldt State University Arcata, CA, USA, 1–611. Elsevier; Arcata.

Miller, M.F. and Byers, C.W. 1984. Abundant and diverse early Paleozoic infauna indicated by the stratigraphic record. *Geology*, **12**, 40-43.

Miller, M.F. and Knox, L.W. 1985. Biogenic structures and depositional environments of a Lower Pennsylvanian coal-bearing sequence, northern Cumberland Plateau, Tennessee, U.S.A. In: H.A. Curran (Ed.), Biogenic structures: their use in interpreting depositional environments. *SEPM, Special Publication*, **35**, 67–97.

Mohseni, H., Behbahani, R., Khodabakhsh, S. and Atashmard, Z. 2011. Depositional environments and trace fossil assemblages in the Pabdeh Formation (Paleogene), Zagros Basin, Iran. *Neues Jahrbuch für Geologie und Paläontologie*, *Abhandlungen*, **262**, 59–77.

Monaco, P. and Giannetti, A. 2002. Three-dimensional burrow systems and taphofacies in shallowing-upward parasequences, Lower Jurassic carbonate platform (Calcan Grigi, Southern Alps, Italy). *Facies*, **47**, 57–82.

Monaco, P., Rodríguez-Tovar, F.J. and Uchman, A. 2012. Ichnological analysis of lateral environmental heterogeneity within the Bonarelli Level (uppermost Cenomanian) in the classical localities near Gubbio, central Apennines, Italy. *Palaios*, **27**, 48–54.

Mørk, A. and Bromley, R. G. 2008. Ichnology of a marine regressive systems tract; the Middle Triassic of Svalbard. *Polar Research*, **27**, 339–359.

Morrisey, R.G., Campbell, K.A., Zuraida, R. and Martin, A.J. 2006. Plant traces resembling *Skolithos*. *Ichnos*, **13**, 205–216.

Morrisey, L.B., Hillier, R.D. and Marriott, S.B. 2012. Late Silurian and Early Devonian terrestrialisation: Ichnological insights from the Lower Old Red Sandstone of the Anglo-Welsh Basin, U.K. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **337–338**, 194–215.

Myrow, P.M. 1995. *Thalassinoides* and the enigma of Early Paleozoic open-framework burrow systems. *Palaios*, **10**, 58–74.

Nagel, S., Castelltort, S., Wetzel, A., Willett, S.D., Mouthereau and Lin, A.T. 2013. Sedimentology and foreland basin paleogeography during Taiwan arc continent collision. *Journal of Asian Earth Sciences*, **62**, 180–204.

Nara, M. and Ikari, Y. 2011. "Deep-sea bivalvian highways": An ethological interpretation of branched *Protovirgularia* of the Palaeogene Muroto-Hanto Group, southwestern Japan. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **305**, 250–255.

Narkiewicz, K. and Szulc, J. 2004. Controls on migration of conodont fauna in peripheral oceanic areas. An example from the Middle Triassic of the Northern Peri-Tethys. *Geobios*, **37,** 425–436.

Narrbone, G.M. 1984. Trace fossil in Upper Silurian flat to basin slope carbonates of Arctic Canada. *Journal of Paleontology*, **58**, 398–415.

Nawrocki, J. and Szulc, J. 2000. Magnetic polarity scale for the Roetian and Muschelkalk deposits from Silesia and northern part of the Holy Cross Mts. (Poland). *Przegląd Geologiczny*, **48**, 236–238. [In Polish, summary in English]

Nesbitt, E.A. and Campbell, K.A. 2002. A new *Psilonichnus* ichnospecies attributed to mud-shrimp *Upogebia* in estuarine settings. *Journal of Paleontology*, **76**, 982–901.

Netto, R.G. 2007. *Skolithos*-dominated piperock In nonmarine environments. An example from the Triassic Caturrita Formation, Southern Brazil. In: R.G. Bromley, L.A. Buatois, G. Mángano, J.F. Genise and R.N. Melchor (Eds), Sediment-organisms interactions: A multifaceted ichnology. *SEPM Special Publication*, **88**, 109–121.

Niedźwiedzki, R. 1999. Ichnofosylia dolnego wapienia muszlowego. In: R.K. Borówka (Ed.), Problemy geologii, hydrogeologii i ochrony środowiska wybrzeża morskiego Pomorza Zachodniego. Sesja referatowa i konferencje terenowe. LXX Zjazd Naukowy PTG, pp. 297–298, Szczecin.

Niedźwiedzki, R. and Salamon, M. 2002. Migration router of the Tethyan fauna in the eastern part of the epicontinental Germanic Basin (Poland). *Freiberger Forschungshefte*, **C 497**, 1–8.

Niedźwiedzki, R., Salamon, M. and Wolkenstein, K. 2011. *Encrinus aculeatus* (Crinoidea: Encrinida) with exceptional

preservation of organic pigments from the Middle Trias-sic of Lower Silesia (SW Poland). *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, **262**, 163–170.

Ogg, J.G. 2012. Triassic. In: F.M. Gradstein, J.G. Ogg, M.D. Schmitz and G.M. Ogg (Eds), The Geologic Time Scale 2012, **2**, pp. 681–730.

Olivero, E.B. 2012. Sedimentary cycles, ammonite diversity and palaeoenvironmental changes in the Upper Cretaceous Marambio Group, Antarctica. *Cretaceous Research*, **34**, 348–366.

Olivero, E.B. and Cabrera, M.I.L. 2013. Euflabella n. igen.: complex horizontal spreite burrows in Upper Cretaceous-Paleogene shallow-marine sandstones of Antarctica and Tierra del Fuego. *Journal of Paleontology*, **87**, 413–426.

Olóriz, F. and Rodríguez-Tovar, F.J. 2002. Trace fossils and minor discontinuities in a marl limestone rhythmite, Lower-Middle Kimmeridgian, southern Spain. *Geobios*, **35**, 581–593.

Palmer, T.J. 1978. Burrows at certain omission surfaces in the Middle Ordovician of the Upper Mississippi Valley. *Journal of Paleontology*, **52**, 109–117.

Pazos, P.J., di Pasquo M. and Amenabar C.R. 2007. Trace fossils of the glacial to postglacial transition in the El Imperial Formation (Upper Carboniferous) San Rafael Basin, Argentina. In: R.G. Bromey, L.A. Butois, G. Mángano, J.F. Genise and R.N. Melchor (Eds), Sediment-organisms interactions: A multifaceted ichnology. *SEPM Special Publication*, **88**, 137–147.

Pearson, N.J., Mángano, M.G., Buatois, L.A., Casadío, S. and Raising, M.R. 2012. Ichnology, sedimentology, and sequence stratigraphy of outer-estuarine and coastal-plain deposits: Implications for the distinction between allogenic and autogenic expressions of the *Glossifungites* Ichnofacies. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **333**, 192–217.

Pearson, N.J., Mángano, M.G., Buatois, L., Casadío, S. and Raising, M.R. 2013. Environmental variability of *Macaronichnus* ichnofabrics in Eocene tidal-embayment deposits of southern Patagonia, Argentina. *Lethaia*, **46**, 341—354.

Pemberton, S.G. and Frey, R.W. 1982. Trace fossil nomenclature and the *Planolites-Palaeophycu*s dilemma. *Journal of Paleontology*, **56**, 843–881.

Pemberton, S.G. and Frey, R.W. 1985. The *Glossifungites* ichnofacies: modern examples from the Georgia Coast, U.S.A. In: H.A. Curran (Ed.), Biogenic structures: their use in interpreting depositional environments. *SEPM, Special Publication*, **35**, 237–259.

Pemberton, S.G. and Jones, B. 1988. Ichnology of the Pleistocene Ironshore Formation, Grand Cayman Island, British West Indies. *Journal of Paleontology*, **62**, 495–505.

Pemberton, S.G., Frey, R.W. and Walker, R.G. 1984. Probable lobster burrows in the Cardium Formation (Upper Cretaceous) of southern Alberta, Canada, and comments on modern burrowing decapods. *Journal of Paleontology*, **58**, 1422–1435.

Pemberton, S.G., MacEachern J.A. and Sauders T. 2004. Stratigraphic applications of substrate-specific ichnofacies: delineating discontinuities in the rock record. In: D. McIlroy (Ed.), The application of ichnology to palaeoenvironmental and stratigraphic analysis. Geological Society, *Special Publication*, **228**, 29–62.

Pemberton, S.G., MacEachern, J.A., Dashtgard, S.E., Bann, K.L., Gingras, M.K. and Zonneveld, J.-P. 2012. Shorefaces. In: D.Knaust and R.G. Bromley (Eds), Trace fossils as indicators of sedimentary environments, *Developments in Sedimentology*, **64**, 563–603.

Pemberton, S.G., Spila, M., Pulham, A.J., Saunders, T., MacEachern, J.A., Robbins, D. and Sinclair, I.K. 2001. Ichnology and sedimentology of shallow to marginal marine systems. Ben Nevis & Avalon Reservoirs, Jeanne d'Arc Basin. Geological Association of Canada, *Short Course Notes*, **15**, 1–343.

Peng, S., Babcock, L.E. and Cooper, R.A. 2012. The Cambrian period. In: F.M. Gradstein, J.G. Ogg, M.D., Schmitz and G.M. Ogg (Eds), The geologic time scale 2012, **2**, pp. 437–488.

Pérez-López, A. 2001. Significance of pot and gutter casts in a Middle Triassic carbonate platform, Betic Cordillera, southern Spain. *Sedimentology*, **48**, 1371–1388.

Pérez-López, A. and Pérez-Valera, F. 2012. Tempestite facies models for the epicontinental Triassic carbonates of the Betic Cordillera (southern Spain). *Sedimentology*, **59**: 646–678.

Pérez-Valera, F. and Pérez-López, A. 2008. Stratigraphy and sedimentology of Muschelkalk carbonates of the Southern Iberian Continental Palaeomargin (Siles and Cehegín Formations, Southern Spain). *Facies*, **54**, 61–87.

Perry, Ch.T. and Smithers, S.G. 2006. Taphonomic signatures of turbid-zone reef development: Examples from Paluma Shoals and Lugger Shoal, inshore central Great Barrier Reef, Australia. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **242**, 1–20.

Pervesler, P. and Uchman, A. 2009. A new Y-shaped trace fossil attributed to upogebiid crustaceans from Early Pleistocene of Italy. *Acta Palaeontologica Polonica*, **54**, 135–142.

Pervesler, P., Uchman, A., Hohenegger J. and Dominici, S. 2011. Ichnological record of environmental changes in Early Quaternary (Gelasian-Calabrian) marine deposits of the Stirone Section, Northern Italy. *Palaios*, **26**, 578–593.

Phillips, Ch., McIlroy, D. and Elliott, T. 2011. Ichnological characterization of Eocene/Oligocene turbidites from the Grès d'Annet Basin, French Alps, SE France. *Palaeo-*

geography, Palaeoclimatology, Palaeoecology, **300**, 67–83.

Pickerill, R.K., Fillion, D. and Harland, T.L. 1984. Middle Ordovician trace fossils in carbonates of the Trenton Group between Montreal and Quebec City, St. Lawrence Lowland, Eastern Canada. *Journal of Paleontology*, **58**, 416–439.

Pleydell, S.M. and Jones, B. 1988. Boring of various faunal elements in the Oligocene-Miocene Bluff Formation of Grand Cayman, British West Indies. *Journal of Paleontology*, **62**, 348–367.

Pollard, J.E. 1981. A comparison between the Triassic trace-fossils of Cheshire and south Germany. *Palaeontology*, **24**, 555–588.

Poursoltani, M.R., Moussavi-Harami, R. and Gibling, M.R. 2007. Jurassic deep-water fans in the Neo-Tethys Ocean: The Kashafrud Formation of the Kopet-Dagh Basin, Iran. *Sedimentary Geology*, **198**, 53–74.

Pruss, S.B. and Bottjer, D.J. 2004. Early Triassic trace fossils of the Western United States and their implications for prolonged environmental stress from the End-Permian mass extinction. *Palaios*, **19**, 551–564.

Radley, J.D. and Barker, M.J. 1998. Palaeoenvironmental analysis of shell beds in the Wealden Group (Lower Cretaceous) of the Isle of Wight, southern England: an initial account. *Cretaceous Research*, **19**, 489–504.

Radley, J.D., Barker, M.J. and Munt, M.C. 1998. Bivalve trace fossils (*Lockeia*) from the Barnes High Sandstone (Wealden Group, Lower Cretaceous) of the Wessex Sub-basin, southern England. *Cretaceous Research*, **19**, 505–509.

Richter, R. 1937. Marken und Spuren aus alten Zeiten I-II. *Senckenbergiana*, **19**, 150–178.

Rieth, A. 1932. Neue Funde spongeliomorpher Fucoiden aus dem Jura Schwabens. *Geologische Paläontologische Abhandlungen, Neue Folge*, **19**, 257–294.

Rindsberg, A.K. 2012. Ichnotaxonomy: finding patterns in a welter of information. In: D. Knaust and R.G. Bromley (Eds), Trace fossils as indicators of sedimentary environments, *Developments in Sedimentology*, **64**, 45–78.

Rodríguez-Tovar, F.J. and Pérez-Valera, F. 2008. Trace fossil *Rhizocorallium* from the Middle Triassic of the Betic Cordillera, Southern Spain: characterization and environmental implications. *Palaios*, **23**, 78–86.

Rodríguez-Tovar, F.J. and Pérez-Valera, F. 2013. Variations in population structure of *Diplocraterion parallelum*: Hydrodynamic influence, food availability, or nursery settlement? *Palaeogeography, Palaeoclimatology, Palaeoecology*, **369**, 501–509.

Rodríguez-Tovar, F.J. and Uchman, A. 2004. Ichnotaxonomic analysis of the Cretaceous/Palaeogene boundary interval in the Agost section, south-east Spain. *Cretaceous Research*, **25**, 635–647.

Rodríguez-Tovar, F.J. and Uchman, A. 2006. Ichnological

analysis of the Cretaceous-Palaeogene boundary interval at the Caravaca section, SE Spain. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **242**, 313–325.

Rodríguez-Tovar, F.J. and Uchman, A. 2010. Ichnofabric evidence for the lack of bottom anoxia during the Lower Toarcian Oceanic Anoxic Event in the Fuente de la Vidriera Section, Betic Cordillera, Spain. *Palaios*, **25**, 576–587.

Rodríguez-Tovar, F.J., Buatois, L.A., Piñuela, L., Mángano, M.G. and García-Ramos, J.C. 2012. Palaeoenvironmental and functional interpretation of *Rhizocorallium jenense spinosus* (ichnosubsp. nov.) from the lower Jurassic of Asturias, northern Spain. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **339–341**, 114–120.

Rodríguez-Tovar, F.J., Orue-Etxebaria, X., Apellaniz, E. And Molina, E. 2010. Sea-level dynamics and palaeoecological factors affecting trace fossil distribution in Eocene turbiditic deposits (Gorrondatxe section, N Spain). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **285**, 50–65.

Rodríguez-Tovar, F.J., Pérez-Valera, F. and Pérez-López, A. 2007. Ichnological analysis in high-resolution sequence stratigraphy: The *Glossifungites* ichnofacies in Triassic successions from the Betic Cordillera (southern Spain). *Sedimentary Geology*, **198**, 293–307.

Rodríguez-Tovar, F.J., Uchman, A., Martín-Algarra, A. 2009a. Oceanic Anoxic Event at the Cenomanian-Turonian boundary interval (OAE-2): ichnological approach from the Betic Cordillera, southern Spain. *Lethaia*, **42**, 407–417.

Rodríguez-Tovar, F.J. and Uchman, A., Martín-Algarra, A. and O'Dogherty, L. 2009b. Nutrient spatial variation during intrabasinal upwelling at the Cenomanian-Turonian Oceanic Anoxic Event in the westernmost Tethys; An ichnological and facies approach. *Sedimentary Geology*, **215**, 83–93.

Rodríguez-Tovar, F.J., Uchman, A., Alegert, L. and Molina, E. 2011a. Impact of the Paleocene-Eocene Thermal Maximum on the macrobenthic community: Ichnological record from the Zumaia section, northern Spain. *Marine Geology*, **282**, 178–187.

Rodríguez-Tovar, F.J., Uchman, A., Molina, E. and Monechi, S. 2011b. Bioturbational redistribution of Danian calcareous nannofossils in the uppermost Maastrichtian across the K-Pg boundary at Bidart, SW France. *Geobios*, **43**, 569–579.

Rodríguez-Tovar, F.J., Uchman, A., Orue-Etxebarria, X., Apellaniz, E. and Baceta, J. 2011c. Ichnological analysis of the Bidart and Sopelana Cretaceous/Paleogene (K/Pg) boundary sections (Basque Basin, W Pyrenees: Refining eco-sedimentary environment. *Sedimentary Geology*, **234**, 42–55.

Rossetti, D.F. and Netto, R.G. 2006. First evidence of marine influence in the Cretaceous of the Amazonas Basin, Brazil. *Cretaceous Research*, **27**, 513–528.

Rossetti, D.F., Bezerra, F.H.R. and Dominguez, J.M.L. 2013. Late Oligocene-Miocene transgressions along the equatorial and eastern margins of Brazil. *Earth-Science Reviews*, **123**, 87–112.

Ruffell, A. and Wach, G. 1998. Firmgrounds – key surfaces in the recognition of parasequences in the Aptian Lower Greensand Group, Isle of Wight (southern England). *Sedimentology*, **45**, 91–107.

Salamon, M., Niedźwiedzki, R. and Walter, R. 2003. New data on Middle Triassic echinoderms from the Sudetes Mountains. *Geological Quarterly*, **47**, 133–138.

Santos, A., Mayoral, E., da Silva, C. M., Cachão, M. And Kullberg, J. C. 2010. *Trypanites* ichnofacies: Palaeoenvironmental and tectonic implications. A case study from the Miocene disconformity at Foz da Fonte (Lower Tagus Basin, Portugal). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **292**, 35–43.

Santos, A., Mayoral, E.J., da Silva, C. M., Cachão, M., Johnson, M.E. and Baarli, B.G. 2011. Miocene intertidal zonation on a volcanically active shoreline: Porto Santo in the Madeira Archipelago, Portugal. *Lethaia*, **44**, 26–32.

Sarkar, S., Ghosh, S. K. and Chakraborty, C. 2009. Ichnology of a Late Palaeozoic ice-marginal shallow marine succession: Talchir Formation, Satpura Gondwana basin, central India. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **283**, 28–45.

Savrda, C.E. 1991. Ichnology in sequence stratigraphic studies: an example from the Lower Paleocene of Alabama. *Palaios*, **6**, 39–53.

Savrda, C.E. 1995. Ichnologic applications in paleoceanographic, paleoclimatic, and sea-level studies. *Palaios,* **10**, 565–577.

Savrda, C.E. 2007. Trace fossils and marine benthic oxygenation. In: W. Miller, III (Ed.), Trace Fossils. Concepts, Problems, Prospects, 149–158. Elsevier.

Savrda, C.E. and Bottjer, D.J. 1986. Trace fossil model for reconstruction of paleo-oxygenation in bottom waters. *Geology*, **14**, 3-6.

Savrda, C.E., Browning, J.V., Krawinkel, H. and Hesselbo, S.P. 2001. Firmground ichnofabrics in deep-water sequence stratigraphy, Tertiary clinoform-toe deposits, New Jersey Slope. *Palaios*, **16**, 294–305.

Sawicki, L. and Teisseyre, H. 1978. Geologic Map of the Lower Silesian Region (without Quaternary sediments). PAN; Warszawa.

Schlirf, M. 2003. Palaeoecologic significance of Late Jurassic trace fossils from the Boulonnais, N France. *Acta Geologica Polonica*, **53**, 123–142.

Schlirf, M. 2011. A new classification concept for U-shaped spreite trace fossils. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, **260**, 33–54.

Schlirf, M. and Uchman, A. 2005. Revision of the ichnogenus *Sabellarifex* Richter, 1921 and its relationship to *Skolithos* Haldeman, 1840 and *Polykladichnus* Fürsich, 198. *Journal of Systematic Palaeontology*, **3**, 5–131.

Schmid, E.E. 1876. Der Muschelkalk des östlichen Thüringen, pp. 1–20. Fromann; Jena.

Scott, J.J., Buatois, L.A. and Mángano, M.G. 2012. Lacustrine environments. In: D. Knaust and R.G. Bromley (Eds), Trace fossils as indicators of sedimentary environments. *Developments in Sedimentology*, **64**, 379–417.

Seilacher, A. 1967. Bathymetry of trace fossils. *Marine Geology*, **5**, 413–428.

Seilacher, A., 2007. Trace fossil analysis, 1–226. Springer-Verlag; Berlin-Heilderberg–New York.

Seilacher, A. and Seilacher, E. 1994. Bivalvian trace fossils: a lesson from actuopaleontology. *Courier Forschung Senckenberg*, **169**, 5–15.

Sheehan, P.M. and Schiefelbein, D.R.J. 1984. The trace-fossil *Thalassinoides* from the Upper Ordovician of the Eastern Great basin: deep burrowing in the Early Paleozoic. *Journal of Paleontology*, **58**, 440–447.

Singh, R.H., Rodríguez-Tovar, F.J. and Ibotombi, S. 2008. Trace Fossils of the Upper Eocene-Lower Oligocene Transition of the Manipur, Indo-Myanmar Ranges (Northeast India). *Turkish Journal of Earth Sciences*, **17**, 821–834.

Szulc, J. 1990a. The Anisian transgression – regression cycles. In: A. Bodzioch, S. Kwiatkowski, M. Michalik, E. Morycowa and J. Szulc (Eds), International Workshop – Field Seminar. The Muschelkalk – Sedimentary Environments, Facies and Diagenesis, pp. 4–13. Kraków.

Szulc, J. 1990 b. Ichnological indicators of the sedimentary environment fluctuation. In: A. Bodzioch, S. Kwiatkowski, M. Michalik, E. Morycowa, and J. Szulc (Eds), International Workshop – Field Seminar. The Muschelkalk – Sedimentary Environments, Facies and Diagenesis, pp. 23–25. Kraków.

Szulc, J. 1991a. The Muschelkalk in Lower Silesia. Stop B11, Raciborowice (Poland, Lower Silesia). In: H. Hagdorn, T. Simon and J. Szulc (Eds), Muschelkalk. A Field Guide, pp. 58–61. Goldschneck-Verlag; Stuttgart.

Szulc, J. 1991b. Stop B13, Strzelce Opolskie (Poland, Upper Silesia). In: H. Hagdorn, T. Simon and J. Szulc (Eds), Muschelkalk. A Field Guide, pp. 67–69. Goldschneck-Verlag; Stuttgart.

Szulc, J. 1993. Early Alpine Tectonics and Lithofacies Succession in the Silesian Part of the Muschelkalk Basin. A Synopsis. In: H. Hagdorn and A. Seilacher (Eds), Muschelkalk. Schöntaler Symposium 1991. Sonderbände der Gesellschaft für Natur-Kunde Württemberg, 2, pp. 19–28. Goldschneck-Verlag; Stuttgart.

Szulc, J. 2000. Middle Triassic evolution of the northern Peri-Tethys area as influenced by early opening of the Tethys Ocean. *Annales Societatis Geologorum Poloniae*, **70**, 1–48.

Szulc, J. 2007a. Structural setting of the Germanic Triassic and problems with its stratigraphical setup. A preface. In: J. Szulc and A. Becker (Eds), International Workshop on the Triassic of southern Poland. Pan-European Correlation of the Epicontinental Triassic 4th Meeting. Fieldtrip Guide, 3–8.09, pp. 5–6. Kraków.

Szulc, J. 2007b. Röt and Muschelkalk. In: J. Szulc and A. Becker (Eds), International Workshop on the Triassic of southern Poland. Pan-European Correlation of the Epicontinental Triassic 4th Meeting. Fieldtrip Guide, 3–8.09, pp. 17–41. Kraków.

Szulc, J. and Głuchowski, E. 1991. Stop B15, Zyglin (Poland, Upper Silesia). In: H. Hagdorn, T. Simon and J. Szulc (Eds), Muschelkalk. A Field Guide, pp. 71–72. Goldschneck-Verlag; Stuttgart.

Szulc, J., Hagdorn, H. and Matysik, M., 2009. Shallow marine carbonate sedimentation in tectonically mobile basin-the Muschelkalk of Silesia (Excursion B1). In: G. Haczewski (Ed.), Abstracts and field guide. 6th Annual Conference of SEPM-CES, SEDIMENT 2009, Kraków, 24–25 June, Polish Geological Institute, pp. 82–110. Warszawa.

Szurlies, M. 2007. Latest Permian to Middle Triassic cycolmagnetostratigraphy from the Central European Basin, Germany: Implications for the geomagnetic polarity timescale. *Earth and Planetary Science Letters*, **261**, 602–619.

Śliwiński, W., Raczyński and Wojewoda, J. 2003. Sedimentation of the epi-Variscian cover in the North-Sudetic Basin. In: W. Ciężkowski, J. Wojewoda and A. Żelaźniewicz (Eds), Sudety Zachodnie: od wendu do czwartorzędu. Polskie Towarzystwo Geologiczne, pp. 119–126. Wrocław. [In Polish]

Taylor, A.M. and Goldring, R. 1993. Description and analysis of bioturbation and ichnofabric. *Journal of the Geological Society*, London, 150, 141–148

Tchoumatchenco, P. and Uchman, A. 1999. Lower and Middle Jurassic flysch trace fossils from the eastern Stara Planina Mountains, Bulgaria: A contribution to the evolution of Mesozoic ichnodiversity. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, **213**, 169–199.

Treter, M. 2003. Środowisko facji dolnego wapienia muszlowego w Sudetach w oparciu o ichnofosylia i makrofaunę, pp. 1–76. Uniwersytet Wrocławski; Wrocław. [In Polish; unpublished report]

Tucker, M.E. and Wright, V.P. 1990. Carbonate sedimentology, pp. 1–482. Blackwell Science; Oxford–London-Edinburgh–Paris–Victoria–Carlton–Malden.

Uchman A. 1991. "Shallow water" trace fossils in Paleogene flysch of the southern part of the Magura Nappe, Polish Outer Carpathians. *Annales Societatis Geologorum Poloniae*, **61**, 61–75.

Uchman, A. 1995. Tiering patterns of trace fossils in the Palaeogene flysch deposits of the Carpathians, Poland. *Geobios*, **28**, 389–394.

Uchman, A. 1998. Taxonomy and ethology of flysch trace fossils: revision of the Marian Książkiewicz Collection and studies of complementary material. *Annales Societatis Geologorum Poloniae*, **68**, 105–218.

Uchman, A. 2004. Deep-sea trace fossils controlled by palaeooxygenation and deposition: an example from the Lower Cretaceous dark flysch deposits of the Silesian unit, Carpathians, Poland. *Fossils and Strata*, **51**, 39–57.

Uchman, A. and Gaździcki, A. 2006. New trace fossils from the La Meseta Formation (Eocene) of Seymour Island, Antarctica. *Polish Polar Research*, **27**, 153–170.

Uchman, A. and Krenmayr 2004. Trace fossils, ichnofabrics and sedimentary facies in the shallow marine Lower Miocene molasse of Upper Austria. *Jahrbuch der Geologischen Bundesanstalt*, **144**, 233–251.

Uchman, A. and Kumpulainen, R.A. 2011. Trace fossils in Quaternary glacial varved clays near Uppsala, Sweden. *Journal of the Geological Society of Sweden*, **133**, 135–140.

Uchman, A. and Rattazzi, B. 2011. The new complex helical trace fossil *Avetoichnus lusae* igen. n. et isp. n. from the Cainozoic deep-sea sediments of the Alpine realm: a non-graphoglyptid mid-tier agrichnion. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, **260**, 319–330.

Uchman, A. and Tchoumatchenco, P. 2003. A mixed assemblage of deep-sea and shelf trace fossils from the Lower Creatceous (Valanginian) Kamchia Formation in the Troyan region, central Fore-Balkan, Bulgaria. *Annales Societatis Geologorum Poloniae*, **73**, 27–34.

Uchman, A., Bubniak, I. and Bubniak, A. 2000. The *Glossifungites* ichnofacies in the area of ist nomenclatural archetype, Lviv, Ukraine. *Ichnos*, **7**, 183–193.

Uchman, A., Drygant, D., Paszkowski, M., Porębski, SZ.J. and Turnau, E. 2004a. Early Devonian trace fossils in marine to non-marine redbeds in Podolia, Ukraine: palaeonvironmental implications. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **214**, 67–83.

Uchman, A., Hanken, N.-M. and Binns, R. 2005. Ordovician bathyal trace fossils from metasiliciclastics in Central Norway and their sedimentological and paleogeographical implications. *Ichnos*, **12**, 105–133.

Uchman, A., Janbu, N.E. and Nemec, W. 2004b. Trace Fossils in the Cretaceous-Eocene Flysch of the Sinop-Boyabat Basin, Central Pontides, Turkey. *Annales Societatis Geologorum Poloniae*, **74**, 197–235.

Uchman, A., Mikuláš, R. and Rindsberg, A.K. 2011. Mollusc trace fossils *Ptychoplasma* Fenton and Fenton, 1937 and *Oravaichnum* Plička and Uhrová, 1990: their type material and ichnospecies. *Geobios*, **44**, 387–397.

Vinn, O. 2004. The earliest known *Trypanites* borings in the

shells of articulated brachiopods from the Arenig (Ordovician) of Baltica. *Proceedings of the Estonian Academy of Sciences, Geology*, **53**, 257–266.

Vinn, O. and Wilson, M.A. 2010. Occurrence of giant borings of *Osprioneides kampto* in the Lower Silurian (Sheinwoodian) stromatoporoids of Saaremaa Estonia. *Ichnos*, **17**, 166–171.

Virtasalo, J.J., Bonsdorff, E., Moros, M., Kabel, K., Kotilainen, A.T., Ryabchuk, D., Kallonen, A. and Hämäläinen, K. 2011. Ichnological trends along an open-water transect across a large marginal-marine epicontinental basin, the modern Baltic Sea. *Sedimentary Geology*, **241**, 40–51.

Vlahović, I., Mikša, G., Mrinjek, E., Hasiotis, S.T., Velić, I, Tišljar, J. and Matičec, D. 2011. Response of tracemakers to temporary platform drowning: Lower Cenomanian of southern Istria (Western Croatia). *Palaios*, **26**, 567–577.

Waite, R., Wetzel, A., Mwyer, C.a. and Strasser, A. 2008. The paleoecological significance of nerineoid mass accumulations from the Kimmeridgian of the Swiss Jura Mountains. *Palaios*, **23**, 548–558.

Waite, R., Marty, D., Strasser, A. and Wetzel, A. 2013. The lost paleosols: Masked evidence for emergence and soil formation on the Kimmeridgian Jura platform. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **376**, 73–90.

Warme, J.E. 1975. Borings as trace fossils, and the processes of marine bioerosion. In R.W. Frey (Ed.), The Study of Trace Fossils, A synthesis of Principles, Problems, and Procedures in Ichnology, pp. 181–227.

Wendland, F. 1980. Zur Feinstratigraphie des Unteren Muschelkalks in der thüringischen Vorderrhon (Bezirk Suhl, DDR), *Zeitschrift für Geologische Wissenschaften*, **8,** 1057–1078.

Wetzel, A. and Uchman, A. 1997. Ichnology of deep-sea fan overbank deposits of the Ganei Slates (Eocene, Switzerland) – a classical flysch trace fossil locality studied first by Oswald Heer. (Overseas Publishers Association) Amsterdam Published in the Netherlands by Harwood Academic Publishers, *Ichnos*, **5**, 139–162.

Wetzel, A. and Uchman, A. 1998a. Biogenic Sedimentary Structures in Mudstones an Overview. In: J. Schiber, W. Zimmerle and P. Sethi (Eds), Shales and Mudstones I, pp. 351–369. E. Schweizerbart'sche Verlagsbuchhandlung (Nagele u. Obermiller); Stuttgart.

Wetzel, A. and Uchman, A. 1998 b. Deep-sea benthic food content recorded by ichnofabrics: a conceptual model based on observations from Paleogene flysch, Carpathians, Poland. *Palaios*, **13**, 533–546.

Wetzel, A. and Uchman, A. 2001. Sequential colonization of muddy turbidites in the Eocene Beloveza Formation, Carpathians, Poland. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **168**, 171–186.

Wetzel, A., Blechschmidt, I., Uchman, A. and Matter, A. 2007. A highly diverse ichnofauna in Late Triassic deep-sea fan deposits of Oman. *Palaios*, **22**, 567–576.

Wiedl, T., Harzhauser M. and Piller, W.E. 2012. Facies and synsedimentary tectonics on a Badenian carbonate platform in the southern Vienna Basin (Austria, Central Paratethys). *Facies*, **58**, 523–548.

Wiedl, T., Harzhauser, M., Kroh, A., Ćorić, S. and Piller, W.E. 2013. Ecospace variability along a carbonate platform at the northern boundary of the Miocene reef belt (upper Langhian, Austria). *Palaeogeography, Palaeoclimatology, Palaeoecology*, **370**, 232–246.

Wignall, P.B. 1991. Dysaerobic trace fossils and ichnofabrics in the Upper Jurassic Kimmeridge clay of southern England. *Palaios*, **6**, 264–270.

Wilson, J.L. 1975. Carbonate facies in geologic history, 1–471. Springer-Verlag.

Wilson, M.A. and Palmer, T.J. 1998. The earliest *Gastrochaenolites* (Early Pennsylvanian, Arkansas, USA): An Upper Paleozoic bivalve boring? *Journal of Paleontology*, **72**, 769–772.

Wilson, M.A., Wolfe, K.R. and Avni, Y. 2005. Development of a Jurassic rocky shore complex (Zahar Formation, Makhtesh Qatan, southern Israel). *Israel Journal of Earth Sciences*, **54**, 171–178.

Wilson, M.A., Feldman, H.R., Bowen, J.C. and Avni, Y. 2008. A new equatorial, very shallow marine sclerozoan fauna from the Middle Jurassic (late Callovian) of southern Israel. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **263**, 24–29.

Wilson, M.A. and Taylor, P.D. 2001. Palaeoecology of hard substrate faunas from the Cretaceous Qahlah Formation of the Oman Mountains. *Palaeontology*, **44**, 21–41.

Wincierz, J. 1973. Kustensedimente und Ichnofauna aus dem oberen Hettangium von Mackendorf (Niedersachsen) – summary in English. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, **144**, 104–141.

Worsley, D. and Mørk, A. 2001. The environmental significance of the trace fossil *Rhizocorallium jenense* in the Lower Triassic of western Spitsbergen. *Polar Research*, **20**, 37–48.

Zenker, J.C. 1836. Historisch-topografisches Taschenbuch von Jena und seiner Umgebung besonders in seiner naturwissen-schaftlicher und medicinischer Beziehung. 1–338. J.C. Zenker; Jena.

Zhang, G., Uchman, A., Chodyń, R. and Bromley, R.G. 2008. Trace fossil *Artichnus pholeoides* igen. nov. isp. nov. in Eocene turbidites, Polish Carpathians: possible ascription to holothurians. *Acta Geologica Polonica*, **58**, 75–86.

Zonneveld, J.-P. and Gingras, M.K. 2013. The ichnotaxonomy of vertical oriented, bivalve-generated equilibrichnia. *Journal of Paleontology*, **87**, 243–253.

Zonneveld, J.-P., Gingras, M. K. and Beatty, T. W. 2010. Diverse ichnofossil assemblages following the P-T mass extinction, Lower Triassic, Alberta and British Columbia, Canada: Evidence for shallow marine refugia on the northwestern coast of Pangaea. *Palaios*, **25**, 368–392.

Zonneveld, J.-P., Zaim, Y., Rizal, Y., Ciochon, R.L., Bettis III, E.A., Aswan, Gunnell, G.F. 2012. Ichnological constraints on the depositional environment of the Sawahlunto Formation, Kandi, northwest Ombilin Basin, west Sumatra, Indonesia. *Journal of Asian Earth Sciences*, **45**, 106–113.

Żelaźniewicz, A. and Aleksandrowski, P. 2008. Tectonic subdivision of Poland: southwestern Poland. *Przegląd Geologiczny*, **56**, 904–911. [In Polish with English summary]

Žítt, J. and Mikuláš, R. 2006. Substrate of bivalve borers as recorded on phosphatic fills of *Gastrochaenolites*, palaeoenvironmental context (Bohemian Cretaceous Basin, Czech Republic). *Ichnos*, **13**, 191–198.

PLATE 1

1 – *Archaeonassa fossulata* (*Ar.f.*) - unit C (MGUWr – 5410s).

2-4 – *Balanoglossites triadicus* (*Ba.t.)* – *Spiriferina* Bed, unit C (MGUWr – 5411s; 5412s; 5413s).

5 – *Balanoglossites triadicus* (*Ba.t.*) and *Trypanites weisei* (*Tr.w.*) in a hardground intraclast from the *Spiriferina* Bed, unit C (MGUWr – 5414s).

6 – ?*Gastrochaenolites* isp. (*?Ga.*) and *Trypanites weisei* (*Tr.w.*) – intraclast from the *Spiriferina* Bed, unit C (MGUWr – 5415s).

7-8 – Long, sinusoidal movement traces of bivalves (repichnia) – ?*Protovirgularia* isp. (*?Pr.*) and resting traces (cubichnia) – *Lockeia* isp. (*Lk.*), unit C (MGUWr – 5416s; 5417s).
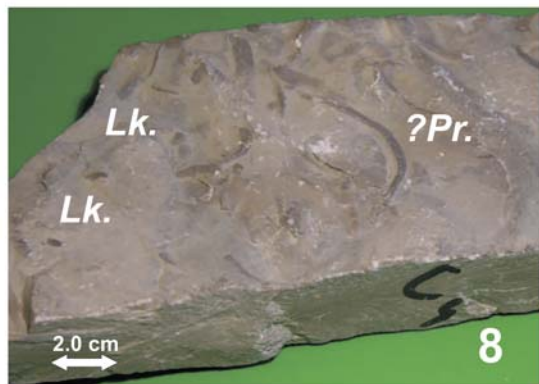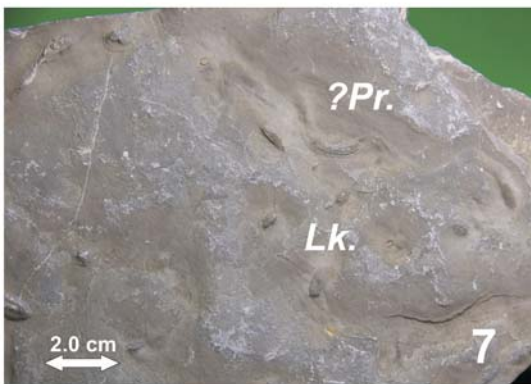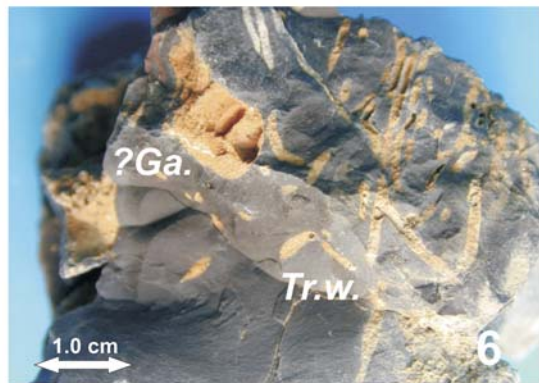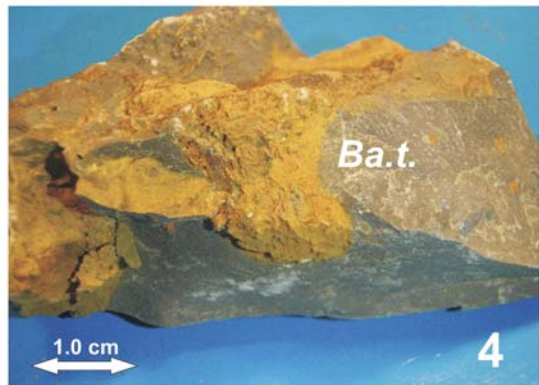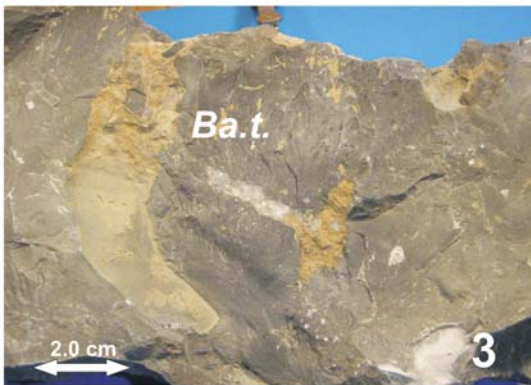
PLATE 2

1 – *Palaeophycus tubularis* (*Pa.t.*) and ?*Palaeophycus* isp. (*?Pa.*) – upper surface of the sample, unit C (MGUWr – 5418s).

2 – *Palaeophycus tubularis* (*Pa.t.*) and "heaps" of ?*Palaeophycus* isp. (*?Pa.*) – upper surface of the same sample.

3-4 – "Heap" of ?*Palaeophycus* isp. – upper surface of the same sample.

5 – Unidentified traces A – bottom surface of the same sample.

6 – Polished slab of the same sample – ?*Palaeophycus* isp. (*?Pa.*): an almost vertical, slightly oblique tunnel, almost horizontal tunnel and planar sections through the tunnels with distinct walls.

7 – Vertical, slightly oblique tunnel of ?*Palaeophycus* isp. (*?Pa.*) – the same polished slab.

8 – Polished slab of the same sample – ?*Palaeophycus* isp. (*?Pa.*) and *Palaeophycus tubularis* (*Pa.t.*) – upper surface of the sample.

9 – *Palaeophycus tubularis* (*Pa.t.*) – unit C (MGUWr – 5419s).
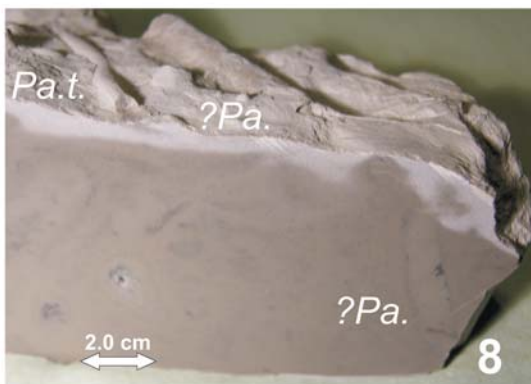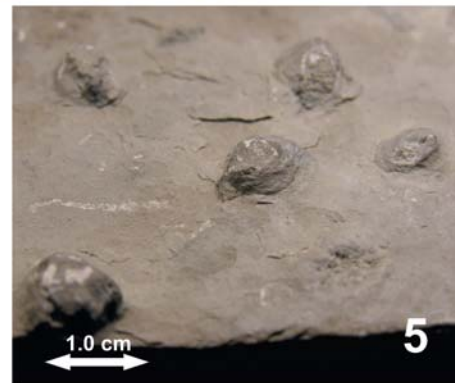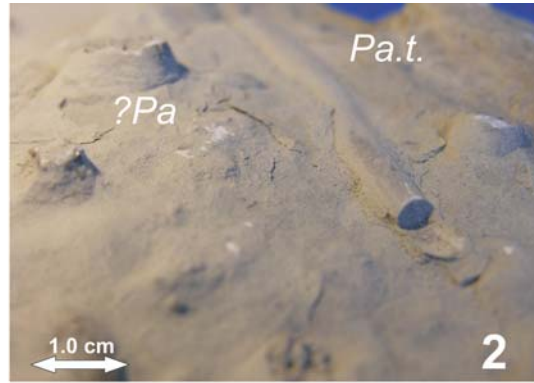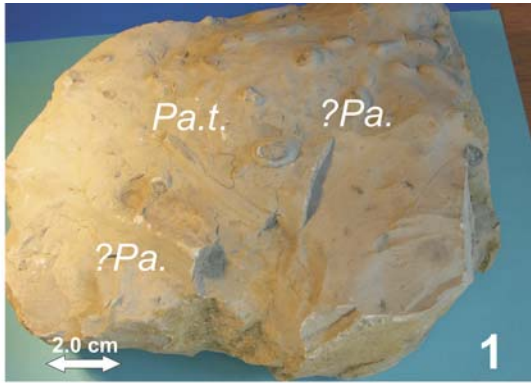
PLATE 3

1-2 – *Palaeophycus tubularis* (*Pa.t.*) – unit C (MGUWr – 5420s; 5421s).

3 – *Palaeophycus* isp. (*Pa.*) – unit C (MGUWr – 5422s).

4 – ?*Palaeophycus* isp. (*?Pa.*) – unit D (MGUWr – 5423s).

5 – ?*Planolites beverleyensis* (*?Pl.b.*) – unit C (MGUWr – 5424s).

6-7 – ?*Planolites beverleyensis* (*?Pl.b.*) – unit D (MGUWr – 5425s; 5426s).

8 – *Planolites montanus* (*Pl.m.*) – unit C (MGUWr – 5427s).
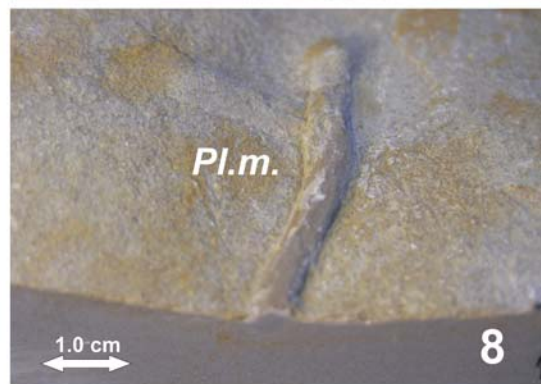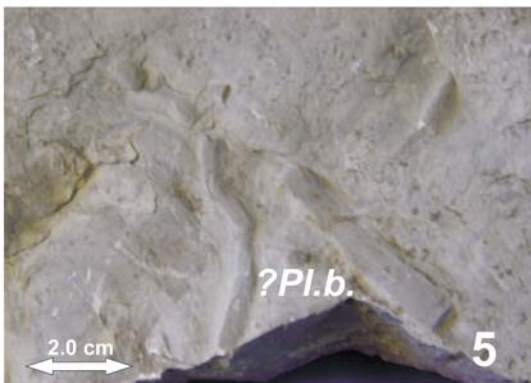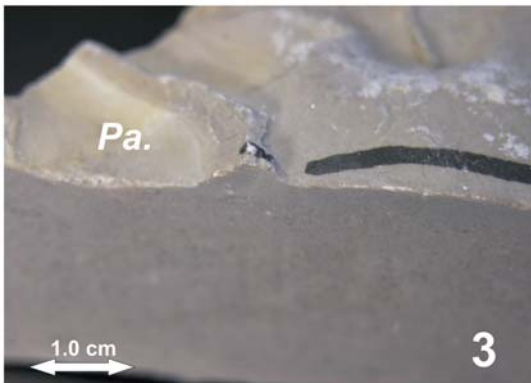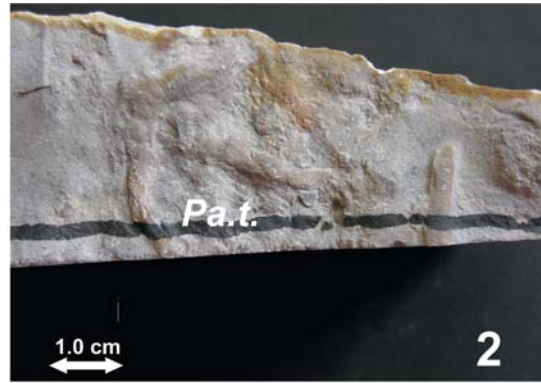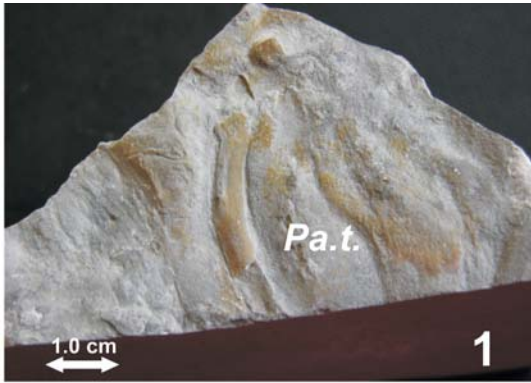
PLATE 4

1 – *Planolites montanus* (*Pl.m.*) – unit C (MGUWr – 5428s).

2 – ?*Protovirgularia* isp. (*?Pr.*) – unit C (MGUWr – 5429s).

3-4 – ?*Rhizocorallium commune* var. *auriforme* – unit C (MGUWr – 5430s; 5431s).

5 – *Rhizocorallium commune* var. *irregulare* – unit B (MGUWr – 5432s).

6 – *Rhizocorallium commune* var. *irregulare* – unit C (MGUWr – 5433s).

7 – *Rhizocorallium commune* var. *irregulare* (*Rh.c.i.*) on a bedding plane (unit C).

8 – Accumulation of *Rhizocorallium commune* var. *irregulare* (*Rh.c.i.*) on a bedding plane (unit C).

.
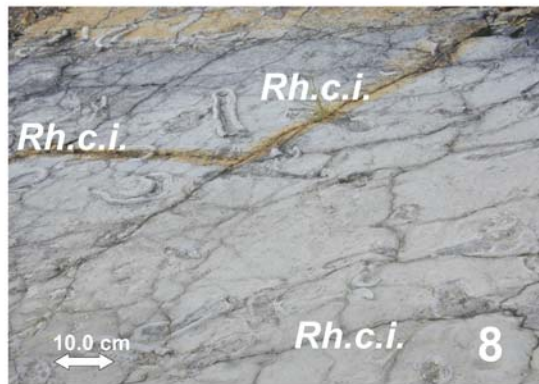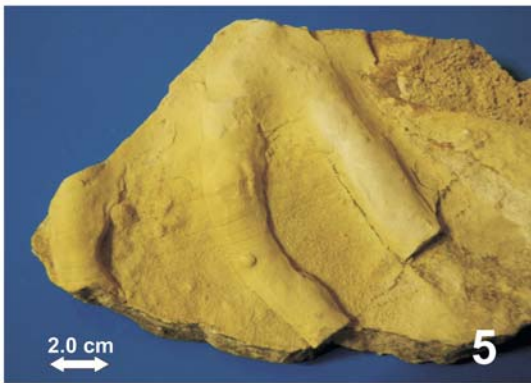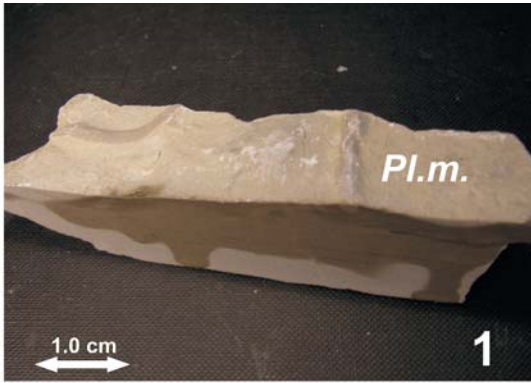
PLATE 5

1-2 – Mass occurrence of *Rhizocorallium commune* var. *irregulare* (*Rh.c.i.*) on a bedding plane - uppermost part of unit C.

3-6 – *Rhizocorallium commune* var. *irregulare* – unit C (fig. 6, MGUWr – 5434s).

7 – *Rhizocorallium commune* var. *irregulare* – unit C (MGUWr – 5435s).

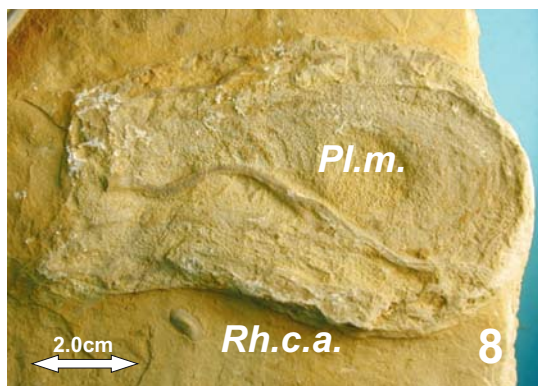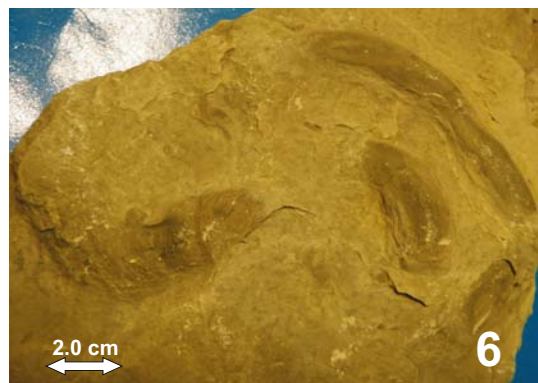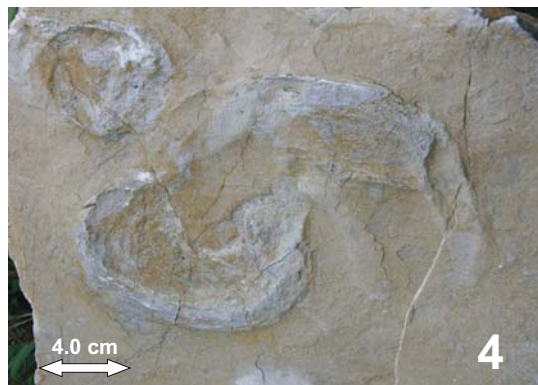8 – *Rhizocorallium commune* var. *auriforme (Rh.c.a.)* and *Planolites montanus* (*Pl.m*) - Unit C (MGUWr - 5436s).

PLATE 6

1-2 – *Rhizocorallium jenense* (*Rh.j.*) – unit B (MGUWr 5437s; 5438s).
  3 – *Rhizocorallium commune* var. *auriforme* – unit C.
  4 – *Skolithos* isp. (*Sk.*) and *Planolites* isp. (*Pl.*) – unit C (MGUWr – 5423s).
5-7 – *Thalassinoides suevicus* – unit C (MGUWr – 5439s; 5440s; 5442s).
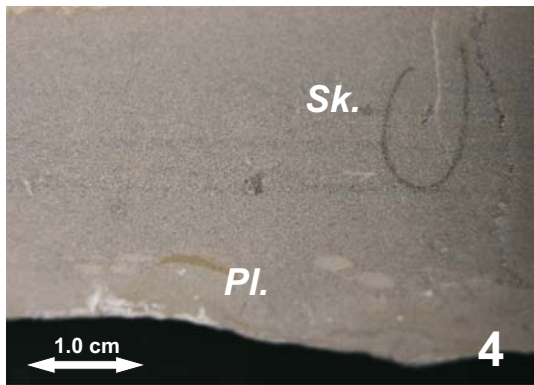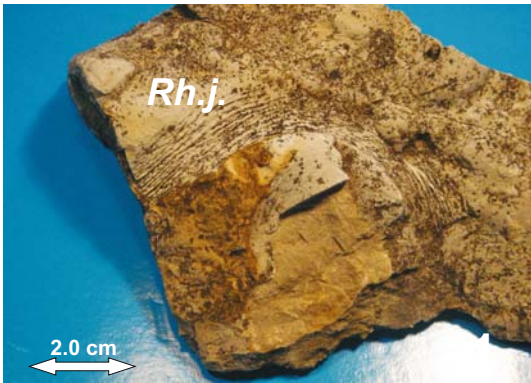 8 – *Thalassinoides suevicus* – unit B (MGUWr – 5443s).

PLATE 7

   1 – *Trypanites weisei* (*Tr.w.*) on the surface of an intraclast from the *Spiriferina* Bed
       (MGUWr – 5444s).
   2 – *Trypanites weisei* (*Tr.w.*) – *Spiriferina* Bed, unit C (MGUWr – 5445s).
   3 – Vertical or slightly oblique *Trypanites weisei* (*Tr.w.*) – unit C (*Spiriferina* Bed).
4-6 – Hardground intraclasts with *Trypanites weisei* (*Tr.w.*) – *Spiriferina* Bed, unit C
       (MGUWr – 5446s; 5447s; 5448s).
   7 – Intraclasts of hardground with *Trypanites weisei* – *Spiriferina* Bed, unit C.
   8 – Fragments of crinoids (*cr.*) attached to hardground intraclast (*in.*) – *Spiriferina* Bed
       (MGUWr – 5449s).