Acta Geologica Polonica, Vol. 63 (2013), No. 3, pp. 315–353
DOI: 10.2478/agp–2013–0015

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

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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; Buatois 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).

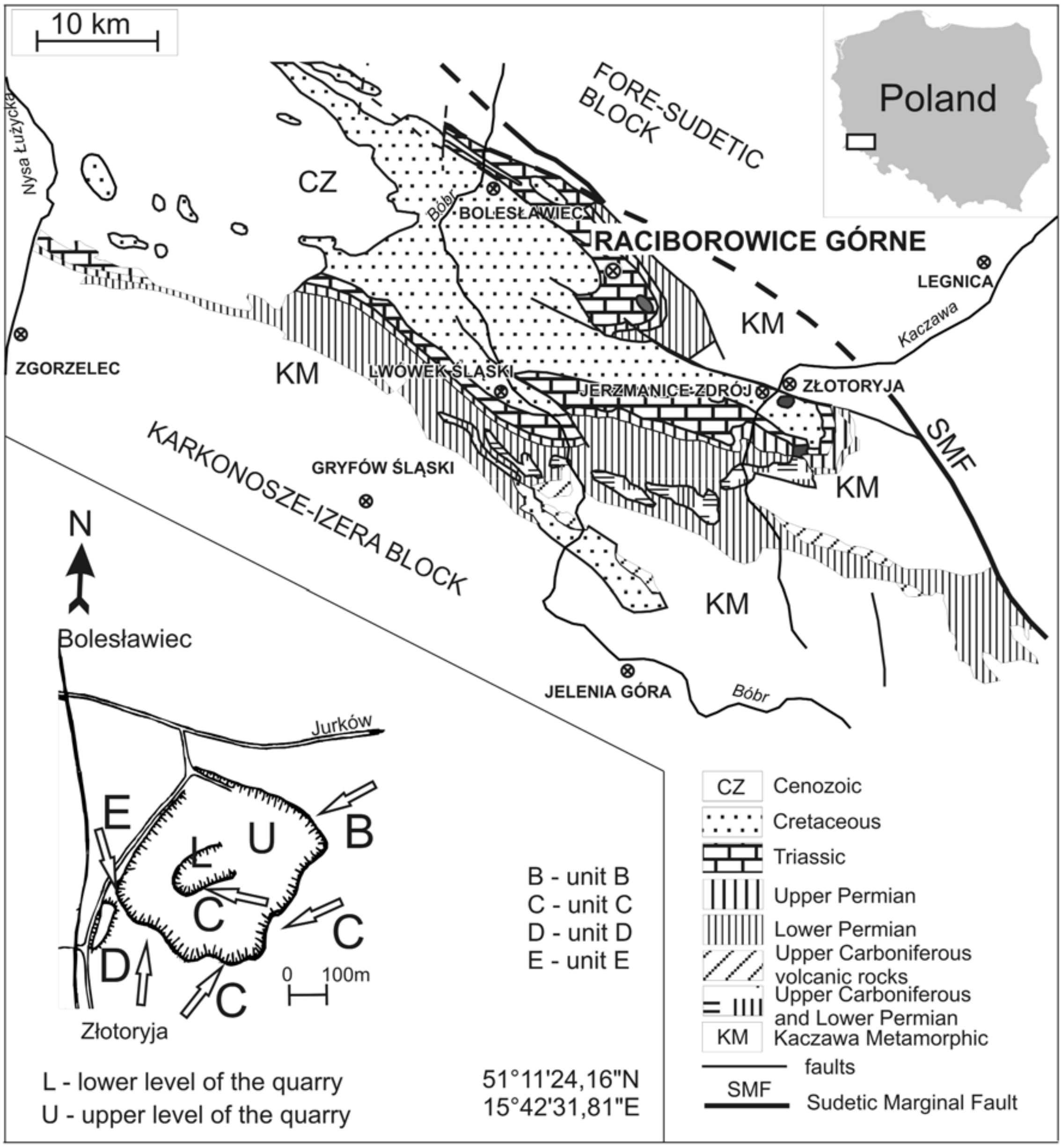
The specimens described are housed in the collection of the Geological Museum of the University of Wrocław (MGUWr-5410s-5449s).

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).



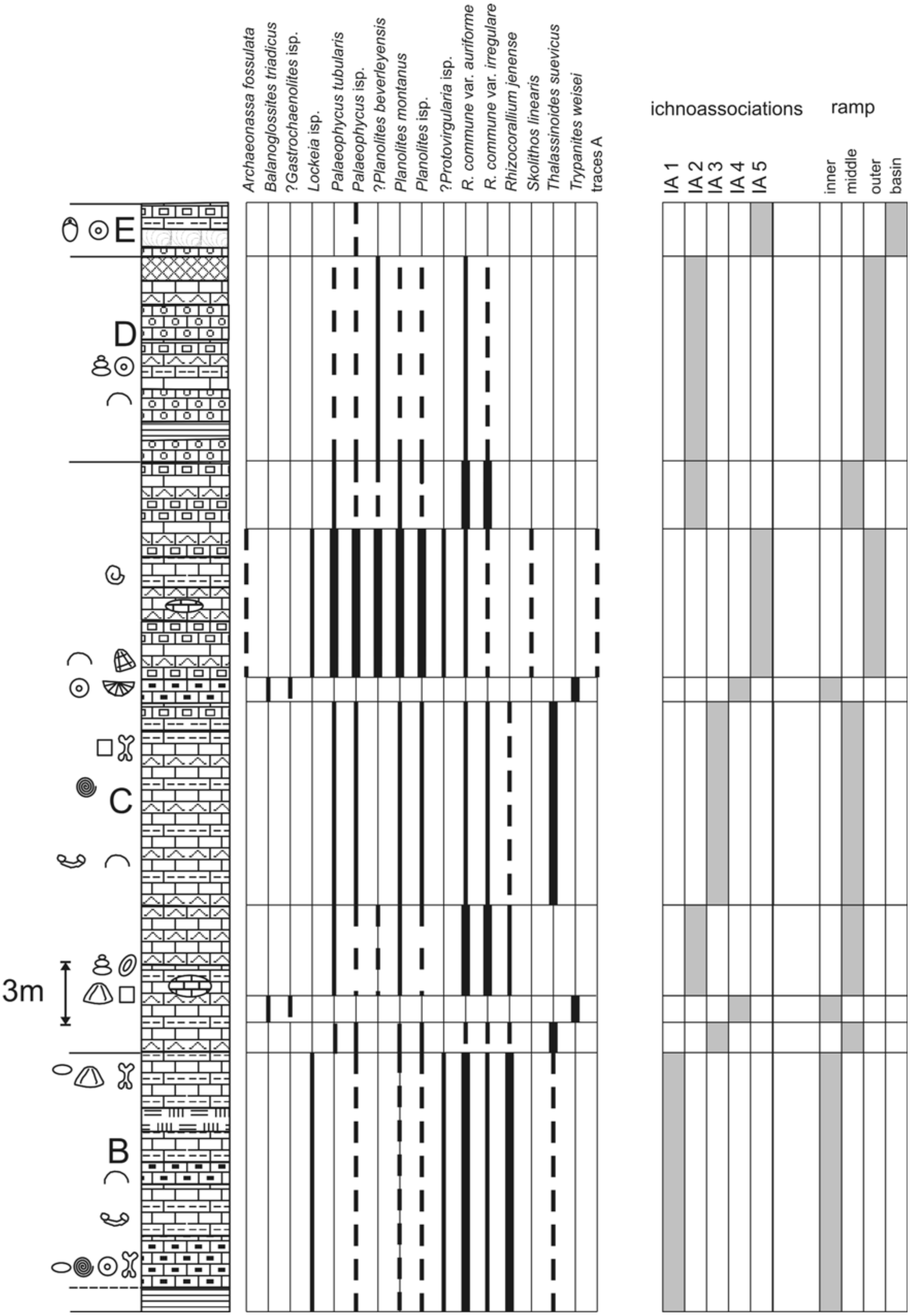
Text-fig. 1. Geological map of the North Sudetic Basin Synclinorium, modified after Sawicki and Teisseyre (1978). Insert: Schematic plan of the Raciborowice Górne quarry. Places where individual units (B to E) are exposed are marked

LOWER MUSCHELKALK OF THE RACIBOROWICE GÓRNE SECTION

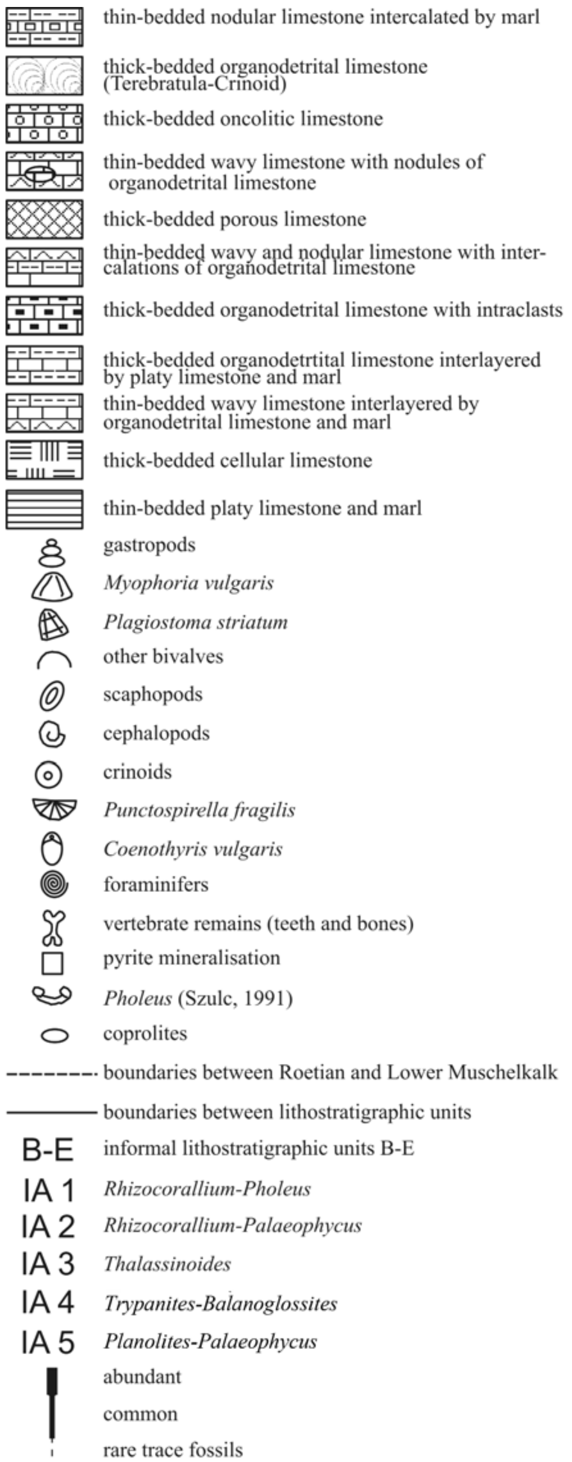
The village of Raciborowice Górne is located southeast of the town of Bolesławiec (Text-fig. 1). An almost complete succession of the Lower Muschelkalk is exposed here, except its uppermost part.

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: *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 *Trypanites* 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), wormlike 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 crustaceans and mayflies. It is a firmground burrow belonging to the *Glossifungites* ichnofacies and lacks faecal pellets (Knaust 2010c). It is typical of firmgrounds and is most typical of the *Glossifungites* ichnofacies. *R. jenense* is a junior synonim of this ichnofacies (see Uchman *et al*. 2000; Knaust *et al*. 2012).

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

It is common in the Upper Buntsandstein (Röt), Lower Muschelkalk (Knaust 2007a) and Eocene (Uchman 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 unbranched separate burrows, cylindrical or sub-cylindrical 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), sipunculans, 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; Loughlin and Hillier 2010). Zonneveld *et al*. (2012) proposed fish, worms, insects and anemones as the potential tracemakers of both *Skolithos* and *Monocraterion*. 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; Pemberton 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 environments (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 burrows are usually more or less horizontal and often elliptical in cross-section. The fill is rather structureless and similar to the host rock. Labyrinth-like interconnected 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 central 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 Costamagna 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 organisms (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*. Cerianthid 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).

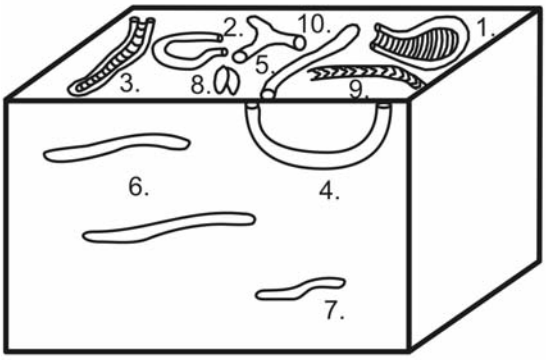
Coprolites. Vertebrate coprolites, elongated and well rounded, 1.5–2.5 cm long and 0.5–1.0 cm wide, occur in the organodetrital limestone (Chrząstek 2008a) in the lower and upper parts of unit B (Text-fig. 2).

TRACE FOSSIL ASSOCIATIONS AND THEIR SEDIMENTARY ENVIRONMENT

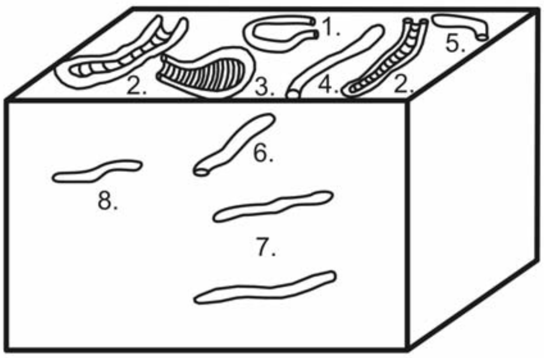
The following ichnoassociations (IA) were distinguished in the Raciborowice Górne section: *Rhizocorallium–Pholeus* (IA 1)*, Rhizocorallium–Palaeophycus* (IA 2), *Thalassinoides* (IA 3), *Trypanites–Balanoglossites* (IA 4) and *Planolites–Palaeophycus* (IA 5) (Text-fig. 3).

Rhizocorallium-Pholeus Ichnoassociation (IA 1)

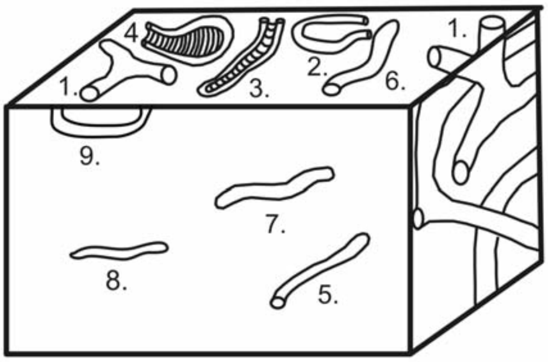
Characteristics: IA 1 comprises very abundant *Rhizocorallium jenense* as well as *R. commune* var. *auriforme*; *R. commune* var. *irregulare*, *Lockeia* isp. and *Protovirgularia* isp. are common, whereas *Palaeo-*



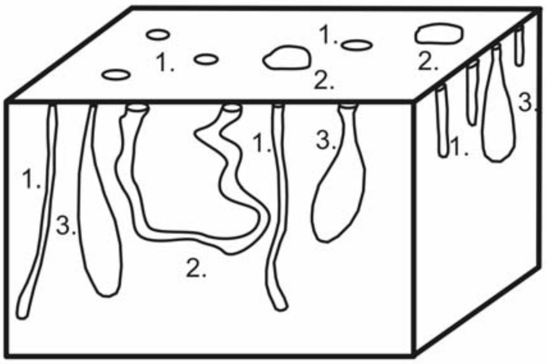
Text-fig. 3a. Ichnoassociation IA1 - *Rhizocorallium-Pholeus.* 1. *Rhizocorallium jenense,* 2. *R. commune* var. *auriforme,* 3. *R. commune var. irregulare,* 4. *Pholeus* isp., 5. *Palaeophycus* isp., 6. *Planolites montanus*, 7. *Planolites* isp., 8. *Lockeia* isp., 9. *Protovirgularia* isp., 10. *Thalassinoides suevicus*



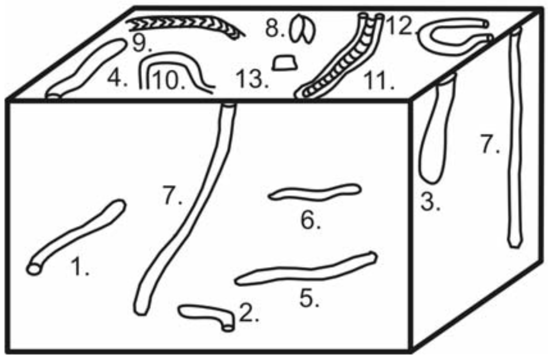
Text-fig. 3b. Ichnoassociation IA2 - *Rhizocorallium-Palaeophycus*
1. *Rhizocorallium commune* var. *auriforme*, 2. *R. commune* var. *irregulare,* 3. *R. jenense*, 4. *Palaeophycus tubularis*, 5. *Palaeophycus* isp., 6. ?*Planolites beverleyensis,* 7. *Planolites montanus,* 8. *Planolites* isp.



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., *Protovirgularia* 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 subtidal 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 a*l. 2012). Based on ichnological analysis, the formation of IA 3 in Raciborowice Górne took place in the middle ramp environment. 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

Chronostratigraphy Nawrocki and Szulc 2000			Opole Region, Upper Silesia	Bodzioch 1991a, b; 1997; Szulc and Głuchowski 1991; Kowal-Linka 2008; Szulc 1990a, b, 1991b, 2000, 2007b	North-Sudetic Basin	Chrząstek 2002, this paper; Szulc 1991a	Thuringia	Knaust 1998, 2007a; Knaust *et al*. 2012	Chronostratigraphy Bachman *et al.* 2009; Szurlies 2007; Ogg 2012		
Lower Muschelkalk	Anisian	Pelsonian	Dziewkowice Formation (Terebratula Beds)	*Alcyonidiopsis*, *Arenicolites*, *Balanoglossites*, *Cliona*, *Palaeophycus*, *Planolites*, *Rhizocorallium*, *Teichichnus*, *Thalassinoides*, *Trypanites*	Unit E	*Palaeophycus*	Upper Wellenkalk	*Planolites*, *Teichichnus*	Pelsonian	Anisian	Lower Muschelkalk
							Terebratula Bed	*Planolites*, *Teichichnus*			
			Górażdże Beds	*Balanoglossites*, *Palaeophycus*, *Planolites*, *Trypanites*	Unit D	*Palaeophycus*, *Planolites*, *Rhizocorallium*	Middle Wellenkalk	*Palaeophycus*, *Pholeus*, *Planolites*, *Thalassinoides*			
							Oolith Bed	*Balanoglossites*, *Pholeus*, *Rhizocorallium*, *Thalassinoides*, *Trypanites*, *Gastrochaenolites*, *Lockeia*, *Protovirgularia*, *Archaeonassa*, *Skolithos*, *Planolites*	Bithynian		
					Unit C	*Archaeonassa*, *Balanoglossites*, ? *Gastrochaenolites*, *Palaeophycus*, *Pholeus*, ? *Protovirgularia*, *Planolites*, *Rhizocorallium*, *Skolithos*, *Thalassinoides*, *Trypanites*, *traces A*	Lower Wellenkalk				
			Upper Gogolin Beds	*Chondrites*, *Palaeophycus*, *Pholeus*, *Planolites*, *Rhizocorallium*							
		Bithynian									
		Aegean			Unit B	*Lockeia*, *Palaeophycus*, *Pholeus*, *Planolites*, ? *Protovirgularia*, *Rhizocorallium*, *Thalassinoides*, coprolites					
			Lower Gogolin Beds	*Palaeophycus*, *Pholeus*, *Planolites*, *Rhizocorallium*, *Thalassinoides*, *Teichichnus*			Röt				Röt
	Olenekian	Spathian									

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

I am very grateful to Prof. Alfred Uchman for his valuable discussion concerning the ichnotaxa distinguished and for the supply of literature. I would like to express my gratitude to the journal reviewer, Dr Dirk Knaust for his critical and helpful comments. Thanks are to the Editor, Prof. I. Walaszczyk, whose comments were of great value in preparing the final version of the manuscript. I am also greatly indebted to Prof. Adam Bodzioch and Dr. Joanna Haydukiewicz for their remarks. I would like to thank Dr. Adam Szuszkiewicz for help with translation of the manuscript. A few trace fossils have been collected by students, supervised by the author, during field practices and one by Dr Robert Niedźwiedzki. I thank Dr. Paweł Raczyński for some photographs of trace fossils. This research was supported by grants: 2022/W/ING/-7 and 1017/S/ING/-4.

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Manuscript submitted: 10th October 2010
Revised version accepted: 15th June 2013

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).

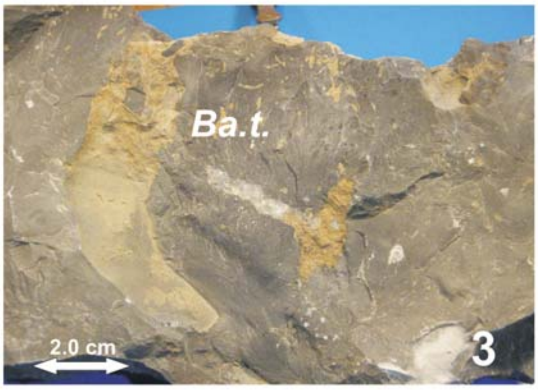
5 – *Balanoglossites triadicus* (*Ba.t.*) and *Trypanites weisei* (*Tr.w.*) in a hardground intraclast from the *Spiriferina* Bed, unit C (MGUWr – 5414s).

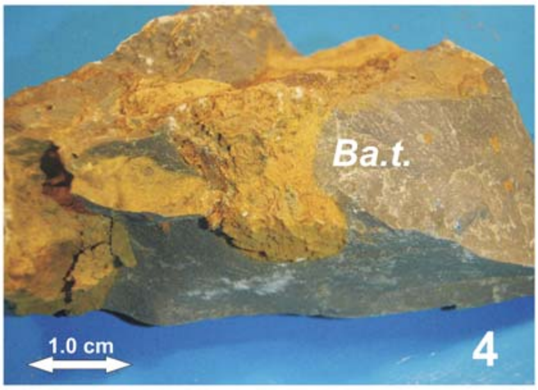
6 – ?*Gastrochaenolites* isp. (*?Ga.*) and *Trypanites weisei* (*Tr.w.*) – intraclast from the *Spiriferina* Bed, unit C (MGUWr – 5415s).

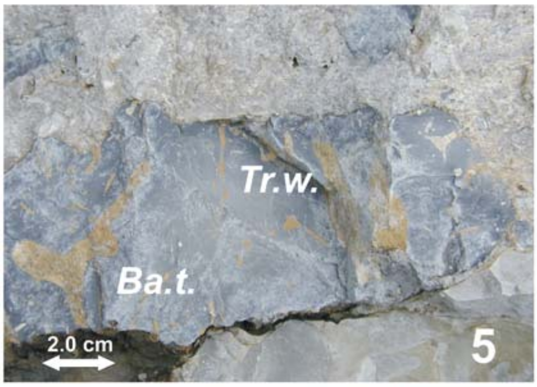
7-8 – Long, sinusoidal movement traces of bivalves (repichnia) – ?*Protovirgularia* isp. (*?Pr.*) and resting traces (cubichnia) – *Lockeia* isp. (*Lk.*), unit C (MGUWr – 5416s; 5417s).

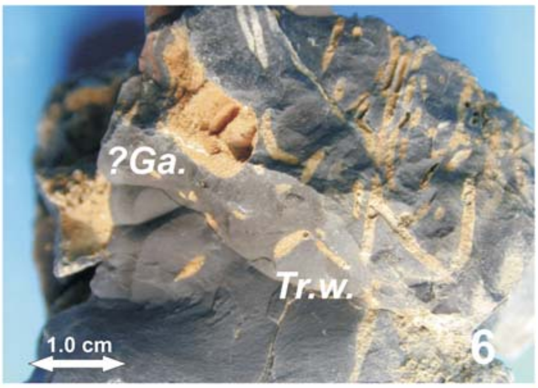

Ar.f.
2.0 cm
1

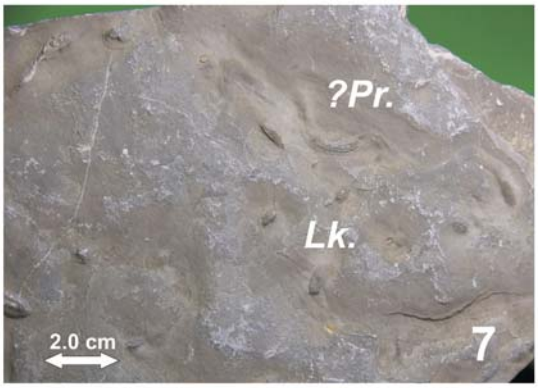

Ba.t.
1.0 cm
2


Ba.t.
2.0 cm
3


Ba.t.
1.0 cm
4


Tr.w.
Ba.t.
2.0 cm
5


?Ga.
Tr.w.
1.0 cm
6


?Pr.
Lk.
2.0 cm
7

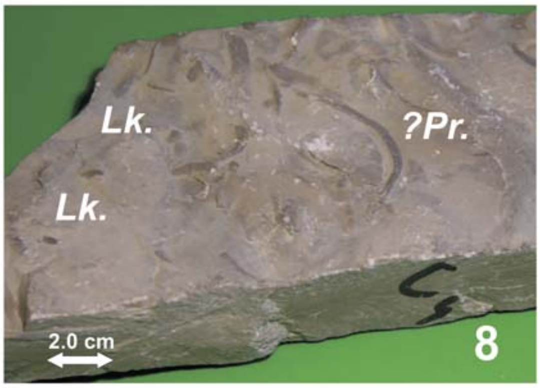
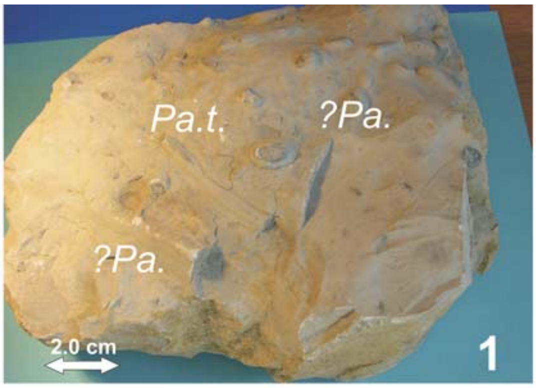
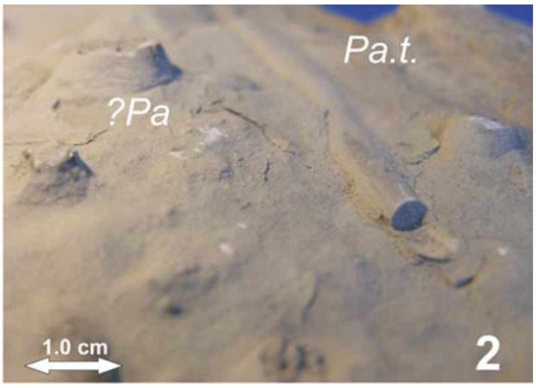

Lk.
?Pr.
Lk.
2.0 cm
8

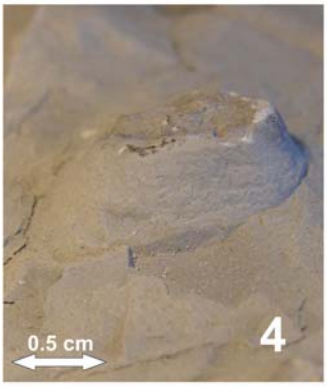
PLATE 2

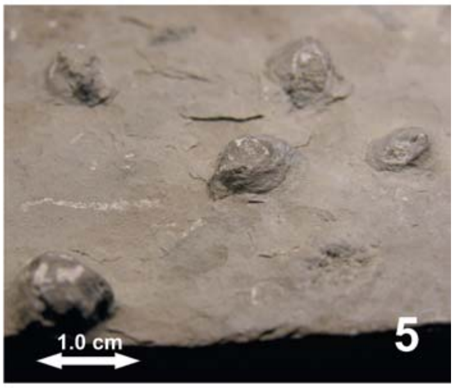
1 – *Palaeophycus tubularis* (*Pa.t.*) and ?*Palaeophycus* isp. (*?Pa.*) – upper surface of the sample, unit C (MGUWr – 5418s).
2 – *Palaeophycus tubularis* (*Pa.t.*) and “heaps” of ?*Palaeophycus* isp. (*?Pa.*) – upper surface of the same sample.
3-4 – “Heap” of ?*Palaeophycus* isp. – upper surface 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).

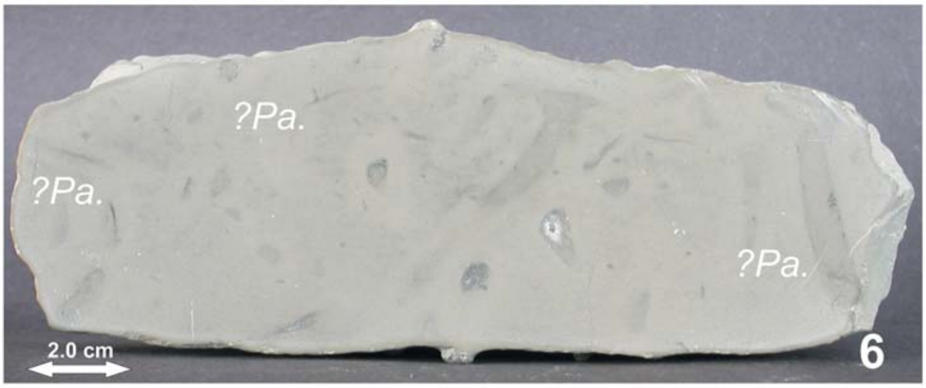

Pa.t.
?Pa.
?Pa.
2.0 cm
1

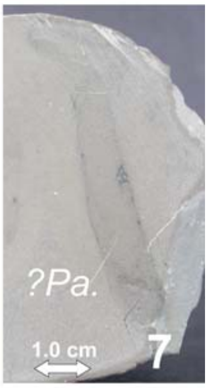

Pa.t.
?Pa
1.0 cm
2

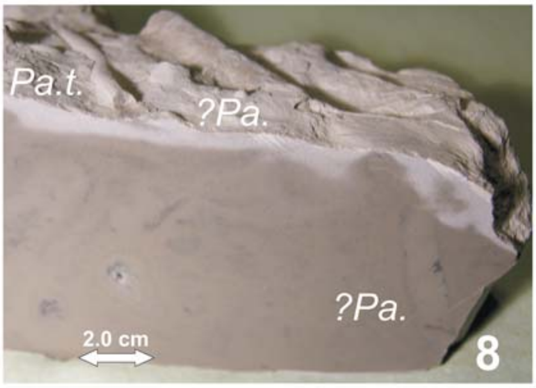

0.5 cm
3


0.5 cm
4


1.0 cm
5


?Pa.
?Pa.
?Pa.
2.0 cm
6


?Pa.
1.0 cm
7


Pa.t.
?Pa.
?Pa.
2.0 cm
8

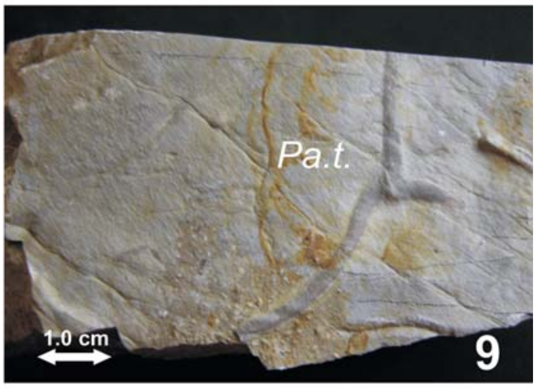
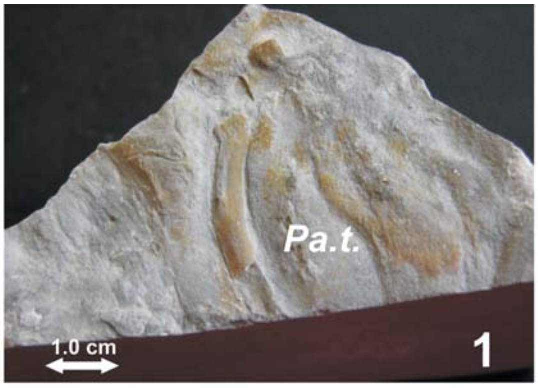
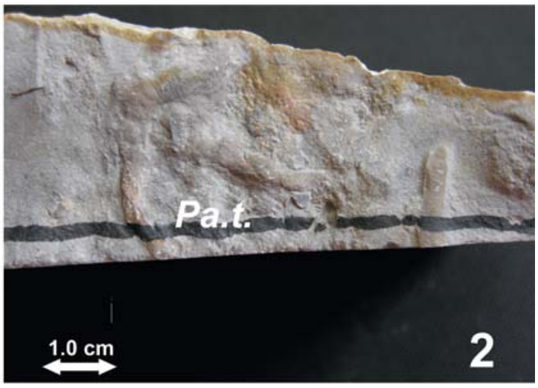
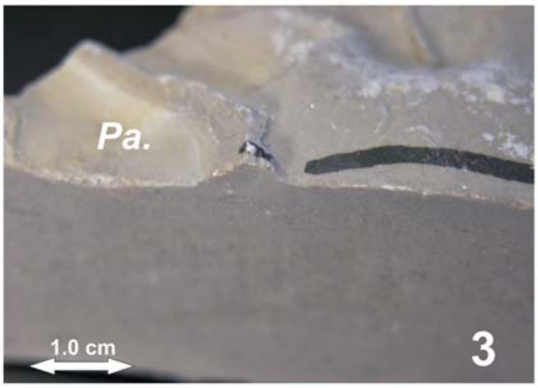

Pa.t.
1.0 cm
9

PLATE 3

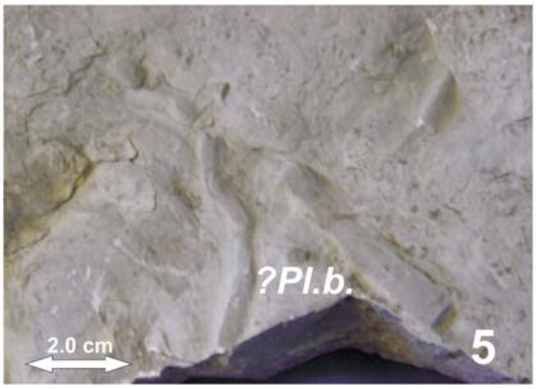
1-2 – *Palaeophycus tubularis* (*Pa.t.*) – unit C (MGUWr – 5420s; 5421s).
3 – *Palaeophycus* isp. (*Pa.*) – unit C (MGUWr – 5422s).
4 – ?*Palaeophycus* isp. (*?Pa.*) – unit D (MGUWr – 5423s).
5 – ?*Planolites beverleyensis* (*?Pl.b.*) – unit C (MGUWr – 5424s).
6-7 – ?*Planolites beverleyensis* (*?Pl.b.*) – unit D (MGUWr – 5425s; 5426s).
8 – *Planolites montanus* (*Pl.m.*) – unit C (MGUWr – 5427s).

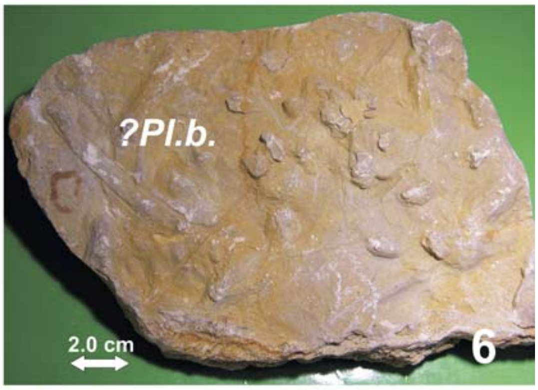

Pa.t.
1.0 cm
1


Pa.t.
1.0 cm
2


Pa.
1.0 cm
3


?Pa.
2.0 cm
4


?Pl.b.
2.0 cm
5


?Pl.b.
2.0 cm
6


?Pl.b.
2.0 cm
7

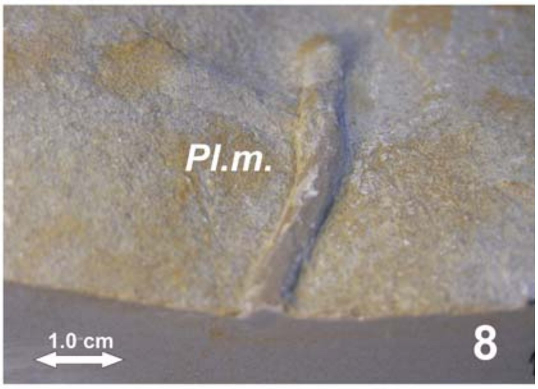
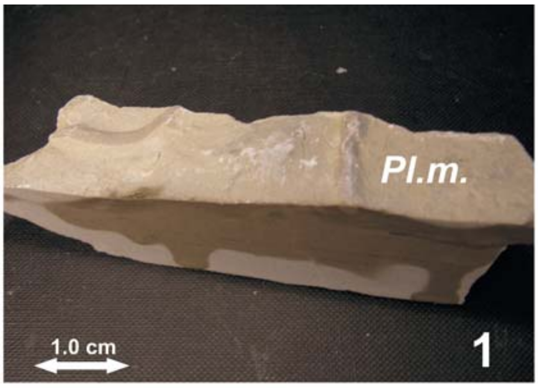

Pl.m.
1.0 cm
8

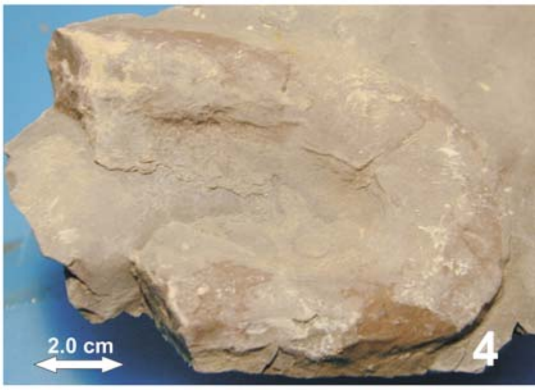
PLATE 4

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).


Pl.m.
1.0 cm
1


?Pr.
1.0 cm
2

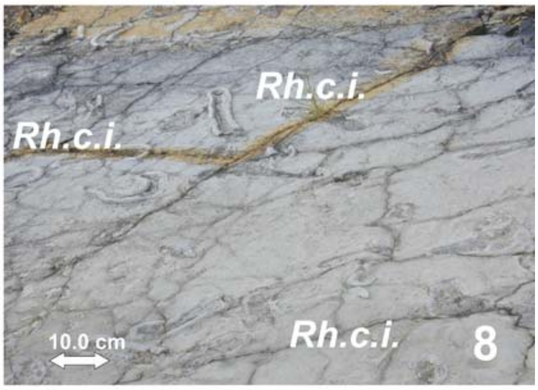

2.0 cm
3


2.0 cm
4


2.0 cm
5


4.0 cm
6


Rh.c.i.
5.0 cm
7

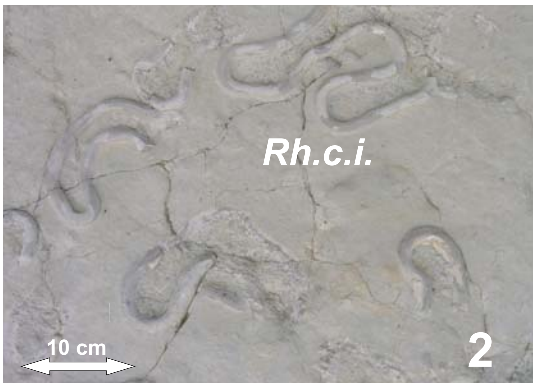

Rh.c.i.
Rh.c.i.
Rh.c.i.
10.0 cm
8

.

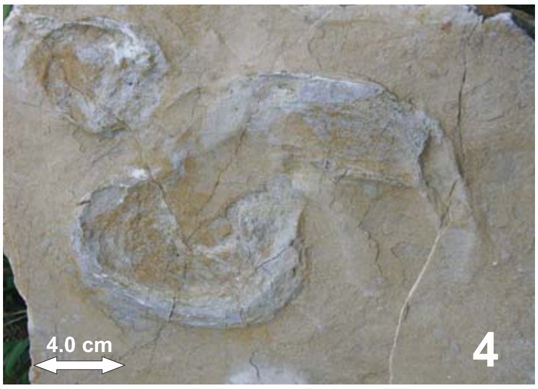
PLATE 5

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).

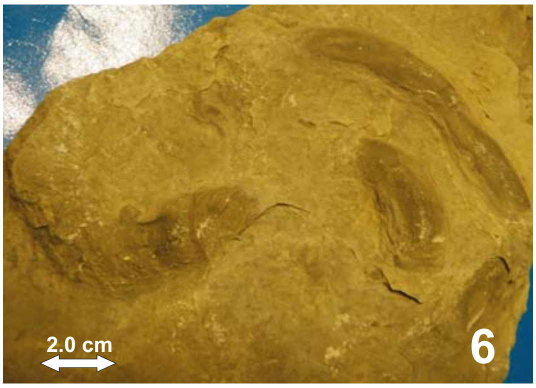

Rh.c.i.
10 cm
1


Rh.c.i.
10 cm
2


4.0 cm
3


4.0 cm
4


4.0 cm
5


2.0 cm
6


3.0 cm
7

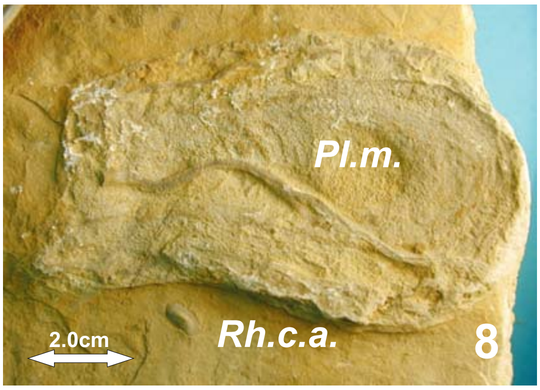
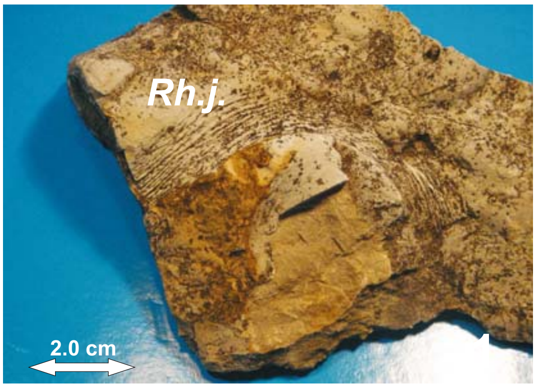

Pl.m.
2.0cm
Rh.c.a.
8

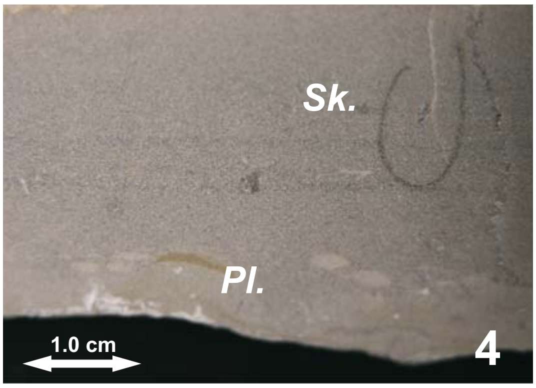
PLATE 6

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).


Rh.j.
2.0 cm


Rh.j.
2.0 cm
2


2.0 cm
3


Sk.
Pl.
1.0 cm
4


2.0 cm
5


1.0 cm
6


0 1 2 3
4.0 cm
7


5.0 cm
8

PLATE 7

1 – *Trypanites weisei* (*Tr.w.*) on the surface of an intraclast from the *Spiriferina* Bed (MGUWr – 5444s).

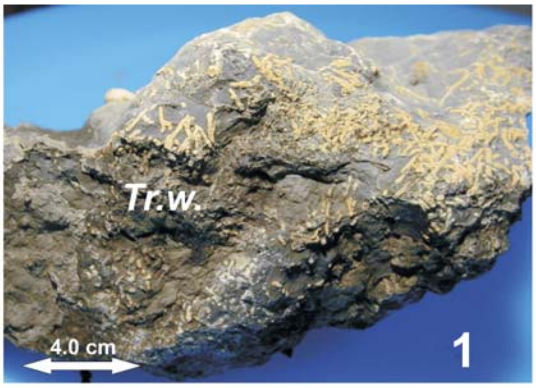
2 – *Trypanites weisei* (*Tr.w.*) – *Spiriferina* Bed, unit C (MGUWr – 5445s).

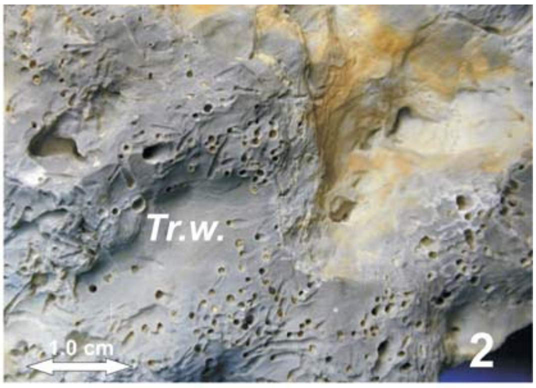
3 – Vertical or slightly oblique *Trypanites weisei* (*Tr.w.*) – unit C (*Spiriferina* Bed).

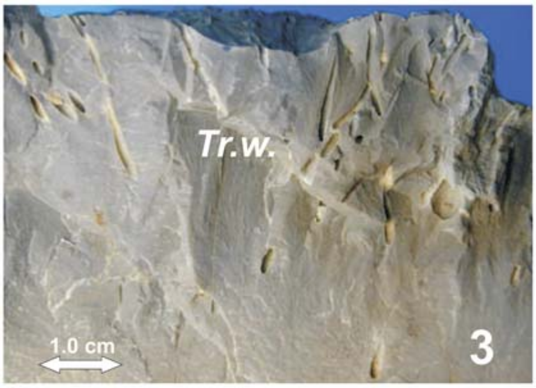
4-6 – Hardground intraclasts with *Trypanites weisei* (*Tr.w.*) – *Spiriferina* Bed, unit C (MGUWr – 5446s; 5447s; 5448s).

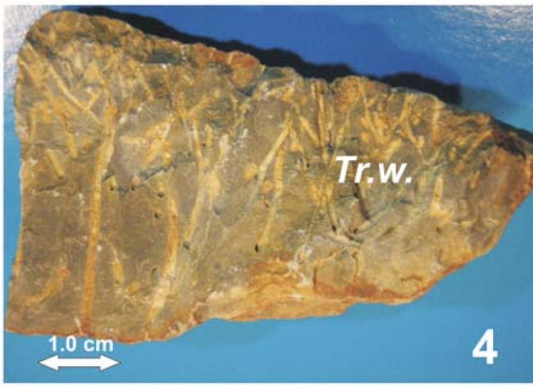
7 – Intraclasts of hardground with *Trypanites weisei* – *Spiriferina* Bed, unit C.

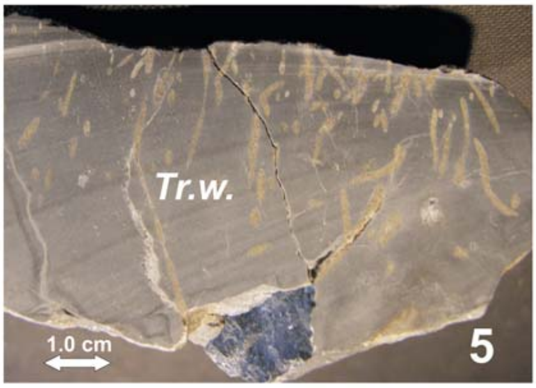
8 – Fragments of crinoids (*cr.*) attached to hardground intraclast (*in.*) – *Spiriferina* Bed (MGUWr – 5449s).

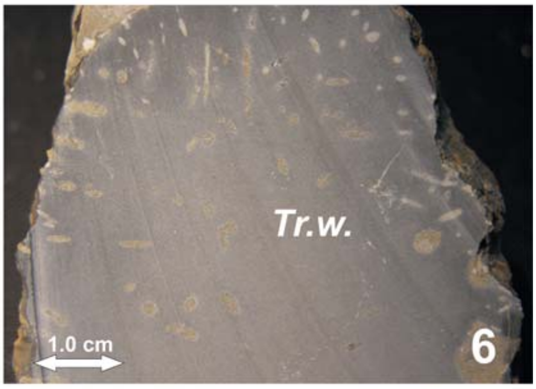

Tr.w.
4.0 cm
1


Tr.w.
1.0 cm
2

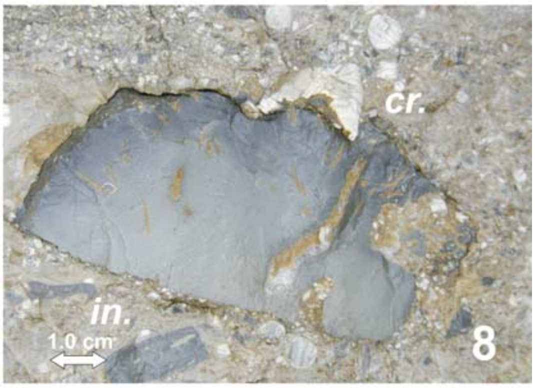

Tr.w.
1.0 cm
3


Tr.w.
1.0 cm
4


Tr.w.
1.0 cm
5


Tr.w.
1.0 cm
6


4.0 cm
7


cr.
in.
1.0 cm
8