Paläontologische Zeitschrift
2006, Vol. **80/2**, p. 156-166, 30-06-2006

Tripartichnus n. igen. – a new trace fossil from the Buntsandstein (Lower Triassic) and from the Solnhofen Lithographic Limestones (Upper Jurassic), Germany

Tripartichnus n. igen. – ein neues Spurenfossil aus dem Buntsandstein (Untertrias) und dem Solnhofener Plattenkalk (Oberjura), Deutschland

LOTHAR H. VALLON, Stuttgart & MARTIN RÖPER, Solnhofen

with 9 figures

VALLON, L.H. & RÖPER, M. 2006. *Tripartichnus* n. igen. – a new trace fossil from the Buntsandstein (Lower Triassic) and from the Solnhofen Lithographic Limestones (Upper Jurassic), Germany. – Paläontologische Zeitschrift **80** (2): 156-166, 9 figs., Stuttgart, 30. 6. 2006.

Abstract: Two species of a new trace fossil genus (cubichnia) are described: *Tripartichnus triassicus* n. igen., n. isp. from the "Plattensandstein" (Upper Buntsandstein, Röt-Folge, Lower Triassic) of Keltern-Dietlingen (Enzkreis, Baden-Württemberg, SW-Germany) and *Tripartichnus imbergi* n. igen., n. isp. from the Solnhofen Lithographic Limestone (Upper Jurassic, Tithonian) from Walting and Pfalzpaint (district of Eichstätt, Bavaria, SE-Germany). Due to the characteristic shape of the new ichnotaxa the tracemakers can be named in all probability: *Tripartichnus triassicus* was most likely made by *Euthycarcinus kessleri* HANDLIRSCH, 1914 and *Tripartichnus imbergi* by *Palinurina* sp.

Keywords: Lower Triassic • Buntsandstein • non-marine • Upper Jurassic • Solnhofen Lithographic Limestones • marine • trace fossils • *Tripartichnus* n. igen. • southern Germany.

Kurzfassung: Beschrieben werden zwei Arten einer neuen Ichnofossilgattung (Cubichnia): Aus dem Plattensandstein (Oberer Buntsandstein, Röt-Folge, Untere Trias) von Keltern-Dietlingen (Enzkreis, Baden-Württemberg; SW-Deutschland) wird *Tripartichnus triassicus* n. igen., n. isp. und aus den Solnhofener Plattenkalken (Oberer Jura, Tithonium) von Walting und Pfalzpaint (Kreis Eichstätt, Bayern, SE-Deutschland) wird *Tripartichnus imbergi* n. igen., n. isp. beschrieben. Wegen der charakteristischen Formen der beiden neuen Ichnotaxa, kann der Spurenerzeuger mit hoher Wahrscheinlichkeit benannt werden: *Tripartichnus triassicus* wurde durch *Euthycarcinus kessleri* HANDLIRSCH, 1914 erzeugt und für *Tripartichnus imbergi* kann *Palinurina* sp. angenommen werden.

Schlüsselwörter: Untere Trias • Buntsandstein • nicht marin • Oberer Jura • Solnhofener Plattenkalke • marin • Spurenfossilien • *Tripartichnus* n. igen. • Süd-Deutschland.

Introduction

Since the beginning of geological research in Germany the Buntsandstein has been considered to be a monotonous, petrologically more or less homogeneous and almost fossil-free package of red-beds. Thus, it is not surprising that there was and is only a small number of scientists working on the sediments and particularly on the fossil contents of the Lower Triassic of southwest Germany. Trace fossils of invertebrates from the Triassic siliciclastic sediments of southern Germany were described for example by LINCK (1943), MÜLLER (1956, 1959), SEILACHER (1963) and SCHLIRF et. al. (2001). Trace fossils of vertebrates, for example, were treated by SOERGEL (1925), DEMATHIEU & HAUBOLD (1974), and HADERER et al. (1995). Both invertebrate and vertebrate trace fossils were discussed by BRÄUHÄUSER (1910), BLANCKENHORN (1924), and KNAUST et al. (1999), amongst others.

Adresses of the authors: Lothar H. Vallon, Institut für Geologie und Paläontologie, Universität Stuttgart, Herdweg 51, D-70174 Stuttgart, Germany; e-mail <lvallon@geologie.uni-stuttgart.de>. - Martin Röper, Bürgermeister-Müller-Museum, Bahnhofstr. 8, D-91807 Solnhofen, Germany; e-mail <m.roeper@solnhofen.de>.

0031–0220/06/0080–0156 $ 4.95

According to SCHNARRENBERGER (1914) remarkable fossils from the Buntsandstein were found in the area of the "Keltern" villages. So it seemed promising to search for fossils in this district. The Triassic finds decribed in this paper come from a building site in the eastern part of Dietlingen (the easternmost village of the "Keltern" villages). Among parts of horsetails and undeterminable remains of wood, some new invertebrate trace fossils were found, which are the subject of this article.

Trace fossils have been known for a long time from the Upper Jurassic lithographic limestones of Walting and Pfalzpaint (Fig. 1), above all repichnia and pascichnia (e.g. those produced by *Solemya* and *Mesolimulus*), *Parahaentzschelinia*, and an ichnotaxon comparable to the new trace fossil from the Buntsandstein (e.g. RÖPER et al. 1999). Likewise, trace fossils were discovered by mapping parties from the University of Erlangen (summary in FREYBERG 1968) but they were neither investigated nor documented in their regional and stratigraphic context. Lately, more attention has been paid to the trace fossils of the Lithographic Limestones of Bavaria. Particularly in the descriptions of some outcrops, e.g. Upper Kimmeridgian lithographic limestones of Brunn (RÖPER et al. 1996), Lower Tithonian lithographic limestones of Hienheim (RÖPER & ROTHGAENGER 1998) and Schernfeld (RÖPER et al. 2000), surprising amounts of material have been brought to light. The lithographic limestones of Pfalzpaint and near Böhm - feld (VIOHL 1998), east of the classical lithographic limestones of Eichstätt and Solnhofen, are particularly productive with respect to trace fossils. While measuring sections in the lithographic limestones of the Franconian "Malm zeta 2a" and "Malm zeta 2b" in the Juma/ Walting and Imberg/Pfalzpaint quarries the trace fossils were recorded bed-by-bed in connection with lithology and body fossils, mostly jellyfish of the genus *Rhizostomites*. A systematic description of these trace fossil associations is still expected (RÖPER et al. 1999).

Upper Jurassic trace fossils from southern Germany have been described earlier on, e.g., by OPPEL (1862), ABEL (1930) and KAUFFMANN (1978). SCHWEIGERT & DIETL (1997) and SCHWEIGERT (1998) worked on trace fossils particularly of the Nusplingen lithographic limestone (Upper Kimmeridgian, Swabian Alb, Baden-Württemberg).

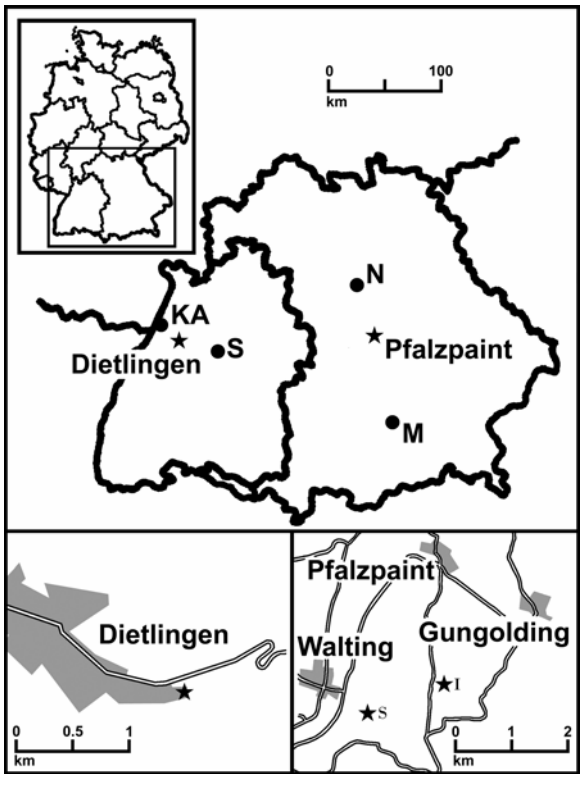

Fig. 1. Location of the study areas in southern Germany. Abbrevations: KA, Karlsruhe, M, Munich, N, Nuremberg, S, Stuttgart. Abbrevations in detail sketches: I, Imberg quarry, S, Schrimmel quarry.

Repositpry: The specimens described in this article are housed in the collection of the Staatliches Museum für Naturkunde Stuttgart (SMNS) and in the collection of the Bürgermeister-Müller-Museum in Solnhofen (BMMS).

The Ichnogenus *Tripartichnus* n. igen.

Type ichnospecies: *Tripartichnus triassicus* n. igen., n. isp.
Derivation of name: From Latin *tres* = three and *pars* = part; after the morphological division of the trace fossils into three parts.
Taxa included: In addition to the type ichnospecies, *Tripartichnus imbergi* n. isp. is also placed in the ichnogenus.

Diagnosis: Bilaterally symmetrical depressions on bedding planes showing a division along the longitudinal axis into three parts: front, middle and rear, being broad, medium and narrow in width respectively.

Tripartichnus triassicus n. isp.

Derivation of name: After the Triassic system.
Holotype: Specimen illustrated in Fig. 2A, SMNS 64849/1.
Paratypes: SMNS 64849/2 – 64849/11.
Material: 11 slabs.
Type locality: Dietlingen ("Keltern" municipality, Enzkreis, to the west of Pforzheim); building site (N 48°53'26'', E 011°37'02'') in the eastern part of Dietlingen (Baden-Württemberg; Fig. 1).
Type horizon: Plattensandstein, Röt-Folge; uppermost part of the Lower Triassic in Germany. Due to the fact that the trace fossils come from a fluvial environment, it is not possible to give a more precise stratigraphic position of the stratum typicum.
Occurrence: Buntsandstein (Lower Triassic) of southwest Germany.

Diagnosis: *Tripartichnus* in which the front and the middle parts are divided longitudinally; elongated and lanceolate at its rear.

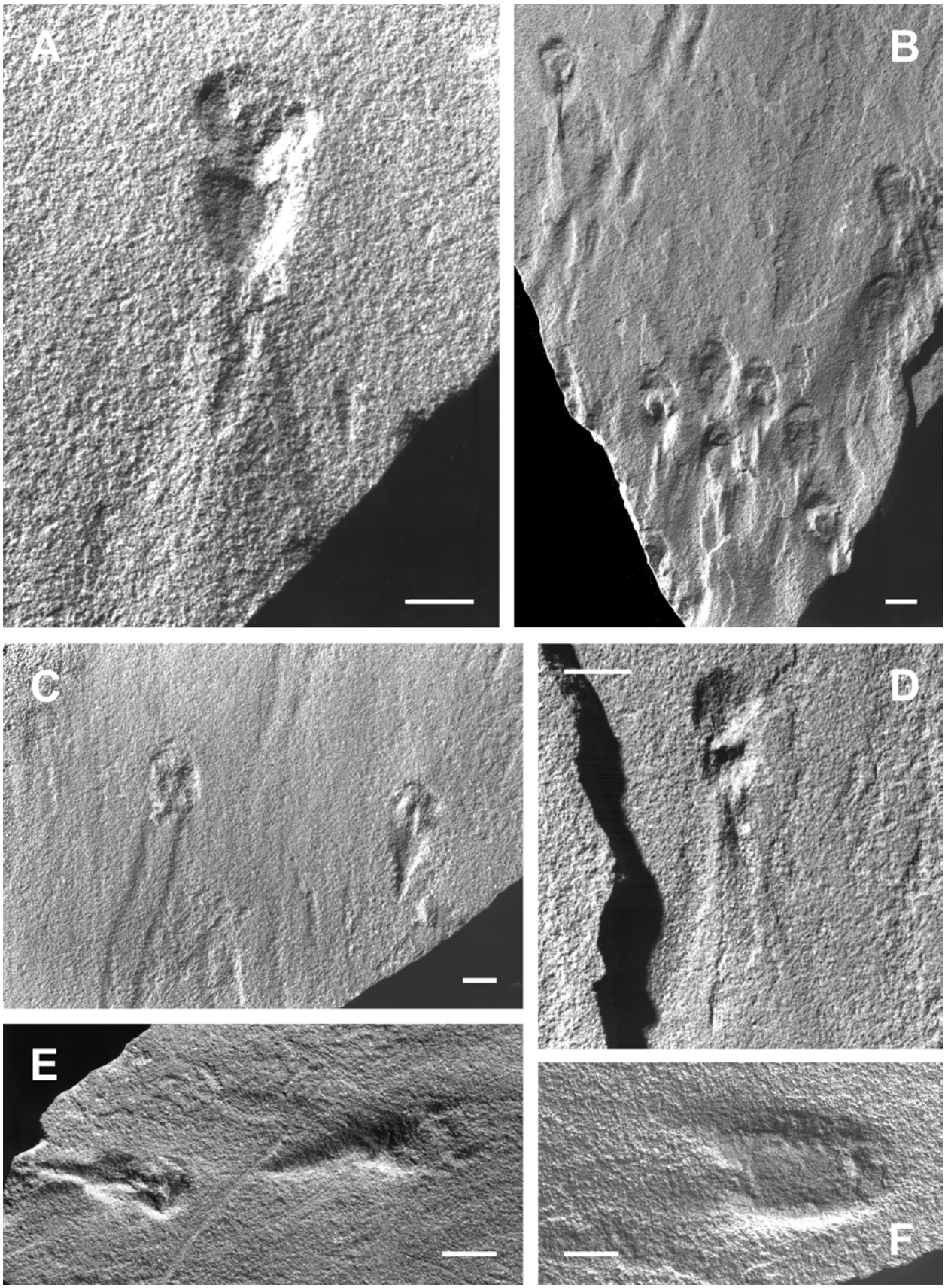

Fig. 2. *Tripartichnus triassicus* n. igen., n. isp. – Scale: 10 mm. – **A**: SMNS 64849/1. Holotype of *T. triassicus*. **B**: SMNS 64849/3. Horizontal repetition of *T. triassicus* and repichnia cf. *Diplichnites* isp. **C:** SMNS 64849/7. Horizontal repetition of *T. triassicus* and repichnia cf. *Diplichnites* isp. **D**: SMNS 64849/10. Semi-conical accumulation at the rear part of *T. triassicus*. **E**: SMNS 64849/2. Horizontal repetition of *T. triassicus* and a repichnion, possibly a dragging trace of a telson. **F**: SMNS 64850/2. The frontal oval part of *T. triassicus* (at the right) between two lines of cf. *Diplichnites* isp.

Description: As holotype of the cubichnion *Tripartichnus triassicus* n. isp. a specimen has been selected with about 55 mm length and 15 mm width at its widest point. It forms a negative epirelief about 5 mm deep on the surface of a fine grained sand layer. The outline is an equilateral, long triangle and the trace fossil is characterized by a clear three-part division. The front part forms the baseline of the supposed triangle. Its shape is oval, orientated across the longitudinal axis of the trace fossil, and it is subdivided into five more areas. These five areas are oval shaped as well. One of these depressions is situated in the middle of the front and is oriented perpendicular to the longitudinal axis. The other four oval depressions are oriented more or less parallel to the longitudinal axis (compare Fig. 3). This part, along the long axis of the vertically orientated depression, occupies about a quarter of the complete length of the trace.

The middle part of the trace fossil has a rounded triangular to trapezoidal shape and corresponds to a quarter of the total length. It is subdivided into three sections including two linear depressions. The sections and the furrows are orientated parallel to the longitudinal axis (Fig. 3).

The rear part is slender, spike-like and ends sharply.

Remarks: On the upper surface of the sandstone slab carrying the holotype there are some more trace fossils. These are repichnia, which are shaped very weakly and can only be seen under low-angle illumination. They can be seen better in the samples SMNS 64849/3 (Fig. 2B) and SMNS 64849/7 (Fig. 2C). These repichnia show some similarity to the ichnogenus *Diplichnites* DAWSON, 1873 and to the two ichnospecies *Beaconichnus gouldi* (GEVERS et al., 1971) and *B. darwinum* (GEVERS et al., 1971). Although we do not know the type material of *Beaconichnus gouldi* and *B. darwinum* described by GEVERS et al. (1971), we assume these ichnospecies to be junior synonyms of *Diplichnites* isp. In this connection PEMBERTON & FREY (1982) recommended that similar ichnogenera and ichnospecies be united in a single, already-existing ichnotaxon. In contrast to *Diplichnites*, this trace fossil does not consist of two parallel lines of separate small depressions, but of two parallel furrows. These lines can be slightly curved or interrupted and staggered. The distance between two paired rows of cf. *Diplichnites* is nearly 10 mm. They mostly are 20 mm long and are repeated several times in succession. Nevertheless, the separated pairs of furrows are slightly staggered in relation to the others so that they can be linked by a line that runs diagonally to an assumed current. Occasionally, the paired furrows show fine striations that run diagonally to their symmetrical axis. BROMLEY (1996) emphasized that the same trace can look very different on various substrates. As *Diplichnites* has been described from finer grained sediments (DAWSON 1873), we assume that the name for our repichnion is used correctly. As cf. *Diplichnites* and *Tripartichnus* can grade into each other (Fig. 2C), they must have been produced by the same animal.

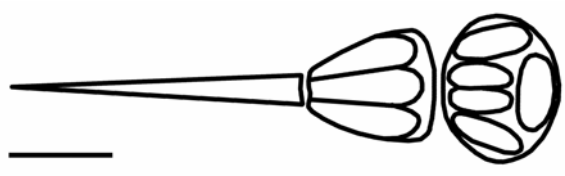

Fig. 3. Sketch of *Tripartichnus triassicus* n. igen., n. isp. – Scale: 10 mm.

Tripartichnus triassicus shows some similarity to *Tonganoxichnus buildexensis* MÁNGANO et al., 1997. The cubichnion *Tonganoxichnus buildexensis* has an anterior region characterized by the presence of a frontal pair of maxillary palp impressions, followed by a head impression and three pairs of conspicuous thoracic appendage imprints symmetrically opposite along a median axis. The posterior region commonly exhibits numerous delicate chevron-like markings, recording the abdominal appendages, and a thin, straight, terminal extension (MÁNGANO et al. 1997). In *Tripartichnus* there are no frontal impressions of maxillary palps. The subdivisions of the trace fossil's first and second part are parallel to the longitudinal axis in *Tripartichnus* but are at right angles to the longutudinal axis in *Tonganoxichnus buildexensis*.

At a first glance it was not clear whether *Tripartichnus triassicus* is a trace fossil or a flutecast marking because the depressions are orientated almost parallel to the interpreted palaeocurrent direction, differing only by an angle of a few degrees. This feature is known from traces, but also commonly from inorganic markings. Obstacles within a traction carpet create turbulence that may erode sediment at the front and at the sides of the obstacle, producing a drop-shaped depression (SENGUPTA 1966). The blunt end of the drop is turned towards the current and its sharp end vanishes into the sediment. Behind the obstacle the eroded sediment is accumulated again and a flat semi-cone is created, the apex of which begins at the rear of the obstacle. Such current-made triangles are orientated parallel towards the current direction and may be similar to *Triaprtichnus*. For having no obstacles left in our structures they had to be either transported further by the current, or to be dissolved or to move themselves. If the obstacles, e.g. coarse sediment particles, wood remains or scales of conifer cones, were swept away by the current, there would have been some identical or very similar structures behind each other in a line parallel to the current direction (roll marks).

Organisms commonly orientate themselves parallel to bottom currents. To stabilize their position, the organisms dig shallow depressions in the sediment. These facts, together with the horizontal and vertical repetition (Fig. 2B) meet the requirements for the definition of cub-

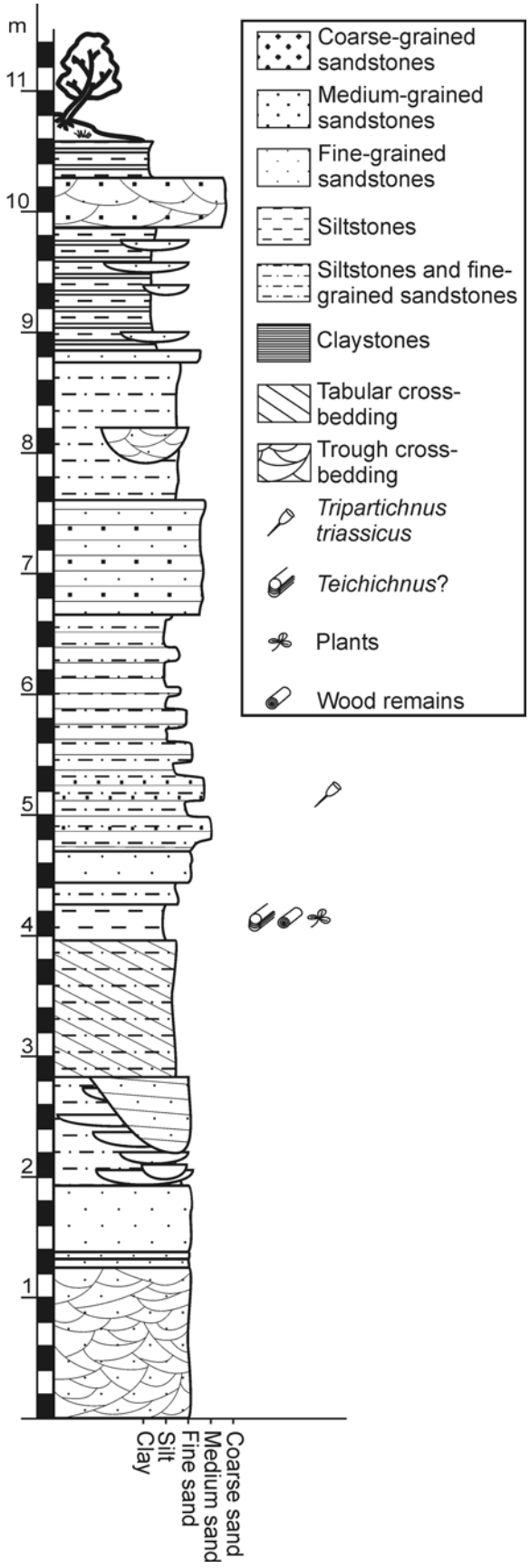

Fig. 4. Profile exposed at the building site in Keltern-Dietlingen.

ichnia according to SEILACHER (1953b). Associations with other unambiguous trace fossils also support the trace hypothesis. Cf. *Diplichnites* is only present in beds that contain *Tripartichnus triassicus* and there is a case of a repichnion merging with *Tripartichnus triassicus* (Fig. 2C). Noticeable as well are the paired halfmoon-shaped lines of cf. *Diplichnites* that commonly have the same length as the middle part of *Tripartichnus triassicus*. The front oval section of *Tripartichnus triassicus* normally lies between the two furrows of cf. *Diplichnites* (SMNS 64850/2, Fig. 2F). The paired halfmoons seem to be a preliminary stage for the construction of the cubichnion.

Finally the subdivided morphology of the investigated structure speaks against inorganic obstacles. Such constantly present subdivisions by ridges and depressions are hardly conceivable as of inorganic origin.

Locality and horizon of the holotype

The building site, from which the described slabs with *Tripartichnus triassicus* n. isp. were collected, is situated at the eastern entrance of the village Dietlingen. At a fault having Rhenish strike (nearly NNW-SSE), sediments of the Upper Buntsandstein crop out in an area dominated by the yellow and grey sediments of the Muschelkalk (Middle Triassic). The Buntsandstein occurrence has received the field-name "Rotenstich" which means reddish tinge.

Palaeogeographically the investigated area is situated within the Mid-European Buntsandstein Basin (Germanic Basin) between the Vindelician High in the southeast and the Rhenish Massif in the northwest. The sediments were deposited within the Pforzheim Basin (= "Pforzheimer Senke"; ORTLAM 1968) which is part of the Thuringian Basin.

The outcrop is situated in the strata of the Lower Plattensandstein. The profile (Fig. 4) mainly consists of fluvial thin beds of fine-grained sandstone which may be separated by thin siltstone interbeds (flood-plain sediments). At the base of the profile channel sediments dominate. These two fine- to medium grained sandstones show weak cross stratification. Up-section the sediments get finer grained and the thicknesses of the sandstone beds diminish while those of the siltstones increase.

In the middle part of the profile a nearly 25 cm thick siltsone layer contains a trace fossil similar to the ichnogenus *Teichichnus* and some silicified wood remains of conifers. At the top of this siltstone bed an alternation of siltstones and fine-grained sandstones follows. The fine-grained sandstones mostly show thin horizontal bedding and rarely small-scale cross-stratification. The amount of mica, especially muscovite, is very high. The mica is relatively coarse-grained (up to 1 mm in diameter) and forms accumulations that resemble channel bars of a braided river. Some large mica fla-

kes show imbrication under the microscope. The high amount of mica and the alternation of silt and sandstone beds suggest that these strata could have been sedimented near the bank of a channel. This speculation was confirmed after a second building site was dug out next to the already existing one a few months later. The finds of *Tripartichnus triassicus* come from the bottom of this part. A SSE-NNW current-direction can be determined from the "mica bars", and from some weak rollmarks at the surfaces of different slabs. On the basis of the arrangement of *Tripartichnus triassicus* it can be assumed that the palaeocurrent came from SSE.

The top of the profile is dominated by siltstones which are rarely interrupted by some sandstone channels and a thick sandstone bed.

Discussion

Usually, the producer of a trace fossil remains unknown. According to the definition by SEILACHER (1953a) they are always made by interactions between a living animal and an inanimate substrate. To limit the producer of a trace as narrowly as possible, all biostratonomic, ecologic and taxonomic information must be analysed.

The trace fossils form shallow depressions in the sediment and were created under the influence of slow currents. To what extent the shape of the traces was influenced by the current cannot be said. Thus, the semiconical sediment accumulation (Figs. 2A and 2D) behind the last, spike-like section of the trace fossil was produced by the organism leaving its resting trace.

The trace fossils represent only superficial disturbance close to the sediment surface, which indicates that the producing organisms were lying on the sediment or were slightly buried in it. Such resting traces therefore sketch the contour of the bodies of the producing organisms. Possible producers have to be searched for within arthropods having a three-part morphology.

A compilation of the crustaceans from the Upper Buntsandstein of the Vosges Mountains (*Voltzia*-Sandstone) can be found in BILL (1914) but there is no species having a sharp telson. Such an anatomy is only found within the Notostraca, within some Xiphosurida, especially Limulacea, and within the Euthycarcinoidea. TRUSHEIM (1931) made actuopalaeontological observations on members of the Notostraca, especially *Triops cancriformis* (BOSC, 1801). He also investigated traces that were left by this taxon on sediments. Unfortunately, however, he did not describe any cubichnia. BROMLEY & ASGAARD (1972a, 1979) described cubichnia of *Triops*, but they do not look like *Tripartichnus triassicus*. The lengthwise oval shape of the fused elements of the cephalon and thorax speaks against these animals as possible producers of *Tripartichnus triassicus*. In addition their abdomen does not taper off and is too wide to produce the spike-like rear of the trace fossil. Neither are there indications for the two furca at the end of the abdomen.

There is one important argument against the Limulacea: the width of the impression of the cephalothorax (= forward part of the trace) is much wider than the middle part. In *Tripartichnus triassicus* the first and middle parts have almost the same width.

The clear triple partition of the anatomy, and the dimensions and proportions of members of the class Euthycarcinoidea correspond to the Buntsandstein trace fossils, suggesting that the trace makers belong to that class. The long postabdomen, which ends in a sharp telson (Fig. 5), is characteristic of the only species, *Euthycarcinus kessleri* HANDLIRSCH, 1914, that occurs in the Buntsandstein. The subdivisions of the first section of *Tripartichnus triassicus* correspond very well with the dimensions and proportions of the arthropod species reconstructed by GALL & GRAUVOGEL (1964). Another point favouring *Euthycarcinus* is its streamlined body, which supports adaptation to current conditions.

A three-fold subdivison of the middle part of the trace fossil is also explainable by means of their reconstruction. From a flat and narrow body the extremities extend laterally. They are protected by dorsal plates covering the legs. The three lengthwise grooves in the middle part of the trace fossil could be produced by drawing up the legs to the body during the first phase of making the cubichnion. But they might also be produced by the biramous limb that every aquatic arthropod has for breathing. According to GALL & GRAUVOGEL (1964) *Euthycarcinus* was a detritus-feeder swimming just above the bottom. *Striatichnus natalis* WALTER, 1982 should be produced by *Euthycarcinus* while swimming close to the bottom (WALTER 1982, SCHNEIDER 1983). *Striatichnus* consists of many reciprocal overlapping bundles of striations which run diagonally to the movement direction. This trace fossil could not be found in Keltern-Dietlingen; there are only the two parallel lines of cf. *Diplichnites*.

Tripartichnus imbergi n. isp.

? 1969 "Körperabdrücke von Crustaceen" – JANICKE: 164; pl. 9 fig. 1.
1999 "Hörnergrabgänge" – RÖPER et al.: 16, figs. 11, 12.

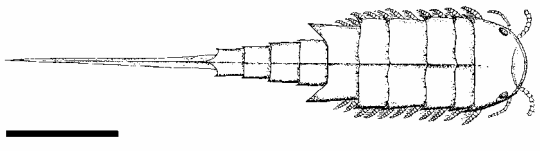

Fig. 5. Reconstruction of *Euthycarcinus kessleri* HANDLIRSCH, 1914 (from GALL & GRAUVOGEL 1964). Possible tracemaker of *Tripartichnus triassicus* n. igen., n. isp. – Scale: 10 mm.

Derivation of name: After Theodor Imberg, founder of the Natursteinwerke Imberg (Bochum, Dortmund, Pfalzpaint, Munich).
Holotype: Specimen illustrated in Fig. 6A, BMMS 537.
Paratypes: BMMS 701-BMMS 703.
Material: About 100 specimens from the excavations conducted by the Bürgermeister-Müller-Museum in the lithographic limestones of Pfalzpaint and Walting. Numerous additional specimens from the collection of Monika Rothgaenger (Bildungs- und Dokumentations-Zentrum Ostbayerische Erdgeschichte e.V.).
Type locality: Imberg quarry (N 48°54'46'', E 011°19'39''), Pfalzpaint, at the Jurassic-plateau between the villages Pfalzpaint, Gungolding, and Walting (Bavaria) (Fig. 1).
Type horizon: Lithographic limestones of Pfalzpaint (Lower Solnhofen Formation; Early Tithonian, *hybonotum* Zone, *rueppellianum* Subzone;).
Occurrence: Lower Solnhofen Formation, Schrimmel quarry near Walting (N 48°54'44'', E 011°19'18''); Upper Solnhofen Formation, Imberg quarry, Pfalzpaint; and others.

Diagnosis: *Tripartichnus* is preserved as a negative epirelief. It consists of a front part bearing two lengthwise-orientated ovals and two antenna-like extensions, a middle rounded triangular part, and a rear rectangular part.

Description: *Tripartichnus imbergi* forms a negative epirelief and is only a superficial disturbance in the sediment. Its outline is a protracted rectangle. The holotype is about 75 mm long in total. The first section, including both antenna-like processes, measures about 30 mm and the middle and last part each about 20 mm.

The front section consists of paired, lengthwise-orientated, oval depressions that are each about 10 mm long and 2 mm wide. Between these two ovals there is a space of about 10 mm in the holotype. This distance corresponds more or less to the general width of the trace fossil. At a distance of 10 mm from the sharp side of the two ovals there are two linear depressions that disappear diagonally into the sediment. These approximately 15 to 20 mm long antenna-like extensions give this part of the trace fossil a Y-shaped appearance. The two lines generate an angle of about 100° (Fig. 7).

The second part of *Tripartichnus imbergi* has a trapezoidal or drop-like outline the sharp end of which is turned to the front. It may show some subdivisions as in *T. triassicus* (Fig. 6B and Fig. 6C). This middle section is not as deep as the following third part of the trace fossil.

The rear section has a rounded rectangular to oval shape that is orientated lengthwise. The depression is about 1 mm deep, i.e. it is twice as deep as the middle section of the trace fossil.

On the slab there is another specimen to the left of the holotype. Having a size of about 25 mm it is much smaller than the holotype. Its longitudinal axis forms an angle of 270° with that of the holotype.

Differential diagnosis: The main difference to *Tripartichnus triassicus* is the lack of the spike-like third section, which is rectangularly shaped instead. A further difference is that *Tripartichnus imbergi* always has two antenna-like processes in front of the first part. The further subdivision of the three parts is only weakly developed, in contrast to *Tripartichnus triassicus*.

Remarks: JANICKE (1969) possibly was the first person mentioning *Tripartichnus imbergi*. But he neither published a meaningful picture nor gave a name to this trace fossil. RÖPER et al. (1999) figured the new trace fossil, but they only gave it a provisional German name "Hörnergrabgang".

Locality and horizon of the holotype

The holotype comes from the abandoned quarry of the Natursteinwerke Imberg. It is the easternmost outcrop of the Jurassic plateau between Pfalzpaint, Walting, Gungolding (Fig. 1), and Hofstetten. About 200 m to the west there was the now-filled and re-landscaped quarry II of the Juma-Natursteinwerke. The Imberg quarry is in the district of Pfalzpaint not far from the classical localities described by WALTHER (1904). After the Pfalzpaint localities had already been portrayed as part of the "Plattenkalkfazies" (lithographic limestone facies) by FREYBERG (1968), JANICKE (1969) particularly studied the lithology and sedimentology, especially of the Imberg quarry. More recent brief descriptions were made on the basis of the fundamental Solnhofen documentation of BARTHEL (1978) by MEYER & SCHMIDT-KALER (1983). But only KEUPP & MEHL (1994) provided a sophisticated palaeoenvironmental view of the deposits from Pfalzpaint on the basis of new palaeontological research.

Finally, RÖPER et al. (1999) described the lithographic limestones of Pfalzpaint together with their fossil content, including a detailed description of the Imberg quarry. The stratigraphic horizon of *Tripartichnus imbergi* is shown in the section (Fig. 8) described by RÖPER et al. (1999). It lies above the so-called "Hangende Krumme Lage" ("Upper Slump Unit") described by JANICKE (1969) i.e., in the stratigraphically youngest horizons of the Solnhofen Formation within the "Franconian Malm zeta 2b" (RÖPER & ROTHGAENGER 1999). According to RÖPER et al. (2000) the uppermost beds of the Pfalzpaint lithographic limestones are still part of the Solnhofen Formation.

At the time when the sediments were deposited, the region around Pfalzpaint was at the northern border of the Tethys Ocean. It formed a strait connecting two lagoonal basins, which were lined by coral and sponge-microbial reefs, the Böhmfeld-Denkendorf Basin in the east and the Eichstätt Basin in the west. Within the connecting strait, benthic organisms dominated, the only pelagic faunal elements being jellyfish. The occurring jellyfish horizons are interpreted as lateral shallows where the jellyfish ran aground (RÖPER et al. 1999).

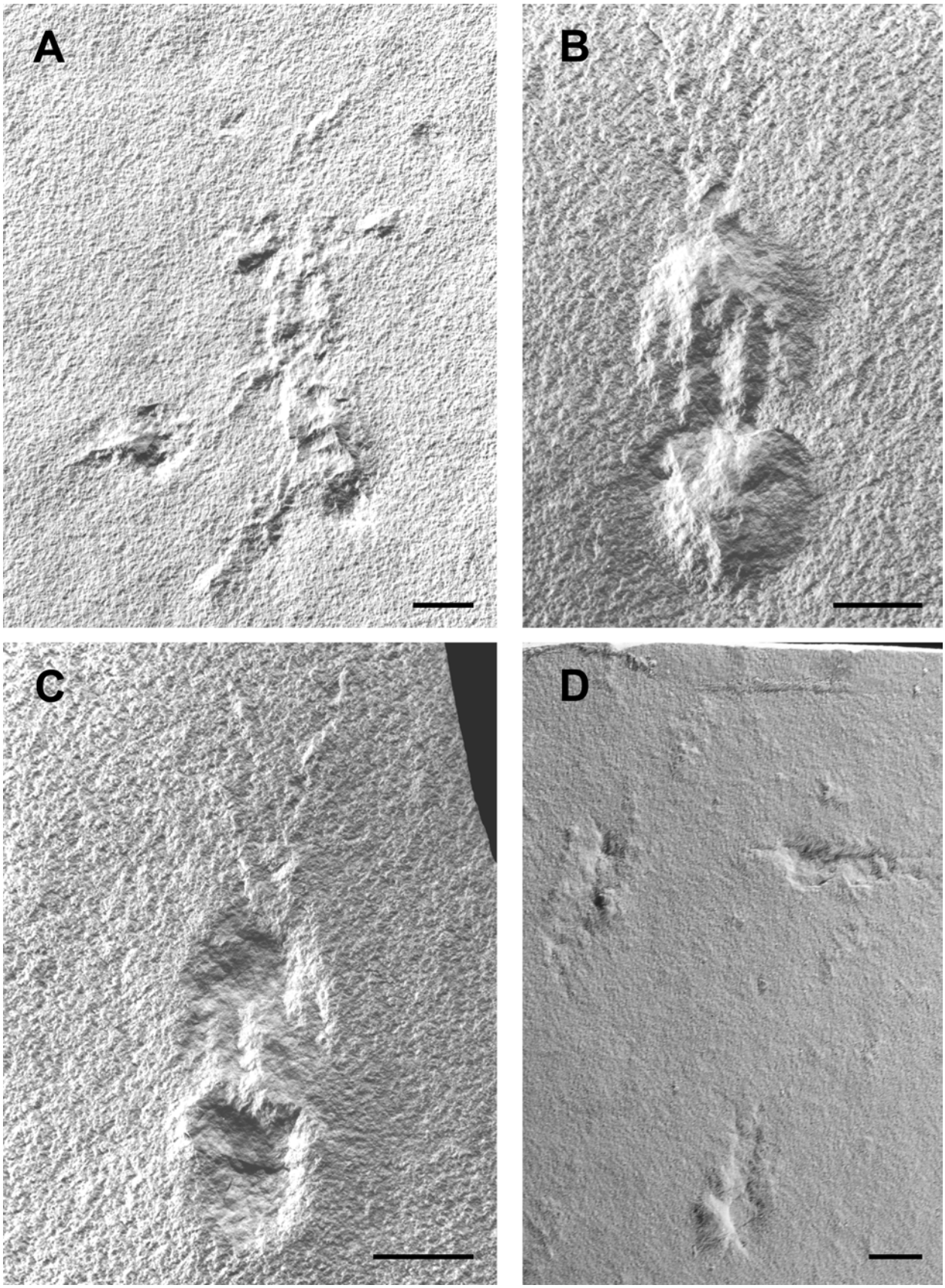

Fig. 6. *Tripartichnus imbergi* n. igen., n. isp. – Scale 10 mm. **A**: BMMS 537. Holotype of *T. imbergi*. **B**: BMMS 701. *T. imbergi* showing subdivisions in its middle section. **C**: BMMS 702. *T. imbergi* showing subdivisions in its middle section. **D**: BMMS 703. *T. imbergi* showing no preferential orientation.

Discussion

Tripartichnus imbergi n. igen., n. isp. is only a shallow depression on the surface of bedding planes, made by a shallow burrowing organism. Ecologically, the trace fossil occurs in a fully marine environment. The lithographic limestones of Pfalzpaint and Walting were deposited in shallow water that was characterized by brief still-water periods interrupted by strong current events. Unlike the Buntsandstein trace fossils, the Jurassic *Tripartichnus imbergi* shows no preferential orientation parallel to the current (Fig. 6D). The current ripples of some of these beds are indented by *Tripartichnus imbergi*, but that does not mean that the organisms populated the area only after the current had waned. Ripples will be mobile while the current is active, which will not allow preservation of cubichnia. Only when the ripples become immobile will the traces be preservable as trace fossils.

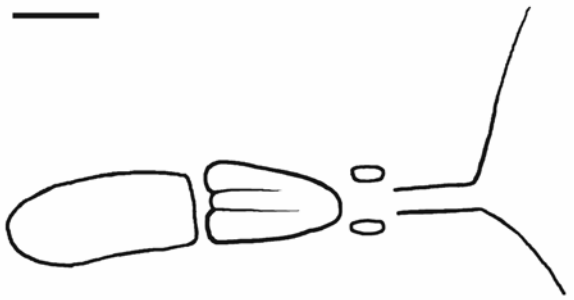

Fig. 7. Sketch of *Tripartichnus imbergi* n. igen., n. isp. – Scale: 10 mm.

The biodiversity is low at both localities and the number of individuals high. There are commonly 20 individual trace fossils side by side within 1 m². They may belong to different generations. Their size varies

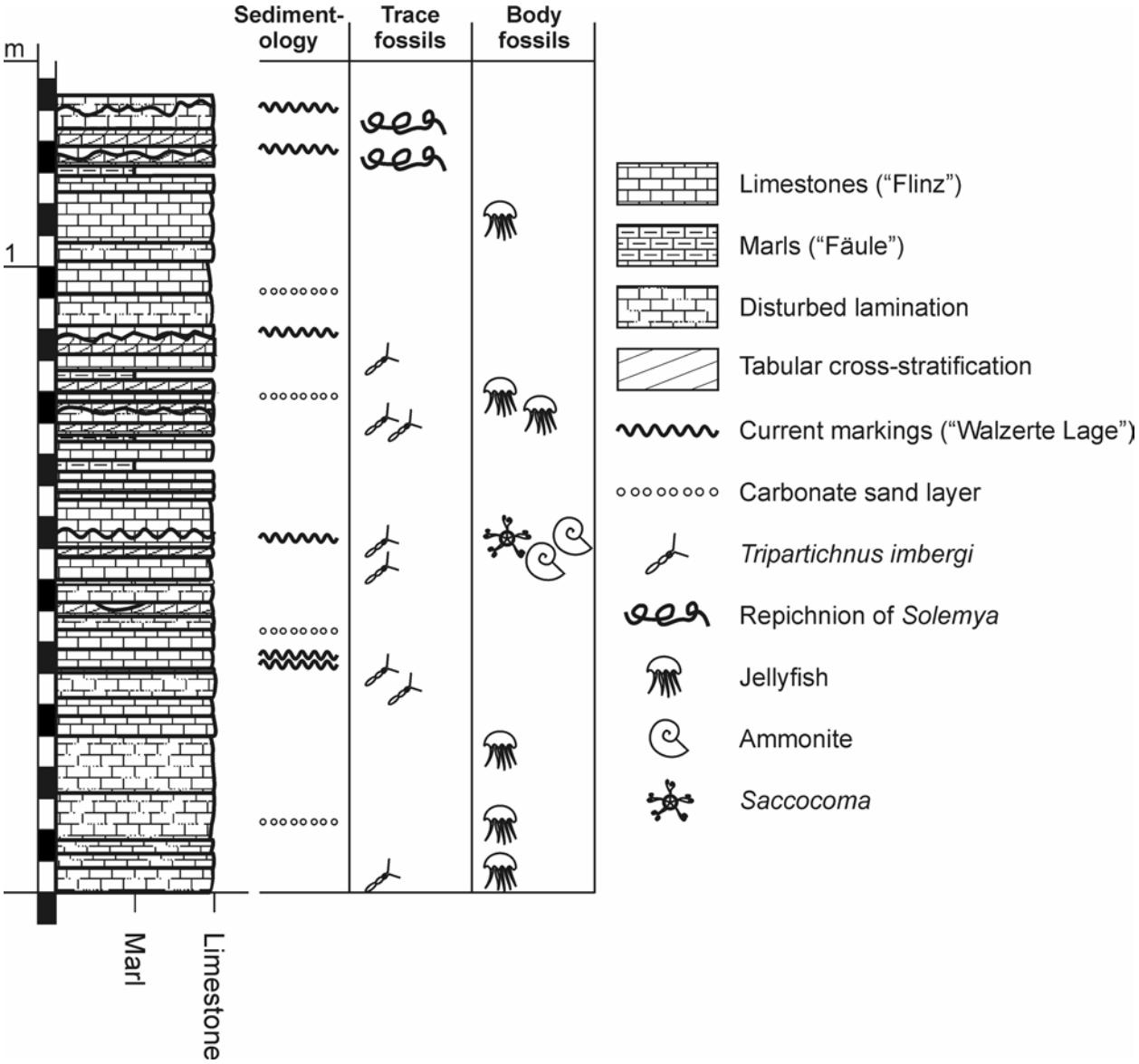

Fig. 8. Typical profile of the strata exposed at the Imberg quarry near Pfalzpaint.

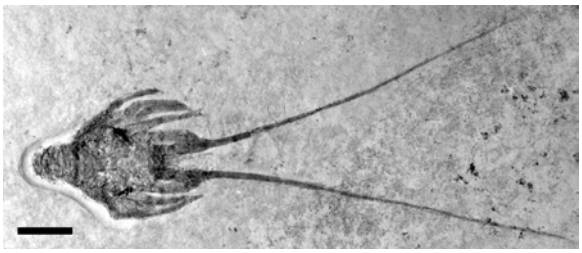

Fig. 9. *Palinurina longipes* MÜNSTER, 1839 (SMNS 65226). Possible tracemaker of *Tripartichnus imbergi* n. igen., n. isp. – Scale: 10 mm.

between 15 and 85 mm. In Walting, *Tripartichnus imbergi* is commonly the sole evidence of benthic life. Although there can be other trace fossils in the lithographic limestones, *Tripartichnus imbergi* dominated the biocoenosis. It seems, therefore, that the trace fossil was produced by specialized opportunists that could only populate shallow marine areas, because the structure does not occur in the deeper marine lithographic limestones of Nusplingen (Baden-Württemberg, Swabian Alb) (SCHWEIGERT, pers. comm. 2003).

As candidates for the producers of *Tripartichnus imbergi*, there are only a few arthropods. The genus *Eryma* is the most abundant decapod in the lithographic limestones of Pfalzpaint and Walting, but it cannot be the tracemaker because the small antennae of this decapod genus would not produce such strong impressions as they are found in the trace fossils. The antenna-like processes of the trace fossil, therefore, would have to be attributed to impressions of the strong claws, but for that the impressions are too weak. Furthermore, the proportions of the individual body sections of *Eryma* and *Tripartichnus imbergi* do not fit. Only the size of the arthropod indicates that *Eryma* could have been the producer of *Tripartichnus imbergi*.

Another commonly occurring arthropod genus is *Mecochirus*. However, the same arguments as with *Eryma* speak against *Mecochirus* being the tracemaker. Furthermore, the adult size of *Mecochirus* is much larger than the largest known *Tripartichnus imbergi*. The trace fossils, therefore, could be produced only by juvenile animals of this genus. Detailed investigations of the Upper Kimmeridgian lithographic limestones of Brunn revealed that *Mecochirus*, together with *Glyphea* and colonies of *Pollicipes*, the latter on ammonite shells, comprise the crustacean fauna living in shallow water (KEUPP et al. 1999). But *Mecochirus* and *Glyphea* constructed burrows of the *Thalassinoides* type (compare BROMLEY & ASGAARD 1972b). *Tripartichnus* is lacking in the bioturbated facies of Brunn dominated by *Mecochirus* and *Glyphea*. But *Thalassinoides* is a deeper-tier structure than *Tripartichnus imbergi* and so *Tripartichnus imbergi* would not be preserved in the *Thalassinoides*-dominated sediments. Such shallow-tier structures can only be preserved where bioturbation is limited to shallow tiers, as e.g., in Pfalzpaint.

The only taxon whose antennae are strong enough to produce impressions is the genus *Palinurina* (Fig. 9). The proportions of this genus are also congruent with those of the trace fossil. Remarkably, *Tripartichnus imbergi* is not limited to the lithographic limestones of the Solnhofen type but also occurs in the "marly lithographic limestones" of Hienheim and Ried (RÖPER 1997). In addition to having its main occurrence in Pfalzpaint, the ichnospecies is part of the biocoenoses at other localities as well.

Acknowledgements

First and foremost our thanks go to Dr. GÜNTER SCHWEIGERT (Stuttgart) who made the joint description of both ichnospecies possible. We also thank Dr. RICHARD G. BROMLEY (Copenhagen) for discussions and critical assessment of this article. He also took on the job of reviewing the English version of this article. Prof. Dr. MANFRED KRAUTTER is thanked for his constructive criticisms, as well as Prof. Dr. HANNELORE KRAWINKEL and Dr. ELMAR BUCHNER for advice on depositional environments (all Stuttgart). We also thank Dr. WINFRIED WERNER and Dr. HELMUT MAYR (Munich) for kind admittance to the collection and photo archives of the Bayerische Staatssammlung für Paläontologie und Geologie. For generous permission to enter the Imberg quarry (Pfalzpaint) and the grounds of the Bogner company (Keltern-Dietlingen) we thank Dipl.-Kauffrau GISELA STRUWE (Pfalzpaint) and the Bogner company (Keltern-Dietlingen). We also thank MONIKA ROTHGAENGER (Bürgermeister-Müller-Museum, Solnhofen), KLAUS ROTHGAENGER for taking the photos, and GERD GROCHTDREIS (Remchingen), ARNDT KNUPFER (Winnenden), and GERARD BOUVÉ (Waiblingen) for logging the sections in the Imberg quarry (Pfalzpaint). Prof. Dr. FRANZ T. FÜRSICH (Würzburg) and Prof. Dr. ALFRED UCHMANN (Krakow) is thanked for reviewing the manuscript.

References

ABEL, O. 1930. Fährtenstudien. 3. Über Schwimmfährten von Fischen und Schildkröten aus dem lithographischen Schiefer Bayerns. – Palaeobiologica **3**: 371-412.

BARTHEL, K.W. 1978. Solnhofen – Ein Blick in die Erdgeschichte. – 393 p., Thun (Ott).

BILL, P.C. 1914. Über Crustaceen aus dem Voltziensandstein des Elsasses. – Mitteilungen der Geologischen Landesanstalt von Elsaß-Lothringen **8**: 289-338.

BLANCKENHORN, M. 1924. Über Fossil- und Fährtenhorizonte im Buntsandstein Deutschlands. – Zeitschrift der deutschen geologischen Gesellschaft **76**: 269-278.

BOSC, L.A.G. 1801-1802. Histoire naturelle des crustacés, contenant leur description et leurs mœurs: avec figures dessinées d'après nature. – **1**: 1-258, **2**: 1-296, Paris (Deterville).

BRÄUHÄUSER, M. 1910. Über Fährtenplatten im oberen Buntsandstein des württembergischen Schwarzwaldes. – Neues Jahrbuch für Mineralogie, Geologie und Paläontologie **1910** (2): 123-130.

BROMLEY, R.G. 1996. Trace Fossils, Biology, Taphonomy and Applications. – 2nd ed., 361 pp., London (Chapman & Hall).

BROMLEY, R.G. & ASGAARD, U. 1972a. Freshwater *Cruziana* from the Upper Triassic of Jameson Land, East Greenland. – Grønlands Geologiske Undersøgelse, Rapport **49**: 7-13.

BROMLEY, R.G. & ASGAARD, U. 1972b. The burrows and microcoprolites of *Glyphea rosenkrantzi*, a Lower Jurassic palinuran crustacean from Jameson Land, East Greenland. – Grønlands Geologiske Undersøgelse, Rapport **49**: 15-21.

BROMLEY, R.G. & ASGAARD, U. 1979. Triassic freshwater ichnocoenoses from Carlsberg Fjord, East Greenland. – Palaeogeography, Palaeoclimatology, Palaeoecology **28**: 39-80.

DAWSON, J.W. 1873. Impressions and footprints of aquatic animals and imitative markings, on Carboniferous rocks. – The American Journal of Science and Arts (3) **5**: 16-24.

DEMATHIEU, G. & HAUBOLD, H. 1974. Evolution und Lebensgemeinschaft terrestrischer Tetrapoden nach ihren Fährten in der Trias. – Freiberger Forschungshefte (C) **298**: 51-72.

FREYBERG, B. VON 1968. Übersicht über den Malm der Altmühlalb. – Erlanger Geologische Abhandlungen **70**: 1-37.

GALL, J.-C. & GRAUVOGEL, L. 1964. Un arthropode peu connu. Le genre *Euthycarcinus* HANDLIRSCH. – Annales de Paléontologie, Invertébrés **50**: 3-18.

GEVERS, T.W.; FRAKES, L.A.; EDWARDS, L.N. & MARZOLF, J.E. 1971. Trace fossils in the Lower Beacon sediments (Devonian), Darwin Mountains, Southern Victoria Land, Antarctica. – Journal of Paleontology **45**: 81-94.

HADERER, F.-O.; DEMATHIEU, G.R. & BÖTTCHER, R. 1995. Wirbeltierfährten aus dem Rötquarzit (Oberer Buntsandstein, Mittlere Trias) von Hardheim bei Wertheim/Main (Süddeutschland). – Stuttgarter Beiträge zur Naturkunde (B) **230**: 1-31.

HANDLIRSCH, A. 1914. Eine interessante Crustaceenform aus der Trias der Vogesen. – Verhandlungen der Kaiserlich-königlichen Zoologisch-botanischen Gesellschaft **64**: 1-8.

JANICKE, V. 1969. Untersuchungen über den Biotop der Solnhofener Plattenkalke. – Mitteilungen der Bayerischen Staatssammlung für Paläontologie und historische Geologie **9**: 117-181.

KAUFFMANN, E. 1978. Short-lived benthic communities in the Solnhofen and Nusplingen Limestones. – Neues Jahrbuch für Geologie und Paläontologie, Monatshefte **1978**: 717-724.

KEUPP, H. & MEHL, D. 1994. *Ammonella quadrata* WALTHER 1904 (Porifera, Hexactinellida) aus den Solnhofener Plattenkalken von Pfalzpaint: Relikt aus dem Altpaläozoikum? – Archaeopteryx **12**: 45-54.

KEUPP, H.; RÖPER, M. & SEILACHER, A. 1999. Paläobiologische Aspekte von synvivo-besiedelten Ammonoideen im Plattenkalk des Ober-Kimmeridgiums von Brunn in Ostbayern. – Berliner geowissenschaftliche Abhandlungen (E) **30**: 121-145.

KNAUST, D.; SZULC, J. & UCHMAN, A. 1999. Spurenfossilien in der Germanischen Trias und deren Bedeutung. – In: HAUSCHKE, N. & WILDE, V., Hrsg., Trias – Eine ganz andere Welt. Mitteleuropa im frühen Erdmittelalter: 229-238, München (Pfeil).

LINCK, O. 1943. Die Buntsandstein-Kleinfährten von Nagold. – Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, Monatshefte **1943**: 9-27.

MÁNGANO, M.G.; BUATOIS, L.A.; MAPLES, C.G. & LANIER, W.P. 1997. *Tonganoxichnus*, a new insect trace from the Upper Carboniferous of eastern Kansas. – Lethaia **30**: 113-125.

MEYER, R.K.F. & SCHMIDT-KALER, H. 1983. Erdgeschichte sichtbar gemacht – Ein geologischer Führer durch die Altmühlalb. – 260 p., München (Bayerisches Geologisches Landesamt).

MÜLLER, A.H. 1956. Weitere Beiträge zur Ichnologie, Stratinomie und Ökologie der germanischen Trias. Teil 1. – Geologie **5**: 405-423.

MÜLLER, A.H. 1959. Weitere Beiträge zur Ichnologie, Stratinomie und Ökologie der germanischen Trias. Teil 2. – Geologie **8**: 239-261.

MÜNSTER, G. VON 1839. Decapoda Macroura. Abbildung und Beschreibung der fossilen langschwänzigen Krebse in den Kalkschiefern von Bayern. – Beiträge zur Petrefactenkunde **2**: 1-88.

OPPEL, A. 1862. Ueber Fährten im lithographischen Schiefer (*Ichnites lithographicus*). – Museum des Königlich Bayerischen Staates, Paläontologische Mittheilungen **1**: 121-125.

ORTLAM, D. 1968. Neue Ergebnisse aus dem höheren Buntsandstein des nördlichen Schwarzwaldes und des Kraichgaus. – Geologisches Jahrbuch **86**: 693-750.

PEMBERTON, S.G. & FREY, R.W. 1982. Trace fossil nomenclature and the *Planolites-Palaeophycus* dilemma. – Journal of Paleontology **56**: 843-881.

RÖPER, M. 1997. Die Plattenkalklagerstätten von Solnhofen unter besonderer Berücksichtigung der Oberkimmeridge-Vorkommen bei Brunn/Oberpfalz. – Acta Albertina Ratisbonensia **50** (2): 201-215.

RÖPER, M. & ROTHGAENGER, M. 1998. Die Plattenkalke von Hienheim (Landkreis Kehlheim) – Echinodermen-Biotope im Südfränkischen Jura. – 110 p., Eichendorf (Eichendorf).

RÖPER, M.; LEICH, H. & ROTHGAENGER, M. 1999. Die Plattenkalke von Pfalzpaint (Landkreis Eichstätt) – Faszination fossiler Quallen. – 119 p., Eichendorf (Eichendorf).

RÖPER, M.; ROTHGAENGER, M. & ROTHGAENGER, K. 1996. Die Plattenkalke von Brunn (Landkreis Regensburg) – Sensationelle Fos - silien aus dem Oberpfälzer Jura. – 102 p., Eichendorf (Eichendorf).

RÖPER, M.; ROTHGAENGER, M. & ROTHGAENGER, K. 2000. Die Plattenkalke von Schernfeld (Landkreis Eichstätt) – Museum Bergér am Blumenberg. – 128 p., Eichendorf (Eichendorf).

SCHLIRF, M.; UCHMANN, A. & KÜMMEL, M. 2001. Upper Triassic (Keuper) non-marine trace fossils from the Haßberge area (Franconia, south-eastern Germany). – Paläontologische Zeitschrift **75** (1): 71-96.

SCHNARRENBERGER, K. 1914. Erläuterungen zu Blatt Königsbach (Nr. 58) – Geologische Specialkarte des Großherzogtums Baden. – 58 p., Heidelberg (unveränderter Nachdruck, 1985, als Geologische Karte 1:25.000 von Baden-Württemberg, Blatt 7017 Pfinztal, Stuttgart).

SCHNEIDER, J. 1983. *Euthycarcinus martensi* n. sp. – ein neuer Arthropode aus dem mitteleuropäischen Rotliegenden (Perm) mit Bemerkungen zu limnischen Arthropoden-Assoziationen. – Freiberger Forschungshefte (C) **384**: 49-55.

SCHWEIGERT, G. 1998. Die Spurenfauna des Nusplinger Plattenkalks (Oberjura, Schwäbische Alb). – Stuttgarter Beiträge zur Naturkunde (B) **262**: 1-47.

SCHWEIGERT, G. & DIETL, G. 1997. Ichnofossilien und Benthos im Nusplinger Plattenkalk (Ober-Kimmeridgium, Schwäbische Alb). – Terra Nostra **97** (6): 115.

SEILACHER, A. 1953a. Studien zur Palichnologie, Teil I: Über die Methoden der Palichnologie. – Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen **96**: 421-452.

SEILACHER, A. 1953b. Studien zur Palichnologie, Teil II: Die fossilen Ruhespuren (Cubichnia). – Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen **98**: 87-124.

SEILACHER, A. 1963. Lebensspuren und Salinitätsfazies. - Fortschritte in der Geologie von Rheinland und Westfalen **10**: 81-94.

SENGUPTA, S. 1966. Studies on orientation and imbrication of pebbles in respect to cross-stratification. – Journal of Sedimentary Petrology **36**: 362-369.

SOERGEL, W. 1925. Die Fährten der Chirotheria – Eine paläobiologische Studie. – 92 p., Jena (Fischer).

TRUSHEIM, F. 1931. Aktuo-paläontologische Beobachtungen an *Triops cancriformis* SCHAEFFER (Crust. Phyll.). – Senckenbergiana **13**: 234-243.

VIOHL, G. 1998. Die Solnhofener Plattenkalke – Entstehung und Lebensräume. – Archaeopteryx **16**: 37-68.

WALTER, H. 1982. Zur Ichnologie der Oberen Hornburger Schichten des östlichen Harzvorlandes. – Freiberger Forschungshefte (C) **366**: 45-64.

WALTHER, J. 1904. Die Fauna der Solnhofener Plattenkalke bionomisch betrachtet. – Denkschriften der Medizinisch-Naturwissenschaftlichen Gesellschaft zu Jena, Festschrift zum siebzigsten Geburtstag von Ernst Haeckel **11**: 135-214.

Manuskripteingang / manuscript received 13. 5. 2004;
Manuskriptannahme / manuscript accepted 28. 11. 2005