A New Y-Shaped Trace Fossil Attributed to Upogebiid Crustaceans from Early Pleistocene of Italy

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A new Y-shaped trace fossil attributed to upogebiid crustaceans from Early Pleistocene of Italy

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Y-shaped trace fossil (U-shaped upper part with a basal shaft), *Parmaichnus stironensis* igen. nov. et isp. nov. penetrates from a discontinuity surface cut in Early Quaternary mudstones in the Stirone Valley, Northern Italy. It is attributed to upogebiid decapod crustaceans. *Parmaichnus* differs from *Psilonichnus* by the presence of turning chambers in the upper part of the burrow. The turning chambers are considered to be an important taxonomic feature of upogebiid burrows. *P. stironensis* occurs together with *Thalassinoides* cf. *paradoxicus* (produced probably by callianassid crustaceans) and wide U-shaped pyritised cylinders (supposedly produced by balanoglossid hemichordates).

Key words: Trace fossils, *Parmaichnus*, *Psilonichnus,* crustacean burrows, *Upogebia*, foredeep, Pleistocene, Italy.

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Introduction

Upogebiid crustaceans are common burrowers in the intertidal and upper subtidal zone (e.g., Dworschak 1983). Along the coast of the Adriatic Sea, these burrows are produced mainly by *Upogebia pusilla* (Petagna, 1792) = *U. litoralis* (Risso, 1816) (Ott et al. 1976; Dworschak 1983, 1987a). It is surprising that very few trace fossils are referred to upogebiids (Nara and Kotake 1997; Nesbitt and Campbell 2002; Curran and Martin 2003). *Psilonichnus* Fürsich, 1981 with its type ichnospecies*, P. tubiformis* Fürsich, 1981 was compared to burrows of *Upogebia affinis* (Holmes, 1900) illustrated by Bromley and Frey (1974: fig. 9) (Fürsich 1981). *Psilonichnus lutimuratus* Nesbitt and Campbell, 2002 was interpreted as an upogebiid burrow (Nara and Kotake 1997; Nesbitt and Campbell 2002). Nara and Kotake (1997) described up to 2 m long "*Psilonichnus* isp." with short side branches and referred it to *Upogebia major* (de Haan, 1841). However, these *Psilonichnus* ichnospecies and *P. upsilon* Frey, Curran, and Pemberton, 1984 differ from recent upogebiid burrows (Dworschak 1983, 1987a, 2004) by the presence of turning chambers, which are considered herein as a significant ichnotaxobase at the ichnogenus level.

Early Quaternary marine sediments of the Stirone section in the Parma region, Italy (Fig. 1), contain trace fossils that share many morphological features with Recent upogebiid crustacean burrows. These trace fossils penetrate from a distinct discontinuity surface. Their description, ichnotaxonomy, and discussion of their ethology and palaeoecology are the main focus of the paper.

Institutional abbreviation.—INGUJ, Institute of Geological Sciences, Jagiellonian University, Kraków, Poland.

Geological setting

The Late Pliocene to early Pleistocene sediments in the Western Emilia Romagna (Parma and Piacenza provinces) were deposited in the north-western extension of the Palaeo-Adriatic Sea. They are part of the Po Plain-Adriatic Foredeep, which is filled with sediments deriving from the Southern Alps and Apennines. The Late Pliocene sediments are interpreted as a regressive succession deposited in the transition from outer to inner shelf. The overlying Pleistocene sediments represent deeper shelf, nearshore, and transitional deposits in a shallowing-upwards trend (Dominici 2001, 2004).

The Upper Pliocene–Lower Pleistocene sections along the Stirone river valley have been more intensively investigated since the 1960s with regard to their sedimentology, palaeoecology, micropalaeontology, taphonomy, and sequence stratigraphy (Pelosio 1960, 1964; Papani and Pelosio 1962; Pelosio and Raffi 1974, 1977; Iaccarino 1996; Mutti 1996; Molinari 1997; Mutti et al. 2000; Dominici 2001, 2004; Monegatti et al. 2001. The initial ichnological report was by Dominici (2001). Uchman and Pervesler (2007) described trace fossils from the Late Pliocene part of the section.

The new trace fossil described in this paper penetrates from a distinct discontinuity surface developed at the top of a 3.2 m thick interval of lower Pleistocene light grey, calcareous, clayey siltstone, which occurs 17 m above the top of

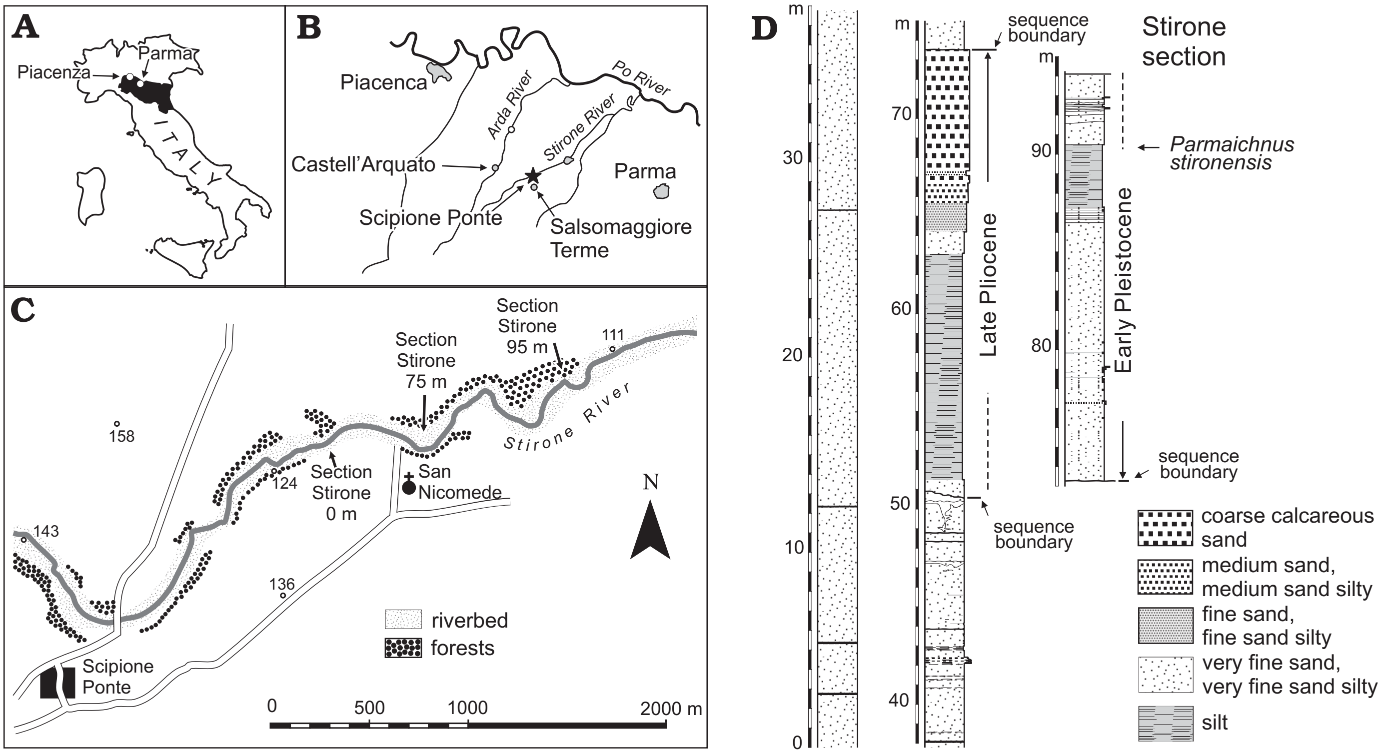

Fig. 1. Location map and the geological section. **A**. The study region on the map of Italy. **B**. Location of the study area. **C**. Location of the studied section. **D**. The studied section with indication of *Parmaichnus stironensis* igen. nov. et isp. nov.

Pliocene sediments (sensu Dominici 2001, 2004) marked by a sequence boundary (Figs. 1, 2). The sequence stratigraphic meaning of this discontinuity surface is not so far decided. This surface was followed for more than 600 m along the river and is sharply demarcated and gently undulated, probably due to erosional truncation. It is covered by discontinuous layers of poorly sorted fine- to medium-grained siliciclastic sands, with poorly expressed bedding surfaces, downlapping the discontinuity at a low angle across the outcrop. The sands are rich in bioclasts, mostly mollusc shells and tubes of the serpulid *Ditrupa*. The trace fossils are filled with the overlying sandy sediment, and their margins are commonly ferruginized or pyritised. Therefore they are highly visible in contrast with the siltstone background (Figs. 3, 4). The geological situation of the discussed trace fossils is similar to that from the Willlapa Bay, Washington, U.S.A, where Y-shaped crustacean burrows penetrate Pleistocene firmground muds (*Glossifungites* ichnofacies) covered by sands in an estuarine setting (Gingras et al. 1999, 2000).

Fig. 2. View of the Early Pleistocene part of the Stirone section (about 90 m), with the distinct unconformity in the middle (pointed by arrow) separating silts covered by sands.

Systematic ichnology

Ichnogenus *Parmaichnus* nov.

Type ichnospecies: *Parmaichnus stironensis* isp. nov.

Etymology: After the Parma region, in which the trace fossil occurs.

Diagnosis.—Vertical to oblique, tubular burrows, circular in cross section, and composed of the U-shaped upper part and a basal shaft. Sub-spherical swellings are present in the upper part of the burrow.

Remarks.—To date, only three Y-shaped ichnogenera (U-shaped upper part with a basal shaft) are distinguished. They can be compared to *Parmaichnus*. *Psilonichnus* Frey, Curran, and Pemberton, 1984, typified by *Psilonichnus tubiformis* (Fürsich, 1981), has no turning chambers and is much larger (Fig. 5U). *Solemyatuba* Seilacher, 1990, with two ichnospecies *S. subcompressa* (Eichwald, 1855) and *S. ypsilon* Seilacher, 1990, and Recent burrows of the bivalve *Solemya velum* Say, 1822 are of comparable size but they do

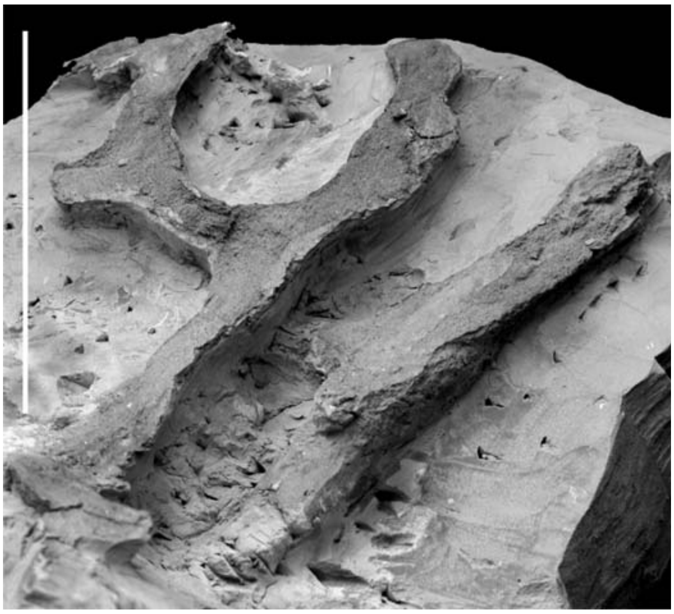

Fig. 3. Holotype (INGUJ 200P11) of allegedly upogebiid trace fossil *Parmaichnus stironensis* igen. nov. et isp. nov. Scale bar 100 mm.

not display turning chambers and their tubes are elliptical in cross section (Fig. 5F, G). *Polykladichnus* Fürsich, 1981, typified by *P. irregularis* Fürsich, 1981 (Fig. 5D), displays multiple Y- or U-shaped bifurcation and slight enlargement at junctions (see Schlirf and Uchman 2005).

Parmaichnus stironensis isp. nov.

Figs. 3, 4, 5P–S.

Etymology: After Stirone river, along which the type horizon is located.

Type material: Holotype: INGUJ 200P11 (a block of impregnated silt containing the burrow) and five photographed and measured specimens in the field.

Type horizon: Distinct discontinuity surface in the Early Pleistocene sediments 17 m above top of the Pliocene.

Type locality: Stirone river valley close to the chapel San Nicomede, 2 km NE from Scipione Ponte, Parma region (Fig. 1).

Diagnosis.—Y-shaped, vertical to oblique tubular, unlined trace fossil; tubes circular in cross section, composed of the U-shaped upper part and a basal shaft coming out from its lower part. Sub-spherical swellings are present close to the two inflection points in the lower part of the U. Moreover, the swellings occur commonly in the lower part of the shaft and, in some specimens, at the shaft entrance.

Description.—As in the diagnosis, with the following additions: The trace fossil is unlined. The burrow margins are sharp, and commonly ferruginised. The surface is smooth, i.e. with no scratch marks. The burrow is filled with the overlying sandy sediment, commonly containing shell debris. The holotype displays all the described features. It is inclined to the discontinuity surface: the plane of the U-part no more than 40° and the basal shaft less than 35° in the upper part and only up to 10° in the lower part. Other specimens observed in the field are nearly vertical. The tube diameter ranges from 9 to 26 mm and in the holotype from 16 to 20 mm. The chambers are irregularly ovoid to ovoid in shape. In the holotype, two chambers are located in the lower part of the U-shaped burrow, and one chamber is located in the lower part of the shaft. The chambers are 25–36 mm wide. In smaller specimens, the chambers are no less than 15 mm wide. The chambers are irregular subovoid in shape. They are located aside of the axis of the tubes. The distance between the U-part openings is 70 mm in the holotype and ranges from 55 to 70 mm in other specimens. The total vertical extent is at least 120 mm in the holotype, but the trace fossils was originally longer (the basal terminus of the shaft is apparently broken. Given that the shaft is inclined, its length is greater than its vertical extent, and it attains a length of 170 mm (at least 95 mm to at least 145 mm in other specimens). The morphometric parameters of the holotype and other five specimens photographed in the field are listed in Table 1. The basal shaft is curved, commonly in its distal part. It starts from the base of the U, commonly aside from the vertical axis of the U and frequently almost in continuation of one of the U limbs. The juncture with the U is slightly swollen.

Remarks.—This is the only known ichnospecies of *Parmaichnus*. Potentially, other ichnospecies can be distinguished in the future on the basis of position of the swellings and other morphological features.

Probably, the upper part of *Parmaichnus stironensis* is truncated by erosion, at least in some cases. This can be judged from significant differences in vertical extent of the U-part of the burrows.

Discussion

Probable tracemaker organisms.—Comparison of the trace fossil morphology with extant burrows—especially considering the Y-shape with turning chambers (Fig. 5A–U)—

Table 1. Morphometric parameters of the holotype and the specimens of *Parmaichnus stironensis* igen. nov. et isp. nov. observed in the field. All values in mm. Specimens abbreviated with P are left in the field.

Specimen	Tube diameter	Maximal swelling width	Distance between the U-part openings	Total vertical extent	Vertical extent of the U- part	Length of the basal shaft
ING UJ 200P11, holotype	16–20	25–36	70	>120	65	>170
P1070182	10–15	21	65	>95	35	>85
P1070193	9	24	~53	>117	84	>40
P1070195	12	15–19	55	>145	37	>114
P1070198	9	~19	79	>138	81	>75
P1140402	~26	–	55	–	101	–

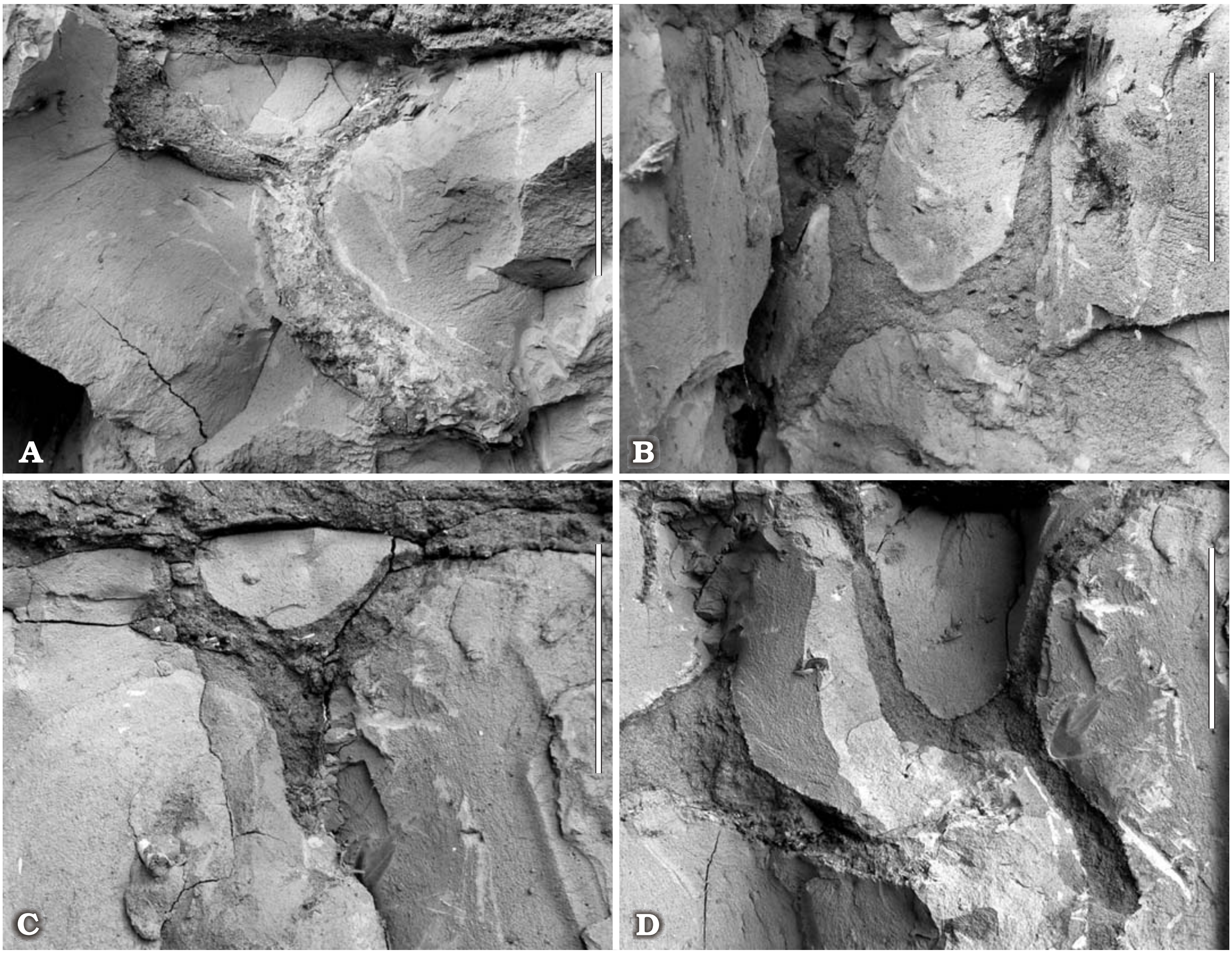

Fig. 4. Allegedly upogebiid Y-shaped trace fossil *Parmaichnus stironensis* igen. nov. et isp. nov. (specimens left in the field) from Early Pleistocene of Italy. **A**. Specimen P1070182 (numbering from the field photograph collection). **B**. Specimen P1070193. **C**. Specimen P1070194. **D**. Specimen P1070196. Scale bars 50 mm.

strongly suggests that thalassinidean shrimp, especially upogebiids, are the tracemakers. *Parmaichnus stironensis* shows the closest similarities to the Recent burrows of *Upogebia mediterranea* Noël, 1992 (Fig. 5O), found in firmground mud of Rhodes, Greece (Asgaard et al. 1997).

Recent upogebiid burrows.—A synopsis of the burrow features of *U. pusilla* given by Dworschak (2004) describes the burrows as Y-shaped, consisting of a U- or double U-shaped gallery and a basal shaft. The burrow openings are simple holes, flush with the substrate surface. The burrows occur in intertidal areas and can penetrate to a depth of up to 0.8 m. Turning chambers occur on each side of the U, and one or more along the shaft. In the Gulf of Trieste, *U. pusilla* occurs also in water depths of more than 7 m. In the subtidal environment, *U. pusilla* burrows (Fig. 5H, J, K) are much shallower than those from the intertidal and generally have mostly one turning chamber on one side; the shaft has none (Dworschak 2004). Pervesler and Hohenegger (2006) show resin casts of subtidal *U. pusilla* burrows from shelly coarse gravels close to the steep coast near Sorgenti di Aurisina in the Gulf of Trieste. The burrows are Y-shaped with two turning chambers in the U-portion, the shafts starting from one turning chamber branch with angles 10–60°. The total depth of these burrows does not exceed 18 cm.

Functional morphology.—Turning chambers (Fig. 5H) are obligatory features of *Upogebia* burrows. They are used to facilitate changes in direction of movement by the shrimp inhabitants of the burrows and also are the place where the tracemaker spends about 40% of its time for feeding. The trace maker is mainly feeding on suspended particles entering the burrow via the ventilation current created by intermittent beating of the pleopods. The animal can also come out of its burrow and browse the sediment around the burrow openings (Dworschak 1987b).

In contrast to the feeding function of *Upogebia* burrows, the burrows of ocypodid crabs are used for shelter against heat

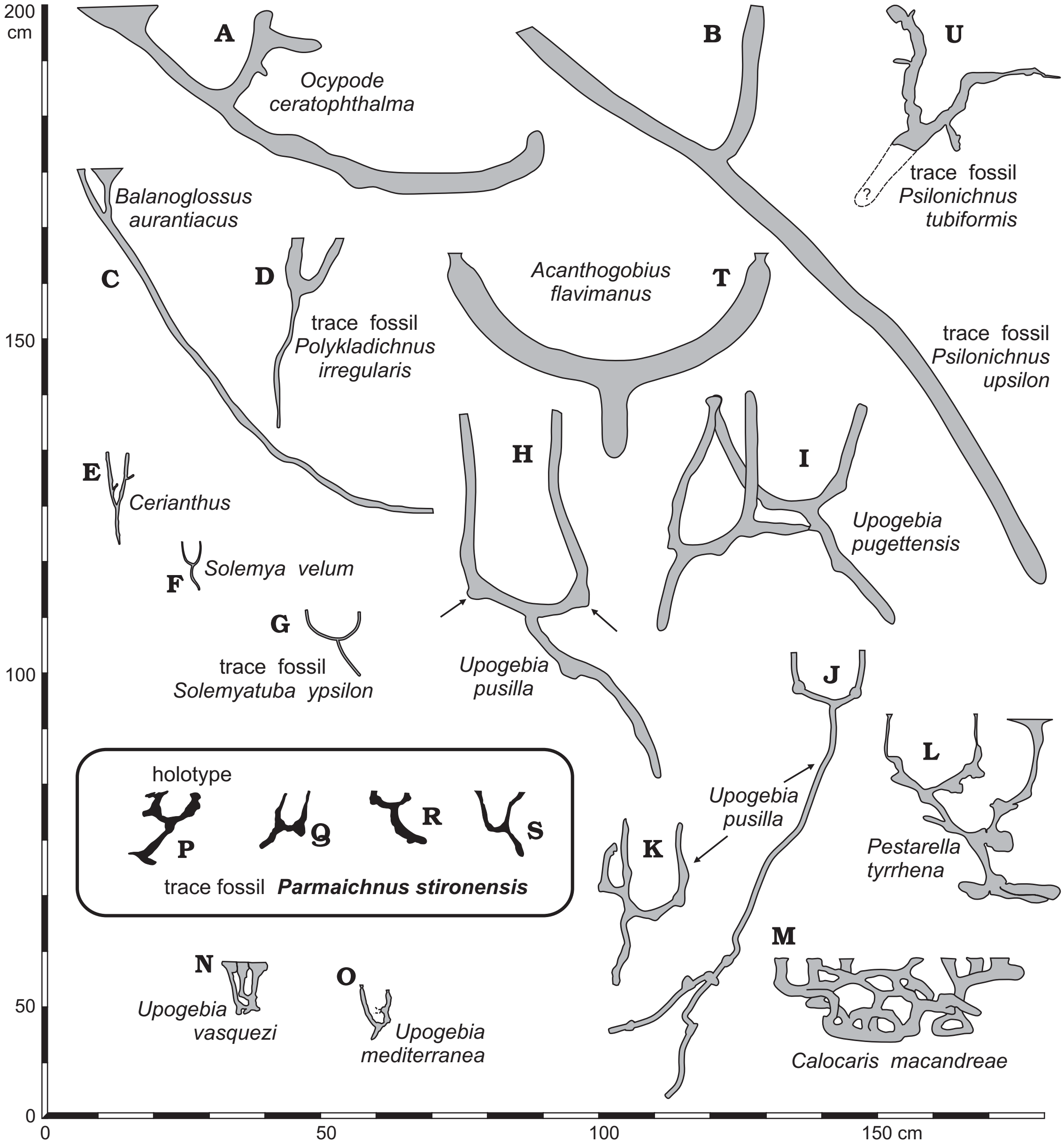

Fig. 5. Different Y-shaped trace fossils (**B**, **D**, **G**, **U**) and Recent burrows compared to *Parmaichnus stironensis* (**P–S**). Redrawn from photographs. **A**. After Seike and Nara (2007: fig. 3c). **B**. Holotype of *Psilonichnus upsilon*, Hanna Bay, San Salvador, Bahamas, from AU photograph. **C**. After Bruce (1987: fig. 6). **D**. After Fürsich (1981: pl. 3: 2). **E**. After Curran and Frey (1977: pl. 1e). **F**. After Frey (1968: text-fig. 1). **G**. After Seilacher (1990: fig. 5D). **H**. After Dworschak (2004: fig. 2B); arrows point the turning chambers. **I**. After Swinbanks and Luternauer (1987: fig. 2.1). **J**. After Ott et al. (1976: pl. 1: 2). **K**. After Ott et al. (1976: pl. 1: 3). **L**. After Dworschak et al. (2006: fig. 1A). **M**. After Nash et al. (1984: pl. 2a); see also Bromley (1996: fig. 4.32). **N**. After Curran and Martin (2003: fig. 6). **O**. After Asgaard et al. (1997: fig. 6). **P–S**. *Parmaichnus stironensis* igen. nov. et isp. nov. **P**. Holotype, ING UJ 200P11, see also Fig. 3. **Q**. P1070193, see also Fig. 4B. **R**. P1070182, see also Fig. 4A. **S**. P1070196, see also Fig. 4D. **T**. After Atkinson and Taylor (1991: fig. 1f). **U**. *Psilonichnus tubiformis*, after Fürsich (1981: pl. 1: 1).

and desiccation and as a refuge against predation (Chakrabarti 1981; Chan et al. 2006). Ocypodids can produce Y-shaped burrows (Fig. 5A) consisting of a primary arm, which extends to the surface forming the opening, and a secondary arm that terminates in a blind hemispherical ending or communicates with the surface. The two arms join in a single shaft and end with a turning chamber at the base. Such burrows closely resemble the ichnofossil *Psilonichnus*, e.g., *Psilonichnus upsilon* Frey, Curran, and Pemberton, 1984 (Fig. 5B) and do not show turning chambers in the upper part of the burrow.

Turning chambers in Y-shaped burrows are the important ichnotaxobase to distinguish *Psilonichnus* from *Parmaichnus*. Fossil burrows without turning chambers should not be attributed to the work of upogebiids.

Ecology of Recent upogebiids.—Upogebiids are known from tropical, subtropical and temperate seas. The subtidal tropical species *Upogebia amboinensis* (de Man, 1888) (Australia) and *U. operculata* Schmitt, 1924 (Caribbean) live in corals (Kleemann 1984) while *Upogebia*. sp. from the Carib-

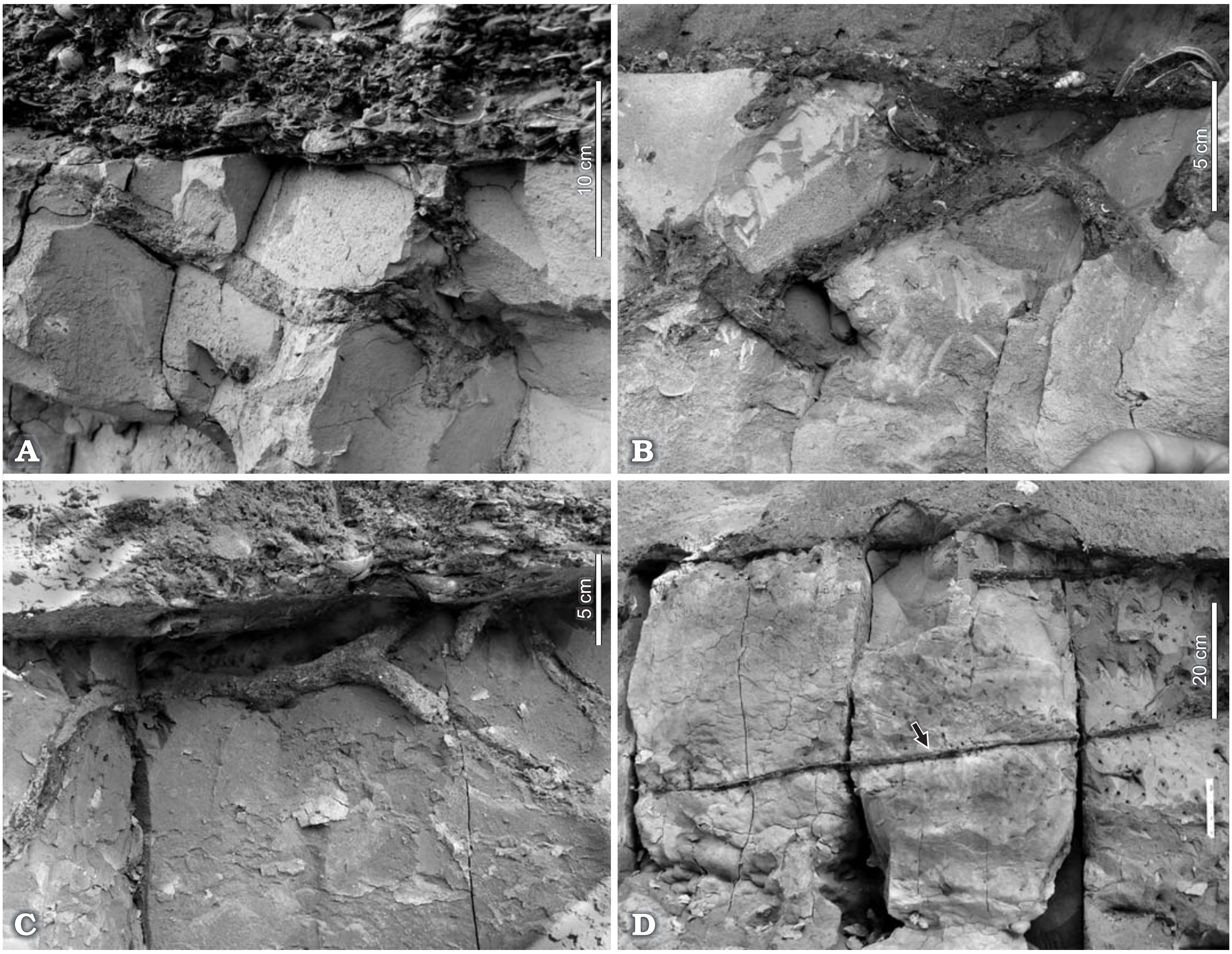

Fig. 6. Trace fossils associated with *Parmaichnus stironensis*. They penetrate from the discontinuity surface in the Quaternary sediments of the Stirone section. **A**–**C**. *Thalassinoides* cf. *paradoxicus* (Woodward, 1830). **D**. Pyritised tube indicated by arrow.

bean lives in sponges (Griffis and Suchanek 1991). *Upogebia vasquezi* Ngoc-Ho, 1989 was reported from intertidal tropical sediments (Curran and Martin 2003). Temperate species settling on soft substrates are described from Southeastern USA (*U. affinis*), Western USA (*U. pugettensis* (Dana, 1852), *U. macginitieorum* Williams, 1986), Southern Africa (*U. africana* (Ortmann, 1894)), India (*U. carinicauda* (Stimpson, 1860)), Japan (*U. major*), and the Mediterranean Sea (*U. tipica* (Nardo, 1868)), *U. pusilla*, *U. deltaura* (Leach, 1815)). The widespread *U. pusilla* was also reported from the Atlantic Ocean, from Mauretania to Britanny (De Saint Laurent and LeLoeuff 1979), and from Norway (Pesta 1918; Bouvier 1940; Zariquiey Álvarez 1968).

Upogebia affinis, *U. africana*, and *U. pusilla* live in intertidal as well as subtidal areas. *U. pusilla* can be found from the intertidal (Ott et al. 1976; Dworschak 1983, 1987a, 2004) down to a water depth of 45 m (Black Sea, Popovici 1940). *U. pugettensis*, *U. macginitieorum*, *U. carinicauda*, and *U. major* are restricted to the intertidal, *U. tipica* and *U. deltaura* to the subtidal. Substrates used by upogebiids are variable, ranging from hardrock, corals (Kleemann 1984) and gravel (Pervesler and Hohenegger 2006) to muds consisting of muddy fine sand or silt (Dworschak 1983).

Densities can go up to several hundred burrows per square meter (Ott et al. 1976; Griffis and Suchanek 1991). Salinity range is from normal marine (36‰) in subtidal areas down to 9‰ in freshwater-influenced areas (Dworschak 1987b). Due to the ventilation activity, the wall of modern burrows throughout its length has the same tan colour as the oxidized sediment surface, whereas the surrounding reduced sediment appears black. Following Griffis and Suchanek's (1991) classification, the trace fossil *Parmaichnus stironensis* can be interpreted as an upogebiid shrimp burrow of the type 5 (simple Y) constructed on seafloors without mounds and eelgrass. Such burrow shapes are used for suspension and filter feeding behaviour. The basal pattern of morphology in Recent Adriatic upogebiid burrows is a simple Y-shape, with turning chambers similar to the fossil examples from the Stirone River Quaternary.

Associated trace fossils

Two different trace fossils, *Thalassinoides* cf. *paradoxicus* (Woodward, 1830) and pyritised cylinders are associated with *Parmaichnus stironensis*. They penetrate from the same discontinuity surface.

***Thalassinoides* cf. *T. paradoxicus* (Woodward, 1830)**.—This trace fossil occurs as branched, cylindrical, unlined burrows, 10–22 mm in diameter, which penetrate obliquely down (commonly under 30–40°) from the discontinuity surface up to at least 32 cm. Some of them contain wide, shallow, irregular, branched U-shaped elements of the same morphology (Fig. 6A–C). Some of the joints are swollen, and measure up to 25 mm in diameter. Also, chambers of the same diameter are scattered along the cylinders. The overlying sand fills this trace fossil. Commonly, its margin is ferruginised. Some specimens display wide and shallow funnel entrances or constrictions.

These branching burrows can be assigned to the trace fossil *Thalassinoides* Ehrenberg, 1944, and are similar to *Thalassinoides paradoxicus* (Woodward, 1830) in their differently oriented elements and lack of dominant horizontal galleries. However, the Parma trace fossils do not display common T-shaped branches without swellings, which are typical of *T. paradoxicus*.

The morphology of these trace fossils, inclined cylinders and wide, irregular U-shaped elements in particular, are typical of unlined callianassid crustacean burrows (Dworschak 1983, 2004).

Pyritised cylinders.—Differently inclined, from sub-vertical to sub-horizontal, long, almost straight to slightly curved, rarely branched, smooth, cylindrical tubes are ascribed to this trace fossil. They are 5–7 mm diameter and at least 90 cm long (Fig. 6D). Some of the longer cylinders form gentle, open up arcs. Their length is probably much larger, because burrow fragments are found up to 53 cm below the discontinuity surface. This trace fossil is filled by pyritised material and is coated by limonite-like iron minerals, which originated probably from oxidisation of the pyrite. The coating probably enlarges the original width of the burrow. The trace fossil displays only rare, short branches up to 30 mm long, coming out from the sub-horizontal part of the burrow.

It is possible that this trace fossil forms very wide and deep U-shaped structures when complete, but only their fragments are observed in outcrops. Thus it is hard to assign this trace fossil to any known ichnotaxon. Strong pyritization and large depth of sediment penetration in comparison to width suggest anoxic conditions inside the burrow. In analogy with much smaller (<1 mm wide) *Trichichnus* Frey, 1970, it can be supposed that this trace fossil was produced by a chemosymbiotic invertebrate. Some enteropneusts produce thin and long burrows, like *Balanoglossus aurantiacus* (Girard, 1853) (Duncan 1987a) (Fig. 5C). It is not excluded that the tracemaker of the pyritised tubes belongs to this group of hemichordates. Other candidates are echiuran worms, like *Maxmuelleria lankesteri* (Herdman, 1898), that produces long, thin horizontal tunnels at about 50 cm depth connected to the substrate surface by two steep shafts (Huges et al. 1996).

Conclusions

Parmaichnus stironensis is a new trace fossil attributed to upogebiid crustaceans, which can be distinguished by its U-shaped cylinders with swellings and a basal shaft. The swellings are significant morphological elements considered as an ichnotaxobase at the ichnogenus level. This element allows separating *Psilonichnus* produced mostly by crabs from *Parmaichnus* produced by upogebiid crustaceans. Morphology of *Parmaichnus stironensis* is very close to morphology of *Upogebia mediterranea* burrows.

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