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MORPHOLOGIC VARIATIONS OF THE TRACE FOSSIL *RUTICHNUS* IN CM-THICK TURBIDITES FROM THE VERGHERETO FORMATION (NORTHERN APENNINES, ITALY)

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Abstract. The analysis of 56 specimens of the branched, walled post-depositional trace fossil *Rutichnus,* sampled from 31 thin-bedded, overbank turbidites from the Verghereto Formation, Romagna Apennines, indicates high morphologic variability of this ichnotaxon in hypichnial preservation. The variability concerns the arrangement of outer and inner walls, number and shape of annulations, distribution of pustules, the (false) branching arrangement and the general external shape. Highest variability has been observed mainly in the *Rutichnus rutis* ichnospecies, clearly less in the *R. irregularis* ichnospecies that is rare. The Dino-Lite microscope camera analysis of oriented thin sections indicates that endichnial preservation exhibits many structures due to burrowing in soft substrate, destroying laminae of sand. Consequently, *Rutichnus* probably was produced by a worm or arthropod, inducing strong deformation in turbidite sand during the feeding activity on phytodetritus and organic matter transported by the turbidity flow.

Riassunto. Vengono analizzati 56 campioni della traccia fossile post deposizionale *Rutichnus* provenienti da 31 livelli centimetrici (da 1 a 5 cm di spessore) di calcareniti torbiditiche di *overbank* intercalate nelle marne della Formazione di Verghereto, affioranti presso la località di Ville di Montecoronaro (Verghereto, Appennino Romagnolo). L'esame mostra una grande variabilità morfologica in questo ichnotaxon, specialmente nella preservazione hypichnia. La variabilità nella specie *Rutichnus rutis* è stata analizzata nella forma esterna, nelle pareti esterna ed interna, nel numero e nella disposizione delle annulazioni, nell'aspetto delle (false) ramificazioni e infine nella distribuzione delle pustule. Lo studio della variabilità morfologica è stato meno agevole nell'altra specie *R. irregularis,* a causa della scarsità degli esemplari raccolti. L'analisi mediante camera microscopica Dino-Lite in sezione sottile ha permesso di evidenziare anche una forte variabilità nella preservazione endichnia; si osservano molte deformazioni avvenute durante la fase post-deposizionale nelle lamine di sabbia alla base delle calcareniti e nella disposizione dei granuli associati, prodotte dalla ricerca e dall'ingestione di fitodetrito e materiale organico da parte di organismi vagili, forse vermiformi (ma senza escludere artropodi), trasportati dai flussi di torbida.

Introduction

For a branched, walled and meniscate trace fossil D'Alessandro et al. (1987) introduced the ichnogenus *Rutichnus*, which typically displays wrinkles that are distributed in the exterior of the wall. These authors analyzed many samples from the Permian of East Greenland and from the Miocene Flysch (Gorgoglione) of southern Italy remarking peculiar morphologic characteristics of this walled ichnogenus: external roughness, branching and the occurrence of menisci. Branches and menisci are typical and well preserved mainly in the Permian specimens (D'Alessandro et al. 1987, figs. 6-7). Some similarities concerning the wall ornamentation have been found mainly in epichnial *Nereites*, although in hypichnial *Neonereites* the wall is thicker and formed by pustules without short annulations, while in *Rutichnus* annulations and roughness are more regularly arranged and the wall is isopachous. Samples of one of the two ichnospecies, *Rutichnus irregularis*, formerly classified as *Radionereites irregularis* by D'Alessandro (1982), has been collected as hyporeliefs from soles of turbidites in the Gorgoglione Flysch deposits, Basilicata region, southern Apennines, while the holotype of the other ichnospecies, *Rutichnus rutis,* comes from the Permian of East Greenland (Domkirken Mount, northern Scoresby; D'Alessandro et al. 1987).

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This paper addresses to describe an unusual concentration of *Rutichnus* trace fossils that is otherwise rarely known (Uchman & Demircan 1999; Demircan 2008). The highly abundant *Rutichnus* has been found in several 3-5 cm-thick calcarenitic turbidites in marly deposits of the Verghereto Formation (Miocene) of the Romagna Apennines (Ville di Montecoronaro, Verghereto area). These calcarenitic turbidites probably represent distal fringe (overbank?) sediments deposited in the marginal Marnoso-arenacea Basin at the transition to the Verghereto High (Milighetti et al. 2009; Monaco et al. 2009). These deposits belong to an area that expresses an excellent preservation and abundance of trace fossils with 50 different ichnotaxa in the ichnofossil-*lagerstätte* of Poggio Alto (Monaco & Checconi 2010). This paper is directed to describe features of hypichnial *Rutichnus* that had not been described before, focusing some taphonomic aspects that can help in the definition of palaeobiological and palaeoenvironmental setting of very thin-bedded turbidites. Trace fossils have been sampled bed by bed and have been observed in variably cut surfaces which were photographed. Analysis of endichnial preservation was performed mainly using the microscope camera Dino-Lite at 10x and 20x magnification, in order to observe textural arrangement of grains close to the burrow.

Investigated locality and geological setting

The Verghereto Formation, Miocene in age, consists of thick, rhythmically-arranged gray marl deposits (up to 600 m thick towards NE at M. Fumaiolo) and sporadic calcarenitic turbidites. The Verghereto Formation was deposited in the Marnoso-arenacea Basin during a multi-phase tectonic activity that in the lower-middle Miocene (Serravallian?) produced ridges and elongated basins in a NW-SE oriented foredeep system of the northern Apennines. In the Verghereto area, that represents probably one of the most important of these intrabasinal highs, fringe and overbank deposits are represented by thin-bedded and fine-grained turbidites that reached the marginal sectors of the Marnoso-arenacea Basin (see the extensive geological description in Monaco et al. 2009; Monaco & Checconi 2010).

In the Poggio C site (N 43°76’93,63”; E 12°03’55,83”), that is located about 1 km at south of Poggio Alto ichnofossil-*lagerstätte* (Monaco & Checconi 2010), about 8 m of section have been logged (Fig. 1). Thirtyone calcarenitic beds, from 1 to 5 cm thick, have been analyzed bed by bed for the ichnofaunal content (Fig. 2). Seven of them exhibit *Rutichnus rutis* which is very common in thicker turbiditic beds (see five asterisks in Fig. 2). In the locality of Poggio B (N 43°77’14,24”; E 12°03’06,05”), just 250 meters to the

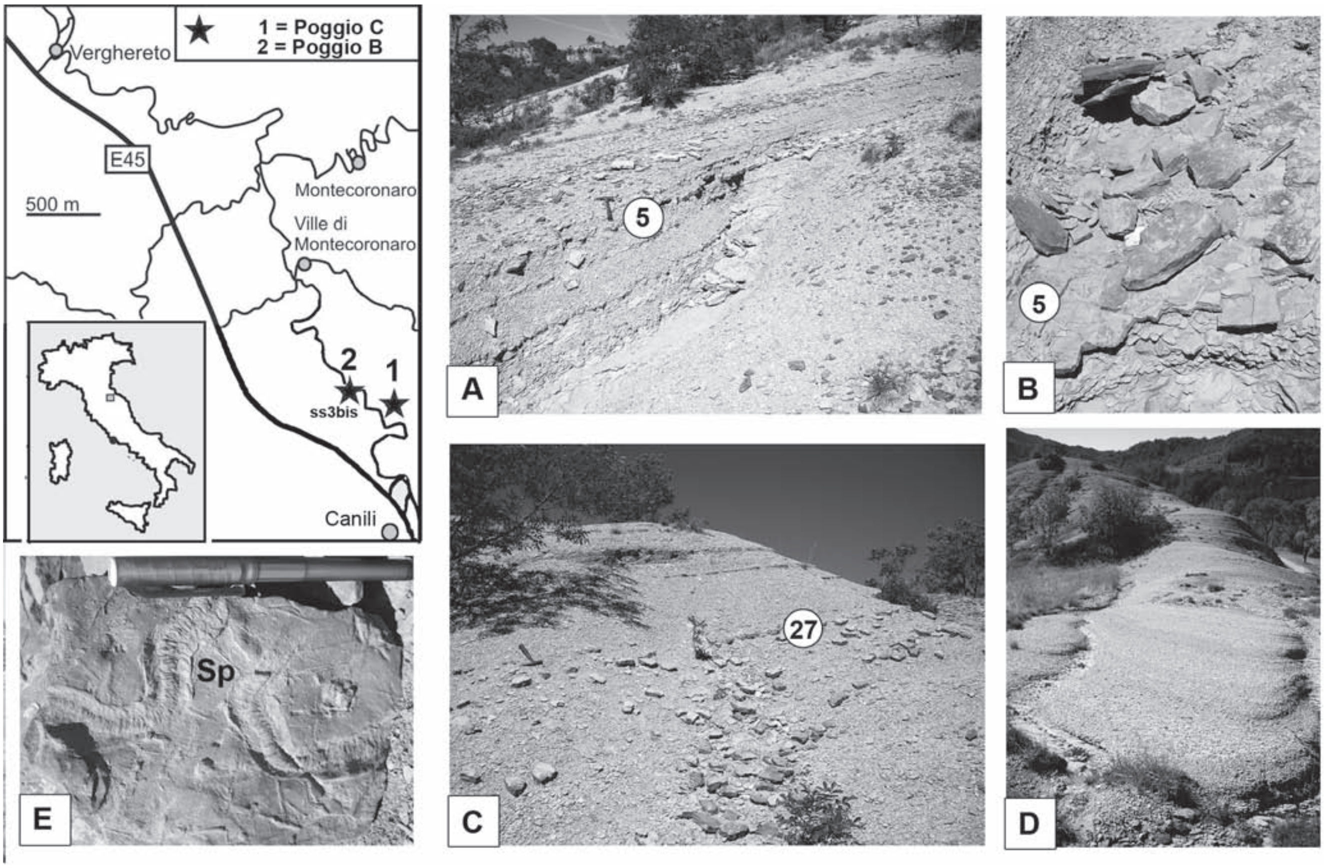
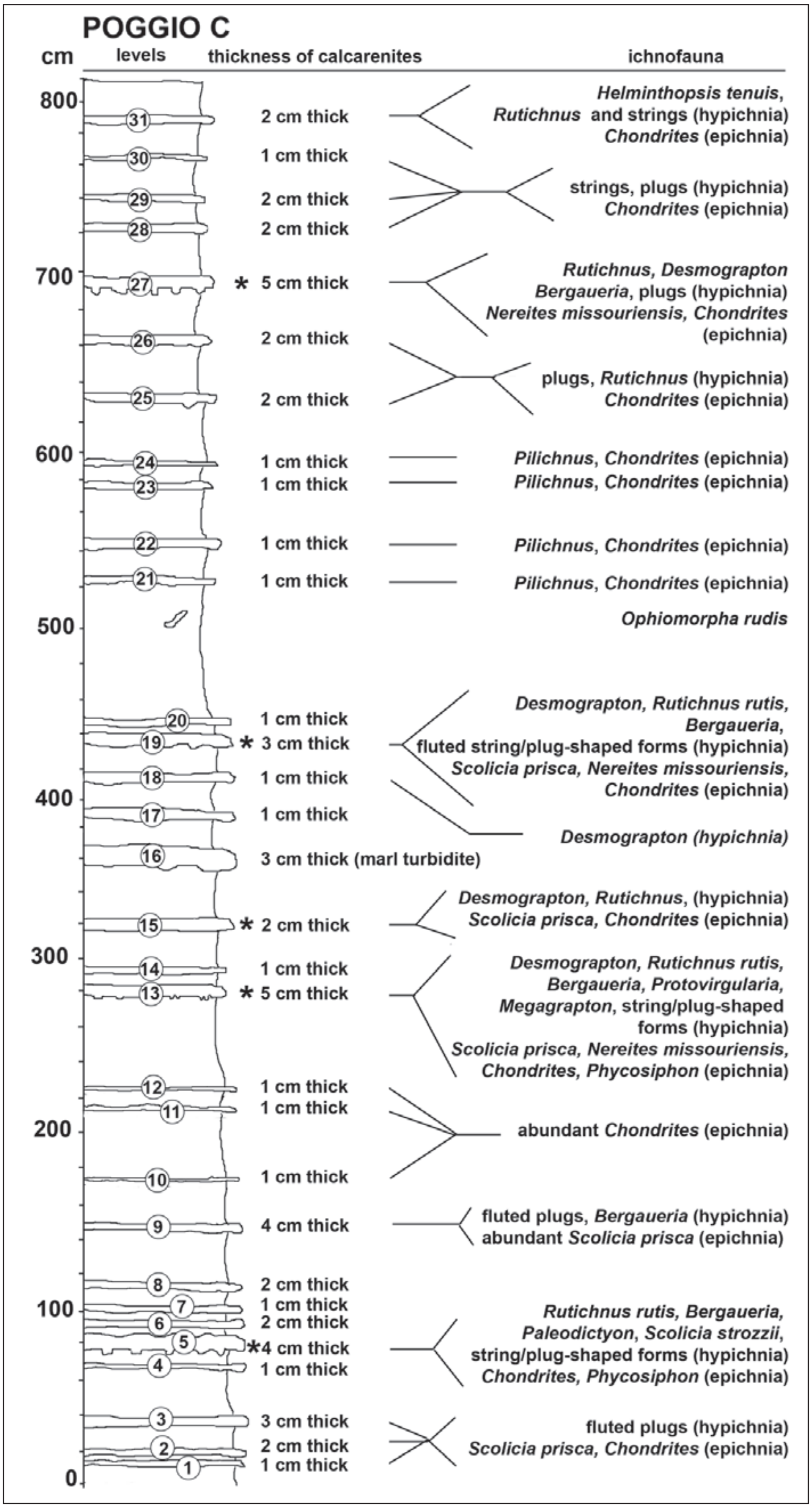


Fig. 1 - Localization of studied sections. (A-D) Marls and cm-thick calcarenite beds in the Poggio C section. Numbers in beds are explained in Figure 2. (E) Epichnial community (mainly *Scolicia prisca*, Sp).

Fig. 2 - The Poggio C stratigraphic column with ichnologic assemblage. Numbers in circle are thin-bedded calcarenites. Asterisks indicate thicker beds where the most abundant concentration of trace fossil *Rutichnus* occurs.



north of Poggio C, eleven samples of *Rutichnus rutis* and six samples of *Rutichnus irregularis* have been collected (Fig. 1). The Poggio B section requires further analyses for its very rich assemblage of trace fossils, and therefore its log and ichnologic data will be provided separately. In the locality of Poggio C calcarenitic beds of 1 to 3 cm thick dominate, but the thickest of them (levels 5, 13, 27), are those with the highest abundance and diversity of ichnofauna (Fig. 2). Calcarenites consist of rhythmical sharp-based beds, fining-upward disposed and brown to yellowish in colour. Quartz, mica flakes, feldspar, lithic fragments, calcium carbonate and clay suggest immature arenites (Milighetti et al. 2009). The basal grain size remains in the range of medium sand while the top is silt or mud; ripple structures are frequent in thicker beds 5, 13 and 27, disposed internally, more rare at the top. Both base and top are strongly bioturbated (Monaco & Checconi 2010). The cm-thick calcarenites correspond to the distal expression of the facies F9b, that is a variety of the facies F9a in the model of Mutti (1992), probably an immature deposit of very small-volume flows from low-density turbidity currents in marginal and very distal environments (see discussion in Monaco 2008; Monaco & Checconi 2010). The material studied was collected at south of the village Ville di Montecoronaro at the foot of a hill that is located about 2 km to the North of the Canili-Piantrebbio exit in the E45 Orte-Ravenna road (Romagna Apennines).

Trace fossil assemblage

The trace fossil assemblage of the Poggio C section consists of rich hypichnia and epichnia in addiction to endichnia that are considered separately (Fig. 2). Hypichnial assemblage is dominated by *Rutich-*

nus rutis and *R. irregularis*, and biramous meandering graphoglyptid *Desmograpton* that in this area is the most abundant among graphoglyptids (Monaco 2010). In the calcarenitic levels 5, 13, 15, 18, 19 and 27 *Desmograpton* can reach a very high ichnodensity, up to four specimens/20 cm^2. The dominant ichnospecies is *D. dertonensis* while *D. ichthyforme* and *D. alternum* are less abundant. Other graphoglyptids include *Megagrapton*, while net-shaped *Paleodictyon* is scarce (*P. strozzii* and *P. minimum*). *Bergaueria*-like structures and many indeterminable small plug-shaped structures dominate in thicker levels 5, 9, 13 and 27, while sporadically they occur in thinner ones. These plug-shaped forms are frequently fluted mainly in thicker levels (5, 13 and 27). Among string-shaped forms *Helminthopsis* (mainly *H. tenuis),* and *Protovirgularia* are the dominant ichnogenera, while *Scolicia strozzii,* which is abundant in the ichnofossil- *lagerstätte* of Poggio Alto, in the Poggio C and B sections is very rare or absent (1 dubitative specimen at level 5).

The epichnial community of thicker levels 5, 13 and 19 is similar to that described in the ichnofossil-*lagerstätte* of Ville di Montecoronaro (Poggio Alto) (Monaco & Checconi 2010), while some differences exist in thinner levels (see Fig. 2). In fact, while *Scolicia prisca* and *Nereites* isp. or *N. missouriensis* are the dominant forms in thicker and rippled beds (Monaco & Checconi 2010), the epichnial community is dominated by delicate forms as *Chondrites* (*C. intricatus, C. targionii), Pilichnus* and *Phycosiphon* that are abundant in the sharp top of thinner calcarenites that not exceeding 1-2 cm in thickness (Fig. 2).

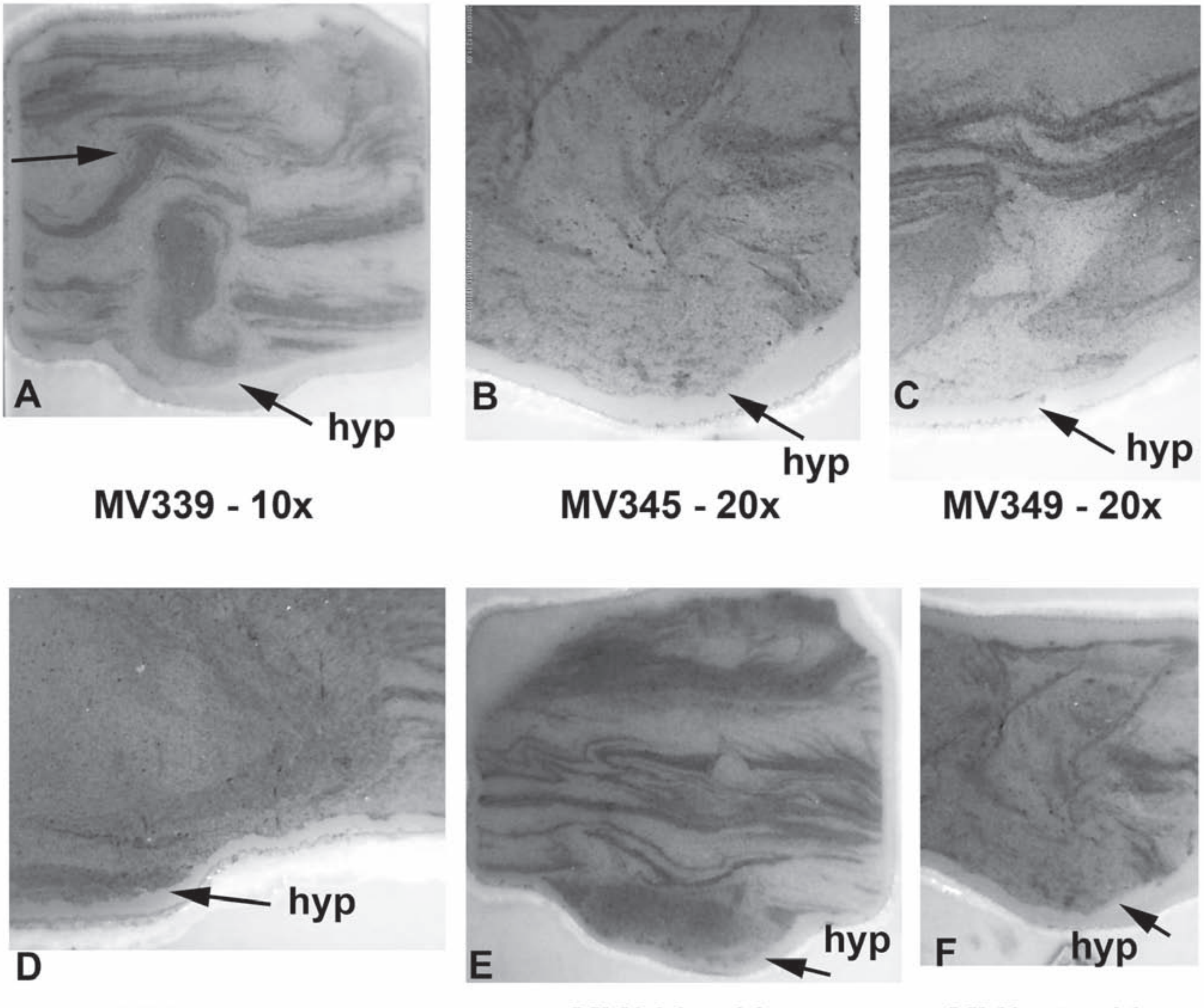


Fig. 3 - Thin sections of *Rutichnus* in Dino-Lite microscope camera. (A-F) Endichnial features are irregular deformations in the sand laminae which are curved or irregularly arranged bands forming micro-convolute structures or micro-patchy structures. Further explanations in the text.

Morphologic variations and taphonomic aspects of *Rutichnus* in endichnial and hypichnial preservations

In order to characterize the morphologic variation and taphonomic aspects of *Rutichnus rutis*, 56 samples have been analyzed (Fig. 2). The ichnospecies *R. irregularis* from the Poggio B locality has not been considered in the morphologic analysis (Tab. 1). Since each studied rock sample usually exhibits different single specimens of *R. rutis* (from 1 to 8 see column 2 in Tab. 1), a total number of 174 single structures are present at sole of calcarenitic beds (Tab. 1). They are studied in hypichnial preservation, since the endichnial structures show a strong morphologic variability and must be analyzed separately, adopting an approach that consists of the newly available Dino-Lite microscope camera. This camera obtains a continuous spectrum of photographs from 5 to 100x magnifications, and can be very useful in cases of structures that were produced by displacement of sand grains induced by burrowing. Image contrast and other settings may be enhanced by Photoshop. To study endichnial deformations numerous thin sections were produced and analyzed, oriented transversally and longitudinally (e.g. samples MV339, 345, 349, 389, Fig. 3). All studied samples are in the repository of the Biosedimentary Laboratory of Earth Science Department of the Perugia University. The deformation structures affect the lower part of a calcarenite (usually 2-3 cm in thickness from the base) but do not correspond to those preserved at the base of a bed. Endichnial features consist of irregular deformations in the sand laminae that appear as curved or irregularly arranged bands forming micro-convolute structures (sample MV339, Fig. 3A arrow). Above the concavity, which demarcates the exterior wall of a hypichnion, a characteristic cutting edges of sand laminae is present which bend upward and return gradually to flat position at the top (Fig. 3A). The core structure, which resembles a bean placed vertically in the central position, is deformed itself by the biogenic compaction during the burrowing (Fig. 3A). Laminae may show a micro-patchy arrangement (samples MV345, Fig. 3B). Vertical dislocations can be seen in the sample MV349 (Fig. 3C). Analysis by Dino-Lite camera confirms that the endichnial preservation of *Rutichnus rutis* never shows a well-defined, repetitive structure but can easily vary from case to case.

In contrast hypichnial preservation exhibits quite different characteristics such as variations in diameter, external and internal shape, wall preservation and wrinkle disposition (Tab. 1). The variability of *Rutichnus rutis* is very high, mainly in the marker level 5 (Fig. 2), where the ichnodensity is highest, reaching up to 10 specimens for a square decimetre, and decreases in other beds (see asterisks in the log of Fig. 2). The diameter of this ichnospecies is usually about 10 mm (occasionally 12 or 13 mm, Tab. 1); a narrowing of the tube has been commonly observed (7-9 mm), while expansions of tunnels (up to 15-17 mm) represent probably abortive branches (MV343, 384). In rare cases the point of expansion can be flattened (MV340, 343). External diameter appears much more constant in *Rutichnus rutis* than in *R. irregularis* that occurs in bundles and shows a complicated arrangement in hypichnial preservation.

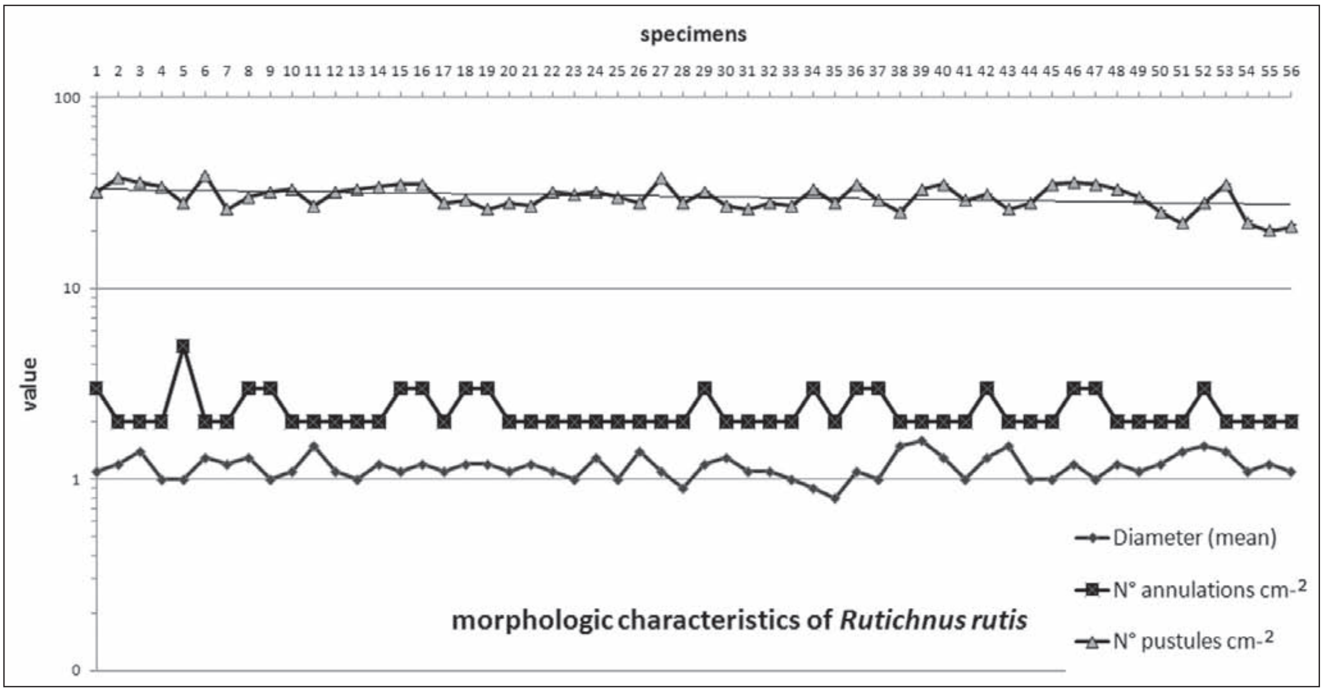


Fig. 4 - Graph showing morphologic characteristics of the endichnial *Rutichnus rutis* in 56 samples.

Samples	*Rutichnus* individuals	TF arrangement	lenght cm (mean)	diameter (mean)	N° annulations/ cm^2	distribution of pustules	N° pustoles/ cm^2	longitud. striation	type of relief	concave relief	inner wall	branching
MV324	7	radiated	2 to 5	1.10	3.00	fractal	32.00	Y	convex	Y	smooth	60°
MV325	3	radiated	2 to 4	1.20	2.00	fractal	38.00	Y	convex	-	-	80°
MV326	6	radiated	4 to 7	1.40	2.00	oriented	36.00	Y	convex	-	-	90°
MV327	1	straight	1 to 2	1.00	2.00	fractal	34.00	-	convex	-	-	-
MV328	1	straight	5	1.00	5.00	oriented	28.00	Y	convex	Y	smooth	-
MV331	5	curved	2 to 6	1.30	2.00	fractal	39.00	-	convex	Y	smooth	40°
MV332	4	branched	3 to 7	1.20	2.00	oriented	26.00	Y	convex	Y	smooth	40°-90°
MV333	3	straight	2 to 6	1.30	3.00	oriented	30.00	Y	convex	Y	irregular	40°
MV334	2	irregular	3 to 5	1.00	3.00	oriented	32.00	Y	convex	Y	smooth	-
MV335	4	irregular	2 to 3	1.10	2.00	fractal	33.00	-	convex	-	-	-
MV336	2	irregular	2 to 3	1.50	2.00	fractal	27.00	-	convex	Y	irregular	-
MV337	2	curved	8	1.10	2.00	oriented	32.00	Y	convex	Y	smooth	30°
MV338a	2	side by side	5 to 7	1.00	2.00	oriented	33.00	-	both	Y	smooth	turn
MV338b	2	straight	1 to 4	1.20	2.00	fractal	34.00	-	convex	-	-	-
MV339	6	straight	2 to 7	1.10	3.00	oriented	35.00	Y	convex	Y	irregular	-
MV340	5	branched	1 to 5	1.20	3.00	oriented	35.00	Y	convex	Y	-	90°
MV341	2	spoon-shaped	4	1.10	2.00	-	28.00	-	concave	Y	ridges	-
MV342	1	curved with ending	9	1.20	3.00	oriented	29.00	Y	convex	-	-	turn
MV343a	1	curved, enlarged	6	1.20	3.00	oriented	26.00	Y	convex	-	-	-
MV343b	2	ending, irregular	1 to 2	1.10	2.00	oriented, elongated	28.00	-	convex	-	-	flat
MV344	2	straight	2 to 8	1.20	2.00	oriented, elongated	27.00	-	both	Y	smooth	-
MV345	5	curved, aligned	3 to 4	1.10	2.00	oriented, elongated	32.00	Y	convex	-	-	turn
MV346	5	irregular	2 to 5	1.00	2.00	oriented, elongated	31.00	Y	convex	Y	irregular	40°
MV347	1	enlarged	8	1.30	2.00	oriented	32.00	Y	both	Y	irregular	-
MV348	3	curved, side by side	3 to 5	1.00	2.00	oriented, elongated	30.00	Y	both	Y	irregular	-
MV349	4	curved, side by side	3 to 8	1.40	2.00	fractal	28.00	-	both	Y	irregular	-
MV350	2	curved	1 to 2	1.10	2.00	oriented	38.00	Y	both	Y	smooth	40°

Tab. 1a, b - Main morphologic variations analyzed in 56 specimens (174 single structures) from Poggio C and B sections, Verghereto Marls Formation (Romagna Apennines).

It shows a great variation in morphology with ring-shaped structures (sample MV370, 374, Pl. 2C), which are developed in different part of a single structure. The ring arrangement in *R. irregularis* has been also shown in the study of D'Alessandro et al. (1987, figs 2-5). The shape variation of tunnels of *Rutichnus rutis* may changes varying from straight (Pl. 1C-D), displaying a winding course (Pl. 2B), or curved (Pl. 1B, H; Pl. 2A). Branching in particular is typical of 60-70% of specimens, as indicated by D'Alessandro et al. (1987), although probably may be commonly a false branching (see discussion). Tunnels usually depart at angles of 30° to 40° (Pl. 1B), reaching occasionally higher values (80° to 90° in a few specimens, Pl. 1D). The branching is commonly dichotomous. While a no preferred direction has been noted in curved and straight specimens, in up to 30% branched specimens the disposition of tunnels is roughly radial (Pl. 1H). In 25% of specimens with dichotomy, the disposition of tunnels is side by side, running tangentially with sudden changes in directions and also in diameter (e.g. sample MV324, Pl. 1L). In this case narrowing and enlargement of tube segments are frequent.

Overcrossing is another interesting aspect that has been noted in 23 samples (Tab. 1). This feature consists of superimposition of many knobby parts over smoother ones (e.g. samples MV365, 332, Pl. 1A). Usually, the lower trace fossil in the hypichnial assemblage is bent downward, overlapping to a previous one; the geometry of the tube and the shape of tunnels seem indicate original overcrossing of burrows without compactional features (e.g. sample MV365).

The ending of the tube is another very typical feature of *Rutichnus rutis*; it consists of a short and thin bulge, usually 4-5 mm wide, that expands sharply in two rings 10 mm wide, made of elongated pellets (samples MV324, 333, 362, Pl. 1E-F). The end has been found in almost 40% of samples and this feature has figured also in the holotype of the East Greenland (D'Alessandro et al. 1987). The ending structure in *Rutichnus irregularis* is similar, although much more gradual and without sharp enlargements of rings of pustules (Pl. 2E, arrow).

The outer wall surface of *Rutichnus rutis* is another very interesting aspect, with changes in their preservation (Fig. 4). Three types have been observed: (1) annulated with oriented and elongated pustules (type 1), (2) poorly annulated with casually oriented pustules (type 2) and (3) smooth to lumpy with few and scattered pustules (type 3) (Tab. 1; Fig. 4).

(1) In the type 1, annulations are well developed (Pl. 1A, B, H) and form somewhat imbricated folds 2-4 mm thick (sample MV326, Pl. 1H), with usually equidistant rings of pustules (2 - 3 rings, rarely more rings/ cm^2). In some samples, annulations are rhythmically

Samples	*Rutichnus* individuals	TF arrangement	lenght cm (mean)	diameter (mean)	N° annulations/ cm^2	distribution of pustules	N° pustoles/ cm^2	longitud. striation	type of relief	concave relief	inner wall	branching
MV351	3	spoon-shaped	2 to 4	0.90	2.00	-	28.00	-	concave	Y	smooth	-
MV352	1	ending, curved	6	1.20	3.00	oriented	32.00	Y	convex	-	-	-
MV353	3	side by side, tangential	4 to 6	1.30	2.00	fractal	27.00	-	convex	Y	irregular	-
MV354	1	spoon-shaped	4	1.10	2.00	oriented, elongated	26.00	-	convex	Y	smooth	-
MV355	4	spoon-shaped	1 to 2	1.10	2.00	-	28.00	-	concave	Y	smooth	-
MV356	3	spoon-shaped	2 to 8	1.00	2.00	oriented, elongated	27.00	Y	both	Y	smooth	-
MV357	3	side by side, tangential	2 to 4	0.90	3.00	oriented	33.00	-	convex	-	-	-
MV358	1	straight	5	0.80	2.00	-	28.00	-	concave	Y	irregular	-
MV359	4	curved, branched	4 to 6	1.10	3.00	fractal	35.00	-	convex	-	-	50°
MV360	1	straight	8	1.00	3.00	oriented, elongated	29.00	Y	both	Y	irregular	side
MV361	1	enlarged	5	1.50	2.00	oriented, flattened	25.00	-	convex	-	-	-
MV362	3	spoon-shaped, ending	3 to 5	1.60	2.00	oriented	33.00	Y	convex	Y	smooth	-
MV363	7	ending, irregular	2 to 6	1.30	2.00	oriented, elongated	35.00	Y	convex	Y	smooth	40*
MV364	1	irregular	4	1.00	2.00	oriented	29.00	-	concave	Y	smooth	-
MV365	6	spoon-shaped, ending	1 to 4	1.30	3.00	oriented, elongated	31.00	Y	convex	Y	smooth, ridges	20°
MV366	3	spoon-shaped, ending	2 to 5	1.50	2.00	oriented, elongated	26.00	Y	convex	Y	smooth	turn
MV367	3	smooth, irregular	5 to 7	1.00	2.00	-	28.00	-	concave	Y	smooth	30°
MV368	5	side by side, tangential	3 to 10	1.00	2.00	oriented, elongated	35.00	-	convex	Y	smooth	30°
MA73	2	curved	3 to 5	1.20	3.00	fractal	36.00	Y	convex	Y	smooth	30°
MV376	8	irregular	3 to 10	1.00	3.00	oriented, elongated	35.00	-	both	Y	irregular	30°
MV377	3	curved, ending	6 to 9	1.20	2.00	oriented	33.00	Y	convex	-	-	40°
MV378	9	curved, ending	3 to 10	1.10	2.00	oriented, elongated	30.00	Y	both	Y	irregular	-
MV379	2	straight	2 to 7	1.20	2.00	smooth prevalent	25.00	-	convex	-	-	-
MV380	2	curved	8 to 10	1.40	2.00	smooth prevalent	22.00	-	both	Y	smooth	50°
MV381	3	straight	4 to 6	1.50	3.00	fractal	28.00	-	both	Y	smooth	-
MV382	3	curved, branched	4 to 8	1.40	2.00	oriented, elongated	35.00	Y	convex	Y	smooth	70°
MV383	3	curved, ending	3 to 5	1.10	2.00	irregular	22.00	-	both	Y	irregular	-
MV384	2	branched, ending	4 to 7	1.20	2.00	irregular	20.00	-	both	Y	smooth	30°
MV385	1	curved	7	1.10	2.00	irregular	21.00	-	convex	-	-	-
	Total: 174											

arranged showing thickest rings alternated with thinner ones (see sample MV324, Pl. 1B). In some specimens rings are obliquely arranged (e.g. sample MV326, Pl. 1H). The distribution and shape of pustules in type 1 are variable: in the majority of analyzed forms (70%), pustules are elongated and oriented orthogonally to annulations, while in few cases (30%) they are short even if oriented (Pl. 1A, F, arrows).

(2) In the type 2, annulations are very poorly developed and pustules are never oriented, usually knob-shaped and larger than type 1 (up to 1 mm thick, samples MV333, 334, 345, 365, Pl. 1E, G, L); in many cases they appear with different sizes producing a fractal disposition (up to 80%).

(3) In the type 3, the outer wall surface is usually fairly smooth and suddenly becomes lumpy with few and scattered knobs (Pl. 2A, B). The outer wall surface of type 3 resembles the exterior surface of *Spirophycus bicornis*, although the spiral whorl forming a convolute ring has never been found in the studied specimens from the Verghereto area (Monaco & Checconi 2008).

The three types may occur in the same sample. Occasionally a transition from type 1 to type 3 has been observed in the same sample (e.g. MV332, Pl. 1A), as gradual transitions from type 1 to type 2 and vice versa can exist (sample MV324, Pl. 1B). In all three types the number of pustules for square centimetre has been measured, even if the measure is easier in type 1 and type 2 than in the other type (Tab. 1). The analysis indicates values of 21 to 38 pustules/cm^2, with 5 to 7 pustules of type 1 that occur in the same line; frequently, the arrangement of pustules in type 1 produces elongated and oriented lines of pustules that are concentrated in 3 rings/cm^2 (Tab. 1). In other specimens they are arranged in two rings/cm^2. In all these cases longitudinal alignments have been observed showing a high degree of regularity. An alignment has never been observed in the type 3.

The distribution of relief (full or semi-relief) has also been analyzed: in the 66% of studied samples *Rutichnus rutis* occurs in convex full relief, while in 33% of samples it appears in concave semi-relief. Both types of preservation can be present in the same sample and usually they are randomly distributed (50%). In the hypichnial concave semi-relief a spoon-like shape (samples MV334, 341, 351, 354, 355, 362) frequently occurs with the interior wall surface usually smooth (about 60% of samples; Pl. 1I).

Longitudinal ridges in the hypichnial concave semi-relief are other very peculiar features. They are 3 to 5 short ridges, 0.2-0.3 mm thick, parallel oriented into direction of the tracemaker locomotion (see sample MV341, 365, Pl. 1I, arrow). These parallel ridges are enigmatic structures, probably produced during the contractions of the body of the animal; however, it cannot be excluded that they were formed by a wormlike organism during the movement by anchoring or elongation (D'Alessandro et al. 1987). When these ridges are present, an irregular development of interior wall surface can also occur (samples MV349, 368, 376). As the rule an unstructured mud infilling is present that rarely shows longitudinal striations (samples MV332, 333, 339, 345, 354, 378, Pl. 1M). The sectioned meniscate interior is very poorly preserved in the studied specimens of the Verghereto Formation (only three doubtful cases, samples MV356, 367, 381), while it has been commonly found in holotype specimen from East Greenland (D'Alessandro et al. 1987, fig. 7). The poor preservation of menisci in the Apennine specimens resulted probably from diagenetic processes that destroyed the meniscate structures or by the infilling of the gray mud that hides this structure.

Discussion and conclusions

A model for the mode of construction of *Rutichnus* structures has been inferred by D'Alessandro et al. (1987). These authors classify *Rutichnus* as a postdepositional feeding structure produced by a worm-like deposit feeder organism, that constructed and reinforced tunnels during their feeding activity in many steps of repeated forward and backward body movements. The meniscate structures represent different phases of anchoring and elongation of the body; menisci in studied specimens of Verghereto are very poorly preserved, so it is difficult to understand their origin.

On the contrary, the branching is a more clear feature than menisci. In the sketch with a sectional view of *Rutichnus rutis* D'Alessandro et al. (1987, fig. 8) show the structure of branching, indicating that it is not typical as the case of many other trace fossils (e.g. *Thalassinoides*, crustaceans), but develops as a false branching with overcrossing of a different tunnel. Usually, the new tunnel departs at the branching point forming a different direction and their external wall cuts the previous burrow. This fact is evident in the figure 9 of the same authors where a false branching is clearly visible in the centre of the photograph. The false branching may be really a normal structure in *Rutichnus rutis* when a changing in direction occur, as observed in many of 22 specimens from the Verghereto study (see Pl. 1B, Tab. 1).

The mode of construction of external ornamentation is another important element; it was not considered in detail by cited authors, although the anchor pressure of the soft body may produce irregularities of the outer surface and ornamentation, mostly during the backward movement. These cited authors in their historical treatment compared *Rutichnus* to other trace fossils mostly in respect to branching, meniscate and walled aspects, but without showing the meaning of morphologic variations in *Rutichnus* and the mode of the wall exterior fabrication. This latter aspect is fundamental for understanding the ethology of wall construction, as in the case of some hypichnial nereitids (*Dreginozoum* preservation, Seilacher 2007), where the burrow exterior shows remarkable similarities with that of *Rutichnus*. Concerning the mode of construc-

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PLATE 1

Hypichnial preservation and morphologic variations of the trace fossil *Rutichnus rutis*, Poggio C (Verghereto Marls Formation). (A) Overcrossing of Type 1 (annulated with oriented and elongated pustules) over type 3 (and lumpy with scattered pustules), sample MV332; (B) false branching in walled specimens of type 1; note rhythmically arranged rings of pustules showing thickest rings alternated with thinner ones, sample MV324; (C) poorly annulated specimen with poorly oriented pustules (type 2), sample MV345; (D) some specimens with different preservation of rings of pustules; note imbrication (arrow), sample MV340; (E) different specimens with small pustules that show fractal arrangement (lower arrow) and end of trace (upper arrow), sample MV333; (F) detail of a end with sharp change in diameter (arrow), sample MV362; (G) specimens showing inner concave (black arrows) and outer convex (white arrow) wall surface with widening and irregular pustules; note elongated, parallel ridges in inner wall surface (lower arrow), sample MV334; (H) radiated, annulated specimens with imbricated folds of oriented pustules, sample MV326; (I) inner wall surface of concave specimens with smooth surface and parallel ridges (arrow), sample MV341; (L) tangentially oriented specimens with short ends, sample MV365; (M) specimens with mud fill and longitudinal striae (arrow), sample MV378.

PLATE 2

Hypichnial preservation and morphologic variations of *Rutichnus rutis* and *R. irregularis* trace fossils, Poggio C (Verghereto Marls Formation). (A-B) The outer wall of *R. rutis* type 3 is usually fairly smooth and suddenly becomes lumpy with scattered knobs; note poorly developed annulations in B, samples MV342 and 359; (C-D) specimens of *Rutichnus irregularis* with characteristic central ring (r), sample MV370; (E) irregular arrangement of a dubious specimen of *Rutichnus irregularis*?, sample MV373; (F) massive, irregular occurrence of pustules (patchwork) of *Rutichnus* cf. *irregularis*, sample MV372.

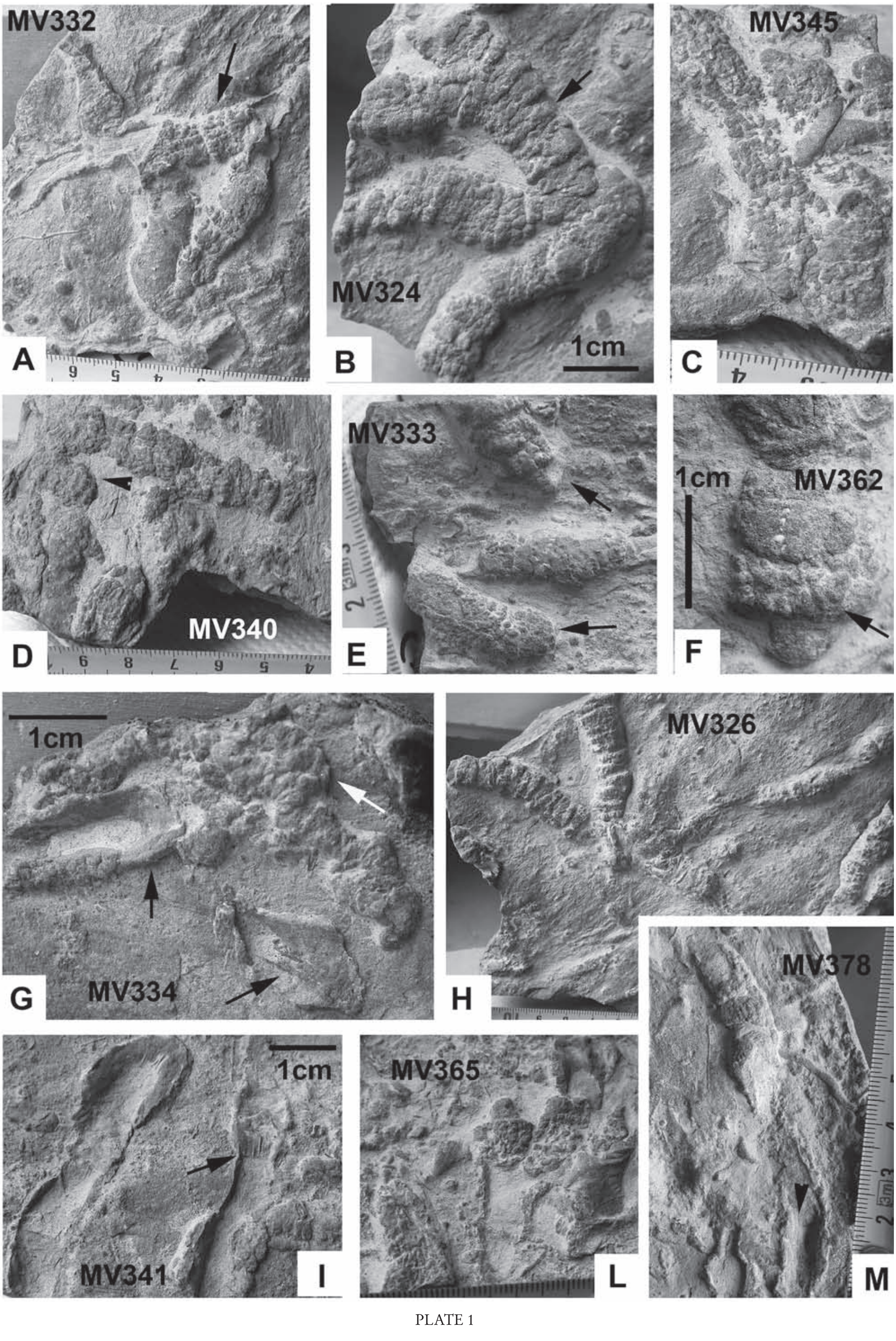
MV332
A
MV324
1cm
B
MV345
C
D
MV340
MV333
E
1cm
MV362
F
1cm
G
MV334
MV326
H
MV378
M
1cm
MV341
I
MV365
L

PLATE 1

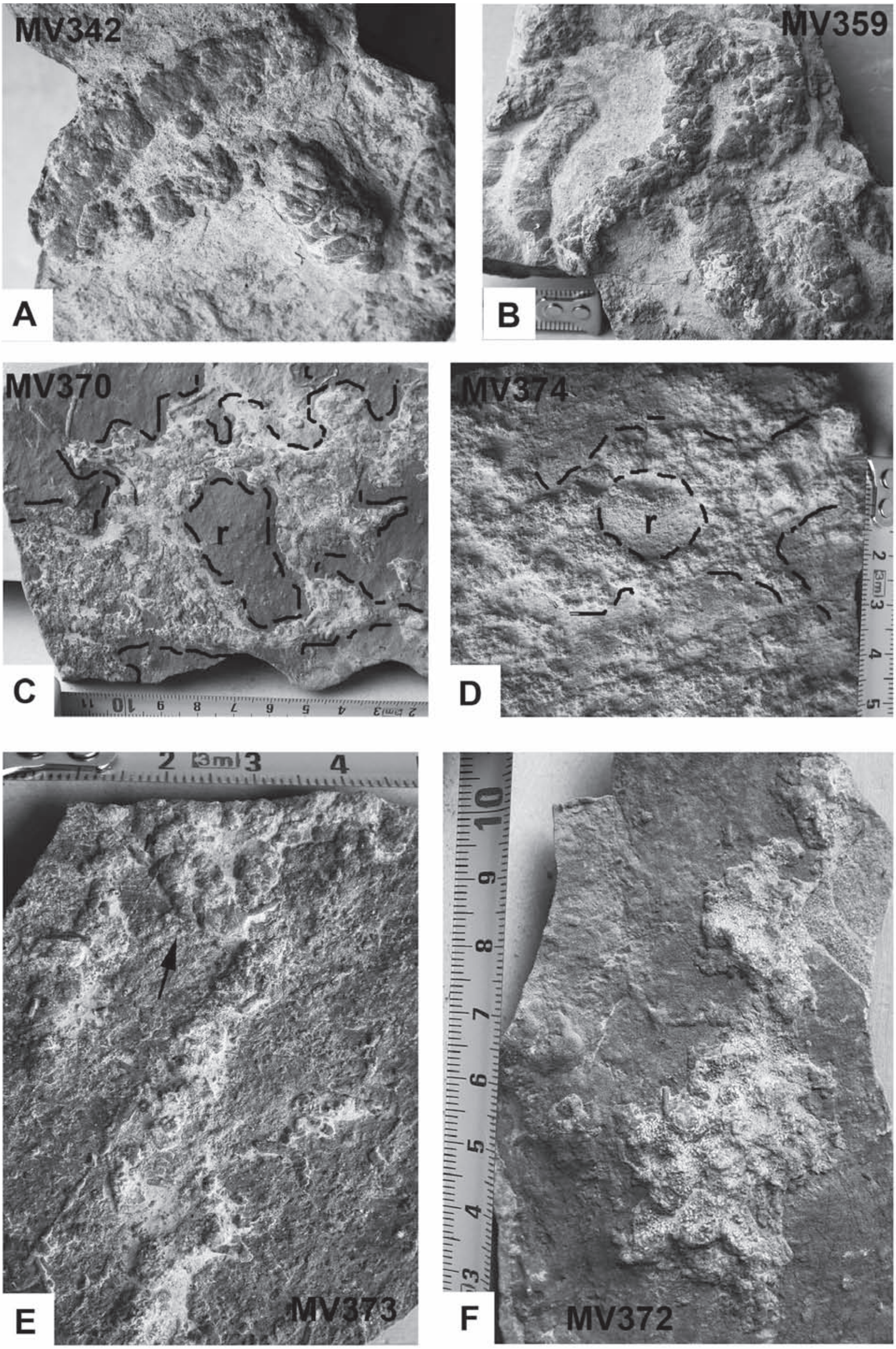

PLATE 2

tion of nereitids, Seilacher (2007) suggested that the annelid worm can remove the sediment in front but not by radial emersion of a voluminous proboscis, but rather probing and backfilling the rejected sediment laterally around the body. The cited author indicated that it is possible for the worm by bending the head with small proboscis in different directions and at regular intervals producing oriented pellets. Arthropods are excluded by cited author because faecal pellets are nearly the size of the body of the worm. In the case of *Rutichnus* from the Verghereto area it is not clear if the material is effectively faecal because it is highly variable in size and distribution, frequently fractal (see three types indicated above), and pellets are smaller than the size of the body. The parallel ridges in the concave wall interior, which are impressed also in the mud fill, are similar to scratch marks produced by arthropods (Curran 2007; Giannetti et al. 2007). The absence of meniscate structures and the high variability in shape and regularity of pellets distribution suggest that arthropods are not excluded, although a worm-like deposit feeder could be most probably the tracemaker.

Another aspect that should be discussed concerns the causes of unusual abundance of *Rutichnus* at the lower sand/mud interface (hypichnial position) of thicker beds when also strong endichnial activity is common. The most concentration of specimens occur in such beds (3 to 5 cm thick) that exhibit most abundant endichnial structures, indicating an intense burrowing perhaps at different tiers in the sand (intense postdepositional activity); on the contrary, in thinner beds (of 1 to 2 cm) the concentration of *Rutichnus* decreases abruptly (few and scattered specimens) and endichnial activity is shallow and rare; in this case other trace fossils prevail such as graphoglyptids (e.g. *Desmograpton)* and plug-shaped forms. In any case, may be excluded the role of erosion induced by turbidity currents that probably was irrelevant and did not involve *Rutichnus* tracemakers. It is worthy to point out that this ichnogenus was never found in any other parts of the Marnoso-arenacea Basin, while locally becomes extremely abundant, as at the transition to the Verghereto High, when marginal, cm-thick calcarenites were deposited (Milighetti et al. 2009; Monaco et al. 2009). The unusual abundance can be due to the availability of a large amount of organic matter and bio- or phytodetritus that could be accumulated rapidly by thin gravity flow inducing an unusual proliferation of deposit feeders (Lutz et al. 2007; Uchman 2007; Wetzel 2010). Sudden fluctuations in the organic matter on the sea floor and changes in detritus abundance induced effects on the benthic habitats as pointed out by Wetzel (2010), reflecting differences in the trace fossil distribution. In several beds we can observe up- and downward shifting of tunnels with overcrossing of many parts of *Rutichnus*, with sharp changes in direction, in thickness and in morphology at lower surface of beds. This has been observed also in endichnia where different types of sand laminae deformations occur. This trace fossil arrangement seems reflect a frenzied behaviour of opportunistic animals during a very short time, perhaps arthropods or worms, probably transported directly by low-density gravity flows; in this case, the survival of such animals during transport and deposition from nearby areas could not be excluded. In this case calcarenites may not represent a typical distal flow deposit but could be material coming directly from proximal areas. Unfortunately, there are no physical evidences (e.g. tool marks) to validate this hypothesis and remains the open question how to estimate the effects of currents on the distribution of organic matter that surely had to be present along the slopes of the Verghereto High. Ripples at top of calcarenitic beds with widely developed epichnial *Nereites missouriensis* and *Scolicia prisca* (or *S. vertebralis*) suggest that concentrations in the organic matter persisted even at the top of beds.

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