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Taphonomy and ichnofabric of the trace fossil *Avetoichnus luisae* Uchman & Rattazzi, 2011 in Paleogene deep-sea fine-grained turbidites: examples from Italy, Poland and Spain

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ABSTRACT - The poorly known, helical spiral trace fossil Avetoichnus luisae *Uchman & Rattazzi, 2011 has been investigated in fine-grained Paleogene turbidites in Italy, Poland and Spain. It shows a typical stratinomic preservation as endichnia and was developed in turbiditic mud and bioclastic deposits occupying the upper intervals (typically E3-F) of turbidite sequences. Other ichnotaxa occur in deeper levels (e.g.,* Alcyonidiopsis *and* Zoophycos *in the Trasimeno area), while tree-like forms (e.g.,* Chondrites intricatus, C. targionii *and* Cladichnus *in the same area), string-like forms (e.g.,* Planolites *or* Palaeophycus*) and other undetermined burrows are usually found in shallower levels. The distribution of the ichnotaxa indicates an upwards increasing ichnodensity towards the higher intervals in many mud-bioclastic turbidite sequences. Detailed taphonomic analysis of 104 specimens of frequently branched* Avetoichnus luisae *has shown that a high degree of variation can be observed in their length, general shape, maximum diameter, maximum width of dots, shape of dots, dot distribution, spiral arrangement, central part (axis) and raised edges. These variations suggest that an unknown organism adjusted its activity (agrichnial or fodinichnial) using different strategies in accordance with changes in the turbiditic environment.*

RIASSUNTO - [Tafonomia e ichnofabric della traccia fossile *Avetoichnus luisae* Uchman & Rattazzi, 2011 in torbiditi fangose del Paleogene: esempi dall'Italia, Polonia e Spagna] - *Nel presente lavoro vengono esposti i risultati di una dettagliata indagine tafonomica di una traccia fossile poco conosciuta, a geometria elicoidale e spiralata, classificata* Avetoichnus luisae *Uchman & Rattazzi (2011). A livello stratinomico questa traccia, molto abbondante in torbiditi paleogeniche fangose in Italia, Polonia e Spagna, mostra una tipica preservazione endichnia ed è stata rinvenuta negli intervalli superiori (nella fattispecie E3-F) di una tipica sequenza torbiditica fangoso-bioclastica. Ichnotaxa del tutto differenti colonizzano livelli più profondi (es.* Alcyonidiopsis *e* Zoophycos *nell'area del Trasimeno), mentre forme ramificate (es.* Chondrites intricatus, C. targionii *e* Cladichnus *nella stessa area), a stringa (es.* Planolites *o* Palaeophycus*) ed altri burrows di dubbia attribuzione appaiono in livelli via via più superficiali. In molte sequenze analizzate, la distribuzione degli ichnotaxa mostra un progressivo incremento dell'ichnodensità verso gli intervalli sommitali di una torbidite. L'analisi tafonomica di dettaglio svolta su 104 campioni di* Avetoichnus luisae *provenienti da Italia, Spagna e Polonia, frequentemente ramificati, ha messo in evidenza un alto grado di variabilità soprattutto per quanto riguarda la morfologia: lunghezza, forma e diametro massimo della traccia, massima ampiezza delle chiazze scure, loro forma e distribuzione (opposte o alternate), assetto della spirale, porzione centrale (asse) e bordi rialzati. Queste variazioni indicano come l'organismo (sconosciuto) produttore di* Avetoichnus luisae *fosse in grado di adattare le sue attività (agrichnia o fodinichnia) usando differenti strategie in funzione dei cambiamenti dell'ambiente torbiditico nel quale si trovava. Lo studio tafonomico di* Avetoichnus luisae*, importante da un punto di vista ichnologico e geochimico, fornisce importanti indicazioni sui contesti deposizionali e ambientali in cui si depositavano le torbiditi fangoso-bioclastiche.*

INTRODUCTION

The mid-tier trace fossil *Avetoichnus luisae* Uchman & Rattazzi, 2011, which appears as a horizontal or sub-horizontal helical spiral with a central core in fine-grained deep sea Cainozoic sediments of the Alpine realm in Italy, Spain, Turkey and Poland, is useful to characterize a new type of ichnofabric in mud to silt clastic turbidites (see O'Brien et al., 1980; Piper & Stow, 1991). The upper portion of these deposits exhibits commonly small but relevant ichnotaxa, including *Avetoichnus luisae*, that occupy different levels, providing information on benthic communities (Rodríguez-Tovar et al., 2011). In the Trasimeno area of central Italy, this form is very abundant in Paleogene deep sea deposits and has been previously considered as a doubtful variation of *Nereites* in the abyssal *Nereites* ichnofacies, which characterizes the distal Scaglia Toscana Formation of western Umbria (Monaco & Uchman, 1999; Piccioni & Monaco, 1999). Recently, Uchman & Rattazzi (2011), using new material from the Northern Apennines (Aveto Formation), Poland (Bystrica Formation, Carpathians), Spain (Bilbao and Zumaia) and Turkey (Sinop Basin, Pontides), have re-interpreted this ichnotaxon as a non-graphoglyptid, mid-tier, complex agrichnion in calcareous and sparsely calcareous deep-sea sediments.

The new material containing *Avetoichnus luisae* collected from the Trasimeno area (Umbria, central Italy) and other areas (Aveto, northern Italy, northern Spain and Carpathians) allows better definition of many taphonomic variations and some typical morphologic characteristics. The taphonomic analysis has been made in those specimens which are selected from the best preserved material. Ichnofabric analysis provides new indications concerning fine-grained turbidite deposits in different geological settings.

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GEOLOGICAL SETTING

Avetoichnus-bearing material in the Trasimeno area (Northern Apennines, Fig. 1) consists of deep-sea sediments belonging to a very complex depositional system of Late Cretaceous-Early Oligocene age, known on a regional scale as the Scaglia Toscana Formation (Merla & Abbate, 1967), Scisti Policromi (Fazzuoli et al., 2002 and references therein) or Argilloscisti Varicolori in western Umbria (Principi, 1924; Damiani & Pannuzi, 1982; Piccioni & Monaco, 1999). Other members and subdivisions (see Fazzuoli et al., 2002) have been introduced in the literature to explain very great lithological differences in the Northern Apennines. In the Trasimeno area, lithology of the Argilloscisti Varicolori is highly variable (Principi, 1924; Damiani & Pannuzi, 1982; Piccioni & Monaco, 1999), including limestones, marly limestones, variegated marls (yellow, reddish, black to green, often rhythmically arranged), turbidites (from coarse- to fine-grained) and dark shales (Damiani & Pannuzi, 1982; Damiani et al., 1989; Piccioni & Monaco, 1999). At M. Solare, the most complete section, thick-bedded limestones dominate in the lower portion (early-middle Eocene), fine-grained turbidites dominate in the middle-upper part (middle Eocene, P10-P12 zones), while shales increase gradually upwards in the middle-late Eocene (Piccioni & Monaco, 1999). These lithological differences have been found also in northernmost Tuscany (e.g., Chianti) (Canuti et al., 1965; Bortolotti et al., 1970; Fazzuoli et al., 1996), in the Falterona-Cervarola-Trasimeno Basin (Boccaletti et al., 1986) and towards the Marchean Apennines (Centamore et al., 1986). Very abundant calcareous turbidites, polymictic breccias and debris flow deposits with neritic bioclasts indicate provenances from nearby ridges and intrabasinal highs implying an eastern provenance in the Tuscan Domain and western provenance in the Umbrian Domain (Canuti et al., 1965; Centamore et al., 2002). Studied sections

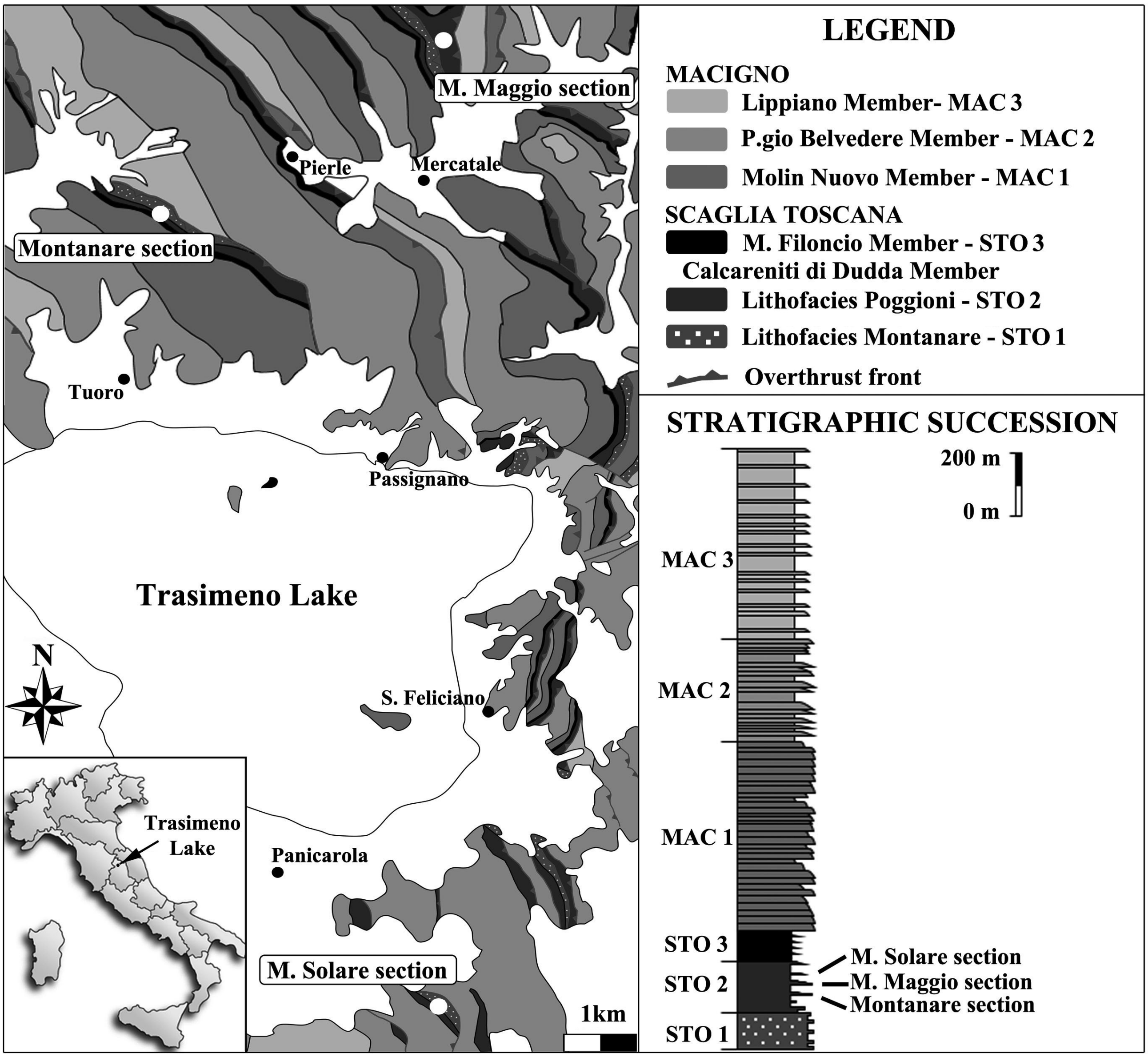

Fig. 1 - Study area and stratigraphy in the Trasimeno area.

crop out in quarries, such as M. Solare (N43°04'36.18; E12°14'85.36) and M. Buono (Fornaciari quarry, N43°07'08.50; E12°18'99.18), among other localities, M. Maggio (N43°28'36.41; E12°14'54.61), Passignano (N43°18'13.82; E12°17'37.69) and Montanare (Scanizza, N43°24'91.65; E12°07'08.31). Sedimentological, biostratigraphical and ichnological analyses were based at M. Solare (Monaco & Uchman, 1999; Piccioni & Monaco, 1999) or other nearby areas (Damiani & Pannuzi, 1982; Milighetti et al., 2009; Trecci & Monaco, 2011) and are useful to characterize geological aspects in southeastern Tuscany and western Umbria. For geological settings of the other localities considered in this study (e.g., Aveto area, northern Italy, Carpathians, Poland and Spain) the works of Uchman & Rattazzi (2011), Rodríguez-Tovar et al. (2011) and Rodríguez-Tovar & Uchman (in press) are recommended.

MATERIAL AND METHODS

The studied material with *Avetoichnus luisae* comes from the Scaglia Toscana in the Trasimeno area (M. Solare = MSOL, Montanare = MONT, M. Maggio = MMAG), Aveto area of the Northern Apennines (Aveto-M. Pescino-Cattaragna = AV-MPESC-CAT), Basque country (Bilbao = BILB and Zumaya = ZUM) and Bystrica Formation of the Carpathians (CARP) (Tab. 1). The taphonomic analysis of this ichnotaxon has been performed analyzing ten morphological characteristics in 104 specimens, which are selected for their good preservation (dark colour) in limestones among other incomplete forms (Figs 2-3). Some of these 104 forms were also studied with Dino Lite digital microscope camera at 8 to 200 magnification to enhance the spiral arrangement and variations in preservation. Taphonomic analysis allows recognition of important morphologic variations of these trace fossils which were marginally considered in literature. In previous studies, the ichnofabrics within the fine-grained turbidites were analyzed, but without considering internal subdivisions of laminae (Stow & Piper, 1984b; Piper & Stow, 1991). Endichnia and epichnia were investigated in the upper, strongly bioturbated layer while the coarser-grained lower layer (if present), being poorly (or not) bioturbated, was considered marginally, being mainly focused on hypichnia. The main method in determining the ichnodensity (the trace fossil density) of each sampled bedding plane was calculated using diagrams for visual estimation of grains (Baccelle & Bosellini, 1965), modified and adapted for fossils or trace fossils (Monaco, 1999; Monaco et al., 2009a). This allows to estimate a percent of elements of different shapes that can be found in a square grid of 10 cm^2. This method for ichnodensity is simpler than that applied by other authors (e.g., Cummings & Hodgson, 2011) and is easy in muddy turbidites due to different (darker) colour of traces in respect to the (lighter) host sediment. The ichnodensity (ICD) was measured, following standard methods in facies analysis (Droser & Bottjer, 1991, 1993; Monaco, 1994; Monaco et al., 1994, 2012; Heard & Pickering, 2008; Wetzel et al., 2008; Cummings & Hodgson, 2011; Trecci & Monaco, 2011). Values range from poor (1), to moderate (2), high (3) and very high (4) or mottled (5) (Fig. 4). In the 126 m thick, well preserved M. Solare section, *Avetoichnus*-bearing beds constitute 30-40% of the total number of density-current flow deposits. *Avetoichnus*-free deposits include limestones, marly limestones, shales, coarse-grained sands and pebbly rudites (debris flows) (Piccioni & Monaco, 1999) and are not considered in this study. *Avetoichnus*-bearing beds contain additional ichnotaxa that are useful to characterize ichnofabric (Uchman, 1998). In many cases, individual ichnotaxa are not recognizable because high ichnodensity results in mottling (Fig. 4). Two types of assemblages may be recognized: a) deep ichnoassemblage (DI) and b) shallow ichnoassemblage (SI). Usually, the base of the DI is partially preserved when the coarse grains of the lower part are present (e.g., abrupt transition from coarse sand to silt and mud).

TAPHONOMY OF *AVETOICHNUS LUISAE*

General description

The trace fossil *Avetoichnus luisae* consists of a thin (3 to 6 mm in diameter) and short (12 to 50 mm, exceptionally up to 62 mm long) structure, horizontally or sub-horizontally visible on parting surfaces in the fine-grained part of bioclastic turbiditic beds. It exhibits two rows of oval, sub-circular or fin-shaped dots, 1 to 2.5 mm in diameter, in alternating or opposite positions along a presumed axial tube (called axis, not always preserved, see Fig. 3). The outer margin of dots can be irregular. The axis is straight or curved and may be bounded by two parallel lines in a central position (Pl. 1, fig. 8). It is seldom preserved and preparatory cross sections show the axis truncating the helical spiral (Uchman & Rattazzi, 2011, fig. 5). Winding of the helical spiral string in up to 20 whorls has been supposed by these authors to explain the alternate position of dots around the central axis. Horizontal spiral arrangement has been found in many other similar ichnotaxa including *Helicolithus* Azpeitia-Moros, 1933, *Helicodromites* Berger, 1957, *Helicorhaphe* Książkiewicz, 1970, *Helicoichnus* Yang in Yang et al., 1982 (see discussion in Uchman & Rattazzi, 2011). Previous stratinomic works in the Trasimeno area did not recognize this spiral arrangement and those specimens were ascribed to the *Nereites* group (Monaco & Uchman, 1999; Piccioni & Monaco, 1999; Monaco & Caracuel, 2007; Monaco & Checconi, 2008); they are now included in the ichnospecies *Avetoichnus luisae*.

Taphonomy

Taphonomic analysis has been performed on 104 specimens, involving different parts of the same trace fossil (Tab. 1). Forms are easily recognizable by the contrasting colour in respect to the host rock, which is usually of a light colour. The trace fossil ranges from black (Polish specimens) to dark gray (Aveto), dark red or greenish (Trasimeno), to brownish or light yellowish (Spain). The typical aspect at first glance is a zig-zag shape in horizontal section, but detailed analysis indicates that the general shape, spiral arrangement and dot distribution (dots being sections of the whorls of the spiral) can produce different aspects (Fig. 3). The typical morphologic parameters which are analyzed in this study are: a) trace fossil length, b) maximum diameter of burrow,

Samples	t.f. length (mm)	t.f. ø max. (mm)	t.f. shape	dot ø (mm)	dot shape	spiral arrang.	dot disposit.	central axis	raised edges	branching
AV P1270282	22	2.5	straight	1	sub-quadrangular	regular	opposite	partial	no	no
AV P1270298	18	2	curved	1.3	round	regular	opposite	no	no	no
AV P1270332a	25	2.2	curved	1.2	fin-shaped	regular	alternate	yes	no	no
AV P1270332b-b’	22	2.2	straight	1.2	sub-quadrangular	regular	opposite, alternate	partial	no	45°
AV 1ab	23	2.3	straight	1.2	sub-quadrangular	regular	opposite, alternate	yes	no	?
AV 2a	33	2.5	curved	1.3	sub-quadrangular	helical	alternate	no	no	no
AV 2b	16	3	straight	1.7	round	regular	alternate	no	no	no
AV 5045a	68	2	straight	1.2	sub-quadrangular	regular	alternate	partial	no	45°
AV 5045b	22	2	curved	1.2	sub-quadrangular, fin-shaped	regular	opposite	partial	no	45°
AV 5060	45	2	straight	1	sub-quadrangular, fin-shaped	displaced	opposite	yes	yes	no
AV 5062	12.5	3.8	straight	1	fin-shaped	irregular	alternate	no	no	no
AV 5151	12	2	curved	1	round, fin-shaped	irregular	alternate	no	partial	no
AV 6276a	35	3	curved	1.8	fin-shaped	regular	opposite	yes	no	45°
AV 6276b	30	3	curved	1	fin-shaped	irregular	opposite, alternate	yes	no	no
AV 6601	25	3	curved	1.5	sub-quadrangular, fin-shaped	regular	opposite	partial	no	no
AV 6630a	22	2.5	straight	1.8	round	v. regular	opposite	partial	no	?
AV 6630b	6	3.2	straight	1.8	sub-quadrangular	dsplaced	opposite	no	no	?
AV 6631a	12	3.2	curved	1.2	fin-shaped	regular	opposite, alternate	partial	no	45°
AV 6631b	11	3	straight	1	fin-shaped	displaced	alternate	no	no	no
AV 6632	60	2.5	long & meander	1	round	v. regular	alternate	partial	partial	45°?
AV 6633	55	2	curved	1	round	regular	alternate	yes	no	?
AV 6685a	30	4	straight	1.5	sub-quadrangular	irregular	opposite, alternate	yes	no	90°
AV 6685b	17	3	straight	1.2	sub-quadrangular	r. stretched	alternate	yes	no	no
AV 6687	14	3	curved	1.3	fin-shaped	irregular	opposite	no	no	45°?
AV 6690	7	2	curved	1	hook-shaped, sub-quadrangular	irregular	alternate	yes	no	no
MPESC 6724	55	6	curved	1.4	round	irregular	alternate	partial	partial	90°
MPESC 6725	11	4.2	three-dimens.	1	fin-shaped	irregular	alternate	?	partial	no
CAT 6772a	45	2,3	curved	1	round, fin-shaped	v. irregular	opposite, alternate	yes, abrupt	no	no
CAT 6772b	23	3.5	straight, angle	1	sub-quadrangular	regular	opposite, alternate	yes, large	no	45°
MSOL 410a	52	3	long & curved	1	round, fin-shaped	regular	opposite, alternate	yes	no	?
MSOL 410b	12	3,2	straight	1	round, fin-shaped	regular	opposite	yes, large	no	no
MSOL 411	35	6	straight, angle	2	round	regular	opposite, alternate	no	yes	no
MSOL 412	42	6	straight	2	round, fin-shaped	displaced	opposite, alternate	no	no	no
MSOL 413	40	6.2	straight	2	round	displaced	opposite, alternate	triserial?	yes	45°
MSOL 414a	42	5	straight	2.2	round	r. displaced	opposite, alternate	no	P.-like	45°
MSOL 414b	24	6	branched?	2	round	displaced	alternate	no	P.-like	45°
MSOL 414c	35	5	slightly curved	2	fin-shaped	displaced	opposite, alternate	no	P.-like	45°
MSOL 414d	20	5	branched?	2	fin-shaped	displaced	opposite, alternate	no	P.-like	45°
MSOL 414e	40	4	straight	1	fin-shaped	displaced	opposite, alternate	no	no	no
MSOL 415a	22	5	straight	1	fin-shaped	displaced	opposite, alternate	no	no	no
MSOL 415b	25	4	curved	1	round, fin-shaped	displaced	opposite	no	no	no
MSOL 415c	15	6	curved	2	round	displaced	alternate	triserial?	no	no
MSOL 415d	15	6	curved	1.5	sub-quadrangular	displaced	alternate	triserial?	no	no
MSOL 416a	28	5	slightly curved	2.3	round	displaced	alternate	no	yes	?
MSOL 416b	75	8	long & curved	2.5	round	v. irregular	opposite, alternate	triserial?	yes	no
MSOL 417	23	6	slightly curved	2.5	round, sub-hexagonal	regular	opposite, alternate	no	P.-like	no
MSOL 418	25	6	slightly curved	1.5	round, sub-hexagonal	regular	alternate	no	P.-like	45°
MSOL 419a	22	6	slightly curved	1.5	round, sub-hexagonal	regular	alternate	no	P.-like	no
MSOL 419b	20	6	slightly curved	1.5	round, sub-hexagonal	regular	alternate	no	P.-like	no
MSOL 420a	35	6	straight, angle	1.5	round, sub-hexagonal	regular	alternate	no	P.-like	90°
MSOL 420b	25	5	slightly curved	1.5	round, sub-hexagonal	regular	alternate	no	P.-like	90°
MSOL 421a	12	5	straight	1.5	sub-quadrangular	regular	opposite	yes	no	90°

Tab. 1 - Chart showing taphonomic characteristics of 104 specimens from Italy, Poland and Spain. t.f. = trace fossil; ø = diameter; arrang. = arrangement; disposit. = disposition; v. = very; r. = regular; ir. = irregularly; P. = *Paleodictyon*.

Samples	t.f. length (mm)	t.f. ø max. (mm)	t.f. shape	dot ø (mm)	dot shape	spiral arrang.	dot disposit.	central axis	raised edges	branching
MSOL 421b	25	6	straight, angle	2	round	displaced	opposite, alternate	no	P.-like	90°
MSOL 422	30	6	straight	2	sub-quadrangular, fin-shaped	regular	really opposite	yes	no	45°
MSOL 423	35	6	straight	2.5	round, sub-hexagonal	regular	alternate	no	P.-like	no
MSOL 424a	20	5	straight	2	round, sub-hexagonal	regular	alternate	no	no	no
MSOL 424b	25	6	straight, angle	2.5	round, sub-hexagonal	r. displaced	opposite, alternate	no	P.-like	no
MSOL 425	22	6	straight, angle	2.5	round, sub-hexagonal	regular	alternate	no	P.-like	no
MSOL 426	20	6	straight, angle	2.5	round, sub-hexagonal	regular	alternate	no	P.-like	no
MONT 391	32	6	straight	1	sub-quadrangular	regular	opposite	triserial?	no	45°
MONT 392	26	5	straight	2	fin-shaped	regular	alternate	partial	no	45°?
MONT 393	33	5	straight	2.5	sub-quadrangular, fin-shaped	regular	alternate	no	no	no
MMAG 394	20	7	straight	2	oval	ir. displaced	opposite, alternate	no	no	no
MMAG 395	30	7	straight	2	sub-quadrangular	regular	alternate	no	no	?
MMAG 396	18	7	straight	2	oval	regular	alternate	no	no	no
MMAG 397	20	5	straight	2	round, sub-hexagonal	regular	alternate	no	P.-like	no
MMAG 398	18	7	straight	2.5	sub-quadrangular, fin-shaped	regular	alternate	no	no	no
MMAG 399	17	7	straight	2.5	sub-quadrangular, fin-shaped	regular	alternate	no	no	no
MMAG 400	16	7	straight	2.5	sub-quadrangular, fin-shaped	irregular	alternate	no	no	no
MMAG 401a	62	5	long & curved	1.5	sub-quadrangular, fin-shaped	irregular	opposite, alternate	yes	no	no
MMAG 401b	15	5	straight	2	sub-quadrangular, fin-shaped	regular	opposite	yes	no	no
MMAG 401c	12	5	straight	2	sub-quadrangular, fin-shaped	regular	opposite, alternate	yes	no	no
MMAG 402	32	5	curved	2	sub-quadrangular, fin-shaped	irregular	opposite, alternate	yes	no	no
MMAG 403	50	5	straight, angle	1.5	sub-quadrangular, fin-shaped	irregular	alternate	no	no	45°
MMAG 404a	17	6	straight	2	sub-quadrangular	regular	alternate	no	no	no
MMAG 404b	25	5	straight, angle	2	sub-quadrangular, fin-shaped	irregular	opposite, alternate	yes, 1 mm	no	45°
MMAG 405	33	7	straight	2	fin-shaped	displaced	opposite, alternate	no	no	no
MMAG 406	22	6	straight	2	fin-shaped	r. displaced	opposite, alternate	no	no	no
MMAG 407a	26	5	curved	1.5	fin-shaped	regular	opposite	yes, partial	no	no
MMAG 407b	20	6	straight	1.5	fin-shaped	regular	opposite	yes	no	90°
MMAG 408a	15	5	straight	2	sub-quadrangular, fin-shaped	regular	opposite	yes, 1 mm	no	45°
MMAG 408b	9	5	straight	2	sub-quadrangular, fin-shaped	regular	opposite	yes, 1 mm	no	45°
MMAG 408c	24	5	curved	2	sub-quadrangular, fin-shaped	displaced	opposite, alternate	no	no	no
MMAG 409a	7	5	straight	2	round	irregular	opposite, alternate	no	no	no
MMAG 409b	9	5	straight	2	round	regular	alternate	no	no	no
CARP 144P97	13	4	straight	1.5	oval	displaced	alternate	no	no	no
CARP P1220709a	20	2	slightly curved	1	fin-shaped	displaced	opposite, alternate	yes	no	45°?
CARP P1220709b	30	3	straight	1	fin-shaped, sub-quadrangular	displaced	alternate	yes, large	no	45°?
CARP P1230723a	27	4	straight	1	fin-shaped	irregular	opposite	yes, large	no	no
CARP P1230723b	13	4	slightly curved	1.5	round, fin-shaped	irregular	alternate	yes	no	no
CARP P1230726a	13	4	slightly curved	1.5	sub-quadrangular, fin-shaped	irregular	alternate	partial	no	no
CARP P1230726b	19	3	straight	1	triangular, fin-shaped	ir.displaced	alternate	no	no	no
CARP P1230734a	45	5	long & curved	1	sub-quadrangular, fin-shaped	v. irregular	opposite, alternate	yes, partial	no	no
CARP P1230734b	30	5	curved	1.5	sub-quadrangular, fin-shaped	regular	opposite, alternate	yes, triserial?	no	?
BILB P1300537	32	4	curved	1.5	round, sub-hexagonal	regular	alternate	no	P.-like	no
BILB P1300538	13	3	straight	1	round, sub-hexagonal	irregular	alternate	no	P.-like	45°
BILB P1300550	35	4	curved	1.5	round, sub-hexagonal	irregular	alternate	no	P.-like	no
BILB P1300551a	15	3	slightly curved	1	round, sub-hexagonal	irregular	alternate	no	P.-like	45°
BILB P1300551b	7	3	slightly curved	1	round, sub-hexagonal	ir.displaced	opposite, alternate	no	P.-like	45°
BILB P1300558	26	3	curved	1.5	sub-quadrangular, fin-shaped	ir.displaced	opposite, alternate	no	P.-like	45°
ZUM P1300400a	40	5	curved	2	sub-quadrangular, fin-shaped	ir. displaced	alternate	no	no	90°
ZUM P1300400a'	13	5	straight, angle?	1.5	sub-quadrangular, fin-shaped	ir. displaced	alternate	no	no	90°
ZUM P1300400b	20	5	curved	1.5	sub-quadrangular, fin-shaped	ir. displaced	alternate	no	no	no
ZUM P1300402	12	4	curved	1.5	sub-quadrangular, fin-shaped	irregular	alternate	no	no	no

Tab. 1 - *continue*

c) general shape, d) maximum width of dots, e) dot shape, f) spiral arrangement, g) dot disposition, h) central axis, i) raised edges and j) branching (Tab. 1).

Trace fossil length and general shape (with branching)

Most length analyses indicate that values are concentrated in a range from 10 to 30 mm (Fig. 2). Some specimens from Aveto are up to 60 mm long, while at other localities such long forms are rare, though specimens from M. Solare can reach 75 mm. The maximum diameter of *Avetoichnus* is 8 mm, although values greater than 5 mm are rare as well as those less than 3 mm (Fig. 2). The largest diameters are found in deeper levels of the Trasimeno area, while smaller or incomplete forms commonly are distributed in shallower levels. Among areas, larger diameter are those of central Italy, while smaller diameters are in northern Italy, Poland and Spain (Fig. 2). General shape ranges from straight, which dominates among other shapes (54/104 specimens), to curved or slightly curved (40/104 specimens), to bent (simple bend without branching, 10/104 specimens). Branching was found in one-third of the studied samples (36/104 specimens), and in many cases it develops in the same plane, although Uchman & Rattazzi (2011) presented branching in different levels. The typical branching is Y-shaped. Rarely, branching junction is poorly preserved or unpreserved but some dots suggest the presence of branching (see samples with a question mark, Tab. 1). Except in a few cases, the secondary branches are about half in length compared to the primary axes (Tab. 1). X-shaped, possibly crossing forms, are very rare. Usually, the branches are disposed at an angle of 45° (e.g., in all areas, as M. Solare, M. Maggio, Aveto, Bilbao and Poland). Also common is the value of 90° (e.g., in Zumaia and Aveto areas, while more rarely at Trasimeno).

Dot shape, diameter and disposition

Dark dots are sections of the spiral in the horizontal plane (Fig. 3). Some of these have been analyzed using the Dino Lite digital microscope, mainly those from Trasimeno. Dots are very labile in shape, dimensions and disposition. The shape varies from sub-quadrangular, round, fin-shaped, and hook-shaped to sub-hexagonal and exceptionally sub-triangular (Tab. 1, Fig. 3). Most variants are present within the same trace fossil, exhibiting transitional shapes and changes mainly in irregular forms (e.g., from round/sub-hexagonal to sub-quadrangular/fin-shaped). The most frequent shape (25/104) is sub-quadrangular/fin-shaped (Fig. 3), although fin-shaped dots alone or with their variants (e.g., round or triangular) may occasionally be present in some cases. Hook-shaped dots can occur randomly in a sub-quadrangular series; usually, hooks are disposed in the same direction. The analysis of dot disposition suggests that the alternate position with

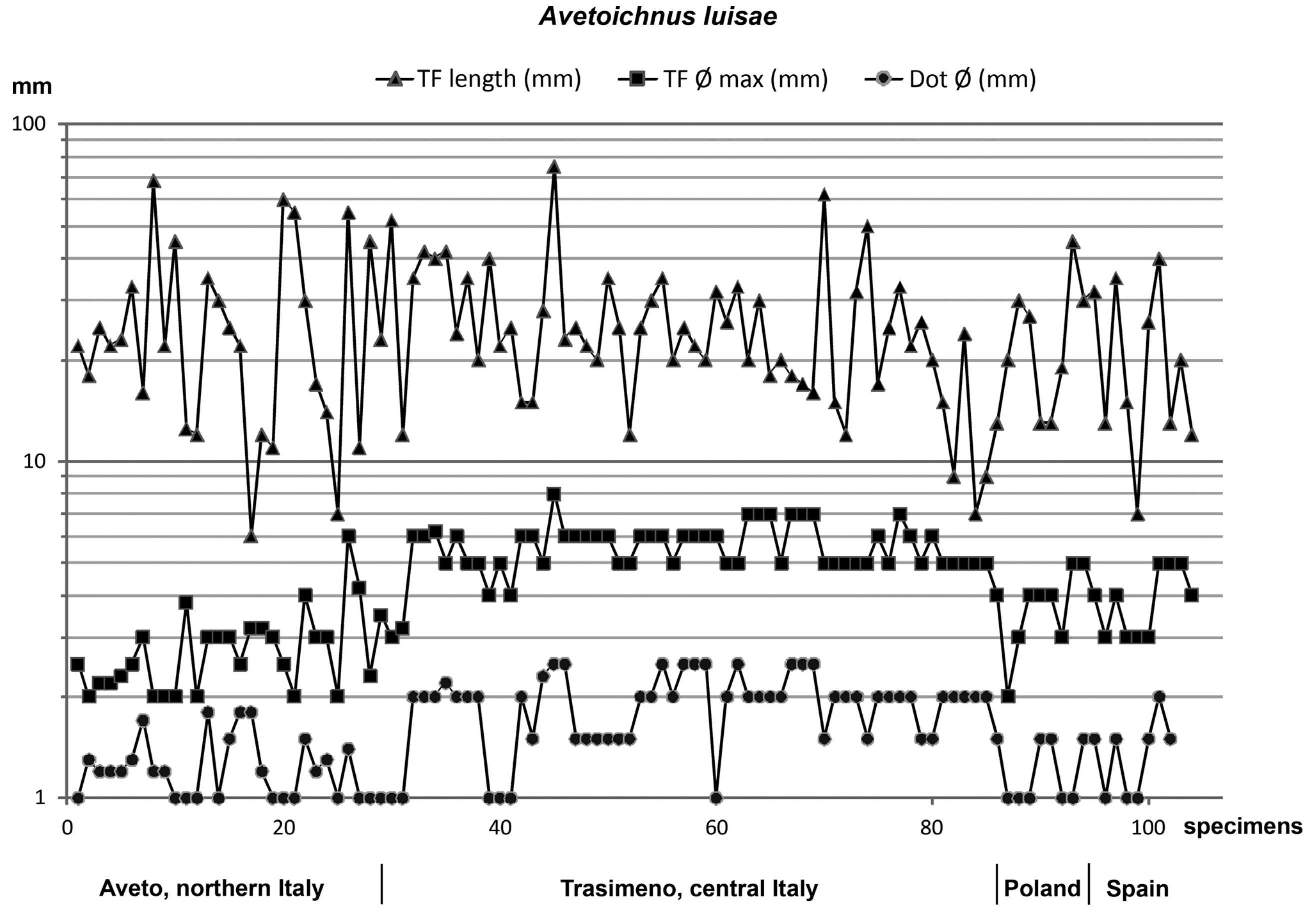

Fig. 2 - Diagrams showing morphologic aspects of studied specimens of *Avetoichnus luisae* (trace fossil length and diameters of such trace fossil and their dots, respectively); see text for explanations.

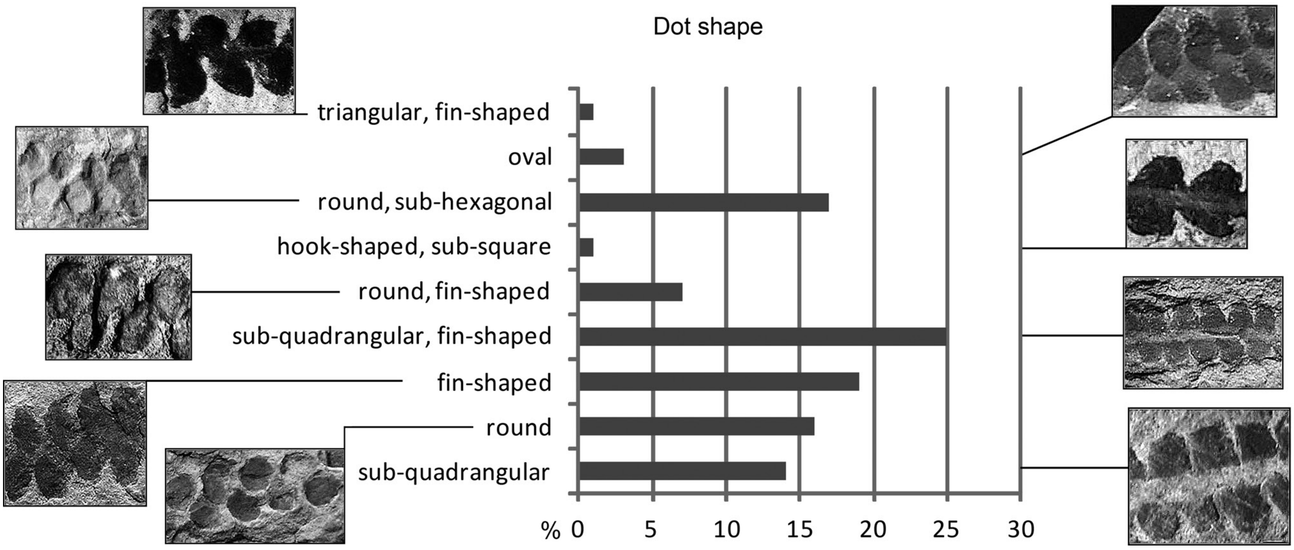

Fig. 3 - Diagram showing variations in dot shape of *Avetoichnus luisae*.

respect to the axis, typical of a regular helix, is not the rule, but about half of the specimens analyzed shows opposite or opposite/alternate dispositions (Pl. 1). Very regular alternation thus is not predominant and also the very regular space between contiguous dots of one side is more common at Aveto (e.g., AV 6630a where a very regular helical spiral is well visible) than in the Trasimeno area or in Spain. Often the strong displacement in some samples (e.g., AV 6630b, MPESC 6724) can produce a falsely opposite disposition of dots.

Spiral arrangement

The helical spiral trace fossil has been recognized and described in a previous work (Uchman & Rattazzi, 2011). These authors serially sliced some specimens of Aveto in order to see three-dimensional aspects of the trace fossil morphology. It appeared that at the end or in some point of the spiral, short vertical to oblique interconnections, composed of 2 to 3 spiral whorls, occur at the vertical distance of about 2 mm, which connect spirals on at least three different levels. The connecting spirals are less irregular, commonly slightly larger than the horizontal ones. The axis continues in the joining parts bending down in an arc. The horizontal spiral runs in different directions differing by 30-40°. A similar trend was observed in the horizontal spiral pattern of the Trasimeno specimens (Tab. 1), but they differ in the whorl arrangement from horizontal to inclined. This is a very common feature (Pl. 1, fig. 3c) that occurs in about half of the analyzed specimens. Tilting in some cases is very strong, producing a horizontal shift of dots, which are arranged oppositely, rather than alternately as expected (e.g., in Aveto and M. Pescino). In other cases whorls of the main branch are regular but shift in the other branch (e.g., at M. Pescino).

Axis

The tubular core of the trace fossil is the central axis, which can be straight or slightly curved in the horizontal or sub-horizontal plane. Its margins are recorded on the surfaces as two parallel strings, 0.5 to 1 mm apart, bounding a central lighter zone of mud which is preserved partially or completely in about half the specimens (45/104). The colour of this zone is the same of the host rock (Pl. 1, fig. 2). Often the axis is incomplete and ends abruptly (e.g., MMAG 407) or appears as a phantom (e.g., MMAG 404b, 405). In other cases a central part is dark, discontinuous and resembles a line of dots then constituting a third row of dots in-between the two others; for this reason some specimens exhibit a three series of dots (e.g., MSOL 413, MONT 391). In a very interesting sample, CARP P1230734a, the interior of the axis shows a small string-shaped trace fossil, 2.5 mm long (post-event?), displacing part of the spiral (Pl. 1, fig. 8).

Raised edges of dots

Another typical characteristic is a thickening of edges of dots (locally also with raised edges); thickening and raising produce the annulated shape of dots as in M. Solare specimens, whereas asymmetry only of the upper part of dots may occur in Bilbao specimens (Tab. 1; Pl. 1, fig. 7). These features have been observed in 31 specimens; moreover, the shape of dots commonly is sub-hexagonal, and specimens are often branched. The shape looks like some hexagonal *Paleodictyon*-like meshes (Monaco, 2008; Monaco & Checconi, 2008). This raising of dot edges seems to be taphonomic rather than diagenetic, as it is found only in some specimens while it is absent in nearby other specimens at the same horizon.

SEDIMENTOLOGICAL CHARACTERISTICS

Fine-grained turbidites

Fine-grained turbidites (siliciclastic, carbonate and bioclastic) are the most abundant type of fossil deep-water sediments (Bouma & Hollister, 1973; Stow & Piper, 1984b; Einsele, 1991; Piper & Stow, 1991). Fine-grained turbidites have been recognized as having distinctive microstructures that are analyzed in many models (O'Brien et al., 1980; Stow & Shanmugam, 1980; Stow & Piper, 1984a; Piper & Stow, 1991). A mud turbidite may occur overlying a sand or silt layer deposited from the same turbidity current or can occur independently (Piper & Stow, 1991). In both cases, as indicated by these authors, there are three divisions upwards: mud with silt laminae (which become finer, thinner and less frequent upwards), graded mud and ungraded mud. These latter two are commonly bioturbated and contain hemipelagic or pelagic sediment. A distinctive hierarchy of structures (intervals a-d of Piper & Stow, 1991) was observed in our material (Pl. 1, fig. 4). Five subdivisions can be recognized from bottom towards the top: E1, E2, E3, E4 (corresponding to the E/F interval of bioclastic turbidites in Piper & Stow, 1991) and F (Pl. 1, fig. 4). Usually, intervals including *Avetoichnus luisae* are subdivisions E4-F in bioclastic turbidites, corresponding also to T7-T8-P intervals of mud turbidites (see classifications of Stow & Shanmugam, 1980; Stow & Piper, 1984a; Einsele, 1991). In the M. Solare section, graded and ungraded mud layers exhibit many trace fossils that, with the *Avetoichnus* ichnofabric, mark a progressive increase upwards in the ichnodensity from 1 to 5 (Fig. 4). The E4 interval shows a slight less abundance of large and complete forms of *Avetoichnus* and *Cladichnus* in respect to F interval where these forms are smaller; usually incomplete forms occur when ichnodensity reaches the maximum value of 5, producing a true mottling (Pl. 2, fig. 5). Grading in these fine-grained deposits may be recognized from both grain size and petrography, as well as colour changes that mirror grain size and textural variations in many fine-grained beds (Piccioni & Monaco, 1999).

Medium-grained turbidites

Medium-grained, bioclastic calcarenites with very abundant shallow-water faunal fragments (Piccioni & Monaco, 1999) are very frequent in the Scaglia Toscana of the Trasimeno area (Trecci & Monaco, 2011). Medium-grained turbidites are considered mainly for the rich trace fossil assemblage (mostly hypichnia and few endichnia). These deposits are interpreted as density-stratified flow deposits *sensu* Sanders (1965), as they exhibit a lower laminar flowing-grain layer and an upper turbulent turbidity current layer (Shanmugam, 2002). Usually the lower layer is a coarse- to medium-grained calcareous sand, while the upper layer (if present) is a very fine sand with some mud, locally bioturbated with scattered endichnia (e.g., *Zoophycos*) and epichnia. These deposits show some similarities with some bioclastic turbidites of Piper & Stow (1991), although the grain size is greater. Usually the vertical transition is sharp, although gradual transitions occur. This fundamental division into two separate parts, laminar and turbulent flow deposits, has been debated by Shanmugam (2002) in his ten myths about turbidites. This author highlights the concept that a turbidity current is a turbulent flow in which the turbulence is the principal sediment-support mechanism (Sanders, 1965; Shanmugam, 2002, text-fig. 1).

Coarse-grained turbidites and debris flow deposits

These calcareous gravity-induced deposits, 30 to 150 cm thick, contain heterogeneous lithoclasts, abundant large foraminifera and many other shallow-water organisms coming from an unknown source area. These deposits are known in many lithostratigraphic units of the Scaglia Toscana from the Trasimeno area to Chianti (e.g., pebbly mudstones and breccias; Fazzuoli et al., 1996; Piccioni & Monaco, 1999; Fazzuoli et al., 2002). They represent high density flows or sandy hyperconcentrated flows, and thus are debris flow deposits *sensu stricto*; they show other trace fossils and are not considered in this study. In all these latter deposits ichnofabrics show many variations and ichnocoenoses (Milighetti et al., 2009; Monaco et al., 2009b; Trecci & Monaco, 2011).

ICHNOFABRIC AND ICHNOTAXA

Several ichnotaxa have been found in the Trasimeno area. Hypichnia include *Bergaueria* (rare), *Cardioichnus* (rare), *Helminthopsis* (rare), *Halopoa* (common), *Lorenzinia* (very rare), *Megagrapton* (rare), *Ophiomorpha* (rare), *Paleodictyon* (rare), *Scolicia strozzii* (common), *Spongeliomorpha* (rare), and *Urohelminthoida* (very rare). Crossichnia that commonly cross fully or partially E1-F intervals of fine-grained turbidites are limited to *Ophiomorpha rudis,* a system of oblique to vertical straight cylinders, 15 to 30 mm in diameter, which differ in colour from the host rock (Fig. 3; Pl. 2, fig. 4). This form, usually found in the *Ophiomorpha rudis* ichnosubfacies in deep-sea fans, has recently been revised by Uchman (2009). For a detailed description of all the above-mentioned ichnotaxa (with ichnospecies) and their abundance in coarse- to fine-grained deposits in the Trasimeno area see Monaco & Checconi (2008). Endichnia include *Alcyonidiopsis longobardiae* (common), *Avetoichnus luisae* (very common), *Palaeophycus tubularis* (rare), *Taenidium* (rare), *Planolites* (common), *Chondrites targionii* (abundant), *Chondrites intricatus* (abundant), and *Cladichnus* (abundant). Epichnia are poorly visible due to mottling; scattered *Nereites* (rare) and many other structures such as vertical forms (*Ophiomorpha rudis*, *Chondrites*? and *Cladichnus*?), small dots and others undetermined ichnotaxa are present (Monaco & Checconi, 2008). Endichnia occupy different levels, producing the densening-upward ichnofabric that is typical of this area (Monaco & Uchman, 1999; Piccioni & Monaco, 1999; Monaco & Checconi, 2008; Monaco et al., 2009a). In this study we prefer to adopt the term "level" rather than "tier" (Fig. 4). A tier is defined by mutually cross-cutting trace fossils, in which their producers inhabited the same sediment interval at the same time (e.g., Uchman, 1995b; Seilacher, 2007). Therefore, shallow- and deep-tier burrows should show different cross-cutting relationships; the burrows within deeper tiers always cross-cut the traces belonging to shallower tiers. If there is a systematic order in cross-cutting relationships, then a succession of burrows or different tiers can be recognized, because it is possible to distinguish burrows emplaced deeper or shallower within the same tier. The main reason is the very abundant occurrence of trace fossils at different levels that vertically and mutually intersect each other. This is not the case of the Trasimeno sections, where it is very difficult to recognize cross-cutting relationships of deep burrows, which are mostly horizontal and distributed in mud (Pl. 1, fig. 5).

A short description of levels and ichnoassemblages is here provided as follows.

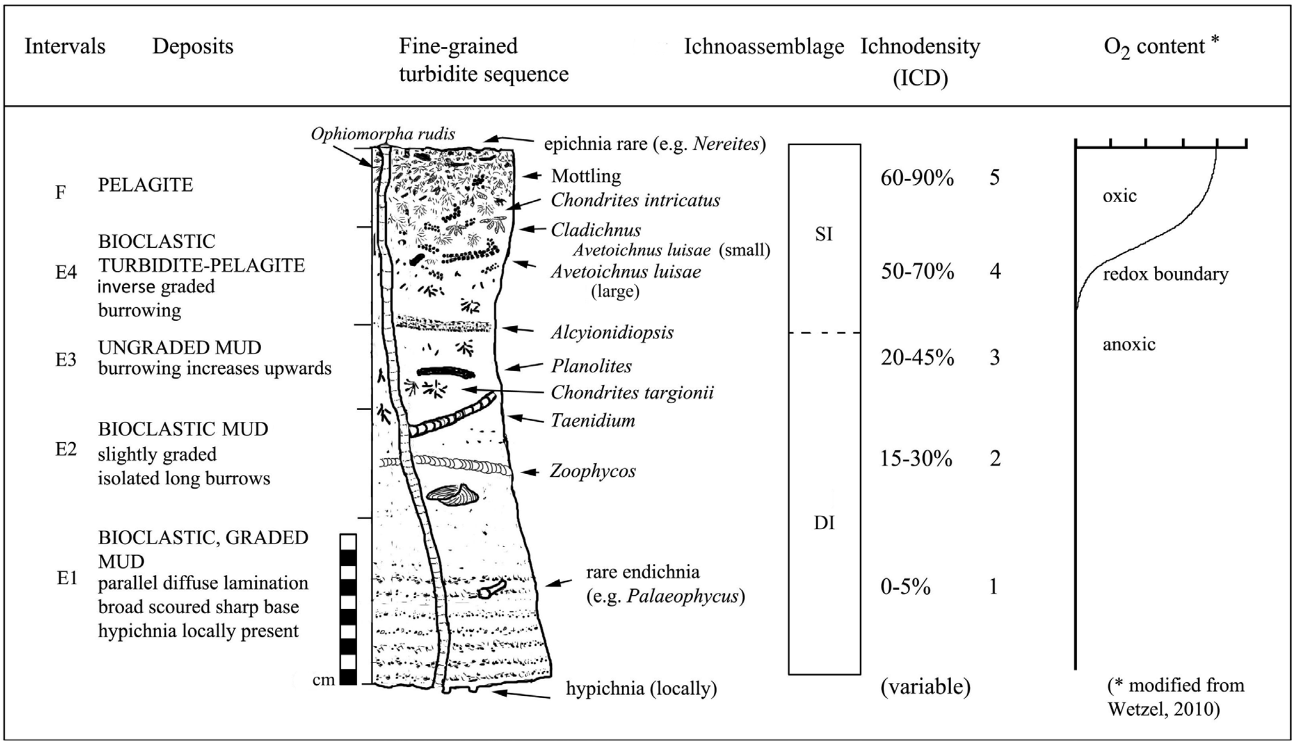

Fig. 4 - The ideal sequence of fine-grained turbidite with levels, ichnodensity (ICD) and oxygen with *Avetoichnus* that occurs close the redox boundary. Intervals are modified from Piper & Stow (1991); E4 interval of this work corresponds to E/F interval of these authors.

a) Deep ichnoassemblage (DI)

This assemblage is associated with E1-E3 intervals of fine-grained turbidites (Fig. 4). It consists of mainly subhorizontal string-shaped trace fossils (e.g., *Alcyonidiopsis, Planolites, Palaeophycus, Taenidium*) and at least partially preserved, complex three-dimensional structures (e.g., *Zoophycos*); locally well preserved root-like forms (e.g., *Chondrites targionii*) and rare scattered dots or dark spots are present (Pl. 2, figs 1-4). The ichnodensity diagram of a horizontal surface expresses typical values which range from 5% (E1) to 45% (E3) (Fig. 4). Usually, the E1 interval is less bioturbated (0-5%). It shows very rare and scattered larger forms (e.g., *Palaeophycus*). In E2, trace fossils are slightly more abundant (15-30%) but usually larger than in E3 interval, in which smaller forms are present (20-45%). Many long and large, deeper traces (e.g. *Zoophycos*, *Taenidium* and *Planolites*) are locally concentrated in E2-E3 intervals.The deepest level is occupied by spreite burrows (e.g., *Zoophycos,* Pl. 2, fig. 4), while other string-like forms occupy progressively shallower levels (e.g., *Planolites* and *Palaeophycus*). The following ichnotaxa occur within the *Avetoichnus*-bearing beds.

Alcyonidiopsis Massalongo, 1856 - *Alcyonidiopsis* occurs as endichnial, straight to slightly winding horizontal cylinder, 5-8 mm in diameter, filled with small ovoid pellets, 0.4-0.6 mm in diameter (Pl. 2, fig. 2). Lining is doubtful and many very small brown ovoid pellets have been found close to the tunnel margin. Pellets are dark and irregularly disposed along the tunnel, giving an easily recognizable outline of a horizontal flat trace fossil (Monaco & Checconi, 2008). But, unlike *Ophiomorpha* where pellets are exclusively in burrow lining, in *Alcyonidiopsis* ovoid pellets fill the burrow (Uchman, 1995a). For the synonymy of the ichnogenus *Alcyonidiopsis* see Chamberlain (1977). This trace fossil is considered as a polychaete feeding burrow and is known from the Ordovician to the Miocene. In the M. Solare section, *Alcyonidiopsis*, mainly *A. longobardiae* Massalongo, usually occurs randomly in E2 (very rare) and E3 intervals of bioclastic turbidites, usually in the deepest levels, 3-6 cm below the level with *Avetoichnus* and 8-10 cm below the supposed turbidite surface.

Planolites Nicholson, 1873 - This is a very common string-like trace fossil, representing a typical facies-crossing ichnogenus (e.g., Monaco et al., 2012). It is unlined and usually not branched, straight or sinuous, elliptical (flattened) in cross-section, smooth or slightly annulated; the fill is essentially structureless and differs in lithology and colour from the host rock. Some specimens show a coarse-grained fill. *Planolites* may be referred to the activity of several, unrelated vermiform deposit-feeders which produce active backfilling (Pemberton & Frey, 1982), occurring from the Precambrian to the Holocene (Häntzschel, 1975). At M. Solare and in other sections of the Trasimeno area, *P. beverleyensis* Billings, 10-30 mm in width, can be found also as simple, undulating hypichnia on the soles of middle-grained turbidites (Monaco & Uchman, 1999). *Planolites* has been found in scattered specimens, up to 300 mm long, at different levels: within the DI is rare, while in the overlying part it occurs at the *Avetoichnus* level (e.g., Pl. 2, fig. 3) or above (but very rare) with many other small traces, where ichnodensity can be higher (ICD = 4). For this reason *Planolites* is not very useful in level characterization.

Palaeophycus Hall, 1847 - This rare and sparsely distributed string-shaped trace fossil is smooth, originally cylindrical (but flattened by compaction), branched or unbranched, straight or curved in the horizontal plane. The fill is typically structureless, and has the same lithology of the host rock. Locally inside, there are some *Chondrites*-like structures that resemble false pellets (Bandchondriten, Pl. 2, fig. 2). Like *Planolites*, *Palaeophycus* is a typical facies-crossing ichnogenus, produced in part by polychaetes and occurring from the Precambrian to the Holocene (Pemberton & Frey, 1982). *Palaeophycus tubularis* Hall reaches 10-20 mm in diameter and occurs as sub-horizontal or oblique endichnion associated with small *Zoophycos* in coarser parts of turbidites. It usually occurs in deeper levels but, as *Planolites*, it is poorly useful in this analysis.

Taenidium Heer, 1877 - This trace fossil is a typically horizontal, meniscate, simple, straight to sinuous string, usually unlined (see D'Alessandro & Bromley, 1987). It is usually an endichnion, up to 24 mm in diameter and up to 120 mm long. It is rare in the studied outcrops, while it typically occurs in eastern Umbria within the reddish mudstones of the "Scaglia" (Monaco & Checconi, 2008). This ichnotaxon has been found in deep and shallow levels, together with vertical shafts and scattered forms. For these reasons it is an accessory form, limited in our characterization.

Chondrites Sternberg, 1833 - This very common ichnotaxon consists of a regularly branching tunnel system, made up of a small number of master shafts, vertically preserved, which ramify deep down to form a dendritic network (Osgood, 1970; Uchman, 1999). *Chondrites* is the feeding system of an unknown organism related to infaunal deposit feeders, and it is now considered a probable chemichnion (e.g., Bromley, 1996).This ichnotaxon is produced by surface ingestors, packing their faecal pellets inside burrows (Kotake, 1991). Some authors conclude that the tracemaker of *Chondrites* would be able to live under dysaerobic conditions as a chemosymbiotic organism (Seilacher, 1990; Fu, 1991). After Fu's (1991) revision of the systematics of *Chondrites*, only four ichnospecies were considered useful, compared to the 170 distinguished in the past (Chamberlain, 1977), although recently new ichnospecies have been introduced (Uchman, 1999). In calcareous turbidite deposits of the studied sequences two ichnospecies have been found: *C. targionii* (Brongniart) and *C. intricatus* (Brongniart). The first occupies mainly deep levels while the other one is typical of shallow ones. *C. targionii* is characterized by well-expressed, primary successive branchings, which are commonly slightly, irregularly curved. The angle of branching is usually sharp. This ichnospecies is a typical post-depositional form, with cylindrical, dark clayey filling. The tunnels show three classes of width: 0.5-1 (rarely more), 1-2 and 4-6 mm; in some specimens tunnels are more winding than in others and the distance between the branching points is variable. Similar forms, but with more winding tunnels, are determined as *Chondrites* isp. *C. targionii* is widespread and very well preserved in the Trasimeno area, and generally through the studied Eocene interval (Monaco & Uchman, 1999; Monaco & Checconi, 2008). It occupies a particular position in E3-F intervals of a typical mud turbidite sequence (Fig. 4); in two samples *Chondrites* isp. occurs about 2-3 cm below the *Avetoichnus* level (Pl. 2, fig. 1) and 2 cm above the *Alcyonidiopsis* level which is the deepest form (Pl. 2, fig. 2). In other cases the level with *C. targionii* is approximately the same as that of *Cladichnus*, although this latter ichnotaxon can be found in other shallower level associated with *Avetoichnus* (Pl. 2, fig. 3).

Zoophycos Massalongo, 1855 - This ichnogenus includes several three-dimensional, helicoidal spreite structures up to 30 cm in diameter (very rarely up to 10 cm) in E1-E2. Spreite structures are locally abundant in soft sediments at M. Solare (Pl. 2, fig. 4). In plain view they exhibit primary and secondary lamellae (Olivero & Gaillard, 2007). A marginal tube is poorly preserved and

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EXPLANATION OF PLATE 1

Avetoichnus luisae specimens.

Fig. 1 - Long and curved specimens (a, b) with central axis and sub-quadrangular, fin-shaped dots, M. Maggio, Trasimeno.

Fig. 2 - Two specimens (a, b) with a central light string of mud and sub-quadrangular lateral dots, M. Maggio, Trasimeno.

Fig. 3 - Four specimens (a, b, c, d) in a typical, high ichnodensity, shallow ichnoassemblage; dot alignment and shape vary (see Tab. 1); note horizontal displacement of spiral whorls (c), M. Solare, Trasimeno.

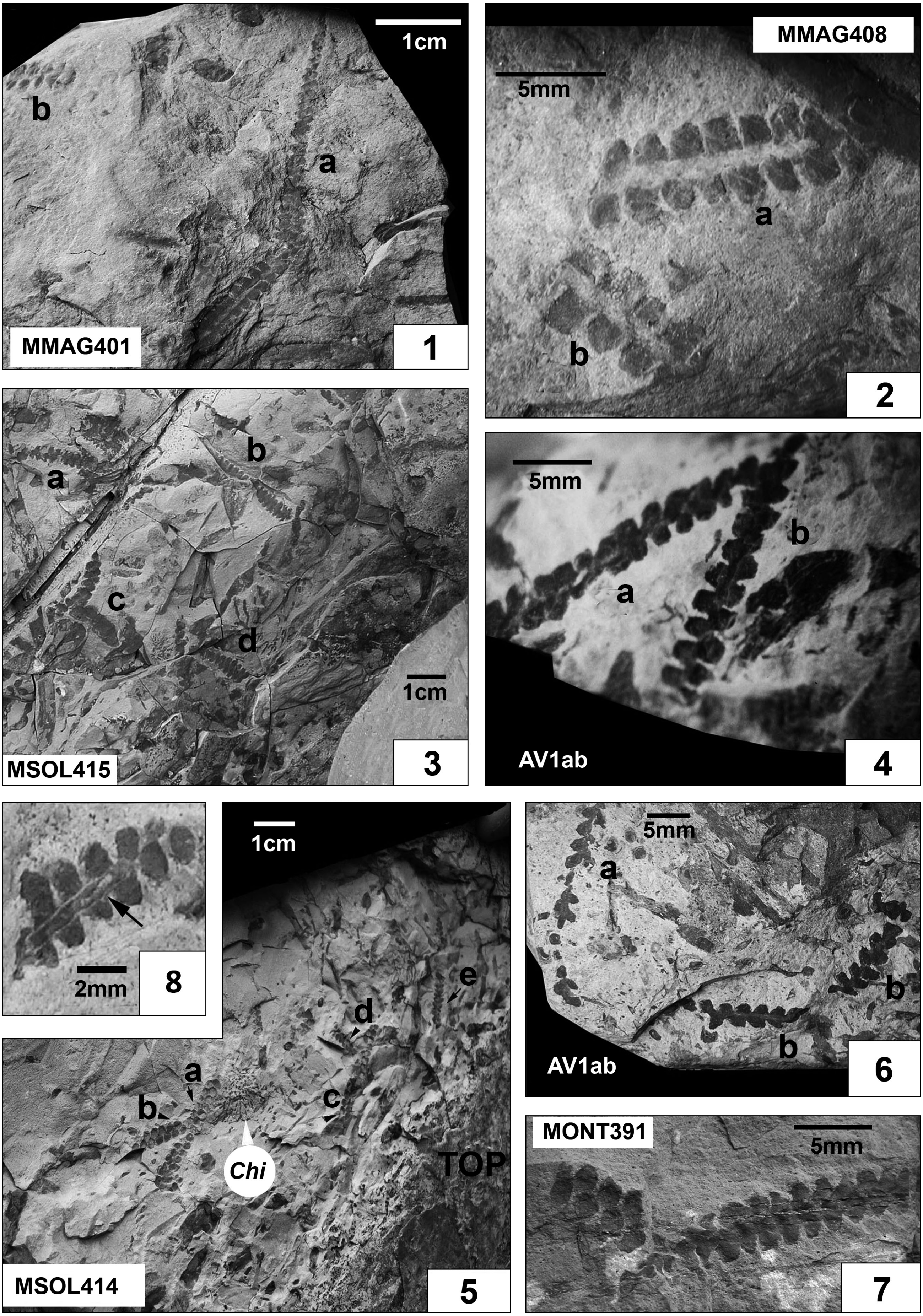
Fig. 4 - Regular spiral winding of two dark specimens (a, b) with sub-quadrangular, fin-shaped, alternate dots (Aveto area, northern Italy).

Fig. 5 - Shallow ichnoassemblage disposed about 6-8 cm below the top, with five, locally branched, *A. luisae* (a-e) specimens and many other trace fossils as *Chondrites intricatus* (*Chi*), M. Solare, Trasimeno.

Fig. 6 - Two specimens (a, b) with fin-shaped or sub-triangular dots in opposite/alternate position (Aveto area, northern Italy).

Fig. 7 - Bended specimen with round, fin-shaped or sub-quadrangular dots, Montanare, Trasimeno.

Fig. 8 - Specimen showing inside the central axis a small string (arrow), 2.5 mm long (post-event?), displacing part of the spire, Carpathians, Poland.


1cm
b
a
MMAG401
1
MMAG408
5mm
a
b
2
b
a
c
d
1cm
MSOL415
3
5mm
b
a
AV1ab
4
8
2mm
1cm
e
d
a
b
c
Chi
TOP
MSOL414
5
5mm
a
b
b
AV1ab
6
MONT391
5mm
7

may be arranged in helicoidal spirals. Central vertical tunnels are locally preserved. This form includes more or less U- or J-shaped protrusive modular burrows (e.g., Wetzel & Werner, 1981). Different ichnogenera and species have been described under the name *Zoophycos*, and recently this ichnogenus has been extensively discussed (Ekdale & Lewis, 1991; Olivero, 2007; Olivero & Gaillard, 2007; Monaco et al., 2012).

b) Shallow ichnoassemblage (SI)

The shallow ichnoassemblage can be detected about some centimetres (usually 2-4) above deep ichnoassemblage for higher (> 50%) value of ichnodensity and occupies most of the shallower intervals of the fine-grained turbidite sequence (E4-F, Fig. 4; Pl. 1, fig. 5; Pl. 2, fig. 5). The main ichnotaxon is *Avetoichnus luisae* that typically occurs in E4 interval at depth of 3-5 cm (exceptionally also 6 cm deep, MSOL samples, see Pl. 1, fig. 5; Pl. 2, fig. 5), but also in the shallower level F at a depth of 0.5-2 cm (MMAG samples). Other ichnotaxa include *Cladichnus*, *Chondrites intricatus, Planolites* and many other undeterminable forms (dots, short strings, and others). Ichnodensity in horizontal surfaces ranges from 50% (lower part of SI) to 90% (upper part of SI), exceptionally up to 95%. Therefore it is high (4) or very high (5) with densely packed biogenic structures (mottling).

Cladichnus D'Alessandro & Bromley, 1987 - This epichnial or shallow endichnial trace fossil is common at M. Solare. It is 60-100 mm in width, and consists of a group of meniscate and branched tunnels, horizontally radiating from a vertical axial zone. This axial zone is preserved as a circular spot at the top of turbidites and the density of these dots can be high (3-5 for 20 cm^2 in mud turbidites at Trasimeno). Each tunnel is 2-6 mm wide and 20-50 mm long. Terminations of tunnels are semi-circular or clavate (D'Alessandro & Bromley, 1987). Meniscate segments are spatially arranged, similarly to the regularly spaced rings described for *Cladichnus fischeri* (Heer) by Uchman (1999, pl. 12, fig. 5) and are typically disposed perpendicular to the tunnel axis (Pl. 2, fig. 3). Menisci and inter-menisci are similar in width and therefore the margins of tunnels are slightly lobate (Pl. 2, fig. 3 arrow). This form is typically preserved as a shallow endichnion for radiate tunnels and an epichnion (in a yellowish concretionary level) for dots. Other circular shafts probably represent vertical shafts of other forms (e.g., *Chondrites targionii*). Usually the ichnodensity is lower than that of *Chondrites intricatus*. *Cladichnus* occurs chiefly in the E4 and F intervals.

Chondrites intricatus Brongniart, 1823 - This small tree-like trace fossil is composed of numerous downward radiating branched tunnels; the angle of branching is usually less than 45° (Fu, 1991); flattened tunnels, 0.2-0.8 mm wide, are filled with sediment darker than the host rock. *C. intricatus* can be distinguished by its small size, for its common, straight branches radiating in all directions, and for its low angle of branching. Distribution and relationships with lithology are different than in *C. targionii,* whose maker colonized deeper tiers. *C. intricatus* usually is distributed at the same or, exceptionally (Pl. 1, fig. 5), at a shallower level than *Avetoichnus,* about 20-30 mm above this ichnotaxon in E4 and F intervals; the density of *C. intricatus* in many mud turbidites is greater by about three times that of *Avetoichnus*.

Nereites MacLeay, 1839 - This epichnial form is very rare. It consists of more or less horizontal trails, winding to regularly meandering, represented by a median back-filled tunnel (core) enveloped by an even to lobate zone of reworked sediment (mantle). Commonly, only the external part of the mantle is preserved as a densely packed chain of uni- or multi-serial small depressions or pustules. In the Trasimeno area, meandering epichnial *Nereites missouriensis* (Weller) and *Nereites irregularis* (Schafhäutl) have been found very rarely at M. Solare (Monaco & Uchman, 1999), while these burrows occur more commonly in other deposits (e.g., siliciclastic turbidites) of the Northern Apennines (Uchman, 2007; Monaco et al., 2009b; Monaco & Checconi, 2010). They usually are closely packed, forming narrow meanders of various size which tend to coil. The tube is ellipsoidal in

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EXPLANATION OF PLATE 2

Ichnoassemblages in the Paleogene fine-grained turbidites, Trasimeno area.

Fig. 1 - Deep ichnoassemblage (DI) with *Chondrites* cfr. *targionii* (*Ch*); note in the lower right *Avetoichnus luisae* (*Av*) that occurs about 3 cm above and characterizes the shallow ichnoassemblage (SI). M. Solare section.

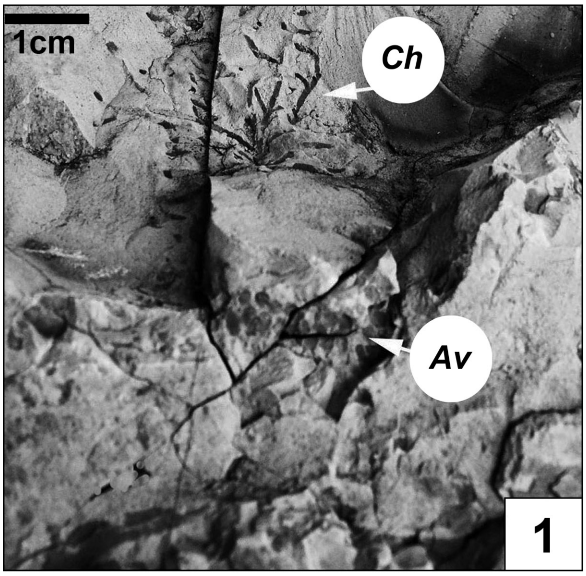
Fig. 2 - The deep ichnoassemblage DI with *Palaeophycus* (*Pal*) reworked preferentially by *Chondrites* (Bandchondriten) and *Chondrites* cfr. *targionii* (*Ch*). In left detail note pellets (arrows) of *Alcyonidiopsis* (*Alc*).

Fig. 3 - The shallow ichnoassemblage (SI) with *Cladichnus* (*Cla*), *Chondrites intricatus* (*Chi*), *Planolites* (*Pl*) and many other trace fossils, including *Avetoichnus* (*Av*). Note the increase of ichnodensity.

Fig. 4 - Deep ichnoassemblage with *Ophiomorpha rudis* (*Opr*) and *Zoophycos* (*Zoo*).

Fig. 5 - Upper part of a fine-grained turbidite with an inverse graded burrowing in E4-F intervals; note *Avetoichnus luisae* (*Av*) in the mid-shallow levels (arrow).

Fig. 6 - *Avetoichnus luisae* in shallow level; note triserial disposition of dots (right arrow).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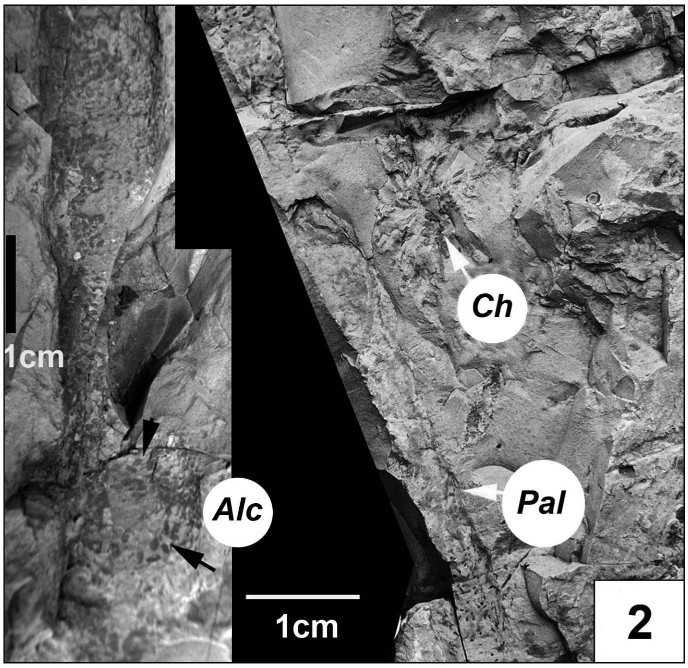
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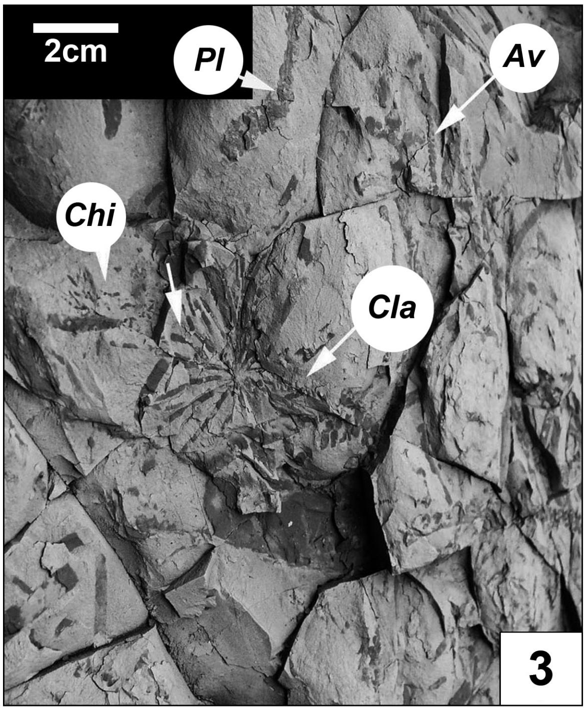
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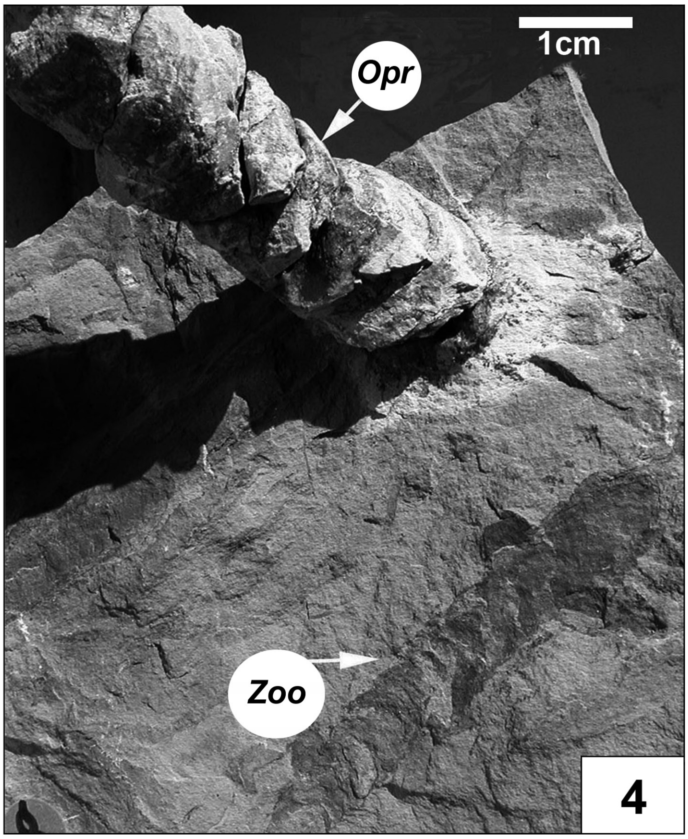
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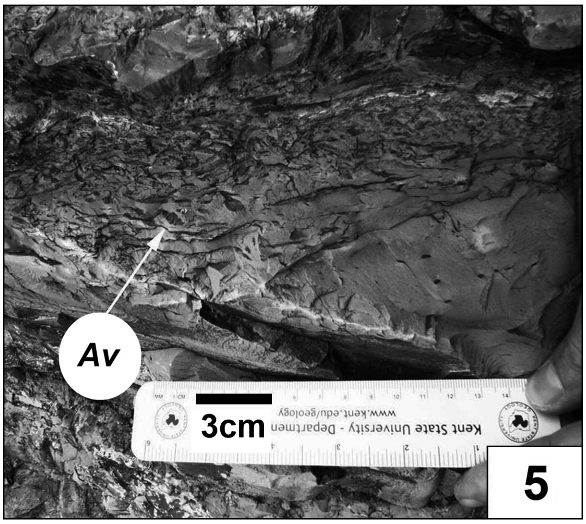
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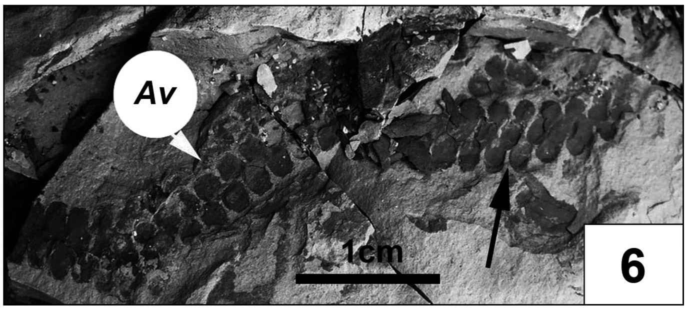
5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cross-section, 3.5-4.0 mm wide, and preserved as epichnial semi-relief. It commonly occurs within the upper part of limestone or marlstone turbidites.

DISCUSSION

The taphonomic study of *Avetoichnus*-bearing beds provides some indications about environmental conditions of fine-grained turbidites. It includes geochemical and ichnological aspects.

Geochemical and ichnological characteristics

As indicated by some authors, who studied ichnology of deep-sea sediments, a geochemical differentiation occurs at the sediment boundary layer. The layer consists of two different intervals, a near-surface interval, whose pore waters contain dissolved O_2 and a deep interval, which lacks dissolved oxygen (Wetzel, 2010). Oxic and anoxic deposits are separated by the redox boundary, usually modified by burrowing activity, and where some elements (e.g., iron, sulphur and manganese) are converted by microbial activity (Forster, 1996). The increasing-upward content of oxygen towards the sediment surface reflects a similar increase in the biomass content, which depends on turbulent flows and bioturbation intensity (Wetzel, 2010). These conditions below the sediment surface induce a development of infaunal activity that produces tiered burrows in different layers (e.g., mixed, lumpy and transitional layers; Berger & Heath, 1968; Savrda, 2007). It reflects a partitioning of the available ecospace by various endobenthic organisms, which occupy different levels at the same time (Ausich & Bottjer, 1982). The bioturbation intensity in E4-F intervals of fine-grained turbidites of the Trasimeno area is totally consistent with an increase of the biomass and oxic conditions close to the sediment surface. It is reflected by an increase in ichnodensity from 50 to 90%. More problematic is the sporadic occurrence of small *Chondrites* and *Cladichnus* in the oxic level, which are fundamentally chemichnia, usually developed in anoxic levels. Their colonization surface can be located at the top of higher bed (cf. Rajchel & Uchman, 1998). Most remarkable is *Avetoichnus* which, in the same area, occurs in large and complete specimens close to the redox boundary, approximately up to 8-10 cm below the sediment surface (Pl. 1, fig. 5), where bacterial activity was probably more intense. Small and incomplete specimens developed in more surface levels, slightly above the redox boundary. Dot distribution, branching and spiral arrangement suggest agrichnial-fodinichnial behaviours, which were better developed under redox conditions where bacteria activity was strongest. The axial part with branches indicates a repetitive movement of the buried animal (polychaete? crustacean?) inside the burrow, inducing a sharp truncation of peripheral dots. Below the redox boundary, the E4 *Avetoichnus*-bearing level, a deep endobenthic fauna developed under anoxic conditions producing the deep ichnoassemblage (*Zoophycos*, *Alcyonidiopsis, Planolites, Palaeophycus, Taenidium*, and large *Chondrites targionii*) with horizontal forms, which are localized at different level in E1-E3 intervals of fine-grained turbidites.

CONCLUSIONS

1. The study of 104 examples from Italy, Poland and Spain confirms that *Avetoichnus luisae* occurs in shallow levels of fine-grained turbidites, with largest burrows developed in Italy (Trasimeno and Aveto areas). In the Trasimeno area *Avetoichnus* occurred together with many other ichnotaxa that are distributed in E-F intervals in mud or bioclastic turbidite sequences.

2. The vertical arrangement of trace fossils in Paleogene fine-grained turbidites of the Trasimeno area indicates that the ichnodensity increases progressively upwards. Many ichnotaxa, such as *Avetoichnus luisae,* are distributed along horizons in overlaid levels, with larger specimens frequently at depths close to the redox boundary. Other trace fossils, such as string-shaped forms or tree-like forms, are also indicative, although sparser and only locally present.

3. A new division of the fine-grained turbidite sequence, the E4 interval, can be here proposed.The ichnofabric of this bioclastic level shows the peculiar trace fossil *Avetoichnus luisae,* which occurs in graded mud containing hemipelagic sediment close to the top of turbidites; this form decreases above, in the F interval, where mottling prevails. The E4 may be more easily preserved in the fine portion of bioclastic turbidites rather than in mud turbidites.

4. Taphonomic analysis of about one hundred specimens from Italy, Poland and Spain indicates a strong variability in external organization of *Avetoichnus* (often branched), in horizontal cross section ("dot") distribution and shape, in central axis and helical arrangement. The results confirm the agrichnial behavior of an unknown tracemaking organism, although fodinichnial behavior cannot be excluded when branching occurs (in about one third of studied specimens). The branching is not only in different levels, as observed in previous studies, but can also be found horizontally as occurs in the Trasimeno area.

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REFERENCES

Ausich W.I. & Bottjer D.J. (1982). Tiering in suspension-feeding communities on soft substrata throughout the Phanerozoic. *Science*, 216: 173-174.

Azpeitia Moros F. (1933). Datos para es estudio paleontólogico del Flysch de la Costa Cantábrica y de algunos otros puntos de España. *Boletín del Instituto Geológico y Minero de España*, 53 (XIII): 1-65.

Baccelle L. & Bosellini A. (1965). Diagrammi per la stima visiva della composizione percentuale nelle rocce sedimentarie. *Annali dell'Università di Ferrara, N.S., Sez. IX, Scienze geologiche e paleontologiche*, 1 (3): 59-62, Ferrara.

Berger W. (1957). Eine spiralförmige Lebensspur aus dem Rupel der bayerischen Beckenmolasse. *Neues Jahrbuch für Geologie und Paläontologie, Monatshefte* (1957): 538-540.

Berger W.H. & Heath G.R. (1968). Vertical mixing in pelagic sediments. *Journal of Marine Science*, 26: 134-147.

Boccaletti M., Calamita F., Centamore E., Chiocchini U., Deiana G., Micarelli A., Moratti G. & Potetti M. (1986). Evoluzione dell'Appennino tosco-umbro-marchigiano durante il Neogene. *Giornale di Geologia*, *Ser. 3*, 48 (1-2): 227-233.

Bortolotti V., Passerini P., Sagri M. & Sestini G. (1970). The miogeosynclinal sequences. *In* Sestini G. (ed.), Development of the Northern Apennines geosyncline. *Sedimentary Geology*, 4 (3-4): 341-444.

Bouma A.H. & Hollister C.D. (1973). Deep ocean basin sedimentation. *In* Middleton G.V. & Bouma A.H. (eds), Turbidites and deep water sedimentation. *Society of Economic Paleontologists and Mineralogists, Pacific Section*: pp. 79-118.

Bromley R.G. (1996). Trace fossils. Biology, taphonomy and application. 361 pp. Chapman & Hall, London.

Brongniart A.T. (1823). Observations sur les Fucoids. *Société d'Histoire Naturelle de Paris*, 1: 301-320.

Canuti P., Focardi P. & Sestini G. (1965). Stratigrafia, correlazione e genesi degli Scisti Policromi dei monti del Chianti (Toscana). *Bollettino della Società Geologica Italiana*, Volume Speciale, 84: 93-166.

Centamore E., Deiana G., Micarelli A. & Potetti M. (1986). Il Trias-Paleogene nelle Marche. *Studi Geologici Camerti*, Volume Speciale, la Geologia delle Marche: 9-27.

Centamore E., Fumanti F. & Nisio S. (2002). The Central-Northern Apennines geological evolution from Triassic to Neogene time. *Bollettino della Società Geologica Italiana*, Volume Speciale, 1: 181-197.

Chamberlain C.K. (1977). Ordovician and Devonian trace fossils from Nevada. *Nevada Bureau of Mines and Geology Bulletin*, 90: 1-24.

Cummings J.P. & Hodgson D.M. (2011). Assessing controls on the distribution of ichnotaxa in submarine fan environments, the Basque Basin, Northern Spain. *Sedimentary Geology*, 239 (3-4): 162-187.

D'Alessandro A. & Bromley R.G. (1987). Meniscate trace fossils and the *Muensteria-Taenidium* problem. *Paleontology*, 30: 743-763.

Damiani A.V., Faramondi S., Nocchi-Lucarelli M. & Pannuzi L. (1989). Bio-cronostratigrafia delle unità litologiche costituenti "l'insieme varicolore" affiorante tra la Val di Chiana ed il fiume Tevere (Italia centrale). *Bollettino del Servizio Geologico d'Italia, Roma*, 106 (1987): 109-160.

Damiani A.V. & Pannuzi L. (1982). Unità litologiche nell'ambito degli Argilloscisti varicolori fra il Cortonese e l'eugubino e preliminari considerazioni paleogeografiche e stratigrafiche. *Bollettino del Servizio Geologico d'Italia*, 103: 241-276.

Droser M.L. & Bottjer D.J. (1991). Trace fossils and ichnofabric in leg 119 cores. *Proceedings of the Ocean Drilling Program, Scientific results*, 119: 635-641.

Droser M.L. & Bottjer D.J. (1993). Trends and patterns of Phanerozoic ichnofabric. *Annual Review of Earth and Planetary Science Letters*, 21: 205-225.

Einsele G. (1991). Submarine mass flow deposits and turbidites. *In* Einsele G., Ricken W. & Seilacher A. (eds), Cycles and Events in Stratigraphy, Springer-Verlag: 313-339.

Ekdale A.A. & Lewis D.W. (1991). The New Zealand *Zoophycos* revisited: morphology, ethology, and paleoecology. *Ichnos*, 1: 183-194.

Fazzuoli M., Pandeli E. & Sandrelli F. (1996). Nuovi dati litostratigrafici della Scaglia toscana (Scisti policromi) dei Monti del Chianti (Appennino settentrionale). *Atti della Società Toscana di Scienze naturali, Memorie, Serie A*, 103: 95-104.

Fazzuoli M., Sartori R. & Vannucci S. (2002). Lithostratigraphy, mineralogy and geochemistry of the Late Cretaceous (?) to Eocene Marne del Sugame, Cintoia section, Northern Monti del Chianti, Northern Apennines. *Bollettino della Società Geologica Italiana*, Volume Speciale, 1: 551-560.

Forster S. (1996). Spatial and temporal distribution of oxidation events occurring below the sediment-water interface. *Marine Ecology,* 17: 309-319.

Fu S. (1991). Funktion, Verhalten und Einteilung fucoider und lophoctenoider Lebensspuren. *Courier Forschunginstitut Senckenberg*, 135: 1-79.

Hall J. (1847). Paleontology of New York. Volume 1. C. Van Benthuysen, Albany, 338 pp.

Häntzschel W. (1975). Trace fossils and problematica. *In* Teichert C. (ed.), Treatise on Invertebrate Paleontology, part W, Miscellanea, Supplement 1. *The Geological Society of America and University of Kansas*: 1-269.

Heard T.G. & Pickering K.T. (2008). Trace fossils as diagnostic indicators of deep-marine environments, Middle Eocene Ainsa-Jaca basin, Spanish Pyrenees. *Sedimentology*, 55: 809-844.

Heer O. (1877). *Flora Fossilis Helvetiae*. Vorweltliche Flora der Schweiz. J. Wurster & Comp. Zurich. 182 pp.

Kotake N. (1991). Packing process for filling material in *Chondrites*. *Ichnos*, 1: 277-285.

Książkiewicz M. (1970). Observations on the ichnofauna of the Polish Carpathians. *In* T.P. Crimes & J.C. Harper (eds), Trace Fossils. *Geological Journal*, Special Issue, Liverpool: 283-322.

MacLeay W.S. (1839). Note on the Anellida. *In* R.I. Murchison (ed.), *The Silurian System. Part II. Organic Remains*. J. Murray, London, pp. 699-701.

Massalongo A.B. (1855). *Zoophycos,* novum genus plantorum fossilium. Antonelli, Verona. 52 pp.

Massalongo A.B. (1856). Studi Paleontologici. Antonelli, Verona. 53 pp.

Merla G. & Abbate E. (1967). Note illustrative della Carta Geologica d'Italia alla scala 1:100.000, Foglio 114 (Arezzo). *Servizio Geologico d'Italia*: 1-49.

Milighetti M., Monaco P. & Checconi A. (2009). Caratteristiche sedimentologico-ichnologiche delle unità silicoclastiche oligo-mioceniche nel transetto Pratomagno-Verghereto, Appennino Settentrionale. *Annali dell'Università degli Studi di Ferrara, Museologia Scientifica e Naturalistica*, 5: 23-129.

Monaco P. (1994). Hummocky cross-stratification and trace fossils in the Middle Toarcian of some sequences of Umbria-Marche Apennines. *Geobios*, 17: 679-688.

Monaco P. (1999). Computer database as a tool to investigate taphonomy and events in carbonate platform environments. *In* Farinacci A. & Lords A.R. (eds), Depositional episodes and bioevents. *Paleopelagos*, Special Publication, 2: 105-122.

Monaco P. (2008). Taphonomic features of *Paleodictyon* and other graphoglyptid trace fossils in Oligo-Miocene thin-bedded turbidites of Northern Apennines flysch deposits (Italy). *Palaios*, 23 (10): 667-682.

Monaco P. & Caracuel J.E. (2007). Il valore stratinomico delle tracce fossili negli strato evento (event bed) del registro geologico: esempi significativi di ichnologia comportamentale dall'Italia e dalla Spagna. *Studi e Ricerche, Museo "G. Zannato" Montecchio Maggiore (VI)*, 14: 43-60.

Monaco P. & Checconi A. (2008). Stratinomic indications by trace fossils in Eocene to Miocene turbidites and hemipelagites of the Northern Apennines (Italy). *In* Avanzini M. &. Petti F.M. (eds), ITALIAN ICHNOLOGY, Proceedings of the Ichnology session of Geoitalia 2007, VI Forum italiano di Scienze della Terra, Rimini – September 12-14, 2007. *Studi Trentini di Scienze Naturali, Acta Geologica*, 83: 133-163.

Monaco P. & Checconi A. (2010). Taphonomic aspects of the Miocene ichnofossil-*lagerstätte* from calcarenite turbiditic beds in the Verghereto Marls Formation (Northern Apennines, Italy). *Rivista Italiana di Paleontologia e Stratigrafia*, 116 (2): 237-252.

Monaco P., Checconi A. & Giannetti A. (2009a). Il database BSED-IDTB, uno strumento digitale per la catalogazione ed il confronto delle tracce fossili nelle successioni torbiditiche.

Studi e Ricerche, Museo "G. Zannato" Montecchio Maggiore (VI), 16: 35-46.

Monaco P., Milighetti M. & Checconi A. (2009b). Ichnocoenoses in the Oligocene to Miocene foredeep basins (Northern Apennines, central Italy) and their relation to turbidite deposition. *Acta Geologica Polonica*, 60 (1): 53-70.

Monaco P., Nocchi M., Ortega-Huertas M., Palomo I., Martinez F. & Chiavini G. (1994). Depositional trends in the Valdorbia section (Central Italy) during the Early Jurassic, as revealed by micropaleontology, sedimentology and geochemistry. *Eclogae Geologicae Helvetiae*, 87 (1): 157-223.

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

Monaco P. & Uchman A. (1999). Deep-sea ichnoassemblages and ichnofabrics of the Eocene Scisti varicolori beds in the Trasimeno area, western Umbria, Italy. *In* Farinacci A. & Lord A.R. (eds), Depositional Episodes and Bioevents. *Paleopelagos*, Special Publication, 2: 39-52.

Nicholson H.A. (1873). Contribution to the study of the errant anellids of the older Palaeozoic rocks. Proceedings of the Royal Society of London, 21: 288-290.

O'Brien N.R., Nakazawa K. & Tokuhashi S. (1980). Use of clay fabric to distinguish turbiditic and hemipelagic siltstones and silts. *Sedimentology*, 27: 47-61.

Olivero D. (2007). *Zoophycos* and the role of type specimens in ichnotaxonomy. *In* Miller III W. (ed.), Trace Fossils, Concepts, Problems, Prospects, *Elsevier B.V.*: 219-231.

Olivero D. & Gaillard C. (2007). A constructional model for *Zoophycos*. *In* Miller III W. (ed.), Trace Fossils, Concepts, Problems, Prospects, Elsevier Science: 466-477.

Osgood R.G. (1970). Trace fossils of the Cincinnati area. *Palaeontographica Americana*, 6: 193-235.

Pemberton G.S. & Frey R.W. (1982). Trace fossil nomenclature and the *Planolites-Palaeophycus* dilemma. *Journal of Paleontology*, 56: 843-881.

Piccioni R. & Monaco P. (1999). Caratteri sedimentologici, icnologici e micropaleontologici delle unità eoceniche degli scisti varicolori nella sezione di M. Solare (Trasimeno, Umbria occidentale). *Bollettino del Servizio Geologico d'Italia*, 115 (1996): 43-188, Roma.

Piper D.J.W. & Stow D.A.V. (1991). Fine-grained turbidites. *In* Einsele G., Ricken W. & Seilacher A. (eds), Cycles and Events in Stratigraphy. Springer-Verlag, pp. 360-376.

Principi P. (1924). I terreni Terziari dell'Alta Valle del Tevere. *Bollettino della Società Geologica Italiana*, 43: 64-80.

Rajchel J. & Uchman A. (1998). Ichnological analysis of an Eocene mixed marly-siliciclastic flysch deposits in the Nienadowa Marls Member, Skole Unit, Polish Flysch Carpathians. *Annales Societatis Geologorum Poloniae*, 68: 61-74.

Rodríguez-Tovar, F.J. & Uchman, A. (in press). First record of *Avetoichnus luisae* Uchman & Ratazzi, 2011 in the Iberian Península: facies relations and palaeoenvironmental implications. *Revista Española de Paleontologia*.

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

Sanders J.E. (1965). Primary sedimentary structures formed by turbidity currents and related resedimentation mechanisms. *In* Middleton G.V. (ed.), Primary sedimentary structures and their hydrodynamic interpretation. Society of Economics Paleontologists and Mineralogists, Special Publication: 192-219.

Savrda, C.E. (2007). Taphonomy of Trace Fossils. *In* Miller W. III (ed.), Trace Fossils, Concepts, Problems, Prospects. Elsevier Science: 92-109.

Seilacher A. (1990). Aberration in bivalve evolution related to photo- and chemosymbiosis. *Historical Biology*, 3: 289-311.

Seilacher A. (2007). Trace Fossil Analysis. 226 pp., Springer Verlag, Berlin.

Shanmugam G. (2002). Ten turbidite myths. *Earth-Science Reviews*, 58: 311-341.

Sternberg G.K. (1833). Versuch einer geognostisch botanischen Durstellung der Flora der Vorvwelt. IV Heft. C.E. Brenk, Regensburg. 48 pp.

Stow D.A.V. & Piper D.J.W. (1984a). Deep-water fine-grained sediments: facies models. *In* Stow D.A.V. & Piper D.J.W. (eds), Fine-grained sediments: deep-water processes and facies. *Geological Society, London,* Special Publication, 15: 611-664.

Stow D.A.V. & Piper D.J.W. (1984b). Fine-grained sediments: deep-water processes and facies. *Geological Society, London,* Special Publication, 15. 659 pp. Blackwell, Oxford.

Stow D.A.V. & Shanmugam G. (1980). Sequence of structures in fine-grained turbidites: comparison of recent deep-sea and ancient flysch sediments. *Sedimentary Geology*, 25: 23-42.

Trecci T. & Monaco P. (2011). Le ichnocenosi delle successioni sedimentarie Eocenico-Mioceniche affioranti tra il Lago Trasimeno e l'Alpe di Poti (Appennino Settentrionale). *Annali dell'Università degli Studi di Ferrara, Museologia Scientifica e Naturalistica*, 7: 1-101.

Uchman A. (1995a). Taxonomy and paleoecology of flysch trace fossils: the Marnoso-arenacea Formation and associated facies (Miocene, Northern Apennines, Italy). *Beringeria*, 15. 116 pp.

Uchman A. (1995b). Tiering patterns of trace fossils in the Paleogene flysch deposits of the Carpathians, Poland. *Geobios*, M.S. 18: 389-394.

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

Uchman A. (1999). Ichnology of the Rheno danubian Flysch (Lower Cretaceous-Eocene) in Austria and Germany. *Beringeria*, 25: 67-173, Würzburg.

Uchman A. (2007). Deep-sea trace fossils from the mixed carbonate-siliciclastic flysch of the Monte Antola Formation (Late Campanian-Maastrichtian), North Apennines, Italy. *Cretaceous Researches*, 28: 980-1004, London.

Uchman A. (2009). The *Ophiomorpha rudis* ichnosubfacies of the *Nereites* ichnofacies: characteristics and costraints: *Palaeogeography, Palaeoclimatology, Palaeoecology,* 276: 107-119.

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

Wetzel A. (2010). Deep-sea ichnology: observations in modern sediments to interpret fossil counterparts. *Acta Geologica Polonica*, 60 (1): 125-138.

Wetzel A. & Werner F. (1981). Morphology and ecological significance of *Zoophycos* in deep-sea sediments of NW Africa. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 32: 185-212.

Wetzel A., Werner F. & Stow D.A.V. (2008). Bioturbation and biogenic sedimentary structures in contourites. *In* M. Rebesco & A. Camerlenghi (eds), Contourites. *Developments in Sedimentology*, 60: 183-202.

Yang Shipu, Song Zhimin & Liang Dingyi (1982). Middle Jurassic to Early Cretaceous flysch trace fossils from Ngari Region, Tibet. *Acta Geologica Sinica*, 1982 (4): 301-313.

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