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Stratinomic indications by trace fossils in Eocene to Miocene turbidites and hemipelagites of the Northern Apennines (Italy)

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SUMMARY - *Stratinomic indications by trace fossils in Eocene to Miocene turbidites and hemipelagites of the Northern Apennines (Italy)* - Ichnology has been only recently reappraised as a good tool for palaeoecological and palaeoenvironmental interpretations, although still few and partial data are nowadays available about tracemakers and their ethology. For these reasons detailed analyses focusing on the characterization of ichnofossil assemblages distributed within different deposits are indispensable. In turbidite and hemipelagite sediments of the Northern Apennines (Italy), early Eocene to late Miocene in age, 317 samples have been investigated, focusing on stratinomy and abundance in depositional units ("scisti varicolori", Scaglia, Bisciaro, "marnoso arenacea", Macigno and Arenarie di Monte Cervarola formations). This study points out the poorly known or undescribed trace fossils from this area and exhibits preliminary results about the relationships between infauna and sedimentation. Stratinomy allowed to recognize five types of trace fossil distributions, each taking account on burrow stratinomic value that reflects their position in the event bed: hypichnia (base of bed), endichnia (inside bed), epichnia (top of bed), exichnia (outside bed) and crossichnia (crossing event bed an overlying and/or underlying marly/silty beds). This work represents the base for further analyses that will focus mainly on the understanding of the relationship between burrow assemblages and sediment characteristics in foredeep basins.

RIASSUNTO - *Indicazioni stratinomiche dalle tracce fossili nelle torbiditi ed emipelagiti eocenico-mioceniche dell'Appennino Settentrionale* - Solo recentemente è stato riconosciuto il potenziale delle tracce fossili come strumento per le interpretazioni paleoecologiche e paleoambientali, ma i dati a disposizione circa la distribuzione e la sinecologia degli icnotaxa sono ancora scarsi. Per questo motivo è indispensabile eseguire studi volti innanzitutto a caratterizzare le varie icnocenosi distribuite all'interno dei vari contesti sedimentari. In tale ambito si inserisce questo lavoro che ha preso in esame le icnoassociazioni preservate nei depositi eocenico-miocenici torbiditici ed emipelagitici delle formazioni degli "scisti varicolori", della Scaglia (Scaglia Rossa, "scaglia variegata" e Scaglia Cinerea), del Bisciaro e delle formazioni silicoclastiche del Macigno, delle Arenarie del Monte Cervarola e della formazione "marnoso arenacea" affioranti in Appennino Settentrionale. Le analisi, svolte su 317 campioni raccolti in 30 diverse località rappresentative, hanno consentito di caratterizzare tassonomicamente le icnocenosi e di comprendere preliminarmente le relazioni stratinomiche delle tracce fossili nei depositi gravitativi. Gli icnotaxa possono essere raggruppati in 5 gruppi stratinomici che riflettono sostanzialmente la loro distribuzione rispetto allo strato-evento: hypichnia, endichnia, epichnia, exichnia e crossichnia. Questo lavoro rappresenta un contributo preliminare alla descrizione delle icnocenosi caratterizzanti l'Appennino Settentrionale e getta le basi per ulteriori studi volti a comprendere a fondo le relazioni che intercorrono tra tracce fossili e depositi torbiditico-emipelagici, così da incrementare le potenzialità dell'icnologia negli studi paleoambientali di mare profondo.

Key words: Turbidites, stratinomy, trace fossils, Miocene, Northern Apennines, Italy
Parole chiave: Torbiditi, stratinomia, tracce fossili, Miocene, Appennino Settentrionale, Italia

1. INTRODUCTION

Ichnofabric and trace fossil differentiation in event beds directly reflect the endobenthos activity, which involved the substrate in all directions. In the photic zone between the beach (Pemberton *et al.* 1992) and the distal shelf (Dörjes & Hertweck 1975) burrowers affect the substrate, developing traces usually in vertical direction for the space availability to compensate sediment erosion produced by storm waves and shelf currents, and ichnocoenoses can be referred to the proliferation of infauna and to competition among organisms (Seilacher 1982b; Frey & Pemberton 1984; Ekdale 1985; Kidwell 1991; MacEachern *et al.* 1992; Goldring 1995; Monaco 1995, 1996; Bromley 1996). Moving in depth from the upper slope to distal basin environments, the burrowing activity increases horizontally, depending on the sediment accumulation and environmental parameters (Seilacher 1967, 1974; 2007; Ekdale 1985). The ethological behaviour of turbidite infauna is influenced by depth and the burrowing activity tries to exploit food resources which are scattered horizontally and inevitably concentrated by currents on the seafloor. At greater depth bioturbation is sensitive to changes in sedimentation rate (e.g. turbidity currents) and substrate consistency, and therefore selected by pressure conditions and specific chemical-physical parameters of the substrate, such as temperature, salinity and oxygenation (Seilacher 1967;

1974, 1977a; Ekdale 1985, 1988; Frey *et al.* 1990; Monaco 1996; Monaco & Uchman 1999; Wetzel 2000; Uchman 2004, 2007; Seilacher 2007).

The group of trace fossils called graphoglyptids (Fuchs 1895) is highly organized; these trace fossils are normally found as casts on the lower surface of distal turbidites (e.g. the typical *Paleodictyon,* see Monaco 2008). Trends in diversity, frequency and complexity of graphoglyptid trace fossils are discussed in Uchman (2003). Washed-out mud burrows are very common on turbidite soles, where these trace fossils were produced "pre-depositionally", prior to turbidite sedimentation (Seilacher 1962, 2007; Tunis & Uchman 1996a). Small and delicate tunnel systems such as *Paleodictyon* occur only in this kind of preservation and their margins are usually very sharp. Under traction current of turbidite flows they are hardly fluted, reflecting the shock erosion in front of fastly approaching density currents, which are immediately followed by sand sedimentation in distal areas (Seilacher 1962, 1977b, 1982a; Monaco 2008). If flute or groove casts are common (e.g. in proximal areas), the preservation of graphoglyptids, which suggests a shallow burrowing into the mud, can be damaged, and delicate mesh-like tube systems can also be partially or totally destroyed (Crimes 1973; Wetzel 2000; Monaco 2008). Conversely, "post-depositional" trace fossils are those that exploit food resources affecting the event sedimentation; commonly they are distributed from the top toward the base of a bed, involving the tail of turbidite which is represented by very fine-grained sand or hemipelagite (Seilacher 1967, 1974, 1977a, 1977b; Uchman 1995a, 1995b, 1998).

The aim of this paper is to investigate the stratinomy of peculiar turbidite ichnocoenoses, considering pre- and post-depositional trace fossils formed from Eocene to late Miocene in different pelagic formations of the northern Apennines: "scisti varicolori", Scaglia (Scaglia Rossa, "scaglia variegata" and Scaglia Cinerea), Bisciaro, "marnoso arenacea", "marne di Verghereto", Macigno (mainly the so-called "arenarie di Monte Falterona"), Arenarie di Monte Cervarola and "marne di Vicchio". This allowed to point out poorly known or undescribed trace fossils from this area and to preliminarly characterize the relationships between infauna and sedimentation.

2. STUDIED AREAS AND GEOLOGICAL SETTING

The present study considers chiefly pre- and post-depositional trace fossils of turbidites largely distributed in the Apennine basins; *Zoophycos*-bearing hemipelagites (from the Contessa section and the Cascia area) are reported as well, for a preliminary comparison with other trace fossils. Four areas have been analyzed and 30 stratigraphic sections have been investigated; studied deposits can be referred to the following four groups (A, B, C, D) that include several units and formations (Fig. 1): A. "scisti varicolori" unit (VA) of western Umbria (4 sections); B. the "Scaglia group" (Scaglia Rossa, "scaglia variegata" and Scaglia Cinerea formations) (SG) in the central-eastern Umbria (8 sections); the Bisciaro formation (BI, 2 sections); C. the "marnoso arenacea" formation (MA) in the northern Umbria - southern Romagna region (11 sections); D. the Macigno formation (mainly "arenarie di Monte Falterona") and Arenarie di Monte Cervarola siliciclastic units (MC, PT-CEV) in Tuscany (Pratomagno ridge, Alpe di Poti, Casentino and Arezzo area) (5 sections).

A. The "scisti varicolori" unit (VA)

This unit (*sensu* Principi 1924) consists of a thick sequence of pelagic stratified deposits, varicoloured hemipelagic mudstones and calcarenitic turbidites (Cretaceous-Paleogene), cropping out in the northern Tuscany and Umbria (central Apennines). They are allochthonous deposits and were unrooted from their original place (from the western Tuscany) and overthrusted eastward during the upper Paleogene and Neogene (Damiani & Pannuzi 1982; Pialli 1994). The VA unit, late Cretaceous - late Eocene, is well exposed in the south-eastern Tuscany and in the western Umbria, overlayed by the "Trasimeno siliciclastic arenites" (external Tuscan units: Damiani & Pannuzi 1982; Damiani *et al.* 1987, 1997; Piccioni & Monaco 1999); according to new unpublished data based on foraminifers collected in the Todi area (Pioppi, pers. communic.), the boundary between the two aforementioned units can be attributed to the early Miocene. The VA unit is coeval with the unit of "scisti policromi" of Siena and Chianti areas in the northern Tuscany (Fazzuoli *et al.* 1996) and with the "scaglia toscana" formation (Merla 1951; Fazzuoli *et al.* 1996). The present study in the western Umbria involves four Eocene stratigraphic sections, distributed along the geographic alignment of the Ansina river to the north, Parrano locality (south of Trasimeno Lake) to the south, and in the locality at SW of Perugia (Umbria) (Fig. 1). The sequences consist of limestones, marly-limestones and varicoloured marls and clays alternated with medium- to coarse-grained calcareous turbidites rich in shallow-water benthic foraminifers (Pl. 1A). Many fine-grained to muddy turbidites, intensely bioturbated, are also present. In the 126 m thick Monte Solare section, which may be considered the reference of the lower-middle Eocene interval in the western Umbria Apennines (Monaco & Uchman 1999; Piccioni & Monaco 1999), a detailed biostratigraphic analysis has been carried out considering both planktonic and benthic foraminifers. This section, cropping at south of Trasimeno lake, ranges from the base of the P6 planktonic foraminiferal Zone (lower Eocene, lower part of middle Eocene) to the base of the P12 Zone (middle Eocene, Piccioni & Monaco 1999). Shallow-water benthic fauna (mainly large foraminifers), granulometric characteristics, mean accumulation rate and sedimentary structures of calcareous turbidites have been analyzed (Piccioni & Monaco 1999).

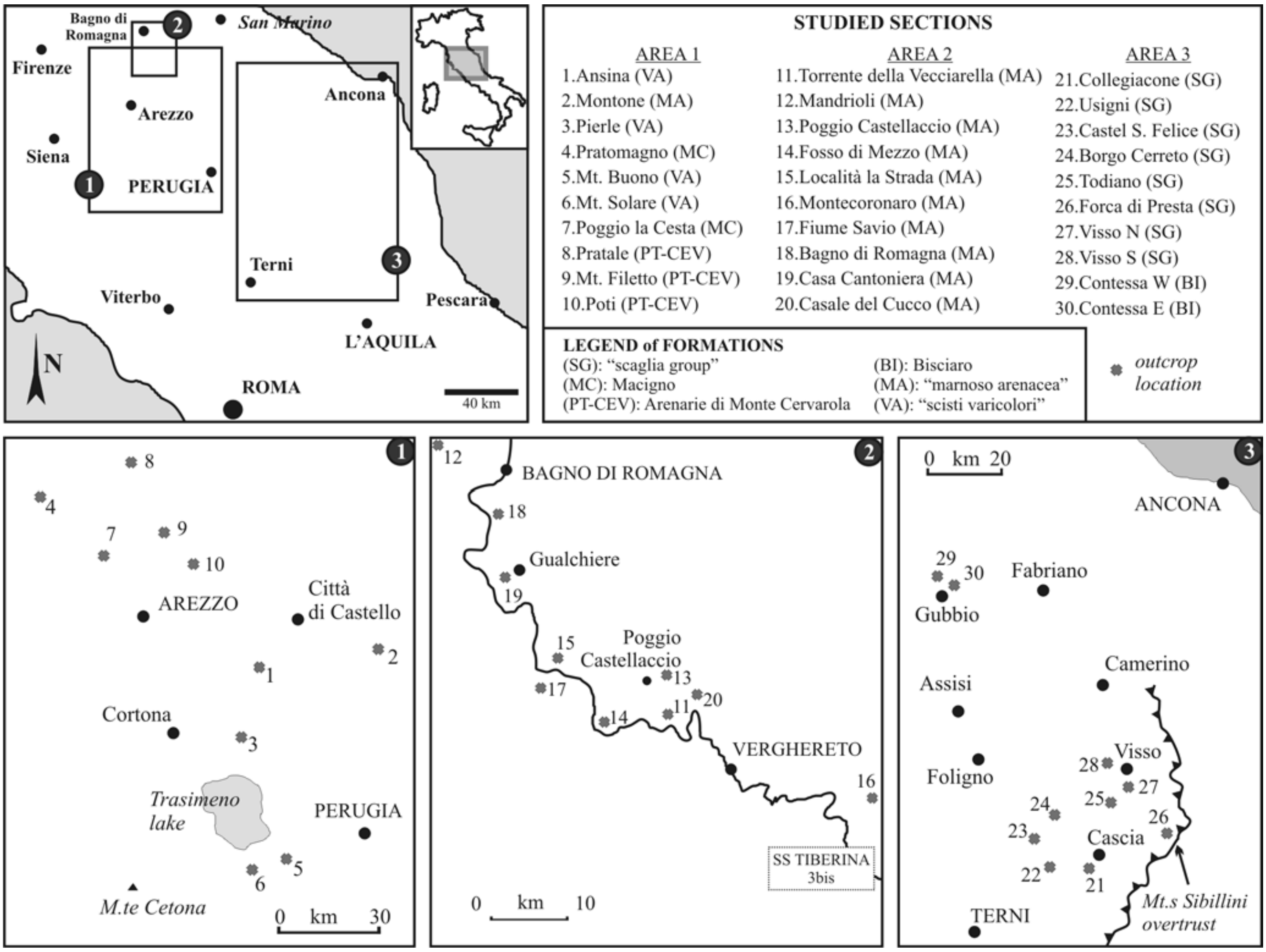
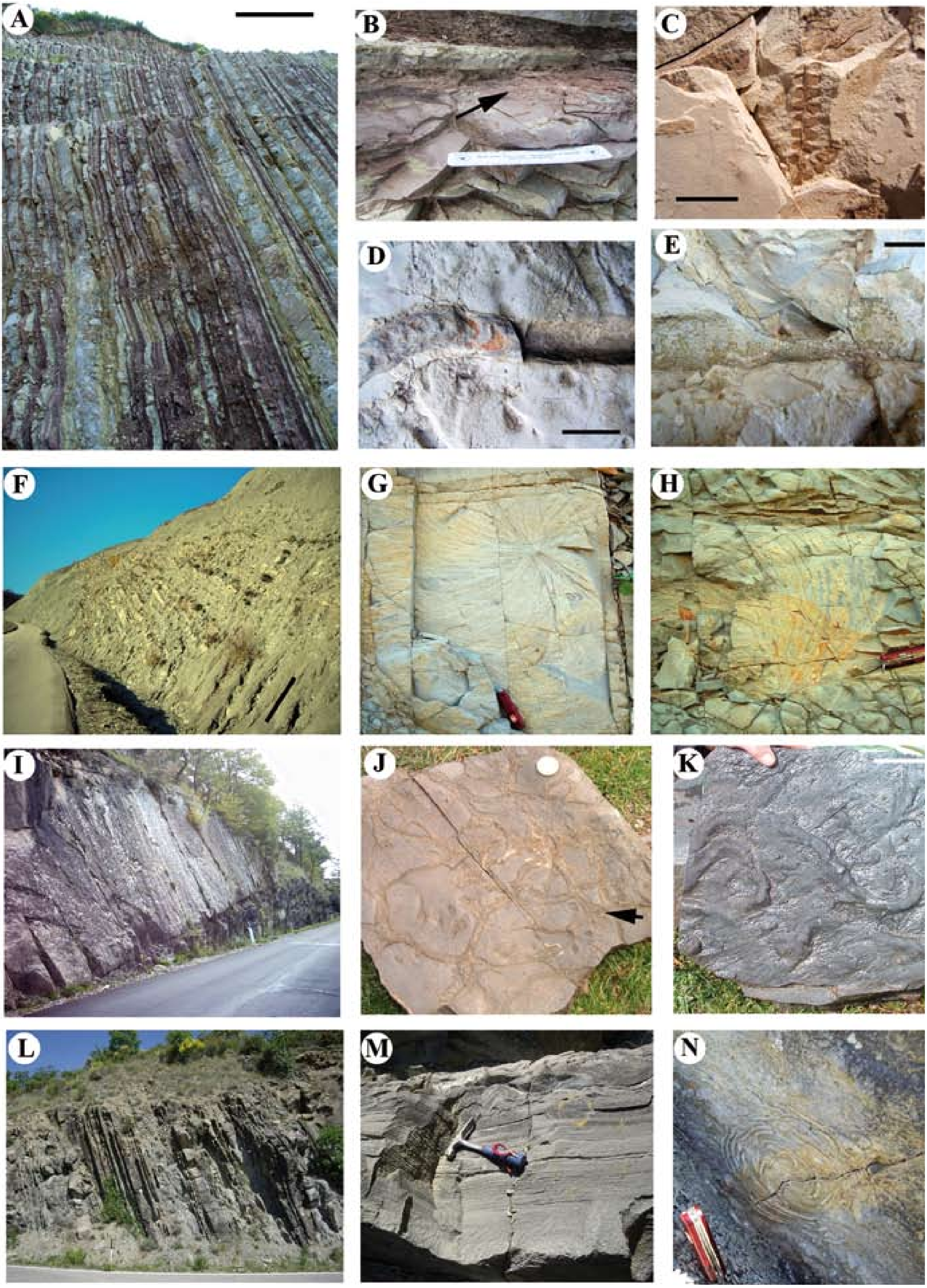


Fig. 1 - Study area with indications of the outcrops of Eocene to Miocene turbidites and hemipelagites.
Fig. 1 - Area di studio e localizzazione degli affioramenti di depositi torbiditici ed emipelagitici eocenico-miocenici presi in esame.

B. The "Scaglia group" (SG) and Bisciaro formation (BI)

The pelagic deposits of the northern Umbria series outcropping in the Contessa-Gubbio sequence are mainly limestones and marls, spanning about 100 million years of almost continuous sedimentation from late Jurassic to early Miocene. In the Contessa valley the almost complete pelagic sequence, from late Cretaceous to late Eocene, is preserved with Scaglia Bianca, Scaglia Rossa and "scaglia variegata" formations but, at this level, faulting erases the overlying Scaglia Cinerea and puts the marly-limestones of Bisciaro formation (early Miocene, Pl. 1F) in sharp contact with the underlying "scaglia variegata" and with overlying Miocene turbiditic deposits of the Umbria-Romagna sequence ("marnoso arenacea" turbidites). The detailed biostratigraphic and magnetostratigraphic assessement of the Contessa-Gubbio deposits is well known in literature, also involving the Eocene/Oligocene boundary (Alvarez *et al.* 1977; Lowrie *et al.* 1982; Premoli Silva *et al.* 1988). The ichnologic analysis in the Contessa section (quarry "il Cavaliere") focuses on the *Zoophycos*-bearing, pelagite-hemipelagite deposits of the upper "Scaglia group" members and Bisciaro formation (see Pl. 1G, H). Lithologies of these units include, from the bottom to the top: thin- to medium bedded gray to varicolored (reddish) limestones, marly-limestones, violet marls, yellowish to gray clayey-marlstones and dark shales (Pl. 1F). Pelagite characterizes the Eocene interval (Scaglia Rossa and "scaglia variegata"), while the hemipelagite increases progressively in the Oligo-Miocene (top of "scaglia variegata" and Bisciaro); turbiditic deposits have not been found in this area. From central to south-eastern Umbria (Cascia area) turbidites increase progressively their frequency and grain size; they are represented by medium- to coarse-grained calcarenites (rudstone/packstones with shallow-water fauna, mainly large foraminifers and calcareous algae) and gravity flow deposits (debrites, slumps and pebbly mudstones) ranging from Cretaceous to Oligocene (Monaco *et al.* 1987; Monaco 1989; Colacicchi & Monaco 1994). In the Cascia area the gray hemipelagic mudstones known as the "marne di Collecastellano" unit (same age of "scaglia variegata" and Scaglia Cinerea in south-eastern Umbria, Monaco *et al.* 1987) over-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lay the pelagic limestones of Scaglia Rossa; they were deposited in a deep-water ramp system, which was subdivided in a scarp-slope-basin margin complex, developing at the transition between the Umbria-Marche basin and the Latium-Abruzzi carbonate platform from Cretaceous to Oligocene (Colacicchi *et al.* 1985; Colacicchi & Baldanza 1986; Colacicchi & Monaco 1994).

C. The "marnoso arenacea" formation (MA)

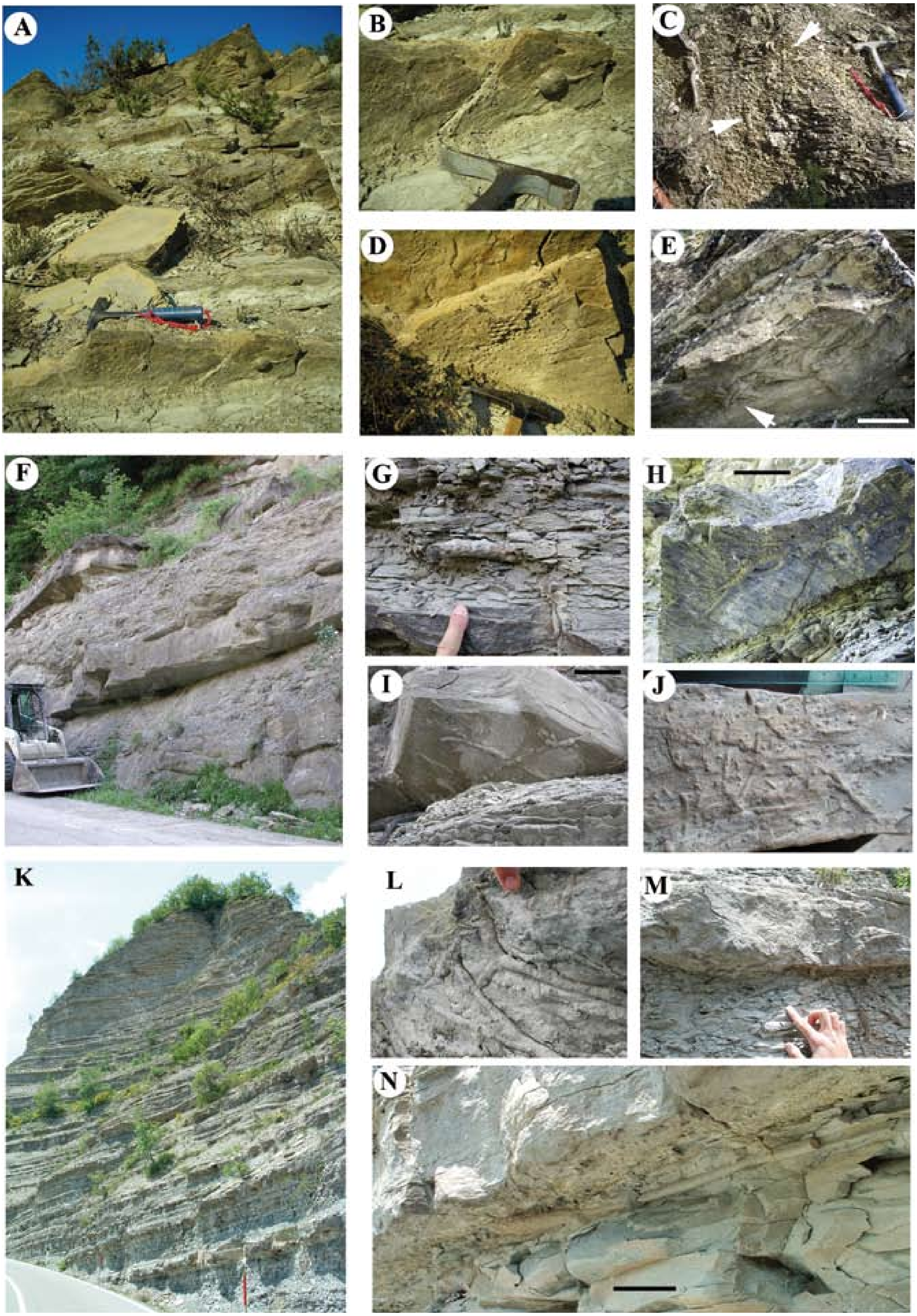
The authochonous Umbria-Marche and Romagna units consist of pre- and syn-orogenic, deformed (from middle-late Miocene to middle Pliocene), but not metamorphosed marine sediments (Jurassic - middle Miocene) volumetrically dominated by siliciclastic deposits of the "marnoso arenacea" (MA) formation. Within the Umbria domain the Inner Basin was filled by a multi-sourced supply, turbidite trough (accumulation at an average rate of 15-40 cm/1000 y), active from Langhian to early Tortonian, and extended from Emilia-Romagna to southern Umbria over a length of almost 400 km. The Inner Basin was flanked eastward by late orogenic post-Tortonian deposits or Periadriatic units of the Adriatic Foredeep (Marche) (Ricci Lucchi 1981). The turbidite filling of the Inner Basin is primarily aggradational although well recognizable "normal" (hemipelagic) sediments as silty-marly mudstones are common, reaching 10-20% of the total volume of MA. This suggests very fast sedimentation of clayey deposits compared to that of adjacent non-turbiditic areas. Trace fossil analysis concerns Miocene siliciclastic, thin-bedded turbidites and medium-bedded sandy turbidites of the Savio-Tiber valleys, of the Mandrioli Pass and of the Montone area (Fig. 1; Pl. 2A, F, K). Moreover, trace fossils from marly deposits with thin-bedded fringe turbidites deposited around the submarine Verghereto High ("marne di Verghereto" unit) have also been investigated.

D. Macigno and Arenarie di Monte Cervarola formations (MC; PT-CEV)

The Macigno formation (Merla 1951), known in the Casentino area (eastern Tuscany) as "arenarie di Monte Falterona" formation (Fazzini 1964) and the Arenarie di Monte Cervarola, represent the two most important turbiditic formations that had been recovered (with different allochthonous rate) in the Tuscany-Romagna sectors of the Northern Apennines. In eastern Tuscany (Casentino and Pratomagno areas, see Fig. 1) the Macigno formation is about 700-750 m thick (Aruta & Pandeli 1995) and it can reach 2000 m in correspondence of Mt. Lori (Losacco 1963). In the Casentino area the "arenarie di Monte Falterona" sandstones (Fazzini 1964) are generally organised in thickening upward sequences characterised by alternations of massive arenitic-conglomeratic bodies with metrical thickness, lenticular geometries and sharp base (Pl. 1I). Thinning upward sequences are very rare. Dark shales/claystone intervals occur only at the top of the arenite banks; they are arranged in beds (>10 cm) that become thicker at the top of the unit. In the area comprised between Badia Prataglia (Pratomagno, northern Casentino) and the Trasimeno Lake, siliciclastic sequences are regularly intercalated with carbonate-marly deposits (Bruni & Pan-

← Pl. 1 - Trace fossils and turbidites from Eocene to Miocene ("scisti varicolori", "Scaglia group", Macigno and Arenarie di Monte Cervarola formations, Northern Apennines). A. Outcrop showing thin-bedded turbidites and reddish limestones of "scisti varicolori", Trasimeno area (M. Solare); bar 2 m; B. detail of thin-bedded reddish calciturbidite with endichnial and epichnia in the mudstone top (see text); C. detail of endichnia/epichnia *Nereites* in mudstone, bar 2 cm; D. detail with endichnial *Taenidium*, bar 1 cm; E. detail with endichnial *Alcyonidiopsis longobardiae,* bar 1 cm; F. outcrop of thin-bedded mudstones and marls of upper Scaglia and Bisciaro units, Contessa area, northern Umbria, bar 1 m; G-H. detail of endichnia/crossichnia represented by *Zoophycos* in marly beds, knife 6 cm; I. outcrop with thick-bedded, massive sandstones, Macigno formation, Pratomagno section; J. detail of hypichnia *Thalassinoides suevicus*, coin 2 cm; K. detail of hypichnia "*Spirophycus*" *bicornis* in dark sandstone, bar 6 cm; L. outcrop showing thin-to medium-bedded sandstones and marls of Arenarie di Monte Cervarola formation (Cortona area, M. Filetto); M. detail of a thin-bedded turbidite with Ta-c Bouma intervals; N. detail of spiral structure of incomplete *Spirorhaphe* preserved as hypichnia, knife 6 cm.

Tav. 1 - Esempi di tracce fossili e depositi torbiditici di età eocenico-miocenici ("scisti varicolori", "gruppo della Scaglia", Macigno e Arenarie di Monte Cervarola) dell'Appennino Settentrionale. A. affioramento caratterizzato da torbiditi sottilmente stratificate e micriti rossastre riferibili al gruppo degli "scisti varicolori" (area del Trasimeno, M. Solare; scala: barra 2 m); B. dettaglio della calci-torbidite sottilmente stratificata illustrata in (A) con endichnia and epichnia al tetto del mudstone (vedi testo); C. dettaglio di Nereites *con sviluppo endichnia/epichnia in corrispondenza del mudstone nei depositi illustrati in (A) (scala: barra 2 cm); D. dettaglio con* Taenidium *di tipo epichnia all'interno dei depositi illustrati in (A) (scala: barra 1 cm); E. dettaglio di* Alcyonidiopsis longobardiae *di tipo endichnia all'interno dei depositi illustrati in (A) (scala: barra 1 cm); F. affioramento di depositi sottilmente stratificati caratterizzati da alternanze di mudstone e marne riferibili alla parte alta del "gruppo della Scaglia" e al Bisciaro (zona della Contessa, Umbria settentrionale; scala: barra 1 m); G-H.* Zoophycos *di tipo endichnia/crossichnia all'interno di sedimenti marnosi illustrati in (F) (scala: barra 6 cm); I. affioramento di depositi arenitici organizzati in banconi e strati molto spessi riferibili alla formazione del Macigno (area del Pratomagno); J.* Thalassinoides suevicus *di tipo hypichnia relativo all'affioramento dell'area del Pratomagno illustrato in (I) (diametro moneta 2 cm); K. dettaglio di "*Spirophycus*"* bicornis *di tipo hypichnia all'interno delle areniti scure presenti nei sedimenti illustrati in (I) (scala: barra 6 cm); L. affioramento caratterizzato da areniti e marne sottilmente o mediamente stratificate appartenenti alla formazione delle Arenarie di Monte Cervarola, (area di Cortona, M. Filetto); M. dettaglio dei depositi torbiditici sottilmente stratificati comprendenti gli intervalli Ta-c di Bouma; N. strutture spiralate riferibili all'ichnogenere* Spirorhaphe *(esemplare incompleto) preservato come hypichnia (scala: barra 6 cm).*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deli 1980). Some of these deposits represent local marker levels, as the 10-12 m thick mega-contourite deposited between the top of "Scaglia toscana" and the base of the overlying Macigno formation. The age of Macigno is uncertain, but Costa *et al.* (1997) dated its base to the upper Chattian (NP25 and NN1-2 nannoplankton zones). The Macigno formation gradually passes into the overlying Arenarie di Monte Cervarola unit: the transition is placed in correspondence of a level particularly rich in planktonic assemblages, attributed to the uppermost Aquitanian. The Arenarie di Monte Cervarola unit shows an average thickness of 500 m, but it exceeds 1000 m in Florence and Pratomagno area. These sediments are characterised by clay-arenitic facies (Pl. 1, Fig. L); the sand/pelite ratio is 1:1 at the base of the formation and it decrease upwardly; on the other hand, carbonate percentage gradually increases moving from the base to the top. In the eastern Tuscany, the Oligo-Miocene turbiditic sequence ends with the "marne di Vicchio" formation (Burdigalian - middle Serravalian), characterised by black chert, thick light blue-gray marls and glauconitic arenites (Merla 1969), with common vulcanoclastic beds and barite nodules. The boundary between the Arenarie di Monte Cervarola and the "marne di Vicchio" formations is placed few centimetres above the regional marker named "black cherty horizon" (Merla 1951). In the Arezzo area, where the "marne di Vicchio" formation does not crop out, this marker level characterises the upper part of the Arenarie di Monte Cervarola. Planktonic foraminifers are abundant in bioturbated beds containing *Zoophycos* (Delle Rose *et al.* 1994). The depositional environment of the "marne di Vicchio" formation is interpreted as a narrow, deep basin formed within the Foredeep (piggy back basins?) isolated and protected from the main siliciclastic input (Centamore et al. 2002).

3. MATERIAL AND METHODS

Trace fossil and ichnofabric analysis started since the end of the eighties, chiefly analyzing carbonate turbidites in the easternmost sector of Northern Apennines (Scaglia deposits of the Umbria-Marche Basin), involving the Eocene-Oligocene interval (Monaco 1989). Since the nineties, the study has been progressively extended also to carbonate turbidites of the westernmost sector of the Trasimeno area (early-middle Eocene in the Monte Solare section) (Monaco & Uchman 1999; Piccioni & Monaco 1999). In recent years siliciclastic turbiditic deposits have been considered as well, analyzing the "marnoso arenacea" formation and associated facies of central Umbria and Romagna, and some siliciclastic units of Tuscany (Monaco 2008). The present study focuses on ichnocoenoses of turbidites and hemipelagites (as indicated in the taxonomic list of main ichnogenera and ichnospecies) and on the stratinomic distribution of ichnotaxa within or external to event beds (Fig. 2; Tab. 1). Ichnofabric differentiations of muddy turbidites follow those introduced by Wetzel & Uchman (2001). Methods here adopted are independent from the age here considered which is not fundamental for trace fossils diversification (Ekdale 1985).

← Pl. 2 - Trace fossils and turbidites of the Miocene ("marnoso arenacea" formation, Northern Apennines). A. Outcrop of thin-bedded turbidites and pelite beds in the Montone section; B. detail of typical hypichnia at sole of thin-bedded turbidite sandstone, *Paleodictyon* (*Ramodictyon*) *hexagonum* (left) and ?*Cardioichnus* (right); C. detail of crossichnia in more pelitic beds (*Ophiomorpha* cf. *annulata*); D. detail of horizontal mesh and vertical shafts of *Paleodictyon hexagonum*; E. detail of *Scolicia strozzii* as sole of sandstone, bar 8 cm; F. outcrop of medium to thick-bedded turbidites of "marnoso arenacea" formation, Bagno di Romagna; G. detail of *Ophiomorpha annulata* (exichnia?) whithin pelitic bed at top of sandstone, finger for scale; H. branched *Ophiomorpha* tunnels preserved as hypichnia at sole of sandstone (Poggio Castellaccio), bar 12 cm; I. hypichnial-endichnial branched *Ophiomorpha rudis*: note large knobby bulges which produce irregular thickening of burrow diameter, bar 10 cm; J. hypichnial bulges of *Arthrophycus strictus* plunging in mud at sole of sandstone; K. outcrop of regular, thin-bedded turbidites, "marnoso arenacea" formation, Mandrioli -Pass; L. detail of hypichnial/endichnial branched tunnels of *Ophiomorpha* isp., bar 2 cm; M. detail of hypichnia/exichnia (crossichnia?) *Thalassinoides*, hand for scale; N. detail of a typical car-silencer shaped trace (*Ophiomorpha*-like), that may be common at the sandstone/pelite transition (hypichnia/endichnia), bar 4 cm.

Tav. 2 - Esempi di tracce fossili e depositi torbiditici di età miocenica relativi alla formazione "marnoso arenacea" (Appennino Settentrionale). A. Torbiditi sottilmente stratificate e orizzonti pelitici sottili affioranti nell'area di Montone (Umbria); B. hypicnia rinvenute alla base di depositi torbiditici di taglia arenitica sottilmente stratificati rappresentate da Paleodictyon (Ramodictyon) hexagonum *(sinistra) e ?*Cardioichnus *(destra); C.* Ophiomorpha *cf.* annulata *di tipo crossichnia all'interno di intervalli pelitici all'interno della successione raffigurata in (A); D. dettaglio del pattern orizzontale e dei canali verticali di* Paleodictyon hexagonum*; E. esemplare di* Scolicia strozzii *alla base di depositi di taglia arenitica (scala: barra 8 cm); F. successione di torbiditi caratterizzate da una stratificazione medio-grossolana riferibili alla "marnoso arenacea" affioranti nell'area di Bagno di Romagna; G.* Ophiomorpha annulata *(exichnia?) all'interno di orizzonti pelitici al tetto di strati arenitici; H. pattern ramificato riferibile all'ichnogenere* Ophiomorpha *preservato come hypichnia alla base di areniti affioranti nell'area di Poggio Castellaccio (scala: barra 12 cm); I. pattern ramificato di* Ophiomorpha rudis *di tipo hypichnia-endichnia: da notare le numerose protuberanze che rendono il diametro della traccia estremamente irregolare (scala: barra 10 cm); J. protuberanze conservate come hypichnia riferibili a* Arthrophycus strictus *che si insinuano nel fango a partire dal letto dello strato arenitico; K. torbiditi sottilmente stratificate affioranti nei pressi del Passo Mandrioli e riferite alla formazione "marnoso arenacea"; L. gallerie ramificate di* Ophiomorpha *isp. conservate come hypichnia/endichnia (scala: barra 2 cm); M.* Thalassinoides *preservato come hypichnia/exichnia (crossichnia?); N. particolare di un traccia riferibile ad* Ophiomorpha *isp., caratterizzata dalla tipica forma a "marmitta d'automobile", che risulta essere comune all'interno del contatto tra areniti e peliti, conservandosi come hypichnia/endichnia (scala: barra 4 cm).*

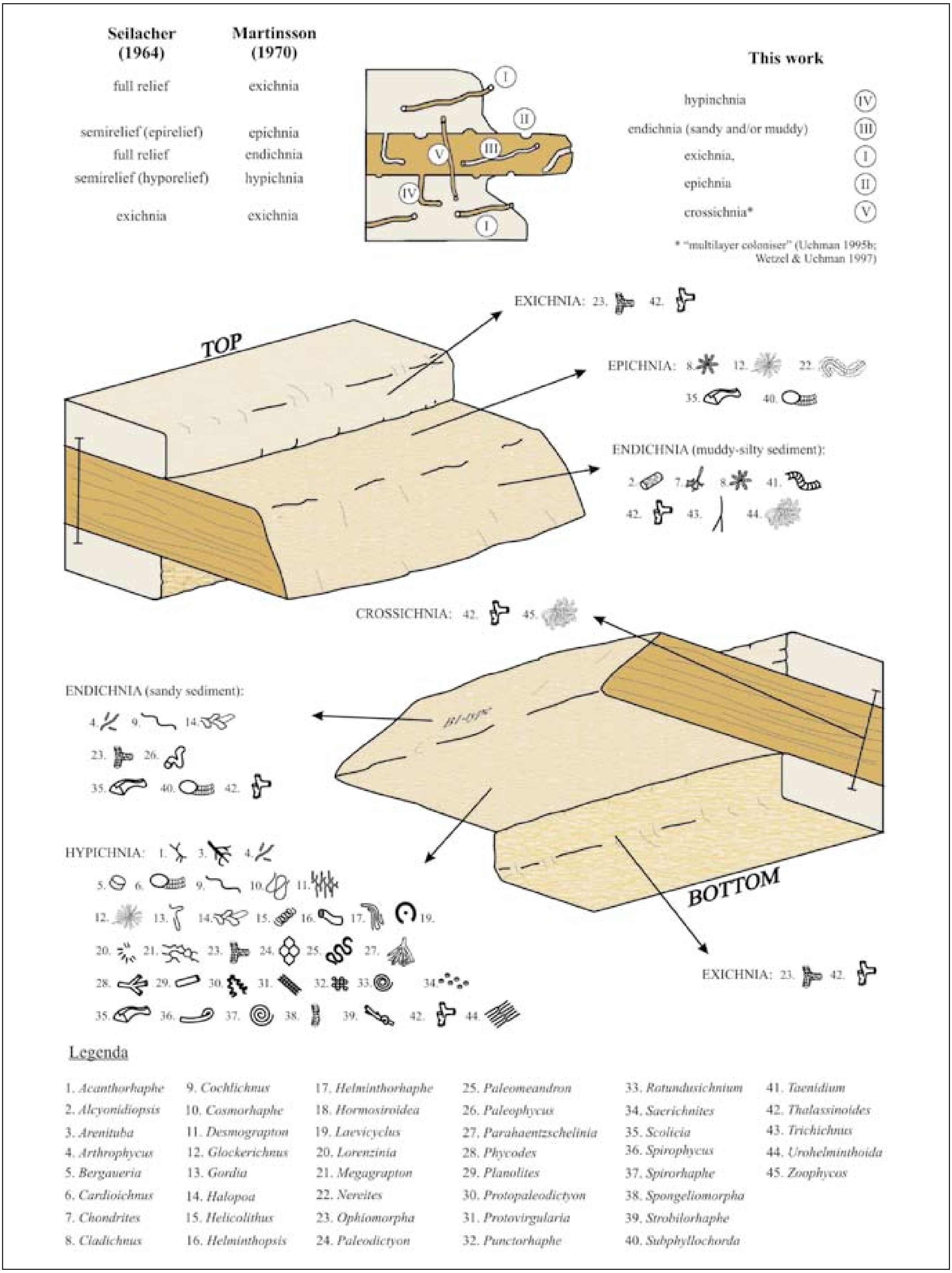

Fig. 2 - Stratinomic distribution of trace fossils within an idealized event bed.

Fig. 2 - Distribuzione stratinomica delle tracce fossili all'interno di un generico strato evento.

Tab. 1 - List of ichnogenera with symbols, occurrence, stratinomy and samples.

Tab. 1 - Elenco (in ordine alfabetico) degli icnogeneri rinvenuti nei depositi presi in esame e relativi simboli, tipo di depositi e/o formazioni in cui sono stati rinvenuti, caratteri stratinomici e sigla del campione.

ICHNOGENUS	SYMBOL	STRATINOMY	OCCURRENCE (FORMATION AND AGE)	SAMPLES
Acanthorhaphe		hypichnia in fine-grained turbidites	PT-CEV, MA (Oligocene-Miocene)	2 specimens: MA 56; PT 142.
Alcyonidiopsis		endichnia in muddy turbidites (very rare as endichnia/hypichnia in sandy turbidites)	mainly in VA (Eocene)	5 specimens: VA 123a-e
Arenituba		hypichnia at sole of sandy turbidite.	MA of Savio valley (Miocene)	1 specimen: MA 56
Arthrophycus		short hypichnia, and endichnia in medium-grained and thick bedded turbidites	MA (Miocene) and PT-CEV (Oligocene-Miocene)	11 specimens: PT 133, MA 22, 33, 76-77, 109-114
Bergaueria		hypichnia at sole of fine-grained (silty) siliciclastic turbidites	MA (Miocene) in Montone and Savio valley (Verghereto)	3 specimens: MA 23a, 213, 216
Cardioichnus		hypichnial trace at sole of siliciclastic turbidite	PT-CEV of Cortona area (Oligocene-Miocene), MA of Montone (Miocene)	3 specimens: CEV156a-b, MA205b
Chondrites		usually as endichnia, in the upper, finer portion of calciturbidites (lutitic interval at the top) and thin-bedded siliciclastic turbidites (e.g. Verghereto High)	SG, VA (Eocene), PT-CEV and MA (Oligo-Miocene)	10 specimens: SG 221a-c, VA 222a-d, Ma 187, PT 223a-b
Cladichnus		endichnia, and locally also as epichnia (lutitic interval at the top of calcareous turbidites).	Varicolori Beds (Eocene)	6 specimens: VA 217, 224a-e
Cochlichnus		hypichnia-endichnia at sole of fine-grained, medium-bedded siliciclastic turbidites.	MA of Savio valley (Miocene)	2 specimens: MA 05a-b
Cosmorhaphe		hypichnia at sole of fine-grained, medium-bedded siliciclastic turbidites	MC, PT-CEV and MA (Oligocene-Miocene).	3 specimens: MA 105, PT 126a-b.
Desmograpton		hypichnia very abundant at sole of fine-grained, thin-bedded turbidites	VA (Eocene), MC, PT-CEV and MA (Oligo-Miocene)	16 specimens: VA 08, MA 25, 30, 36, 81, 88, 93, 94, 168, 175, 184, 186, 190, 194, 205, 211n
Glockerichnus		hypichnia and some doubtful forms as epichnia in very thin-bedded (5 cm) turbidites	mainly MA (fringing facies close the Verghereto High)	3 specimens: MA 89, 96, 97
Gordia		hypichnia mainly at sole of thin-bedded (5-10 cm) but sporadically of thick-bedded turbidites	MC of Pratomagno (Oligocene?), MA of Verghereto (Miocene)	3 specimens: MA 39, 71, PT 130
Halopoa		hypichnia and endichnia mainly at soles of of thin-bedded turbidites	abundant in PT-CEV (Oligocene-Lower Miocene) and MA (Miocene), very rare in VA (Eocene)	12 specimens: CEV 146, 147, 152, 153, 155, MA 21, 40, 47, 74, 78, 80, 83
Helicolithus		hypichnia at soles of thin-bedded turbidites	MA (Miocene)	3 specimens: Ma58a-b, 188
Helminthopsis		hypichnia at the soles of fine-grained and usually thin-bedded calcarenitic turbidites	VA (Eocene), MC and PT-CEV (Oligocene-Miocene), MA (Miocene)	7 specimens: VA 10, 17, Ma 11, 75, 107, 128, 136
Helminthorhaphe		hypichnia	PT-CEV and MA (Oligo-Miocene)	6 specimens: MA 111q, 199, 220, CEV 48a-c

(Tab. 1 - continued)
(Tab. 1 - continua)

ICHNOGENUS	SYMBOL	STRATINOMY	OCCURRENCE (FORMATION AND AGE)	SAMPLES
Hormosiroidea		uncertain	VA of Trasimeno area (Eocene?)	1 specimen: VA 24
Lorenzinia		hypichnia at soles of medium-bedded and thin-bedded (5-15 cm) turbidites	MC, PT-CEV and MA (Oligocene-Miocene)	6 specimens: MA 61, 108, 169, 173, 211d, PT 141
Megagrapton		hypichnia at sole of every turbidite beds, from thick to thin-bedded turbidites (abundant in thin beds)	PT-CEV and MA (Oligocene-Miocene)	10 specimens: MA 66, 85, 91, PT 127, 134, 149, 150, 183, 193, 202
Muensteria		hypichnial and endichnial form in mudstones	SG (mainly Scaglia Rossa and "scaglia variegata"), VA; doubtful in MA	8 specimens: SG 235a-d, VA 236a-c, ?MA236b
Nereites		mainly epichnia at the top of calcilutitic and of fine-grained siliciclastic turbidites	VA of western Umbria and eastern Tuscany (Eocene), and MA of Romagna (Miocene)	10 specimens: VA 12, 225a-c, MA 20, 72, 73, 82, 84, 135
Ophiomorpha		hypichnia, exichnia, endichnia in every facies, but very abundant in m-thick, high-density sandy turbidites	VA, MC, PT-CEV and MA (Eocene-Miocene)	17 specimens: MA 09, 34, 43, 45, 52, 103, 104, 106, 137, 138, 139, 144, 160, 181, 198, 209, VA 144
Paleodictyon		hypichnia. Mainly at soles of fine-grained and thin-bedded turbidites but occur also in medium to thick-bedded turbidites (fluted or partially preserved)	VA (Eocene), MC, PT-CEV and MA (Oligocene-Miocene). Very rare in SG	63 specimens: MA13a-b, 14a-b, 18, 28a-b, 29, 32, 57a-b, 67, 101a-b, 102, 115, 117, 118, 140, 145a-b, 160, 164, 179, 182, 183, 189, 200, 202, 208a-c, 211a-k (12), 211(bis)a-e (5), 212a-i (9), 213, CEV148, PT129a-c
Paleomeandron		hypichnia in thin-bedded turbidites	PT-CEV (large specimens, Oligocene) and MA (small specimens, Miocene)	3 specimens: CEV 53, 178, MA 192
Palaeophycus		rare as hypichnia at the sole of fine-grained turbidite, commonly found mainly as endichnia	VA (mainly Eocene), MA (Miocene)	3 specimens: VA 226a-b, MA 227
Parahaentzschelinia		hypichnia, very common in thin-bedded (5-cm thick) turbidites	mainly MA (Miocene)	4 specimens: MA 90, 92, 165, 174
Phycodes		hypichnia in thin-bedded (5 cm thick) turbidite	MA (Miocene)	1 specimen: MA 99
Planolites		hypichnia in fine-grained turbidites, uncertain if endichnia and epichnia in hemipelagites	VA (Eocene), MC, PT-CEV (bad preservation) and MA (Oligo-Miocene)	3 specimens: VA 228a-b, MA 229
Protopaleodictyon		hypichnia in thin-bedded turbidites	MA (Miocene)	3 specimens: MA 35, 203, 214
Protovirgularia		mainly hypichnia, but may be found also as endichnia in medium-bedded turbidites	PT-CEV (Oligocene?), MA (Miocene)	9 specimens: MA 15, 19, 44, 87, 116, 196, 197, 201, CEV 159
Punctorhaphe		hypichnia at soles of thin-bedded turbidites	MA (Miocene)	3 specimens: Ma58a-b, 188
Rotundusichnium		hypichnia of massive, thick-bedded sandstones	PT-CEV, MC and MA (Oligo-Miocene)	8 specimens: PT 125, 132, CEV 154, 157, 158, MA 161, 176, 177
Saerichnites		hypichnia in thin-bedded turbidite	MA (Miocene)	1 specimen: MA 41

(Tab. 1 - continued)
(Tab. 1 - continua)

ICHNOGENUS	SYMBOL	STRATINOMY	OCCURRENCE (FORMATION AND AGE)	SAMPLES
Scolicia		hypichnia, endichnia and epichnia as different ichnospecies	VA and SG (mainly Eocene), MC, PT-CEV and mainly MA (Oligo-Miocene)	23 specimens: VA 07, 17, Ma 00, 31, 63, 79, 95, 98, 100, 119, 120, 121, 163, 166, 167, 180, 185, 207, 210, 218, PT 131a-b, SG 131c
Spirophycus		hypichnia of massive, thick-bedded sandstones	PT-CEV, MC and MA (Oligo-Miocene)	8 specimens: PT 125, 132, CEV 154, 157, 158, MA 161, 176, 177
Spirorhaphe		hypichnia of massive, thick-bedded sandstones	PT-CEV, MC and MA (Oligo-Miocene)	8 specimens: PT 125, 132, CEV 154, 157, 158, MA 161, 176, 177
Spongeliomorpha		hypichnia at soles of thin-bedded calcarenites	MA (Miocene)	3 specimens: MA 86, 195, 206
Strobilorhaphe		hypichnia in thin-bedded calcarenite	MA (Miocene)	1 specimen: MA 38
Subphyllochorda		epichnia (?) at the top of cm-thick sandy turbidites (maybe hypichnia)	MA (Miocene)	7 specimens: MA 98a-d, 166a-c
Taenidium		hypichnial and endichnial form in mudstones	SG (mainly Scaglia Rossa and "scaglia variegata"), VA; doubtful in MA	8 specimens: SG 235a-d, VA 236a-c, ?MA236b
Thalassinoides		exichnia, endichnia towards hypichnia and crossichnia (multilayer colonizer) in every beds	SG, VA, PT-CEV, MC, MA (Eocene to Miocene)	10 specimens: SG 231a-b, VA 231c-d, PT 124, 143, 151, MA 50, 70, 219
Trichichnus		mainly endichnia in calcareous fine-grained turbidites	VA and MA (Eocene to Miocene)	4 specimens: 230a-d
Urohelminthoida		hypichnia from muddy to sandy turbidites	mainly in siliciclastic turbidites of the PT-CEV and MA (usually from Oligocene to Miocene)	12 specimens: PT 232a-b, MA 27, 37, 54, 60, 62, 64, 68, 69, 122, 191
Zoophycos		endichnia to crossichnia mainly in hemipelagites	in muddy deposits of carbonate and siliciclastic turbidites of VA and MA (e.g., M. Solare and Valsavignone area); very abundant in the SG and BI (Paleogene-Neogene) of Umbria	28 specimens: VA 200a-b; MA 201a-f; SG 202a-d (Scaglia Rossa); 203a-e (S. Variegata); 204a-m (S. Cinerea-Bisciaro)

In continuous outcrops trace fossils have been analyzed vertically (e.g. shafts of deep-tier burrows piping down from above and vice versa) and horizontally (e.g. at the soles of turbidites). In some rare instances, traces cut obliquely different turbidites as "deep-water" *Ophiomorpha* (Uchman & Demircan 1999). Ichnotaxa are analyzed selectively in each level from the base towards the top of turbidites in order to characterize ichno-assemblage distribution (Fig. 2). Trace fossils in coarse- to fine-grained turbidite deposits have been compared as well, according to facies distribution in foredeep basins. All ichnotaxa here considered are in the ICHNOTHECA of the Biosedimentary Lab, Earth Science Department of Perugia University (BSED-IDTB 3.0 database).

Grain size of ichnocoenosis-bearing turbiditic beds (calcareous or siliciclastic) varies from coarse- to medium-grained sand (usually 60-150 cm thick, e.g. in the Macigno and Arenarie di Monte Cervarola) to fine sandy to silty or muddy beds (usually 5-30 cm thick, e.g. in the "marnoso arenacea", "marne di Verghereto" and "scisti varicolori" units) (see Pls 1A, F, I, L, 2A, F, K). Medium and medium-coarse or massive sand is very common in the Macigno and "marnoso arenacea" formations. Sorting is moderate to good (but also poor; e.g. in the Macigno and in Arenarie di Monte Cervarola) and silty-clayey matrix or micrite is abundant (at least 60-90% in the Scaglia formations and in "scisti varicolori"). In turbidites of "scisti varicolori" and Scaglia (mainly Scaglia Rossa and "scaglia variegata") most grains are constituted by planktonic and benthic foraminifers with very abundant shallow-water elements (Monaco 1989; Monaco & Uchman 1999). In "marnoso arenacea" mica flakes and carbonate matter are very abundant and selectively concentrated in laminae. Pelite beds are made of sandy silt, clayey silt, silty clay or carbonate mud. Internally, siliciclastic sandstones are completely and thinly laminated (e.g. "marnoso arenacea" and Arenarie di Monte Cervarola), with graded, parallel, wavy, cross, climbing to oscillatory ripples, convolute and water-escaped structures. In pure carbonate arenites of "scisti varicolori" laminae are seldom or not preserved when clay is lacking (Colacicchi & Monaco 1994). In thick-bedded, coarse to medium-grained turbidites (e.g. Macigno) ichnotaxa are poorly preserved due to very high flow processes and very rapid sedimentation which tend to destruct all pre-depositional trace fossils. In fact, traction carpets, large groove casts and high sand/mud ratio of sandy, high-density flow deposits (facies F4-F5-F6-F7 of Mutti 1992) are not ideal factors for the trace fossil preservation (Monaco 2008). In facies F8 (medium-grained structureless sandstones of high density turbidity currents SHDTC) and even more in F9 (fine-grained thin-bedded of low-density turbidite currents LDTC), trace fossils are usually well preserved and ichnotaxa can be characterized. In F9 deposits the complete Ta-e sequence of Bouma is preserved in the Arenarie di Monte Cervarola unit (Pl. 1M), while in "scisti varicolori" and "marnoso arenacea" the sequence Tc-e/Td-e (base missing type of Bouma) commonly occurs. Concerning very fine-grained turbidites (muddy turbidites) our classification follows the turbidite mud sequence T0-T8-P and the bioclastic turbidite sequence E1-E3-F (Stow & Piper 1984; Piper & Stow 1991). Hemipelagite/pelagite transition (T8/P or E/F, respectively), which reaches in thickness 25 mm, is strongly bioturbated (Wetzel & Uchman 2001); it has been investigated when trace fossils are preserved, as in the typical case of the Trasimeno area (see arrow in Pl. 1B).

Flute and groove casts are often associated with some trace fossils at the sole of turbidites; in this case the angle between direction of casts and trace fossils has been measured, considering the role of currents in destroying or redistributing grains previously utilized by tracemakers.

4. RESULTS: SYNOPSIS OF TRACE FOSSILS

In this paper the classification of turbidite trace fossils follows the nomenclature applied to the Polish Carpathians (Książkiewicz 1970, 1977; Uchman 1998). The discussion of taxonomy, taphonomy and palaeoecology of trace fossils is beyond the purpose of this paper (see discussion in Monaco 2000a); for these arguments see Monaco & Uchman (1999), about "scisti varicolori" of the M. Solare, Uchman (1995a) about "marnoso arenacea" and "Laga flysch" and Monaco (2008). Other deep-water trace fossils are here considered for their preservational features in flysch palaeoenvironments (Tunis & Uchman 1996a, 1996b; Tchoumatchenco & Uchman 2001; Uchman 2001; Wetzel & Uchman 2001; Uchman *et al.* 2004). The alphabetic arrangement of ichnotaxa is not required (Seilacher 1992), but it has been here adopted. Description, category, stratinomy, occurrence and samples are reported for all ichnogenera in Tab. 1a, b, c. Stratinomic classification follows those introduced by Seilacher (1964) and Martinsson (1970), as discussed in Monaco & Caracuel (2007). The taxonomic characterization of some specimens is still doubtful; for this reason some problematic ichnogenera (e.g. *Gyrochorte*) actually occurring in the studied sections are not reported; further analyses are needed to confirm their presence.

Acanthorhaphe Książkiewicz 1970

Description: this delicate graphogliptid trace fossil has been described by Książkiewicz (1970, 1977) and typically appears as a branched winding or arcuate thin strings with short appendages usually disposed on the convex side (Uchman 1998, p.186, fig. 94). *Acanthorhaphe* is rare in the sole of sandy turbidites of the "marnoso arenacea" of the Verghereto area, where *Acanthorhaphe* cf. *delicatula* Książkiewicz has been found showing diameter of string of 2 mm and length of 25 mm.

Category: branched.

Stratinomy: hypichnia in fine-grained turbidites.

Occurrence: Arenarie di Monte Cervarola and "marnoso arenacea" formations (Oligocene-Miocene).

Samples: 2 specimens, MA 56; PT 142.

Alcyonidiopsis Massalongo 1856

Description: a endichnial unlined cylinder, 5-8 mm in diameter and straight to slightly winding in shape, filled with small ovoid pellets, 0.4-0.6 mm in diameter. In calcilutitic turbidites of M. Solare, *Alcyonidiopsis longobardiae* Massalongo occurs: it reaches 9 mm in diameter and was followed by 20 cm in a thin yellow muddy turbidite; pellets are dark (Pl. 1, Fig. E). In the "marnoso arenacea" the presence of *Alcyonidiopsis* is doubtful: a similar trace fossil (cf. *Ophiomorpha*), straight and clearly filled with scattered ovoid pellets (cfr. Uchman 1995a, pl. 11, fig. 2; Uchman 1999, pl. 3-4) has been found at the sole of turbidite bed as slightly meandering form. Locally indistinct menisci are seldom present. As reported by Uchman (1995a) some differences exist between *Ophiomorpha,* where pellets are distributed on lined tube, and *Alcyonidiopsis* which shows ovoid pellets outside and inside the burrow. For a synonymy of the ichnogenus *Alcyonidiopsis* see Chamberlain (1977). This trace fossil is considered as a polychaetes feeding burrow and is known from Ordovician to Miocene.

Category: string-shaped.

Stratinomy: endichnia in muddy turbidites (very rare as endichnia/hypichnia in sandy turbidites).

Occurrence: mainly in "scisti varicolori" (Eocene).

Samples: 5 specimens, VA 123a-e.

Arenituba Stanley & Pickerill 1995

Description: this is an epichnial, irregularly arranged trace fossil, radiating from a central large tunnel showing rays, locally with V-shaped branches, which are very different in length (up 35 mm long) and size (2 mm wide). This ichnogenus shows some similarities with *Chondrites* but it was recently considered as a new ichnogenus (Stanley & Pickerill 1995; Uchman 1998, p.145, fig. 48). In the Savio valley, *Arenituba* is rare and has been found as sand-filled radial trace fossil at the sole of medium-size calciturbidites.

Category: branched.

Stratinomy: hypichnia at the sole of sandy turbidite.

Occurrence: "Marnoso arenacea" of the Savio valley (Miocene).

Samples: 1 specimen, MA 56.

Arthrophycus Hall 1852

Description: *Arthrophycus* is an oblique to horizontal, cylindrical or subcylindrical trace fossil with regular, perpendicular fine ribs and tendency to plunging into bed surfaces. Commonly these traces are very abundant on the sole of turbidites, where they are grouped in bundles. Typical characters are transverse striae, as the case of *Arthrophycus strictus* Książkiewicz which is common on the sole of a turbiditic sandstone bed of Polish Carpathians (Książkiewicz 1977; Uchman 1998, fig. 6), although the preservation of the fine striation depends strongly by the the substrate cohesion and by weathering. Książkiewicz (1977) described *A. strictus* as circular in cross-section and with very fine, delicate perpendicular ribs, distinctly arcuate in vertical plane and plunging into sole of beds at both ends (short hypichnial and endichnial). The author pointed out an elevation in the middle part and wide, variably oriented arches, 4-6 mm in diameter. In some complete specimens of *A. strictus* found in the "marnoso arenacea" of Verghereto the ridges are randomly packed and dip into the sole of turbidite bed at every direction (Pl. 2J).

The stratigraphic range: early Cambrian - early Miocene.

Category: simple.

Stratinomy: short hypichnia and endichnia in medium-grained and thick bedded turbidites.

Occurrence: "marnoso arenacea" (Miocene) and Arenarie di Monte Cervarola (Oligocene-Miocene).

Samples: 11 samples, PT 133, MA 22, 33, 76-77, 109-114.

Bergaueria Prantl 1945

Description: *Bergaueria* is a typical knob-shaped form, vertically arranged, circular to elliptical in cross-section with a rounded base; the sandy fill is essentially structureless (Prantl 1945). The name plug-shaped has been introduced for these peculiar biogenic (endichnial?) structures by Pemberton *et al.* (1988); they are indicated as cubichnia and probably they were produced by suspension-feeders as sea-anemones (Pemberton *et al.* 1988; Uchman 1995a, pl. 2, figs 4-5). In the Savio valley few specimens of *Bergaueria* cf. *hemispherica* Crimes, Legg, Marcos & Arboleya (see Crimes *et al.* 1977, pl. 6c) have been found, preserved as hypichnial mounds, 15-25 mm long and 15-17 mm high, oval in outline at the bottom surface of a fine-grained (silty) turbidite (cf. Uchman 1995a, pl. 2, fig. 4a-b).

Category: knob-shaped.

Stratinomy: hypichnia at the sole of fine-grained (silty) siliciclastic turbidites.

Occurrence: "marnoso arenacea" (Miocene), Montone and Savio valleys (Verghereto).

Samples: 3 specimens, MA 23a, 213, 216.

Cardioichnus Smith & Crimes 1983

Description: this trace fossil is a typical convex-shaped resting impression that usually occurs as a isolated knob or located at the end of *Scolicia*-like trace fossils at the sole of sandstone turbidites. In a specimen of the Arenarie di Monte Cervarola *Cardioichnus* appears essentially ovoid in outline, up to 2 cm wide, with a more depressed area on one side and disposed at the centre of two parallel ridges of *Scolicia*; in this sample bilaterally symmetrical parts are poorly preserved (see Smith & Crimes 1983, fig. 7). A doubtful isolated specimen, 4-6 cm in diameter, very similar to that illustrated by Smith & Crimes (1983, fig. 7B), has been observed at the sole of thin-bedded turbidites in the "marnoso arenacea" of the Montone section, but in this case it does not seem associated with *Scolicia* (Pl. 2B). *Cardioichnus* seems to be produced by the different work of a same heart urchin, and included by some authors (e.g. Uchman 1995a, 1998) in the *Scolicia* group.

Category: knob-shaped.

Stratinomy: hypichnial trace at the sole of siliciclastic turbidites.

Occurrence: Arenarie di Monte Cervarola of Cortona area (Oligocene-Miocene), "marnoso arenacea" of Montone (Miocene).

Samples: 3 specimens, CEV156a-b, MA205b.

Chondrites von Sternberg 1833

Description: this very common trace fossil consists of a regularly branching tunnel system, made up of a small number of master shafts opened to the surface, which ramify at depth to form a dendritic network (Osgood 1970; Fürsich 1974). *Chondrites* is the feeding system of an unknown organism related to infaunal deposit feeders, and it is now considered a typical chemichnia, which is a new ethological category (Bromley 1996). According to Kotake (1991), this ichnotaxon is produced by surface ingestors, packing their faecal pellets inside burrows. Some authors (Seilacher 1990; Fu 1991) believe that the tracemaker of *Chondrites* would be able to live under disaerobic conditions as a chemosymbiotic organism.

After the revision of the systematics of *Chondrites*, only 4 ichnospecies are considered useful, compared to the 170 distinguished in the past (Fu 1991), although recently new ichnospecies have been indicated (Uchman 1999). *Chondrites* occurs from the Tommotian (Crimes 1987) to the Holocene (Werner & Wetzel 1981).

In turbidite deposits of the studied sequences three ichnospecies have been found: *C. targionii* (Brongniart), *C. intricatus* (Brongniart) and *C.* cf. *patulus* (Fischer-Ooster). The first two forms are typical of calcareous turbidites, while the latter one has been found exclusively in siliciclastic deposits.

C. targionii is characterised by well-expressed, primary successive branchings, which are commonly slightly curved. The angle of branching is usually sharp (Fu 1991). This ichnospecies is a typical post-depositional form, with cylindrical, dark argillaceous filling. The tunnels show three classes of width: 0.5-1.5, 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. This ichnospecies is widespread and very well preserved in the "scisti varicolori" of Trasimeno area, and more in general throughout all the studied Eocene interval (Monaco & Uchman 1999). It forms a peculiar ichnofabric in the upper calcilutitic portion of turbidites, occurring also with other branched trace fossils (e.g. *Cladichnus*).

C. intricatus is a small trace fossil composed of numerous downward radiating branches; the angle of branching is usually less than 45 degrees (modified after Fu 1991). The system consists of tree-like branching, downward penetrating, markedly flattened tunnels, 0.5-1.5 mm in diameter. Branches form sharp angles and tunnels are filled with sediment darker than the host rock. *C. intricatus* can be distinguished for its small size, for its common, straight branches radiating in all directions, and for its small angle of branching. Distribution and relationships to lithology are the same as for *C. targionii*.

C. cf. *patulus* is formed by long (up to 4 cm and 1 mm thick) and straight (or slightly sinusoidal) branched tunnels located at alternating position from a central axis (see Fischer-Ooster 1858; Rhenodanubian Flysch, Uchman 1999, pl. 6, fig. 4). In studied beds it appears usually lighter in colour compared to the host rock. This form has been recovered in dark calcarenitic turbidites (endichnia) of the "marnoso arenacea", and Arenarie di Monte Cervarola.

Category: branched (vertical).

Stratinomy: usually as endichnia, in the upper, finer portion of calciturbidites (lutitic interval at the top) and thin-bedded siliciclastic turbidites (e.g. Verghereto High).

Occurrence: Scaglia (mainly Scaglia Rossa and "scaglia variegata"), "scisti varicolori" (Eocene), Arenarie di Monte Cervarola and "marnoso arenacea" (Oligo-Miocene).

Samples: 10 specimens, SG 221a-c, VA 222a-d, Ma 187, PT 223a-b.

Cladichnus D'Alessandro & Bromley 1987

Description: this trace fossil is composed by meniscate and branched tunnels, disposed horizontally; each tunnel is 2-6 mm wide and 20-50 mm long (the whole burrow is 60-100 mm in width), radiating from a vertical axial zone. Terminations of tunnels are semi-circular or clavate (D'Alessandro & Bromley 1987). Meniscous-shaped segments are regularly arranged, similarly to the regularly spaced rings described for *C. fischeri* (Heer) by Uchman (1999, pl. 12, fig. 5) and are typically disposed perpendicular to the tunnel elongation. Menisci and inter-menisci are similar in width and therefore the margins of tunnels are slightly lobate. This form is very common in muddy calciturbidites; at the top of calcilutitic turbidites of "scisti varicolori" of the Trasimeno area these radiate and branched trace fossils may reach a very high ichnodensity (20 specimens/m^2) and are generally associated with *Chondrites* and *Nereites*.

Category: branched (vertical).

Stratinomy: endichnia, and locally also as epichnia (lutitic interval at the top of calcareous turbidites).

Occurrence: "Scisti varicolori" formation (Eocene).

Samples: 6 specimens: VA 217, 224a-e.

Cochlichnus Hitchcock 1858

Description: this rare hypichnial-endichnial trail, 0.2-0.3 cm wide and 15 cm long, has a particular horizontal disposition represented by a sinusoidal, "corksrew" string. Rare specimens of *C. anguineus* Hitchcock have been found as regular, sinusoidal burrow at the sole of a fine-grained calciturbidite bed in the outer fan deposits of the Savio Valley, north of the Verghereto High.

Category: sinusoidal.

Stratinomy: hypichnia-endichnia at the sole of fine-grained, medium-bedded siliciclastic turbidites.

Occurrence: "marnoso arenacea" of the Savio Valley (Miocene).

Samples: 2 specimens, MA 05a-b.

Cosmorhaphe Fuchs 1895

Description: this graphogliptid trace fossil occurs as small burrows in flysch deposits of "marnoso arenacea" of Verghereto and Casentino areas, but two well preserved large hypichnial specimens (*Cosmorhaphe* isp.) have been recovered in the "Macigno" (Pratomagno) and Arenarie di Monte Cervarola (Cortona). It forms regular and delicate meanders at the sole of fine-grained turbidites, mainly of facies F8 and F9. The *Cosmorhaphe* group is represented by ichnospecies *C. parva* (Seilacher), which consists of close second-order meanders with string diameter of 2 mm and length up to 100 mm (Seilacher 1977b, fig. 3), and by *C. lobata* Seilacher. The latter shows first-order and second-order meanders, which are well developed as strings of 5 mm in diameter and wavelength of 25 mm. First-order meanders are widely spaced and contain 15-18 turns of regular second-order undulations which are slightly higher than wide (Seilacher 1977b, fig. 3). The holotype from the Eocene flysch of Vienna area was figured by Fuchs (1895).

Category: meandering.

Stratinomy: hypichnia at the sole of fine-grained, medium-bedded siliciclastic turbidites.

Occurrence: Macigno, Arenarie di Monte Cervarola and "marnoso arenacea" (Oligocene-Miocene).

Samples: 3 specimens, MA 105, PT 126a-b.

Desmograpton Fuchs 1895

Description: this ichnogenus represents a classic hypichnial system of double rows of string-sized, J- or U-shaped, semi-meanders joined by bars. This form belongs to the so-called "biramous graphoglyptid burrows" (Seilacher 1977b) and it appears as biramous meanders for the presence of two side branches per bend. As reported by Uchman (1995a) the curved segments are inwardly oriented in alternating position and two opposite semi-meanders are joined by short bars.

In the *Desmograpton ichthyforme* (Macsotay) specimens of the Savio Valley, preserved on soles of several fine-grained turbidites, the appendages are very narrowly aligned and appear as parallel and very long ridges; perpendicular bars are seldom preserved, displaying distinct transverse elevation in the central part (Macsotay 1967; Uchman 1998, fig. 98a). Therefore, as pointed out by Seilacher (1977b, fig. 7d), *D. ichthyforme* from the "marnoso arenacea" and "scisti varicolori" resembles a series of horizontal sticks rather than a meandering system.

On the other hand, *D. dertonensis* (Sacco) shows narrow U-shaped semi-meanders, and strings tend to be obliquely oriented (preservation depends by the erosion; see Uchman 1995a, text-fig. 18). The connecting bars are generally parallel and more spaced than in *D. ichthyforme*, although the distinction among these two ichnospecies may be doubtful (Seilacher 1977b). This ichnospecies has been found commonly at the sole of fine-grained calcareous turbidites of the "scisti varicolori" (Parrano) and fine-grained siliciclastic turbidites of the "marnoso arenacea" in the Verghereto High (Montecoronaro). In these areas several specimens of *D. dertonensis* display different values of the distance between parallel strings, from 1.5 to 3 mm, and oblique connecting bars are also preserved. Very few specimens show very thin concave strings (0.5 mm in diameter) similar to *D.* cf. *alternum* (Książkiewicz). They characterize the soles of fine-grained turbidites in the Verghereto area, displaying alternate semimeanders which are elevated in the curved positions (Uchman 1998, fig. 97).

Category: meandering (biramous).

Stratinomy: hypichnia very abundant at the sole of fine-grained, thin-bedded turbidites.

Occurrence: "scisti varicolori" (Eocene), Macigno, Arenarie di Monte Cervarola and "marnoso arenacea" (Oligo-Miocene).

Samples: 16 specimens, VA 08, MA 25, 30, 36, 81, 88, 93, 94, 168, 175, 184, 186, 190, 194, 205, 211n.

Glockerichnus Pickerill 1982

Description: *Glockerichnus* is a typical radiate trace fossil formed by linear strings of the same diameter, usually radiating from a hollow central area. The type species *G. glockeri* Książkiewicz it is preserved as commonly dichotomous hypichnial branched strings (Uchman 1998, fig. 43). At the soles of thin- and fine-grained turbidites of the "marnoso arenacea" of Verghereto area (Montecoronaro) specimes referable to this ichnospecies show a depressed central area preserved as hypichnial structure, from which the stellatae strings radiate (Książkiewicz 1968). Another large form occurs as epichnial trace at the top of a thin-bedded turbidite in the Verghereto (Montecoronaro): probably it may belong to *Glockerichnus*, and here it is indicated as *Glockerichnus* isp.; it consists of long (up to 150 mm) and large strings, 2-4 mm wide, which radiate dichotomously from a central area. This form has been partially reworked by other burrowers, as indicated by its association with *Scolicia prisca* de Quatrefages and other trace fossils.

Category: radiate.

Stratinomy: hypichnia and some doubtful forms as epichnia in very thin-bedded (5 cm) turbidites.

Occurrence: mainly "marnoso arenacea" (fringing facies close the Verghereto High).

Samples: 3 specimens, MA 89, 96, 97.

Gordia Emmons 1844

Description: this ichnogenus appears as a thin (0.6-1 mm) and discontinuous hypichnial string, found at the sole of medium to fine-grained siliciclastic turbidites of the "marnoso arenacea" and Arenarie di Monte Cervarola formations. The shape is semi-arcuate, with many thin traces disposed in different directions and commonly overlapping each other. *Gordia* has been described with different ichnospecies in many flysch deposits from Cambrian to Tertiary (Pickerill & Peel 1991). *G. marina* Emmons has been indicated as an irregular winding and meandering structure (often its turns intersect each other: Uchman 1998, fig. 73a); due to its unguided meanders and anomalous thickness (5 mm), it reveals some similarities with other trace fossils (e.g. *Helminthopsis hieroglyphica* Wetzel & Bromley 1996).

Category: meandering.

Stratinomy: hypichnia mainly at the sole of thin-bedded (5-10 cm) but sporadically of thick-bedded turbidites.

Occurrence: Macigno of Pratomagno (Oligocene?), Arenarie di Monte Cervarola and "marnoso arenacea" of Verghereto (Oligo-Miocene).

Samples: 3 specimens, MA 39, 71, PT 130.

Halopoa Torell 1870

Description: this long, unbranched and generally horizontal ichnogenus, 5-10 mm wide, is characterized by longitudinal discontinuous ridges or wrinkles, composed by cylindrical probes which imperfectly overlap the central tube. This (post-depositional?) trace fossil has been commonly recovered in siliciclastic turbidite deposits as hypichnial ridge, mainly with *H. imbricata* Torell, *H. annulata* (Książkiewicz) and *H. storeana* (Uchman) (Książkiewicz 1977; Tchoumatchenco & Uchman 2001; Uchman 2001). Ichnospecies differ for their wrinkles: they are long and anastomosing in *H. imbricata*, whereas in *H. annulata* they appear as short cylinders segmented by transverse grooves (Uchman 2001, pl. 4.1-4.2; Tchoumatchenco & Uchman 2001, fig. 4), and in *H. storeana* they are inclined along the main axis at an angle of 10-20°, arranged in plait-like, oriented fashion (Uchman 2001, pl. 3). In the Arenarie di Monte Cervarola these traces are common and locally are associated with *Spongeliomorpha, Cardioichnus* and *Spirorhaphe* (*Rotundusichnium)* at the soles of thin-bedded turbidites (Cortona area, southern-eastern Tuscany). In some specimens of *Halopoa* found at sole of turbidites in the Arenarie di Monte Cervarola formation of Cortona, the preservation is very similar to ichnogenus *Fucusopsis* which has been included in *Halopoa* by Uchman (1998, p. 196). But Seilacher (2007, p. 134) indicate that *Fucusopsis* preservation occurs and it may be considered a post-turbidite burrow produced as hypichnia by a typical burrowing technique (asterosomids). Seilacher indicates that the material was stowed away in the form of radial backfill and pressed it radially out by the animal in the wall of their burrow, producing typical longitudinal cracking structures.

In the "marnoso arenacea" *Halopoa* is an hypichnial/endichnial form at the sole of fine-grained turbidites, mainly represented by *H.* cf. *storeana* and *H.* cf. *imbricata*; on the other hand these traces are very rare in the "scisti varicolori". In some turbidite soles that are rich in tool marks (NE of Verghereto area), *H.* cf. *annulata* appears as endichnial or hypichnial cylinders, slightly winding in shape, disposed with an angle of 30-40° compared to groove casts.

Category: string-shaped.

Stratinomy: hypichnia and endichnia mainly at the soles of thin-bedded turbidites.

Occurrence: abundant in Arenarie di Monte Cervarola (Oligocene-Lower Miocene) and in "marnoso arenacea" (Miocene), very rare in "scisti varicolori" (Eocene).

Samples: 12 specimens, CEV 146, 147, 152, 153, 155, MA 21, 40, 47, 74, 78, 80, 83.

Helicolithus Azpeitia Moros 1933

Description: small knob-shaped trace fossil appearing as a dense (up to an hundred per square decimetre) and regularly spaced series of regular knobs, 0.3 to 1 mm in diameter, on the sole of fine-grained turbidites. These structures, recently included in the ichnospecies *Helicolithus ramous* Tunis & Uchman (Tunis & Uchman 1996a, fig. 14D), probably represent vertical shafts of some thin axial and twisted tunnels developed in the sediment. But in studied specimens, similarly to the *Punctorhaphe* described by Seilacher (1977b, figs. 6e, 8a), many small knobs are parallel and follow closely spaced meanders.

Category: knob-shaped.

Stratinomy: hypichnia at soles of thin-bedded turbidites.

Occurrence: "marnoso arenacea" (Miocene).

Samples: 3 specimens, Ma58a-b, 188

Helminthopsis Heer 1877

Description: this horizontal trace is simple (6-22 mm in width), unbranched, internally unstructured and follows a sinuous or irregularly winding course which forms serpentine convolutions over the surfaces of slabs of arenaceous deposits. This ichnofossil is very common in the geological record, and due to the confusion regarding its many species it has been recently undergone a taxonomic review (Książkiewicz 1977; Han & Pickerill 1995; Wetzel & Bromley 1996). From the ethological point of view, *Helminthopsis* has been considered a representative of pascichnia (structures produced in response to feeding during locomotory activity), and it is attributed to the worm-like organisms, particularly polychaete annelids or priapulids. In "scisti varicolori" formation an uncertain specimen of *Helminthopsis* appears as a sinuous hypichnia, locally endichnia, particularly large in width, reaching 22 mm, with irregularly distributed windings, disposed parallel to the stratification on the sole of a calcareous turbidite bed. Here this specimen is very similar to ?*Helminthopsis* cf. *magna* Heer, a species which original holotype (Heer 1877) was lately classified as *Scolicia* because of its general geometry, bilobate form and internal structure (Wetzel & Bromley 1996, fig. 2). Indeed, the incomplete preservation of the specimen of the "scisti varicolori" formation reveals external shape and internal structures similar to Heer's specimen; however, the burrow is partially destroyed by other trace fossils, tool marks and diagenetic overprint, and therefore the taxonomic attribution of this sample in the *sensu* of Wetzel & Bromley (1996) is difficult.

In the "marnoso arenacea" *H.* cf. *hieroglyphica* has been recovered at the sole of turbidite beds as hypichnial, loosely winding string, 0.6 mm in width, forming an angle of 25° respect to flute casts. This trace fossil from the "marnoso arenacea" is very similar to the designated holotype of *H. hieroglyphica* firstly figured by Maillard (1887, pl. 2, fig. 4). Other specimens, recovered as hypichnia-endichnia at the sole of fine-grained calciturbidite in the Savio valley can be referred as *Helminthopsis* cf. *tenuis* Uchman (see Uchman 1998, fig. 83). In the "Macigno" of the Pratomagno Ridge and in Arenarie di Monte Cervarola of eastern Tuscany *H. tenuis* occurs as thin slightly meandering strings.

Category: winding.

Stratinomy: hypichnia at the soles of fine-grained and usually thin-bedded calcarenitic turbidites.

Occurrence: "scisti varicolori" (Eocene), Macigno and Arenarie di Monte Cervarola (Oligocene-Miocene), "marnoso arenacea" (Miocene) formations.

Samples: 7 specimens, VA 10, 17, Ma 11, 75, 107, 128, 136.

Helminthorhaphe Seilacher 1977b

Description: this is a non-branching graphoglyptid trace fossil showing only one order of meanders. Tunnels, usually 3-5 mm wide, are usually long (100-180 mm) and rather straight; meanders are smooth and locally pressed, maintaining a fairly uniform amplitude. Three specimens of *Helminthorhaphe japonica* (Tanaka) with round turns have been found in the studied sections: one of these comes from the Arenarie di Monte Cervarola formation of the Casentino area (Moggiano) and shows well preserved and regular meanders; other two come from the "marnoso arenacea" of Mandrioli and Alpe di Poti area (Arezzo) but are partially destroyed. Further three specimens, classified as *Helminthorhaphe* isp. have been observed in Arenarie di Monte Cervarola (Castiglion Fiorentino and Cortona) at the sole of fine-grained turbidites.

Category: meandering.

Stratinomy: hypichnia.

Occurrence: Arenarie di Monte Cervarola and "marnoso arenacea" formations (Oligo-Miocene).

Samples: 6 specimens, MA 111q, 199, 220, CEV 48a-c.

Hormosiroidea Shaffer 1928

Description: this rare ichnogenus consists of subspherical or clavate bodies joined by an horizontal string which is disposed in the central part. One 2 cm long specimen of *Hormosiroidea* cf. *annulata* (Vialov) has been recovered in a calcilutitic bed of "scisti varicolori" formation in the Trasimeno area. Its bodies are subquadrate or laterally elongated, forming clavate-shaped structures joined by a central string. The axial burrow is straight, while lateral branches are vertical and considerably wider than the axis; therefore, in section the trace appears irregularly distributed. This trace looks to *Hormosiroidea annulata* from the Cretaceous flysch deposit near Salzburg; for the discussion about their problematic preservation and diagnostic features in flysch sediments see Seilacher (1977b, fig. 6 k-n; Uchman 1998, fig. 12d).

Category: clavate-shaped.

Stratinomy: uncertain

Occurrence: "scisti varicolori" formation, North of Trasimeno Lake (Eocene?).

Samples: 1 specimen, VA 24.

Laevicyclus Quenstedt 1881

Description: this circular trace fossil appears as a typical delicate and regular hyporelief at the sole of turbidites with a small central knob in the center of the structure. The structure is 30–50 mm wide and the string diameter is 1-2 mm thick with the same thickness of the central knob. In some specimens of Montone area the shape of external ring is elliptical and the string is incompletely preserved, while the central knob (vertical canal) is perfectly circular. Many specimens may be referred to the ichnospecies *Laevicyclus mongraensis* Verma 1970 that are present in a same turbiditic sample as in the "marnoso arenacea" formation of Montone area (cf. Uchman 1995a, pl. 2, fig. 6; Tunis & Uchman, 1996b, fig. 3b). As indicated by Uchman (1995a) the origin of this ichnogenus is not clear: it has been compared to circular feeding traces of sedentary anellids, or related to other organic structures in the deep water environment; inorganic structures like crater-like structures produced by gas have also been considered but this hypothesis is unlikely because this structure is very small and with a very regular shape.

Category: circular.

Stratinomy: hypichnia at soles of medium-bedded turbidites.

Occurrence: "marnoso arenacea".

Samples: 4 specimens, MA 236a-d.

Lorenzinia De Gabelli 1900

Description: this is a trace fossil with a typical radial structure, showing short, smooth, hypichnial ridges arranged in one or two circular rows, radiating from a central area. Ridges are different in length and width and regularly or irregularly distributed. On the sole of turbidite beds different levels of the system are exposed by erosion before immediate casting. Many ichnospecies have been described basing on differences in inclination of the radiating elements and a wide revision exists on them (Książkiewicz 1970; 1977; Uchman 1995a, 1998, figs 32-33). *Lorenzinia* is interpreted as produced by different organisms such as holothurians, crabs, polychaetid anellids, sipunculoids, hydromedusae and others. It occurs from lower Cambrian to Miocene, although some holes similar to *Lorenzinia* have been photographed on modern deep-sea floors: see references in Gaillard (1991) and in Uchman (1998).

In the "marnoso arenacea", "Macigno" ("arenarie di Monte Falterona) and Arenarie di Monte Cervarola formations *Lorenzinia plana* (Książkiewicz) is associated with *Paleodictyon minimum* Sacco; both these traces display typical taphonomic features induced by currents (Monaco 2008). *Lorenzinia pustulosa* (Książkiewicz), formerly known as *Sublorenzinia pustulosa* (see Uchman, 1995a, pl. 7, fig. 1), shows almost twelve very short radiating ridges; in the "marnoso arenacea" of Romagna this trace is preserved usually at the sole of thin-bedded turbidites of Verghereto High (Montecoronaro). In "scisti varicolori" formation trace fossils of the *Lorenzinia* group have been found partially destroyed due to poor preservation of such structures in calciturbidites.

Category: radial.

Stratinomy: hypichnia at soles of medium-bedded and thin-bedded (5-15 cm) turbidites.

Occurrence: Macigno ("arenarie di Monte Falterona"), Arenarie di Monte Cervarola and "marnoso arenacea" formations (Oligocene-Miocene).

Samples: 6 specimens, MA 61, 108, 169, 173, 211d, PT 141.

Megagrapton Książkiewicz 1968

Description: *Megagrapton* is common in studied turbidites but its preservation varies considerably with sand fill. This trace fossil occurs usually as hypichnial irregular nets, sinuose or slightly meandering. The string diameter varies for different ichnospecies from 0.3 to 4 mm in thickness, bearing lateral appendages which tend to form irregular nets. Meshes are bordered by distinctly winding strings, and acute angles of branching occur. Some ichnotaxa have been recovered: *Megagrapton* cf. *irregulare* Książkiewicz, *M.* cf. *submontanum* (Azpeitia Moros) and *Megagrapton* isp. A. The specimens of the Corniolo Pass ("marnoso arenacea") are similar in shape to *Megagrapton irregulare*, but some parts of their meanders are eroded; for a discussion about this ichnospecies see Uchman (1998). *M. submontanum* was formerly ascribed to *Protopaleodictyon*, but for the weakly regular shape of its nets this species has been recently included in *Megagrapton* (Uchman 1998, fig. 105); in Verghereto and also in the Pratomagno brown micaceous sandstones, *M.* cf. *submontanum* occurs as well preserved specimens, 0.8 to 1 cm in diameter. *Megagrapton* isp. A constitutes irregular nets of delicate strings (maximum diameter 0.5-0.8 mm), recovered at the sole of thin turbidite beds of Verghereto High (Montecoronaro).

Category: meandering.

Stratinomy: hypichnia at the sole of every turbidite beds, from thick to thin-bedded turbidites (abundant in thin beds).

Occurrence: Macigno, Arenarie di Monte Cervarola and "marnoso arenacea" formations (Oligocene-Miocene).

Samples: 10 specimens, MA 66, 85, 91, PT 127, 134, 149, 150, 183, 193, 202.

Muensteria Sternberg 1833

Description, stratinomy, occurrence and samples: see *Taenidium*.

Nereites Mac Leay 1839

Description: more or less horizontal trails, winding to regularly meandering, consisting of 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. The so-called *Nereites* Group (Chamberlain & Clark 1973) is composed by several ichnotaxa, such as *Scalarituba* Weller, *Neonereites* Seilacher, *Nereites* Mac Leay and *Helminthoida* Schafhäutl (Uchman 1995a). In the "marnoso arenacea" of the Savio Valley *Nereites missouriensis* (Weller) is the most common ichnotaxon, while some specimens of *Neonereites* have been found in the "marne di Vicchio" formation (Casentino area). *Nereites* has been usually recovered at the top of rippled, fine-grained turbidite, while *Scolicia* burrows are present at the sole of bed. *N. missouriensis* of the Savio Valley and of Montecoronaro show a broad central tunnel, 8-12 mm wide, enveloped by a zone of similar thickness which displays low-sided lobes (cf. Uchman 1995a, pl. 8, fig. 10). Meandering trace fossils classifiable as *Nereites irregularis* (Schafhäutl) have been found in "scisti varicolori" formation of the M. Solare (Monaco & Uchman 1999) and in Arenarie di Monte Cervarola unit. They usually are closely packed, forming narrow meanders which tend to coil. As a rule, meanders are various-sized, ellipsoidal in cross-section, 3.5-4.0 mm wide, and are preserved as epichnial full-relief structures developing mainly within the upper part of limestone or marlstone turbidites. The lighter-coloured core occasionally shows an indistinct backfill structure appearing as transverse ribs. In some specimens the core was removed by weathering. Locally, these trace fossils are preserved as a chain of biserial pustules (cf. Pl. 1C). *Nereites* epichnia are dominant in deep-sea calcilutitic turbidites of "scisti varicolori" formation where the ichnodensity may be very high (up to 30 specimens/m^2). This form characterizes particularly the middle-upper part of the middle Eocene (P10 to P12 zones, Piccioni & Monaco 1999). Closely packed meanders, which tend to coil and mutually touch each other in a short space, have been found on large surfaces of the calcareous rocks of the middle Eocene (P11-P12 zones, Piccioni & Monaco 1999). Backfill structures are also present in the lower part of P12 zone. Densely packed chains of biserial pustules, such as *Nereites* cf. *macleavy* (Murchkon) and *Nereites* isp. have been preserved in different tiers on the topmost level of calcilutitic turbidites in the Eocene deposits of Trasimeno area (Pl. 1B, C).

Category: meandering.

Stratinomy: mainly epichnia at the top of calcilutitic and of fine-grained siliciclastic turbidites.

Occurrence: "scisti varicolori" of western Umbria and eastern Tuscany (Eocene), Arenarie di Monte Cervarola (Casentino), and "marnoso arenacea" formation of Romagna (Miocene).

Samples: 10 specimens, VA 12, 225a-c, MA 20, 72, 73, 82, 84, 135.

Ophiomorpha Lundgren 1891

Description: *Ophiomorpha* commonly occurs in high sedimentation rate conditions (Frey *et al.* 1978). In studied turbidites this trace fossil is represented by horizontal or vertical cylindrical tunnel systems, seldom branched; they are covered with elongate or irregular pellets and mainly arranged perpendicularly to the long axis; lined vertical portions are also present (Frey *et al.* 1978; Uchman 1995a; Monaco 2000b). Branching points are preserved, revealing sharp angles, locally with characteristic enlargements (Monaco & Giannetti 2002; Giannetti & Monaco 2004), but horizontal segments, lacking knobby exteriors, resemble the typical *Thalassinoides*. As indicated by Uchman (1998), in flysch deposits *Ophiomorpha* occurs commonly as small hypichnial branched specimens. Usually they appear as smooth and straight long strings at the bottom of deep water turbidites (Pl. 2L); many specimens resemble forms commonly identified as *Sabularia simplex* (Książkiewicz) and *Granularia* (Książkiewicz 1977; Seilacher 2007). However, as indicated by Uchman (1998), the two ichnogenera *Sabularia* and *Granularia* are not recommended for further use: when annular structures are preserved (Uchman 1995a) they should be considered synonyms of *Ophiomorpha annulata* (Książkiewicz). In the "marnoso arenacea" formation hypichnial specimens of *O. annulata* occur in medium- to coarse-grained turbidites as hypichnial cylinders of 2-4 cm in diameter (Pl. 2L) or endichnial horizontal burrows in inter-turbidite marls (Pl. 2G). In the "scisti varicolori" unit of the Trasimeno area the most frequent ichnofossils from in the turbidite and hemipelagite beds are *Thalassinoides*-like specimens. Here *Ophiomorpha* isp. is not so common as in the Macigno, Arenarie di Monte Cervarola and "marnoso arenacea" formations, where the genus is represented by *O. rudis* (Książkiewicz) (see also the Brkini Flysch in Slovenia: Tunis & Uchman 2003). This very large trace fossil (up to 8 cm in diameter) appears as subhorizontal hypichnial-endichnial burrows distributed in the lower portion of turbidite beds; it shows irregular ridges up to 3-4 cm thick, usually developed as large knobby bulges which produce irregular thickening of burrow diameters (Pl. 2H, I). Locally, branches are very short and represent dead ends. Half of all specimens attributable to this form are distributed close to the bottom of metre-thick sandy turbidites (typically in Bidente and Savio Valleys). They cross giant groove casts forming angles up to 90°, suggesting burrowing strategies that were developed after energetic and tractive current flows.

In other cases *Ophiomorpha*-like trace fossils change their shape and diameter, appearing as car silencer-shaped hypichnia/endichnia ("car-silencer shaped" *Ophiomorpha*, Monaco *et al.* 2007; Pl. 2N). Other forms are preserved as vertical or oblique cylindrical trace fossils, vertically crossing some calcarenite or marly beds (see "multilayer colonizers" in Uchman 1995b; "crossichnia" in Monaco *et al.* 2007). They are unwalled, usually silt-filled, 18-22 mm in diameter and up 30 cm in length, showing typical ring-shaped transverse segments (Uchman & Demircan 1999, fig. 6 B-D) (Pl. 2C, G). *O. rectus* (Fischer-Ooster) is rare, being found only with 2 specimens in the sole of a turbidite bed of the Verghereto; it is obliquely distributed as flattened tube, lined with small muddy pellets (cfr. Uchman 1998, fig. 26).

Category: branched (horizontal).

Stratinomy: hypichnia, endichnia in every facies, but very abundant in m-thick, high-density sandy turbidites.

Occurrence: "scisti varicolori", Macigno ("arenarie di Monte Falterona"), Arenarie di Monte Cervarola and "marnoso arenacea" formations (Eocene-Miocene).

Samples: 17 specimens, MA 09, 34, 43, 45, 52, 103, 104, 106, 137, 138, 139, 144, 160, 181, 198, 209, VA 144.

Paleodictyon Meneghini 1850

Description: the *Paleodictyon* ichnogenus is well known in the literature (Seilacher 1977b; Uchman 1995a, 1998 cum biblio); it includes several types of hexagonal nets, more or less regular in shape ("regular nets" of Seilacher 1977b) and vertical shaft. This group, formed by many ichnospecies, is very commonly recovered in the studied sequences as pre-depositional trace fossils at the soles of turbidites, mainly in flysch deposits. Many biogenic and physical agents (e.g. burrowing, bulldozing and currents) deform mesh regularity (Monaco 2008). *Paleodictyon* essentially consists of three-dimensional burrow systems formed by horizontal nets composed by regular hexagonal meshes developing on a plane surface (commonly represented by the sole of turbidite beds), and, if preserved, vertical outlets. Seilacher (1977b, 2007) proposed sub-ichnogeneric names such as *Glenodictyum* to indicate only hexagonal meshes, *Ramodictyon* when vertical outlets are preserved, *Squamodictyon* to indicate scale-like meshes. Uchman (1995a) redefined their morphometric range using the maximum mesh size and string diameters.

In the studied sequences several forms have been found (63 specimens). According to the classification of Uchman (1995a, text-fig. 23) some of these (40) may be identified as very small or medium-sized forms: *P. minimum* Sacco (11 specimens), *P. strozzii* Meneghini (2 specimens), *P. majus* Meneghini (6 specimens), *P. latum* Vyialov & Golev (5 specimens), *Paleodictyon* isp. (13 specimens) and *Squamodictyon* (3 specimens). Their maximum mesh size varies from 0.1 to 10 mm and the string diameter from 0.2 to 2.5 mm (except *Squamodictyon*). Other larger forms (23) have been found: they include wider and/or thicker hexagons, such as *P. italicum* Vyialov & Golev (6 specimens), *P. hexagonum* (van der Marck) (17 specimens, 12 of which preserved as *Glenodictyum* and 5 as *Ramodictyon)* and *P. maximum* Eichwald. These large forms exhibit maximum mesh size >10 mm and string diameter >2.5 mm. Many specimens of *P. hexagonum* have been analyzed to define taphonomic characteristics (Monaco 2008). In the "marnoso arenacea" formation, nets and vertical outlets are preserved together at the sole of fine-grained calciturbidites in the Savio Valley, Corniolo Pass and the Montone area (Pl. 2D), while many small forms (*P. minimum*, *P. strozzii*, *P. majus*) have been collected mainly in the "Macigno" and in Arenarie di Monte Cervarola formations.

Stratinomy: hypichnia, mainly at soles of fine-grained and thin-bedded turbidites but occur also in medium to thick-bedded turbidites (fluted or partially preserved).

Category: network.

Occurrence: largely distributed in "scisti varicolori" (Eocene), Macigno ("arenarie di Monte Falterona"), Arenarie di Monte Cervarola, "marne di Vicchio" and "marnoso arenacea" formations (Oligocene-Miocene). Very rare in the Scaglia formation.

Samples: 63 specimens, MA13a-b, 14a-b, 18, 28a-b, 29, 32, 57a-b, 67, 101a-b, 102, 115, 117, 118, 140, 145a-b, 160, 164, 179, 182, 183, 189, 200, 202, 208a-c, 211a-k (12), 211(bis)a-e (5), 212a-i (9), 213, CEV148, PT129a-c.

Paleomeandron Peruzzi 1881

Description: this trace has been included with *Desmograpton* in the group of biramous meanders graphoglyptids (Seilacher 1977b), characterized by widely spaced meanders. Two ichnospecies have been found at the soles of siliciclastic turbidites: *P. elegans* Peruzzi and *P. transversum* Peruzzi. The first one is straight or gently arcuated, very large in diameter (up to 2 cm) and shows regularly spaced meanders that end with alternating bulges; the general aspect of this trace resembles a large zip. In *P. transversum* of Mandrioli Pass the first-order meander shows sharp turning points, marked by cross bars. At the sole of fine-grained turbidite, a pairs of bulges, 2-4 mm in width, is distributed inside meanders, representing vertical shafts (Seilacher 1977b, fig. 7c).

Category: meandering biramous.

Stratinomy: hypichnia in thin-bedded turbidites.

Occurrence: Arenarie di Monte Cervarola (large specimens, Oligocene) and "marnoso arenacea" formations (small specimens Miocene).

Samples: 3 specimens, CEV 53, 178, MA 192.

Palaeophycus Hall 1847

Description: this trace fossil is smooth, essentially cylindrical, branched or unbranched, straight or curved in the horizontal plane. The fill is typically structureless, and has the same lithology of the host rock. It is a typical facies-crossing ichnogenus, produced probably by polychaetes and occurring from Precambrian to the Recent (Pemberton & Frey 1982). In the "scisti varicolori" formation *Palaeophycus tubularis* Hall reaches 10-20 mm in diameter, and it may be found in the middle part of laminated, coarse-grained calcarenites as subhorizontal endichnion associated with small *Zoophycos* specimens. Less commonly it occurs as hypichnia at the sole of fine-grained calciturbidites, mostly in the middle-upper part of middle Eocene (Monaco & Uchman 1999). In the "marnoso arenacea", *Palaeophycus* isp. occurs commonly as hypichnial cylinders at the sole of arenaceous turbidites, whereas *P. tubularis* is found as smooth and unornamented, unbranched trace fossil, 3-8 mm in diameter, filled with the same sediment of the host rock (Uchman 1998, p.121, fig. 17). This tubular, straight ichnospecies is predominantly horizontal and lined, essentially cylindrical in shape; it occurs commonly in the Corniolo Pass with *Scolicia* isp. specimens.

Category: string-shaped.

Stratinomy: rare as hypichnia at the sole of fine-grained turbidite, commonly found mainly as endichnia.

Occurrence: "scisti varicolori" (mainly Eocene), "marnoso arenacea" formations (Miocene).

Samples: 3 specimens, VA 226a-b, MA 227.

Parahaentzschelinia Chamberlain 1971.

Description: the *Parahaentzschelinia* burrow is composed of numerous vertical shafts (normally up to 12), radiating vertically from one mastershaft (usually not preserved). According to the model of Chamberlain (1971), *Parahaentzschelinia* displays ridges which are often fluted and bended by the action of unidirectional currents on the seafloor (Monaco 2008). At the sole of thin-bedded turbidites (e.g. Verghereto High) this endichnial/hypichnial trace may be preserved as groups (up to twenty, irregularly disposed) of oval to circular bulges (Uchman 1995a, text-fig. 17, pl. 12, figs. 5-8; 1998, fig. 31). In the "marnoso arenacea" formation, groups of bulges are very abundant in the same level and they be referred to a section of the radial shafts typical of this ichnogenus. In a well exposed, thin-bedded turbidite (5 cm thick) in the Verghereto High (Montecoronaro) *Parahaentzschelinia* hypichnia are associated with *Desmograpton* and other delicate graphoglyptids; at its top, the bed shows very abundant *Scolicia* epichnia.

Category: knob-shaped.

Stratinomy: hypichnia, very common in thin-bedded (5 cm thick) turbidites.

Occurrence: mainly "marnoso arenacea" formation (Miocene).

Samples: 4 specimens, MA 90, 92, 165, 174.

Phycodes Richter 1850

Description: *Phycodes* is rare in the studied sections. It consists of a densely packed bundle of gently curved tunnels, 5-8 mm in diameter, joined as tightly packed group at the sole of sandy turbidites. In cross section it appears as a bunch of cylinders converging in one direction, usually elliptical in shape. In the "marnoso arenacea" formation this form is uncommon and has been recovered only in the Verghereto area (Balze) (MA 99).

Category: string-shaped.

Stratinomy: hypichnia in thin-bedded (5 cm thick) turbidite.

Occurrence: "marnoso arenacea" formation (Miocene).

Samples: 1 specimen, MA 99.

Planolites Nicholson 1873

Description: this is a very common and ordinary trace fossil, representing a typical facies-crossing ichnogenus. It is unlined and usually no branched, straight or sinous, circular to elliptical in cross-section, smooth to irregularly walled or slightly annulated; the fill is essentially structureless and differs in lithology and colour from the host rock. *Planolites* may be referred to the activity of several, unrelated vermiform deposit-feeders which produce active backfilling (Pemberton & Frey 1982), occurring from Precambrian to the Recent (Häntzschel 1975). At M. Solare and in other sections of the Trasimeno area, *P. beverleyensis* Billings occurs as simple, undulate hypichnia at the sole of calciturbidites of the middle calcareous-marly unit, 10-30 mm in width (Monaco & Uchman 1999). Some specimens show a coarse-grained fill.

Category: string-shaped.

Stratinomy: hypichnia in fine-grained turbidites, uncertain position in hemipelagites.

Occurrence: "scisti varicolori" (Eocene), Macigno Arenarie di Monte Cervarola (bad preservation) and "marnoso arenacea" (Oligo-Miocene).

Samples: 3 specimens, VA 228a-b, MA 229.

Protopaleodictyon Książkiewicz 1958

Description: As pointed out by Książkiewicz (1958), this type of meandering trace fossil with appendages, more or less regular in shape, appears as a long chain of regular (first-order) and winding (second-order) meanders, with short appendages branching from the apex (see Uchman 1998, fig. 100a). *Protopaleodictyon* occur in flysch deposits, but one specimen has been found also in a calcareous fine-grained turbidite level of early Toarcian (Monaco *et al.* 1994). In the "marnoso arenacea" formation, *P. minutum* Książkiewicz is hypichnial on the sole of fine-grained planar bedded arenite at SE of the Mandrioli Pass and in the Verghereto area. On the sole of turbidites, the angle formed by flute casts direction and *Protopaleodictyon* hypichnia is mainly of 90°.

Category: meandering.

Stratinomy: hypichnia in thin-bedded turbidites.

Occurrence: "marnoso arenacea" formation (Miocene).

Samples: 3 specimens, MA 35, 203, 214.

Protovirgularia McCoy 1850

Description: horizontal, cylindrical trace fossils, distinctly or indistinctly bilobate, straight or slightly meandering, occuring as endichnia-hypichnia at the soles of fine-grained turbidites. They contain successive pads of sediment disposed at both sides, expressed on the exterior as typical ribs arranged in chevron-like biserial pattern. Basing on neoichnologic observations (Seilacher & Seilacher 1994), this trace fossil is a locomotive trace of bivalves with a cleft foot. Several problematic ichnogenera which show ribs (Hallam 1970; Rindsberg 1994; Caracuel *et al.* 2002), such as *Uchirites* Macsotay, *Walcottia* Miller & Dyer and *Imbrichnus* Hallam, are considered as synonyms of *Protovirgularia* b some authors (Seilacher & Seilacher 1994; Uchman 1998). In the "marnoso arenacea" of the Savio valley, Città di Castello and Mandrioli Pass, *Protovirgularia* isp. is seldom present as endichnia-hypichnia in fine-grained turbidites. In the Città di Castello area, a poorly preserved specimen of *Protovirgularia* cf. *vagans* Książkiewicz, 2-3 cm wide and up to 60 cm long, has been found on the sole of a fine-grained calciturbidite (cf. *Tuberculichnus vagans* Książkiewicz in Buatois *et al.* 1996). The specimen of Città di Castello is undulate in the vertical plane, revealing hypichnial-endichnial disrupted ridges located close to flute casts on sole of a turbiditic sandstone, and it forms an arcuate course on the bedding plane. The arcuate shape probably represents part of a regular meander (not completely preserved), although the typical keeled profile (amygdaloid in cross-section) is not completely visible.

Category: string-shaped.

Stratinomy: mainly hypichnia, but may be found also as endichnia in medium-bedded turbidites.

Occurrence: Arenarie di Monte Cervarola (Oligocene?), "marnoso arenacea" (Miocene) formations.

Samples: 9 specimens, MA 15, 19, 44, 87, 116, , 196, 197, 201, CEV 159.

Punctorhaphe Seilacher 1977

Description, stratinomy, occurrence and samples: see *Helicolithus*.

Rotundusichnium Plička 1989

Description, stratinomy, occurrence and samples: see "Spiral structures".

Saerichnites Billings 1866

Description: this peculiar form can be recognized for the presence of single or double parallel rows of circular or semicircular spots or pustules, 0.3 to 3 mm in diameter, regularly distributed on the sole of turbidites as preservational variants of a three-dimensional branched structure (Uchman 1995a, text-fig. 16). These pustules represent the vertical ends of a burrow system and reveal some analogies with other *Saerichnites*-like traces such as the single row of spots of the *Hormosiroidea* group and other similar holes produced by unknown organisms on the modern seafloor (Hinga 1981). Many turbidite interfaces in the "marnoso arenacea" formation reveal groups of circular mound, spots or rows, but double rows are rare and typically concentrated with flute casts on the soles of turbidites of Città di Castello area.

Category: knob-shaped.

Stratinomy: hypichnia in thin-bedded turbidite.

Occurrence: "marnoso arenacea" formation (Miocene).

Samples: 1 specimen, MA 41.

Scolicia de Quatrefages 1849

Description: this ichnogenus is very common in the Northern Apennines but requires further studies. *Scolicia* consists of horizontal, winding to meandering, back-filled structure, 0.8-2.5 cm width, mainly preserved as endichnia/hypichnia but also as epichnia. Each meander is up to 12 cm wide. This ichnogenus occurs at different levels in the sediment: at the sole of thick-bedded turbidites (hypichnia-endichnia) and also at the top (epichnia) of thin-bedded turbidites. At the sole of thick-bedded turbidites *S. strozzii* (Savi & Meneghini 1850) is the most common ichnospecies. It appears as a bilobate or trilobate ridge, 1.3 to 2.3 cm wide, with two parallel, locally discontinuous, sediment strings along the lower side, as well as a median part resembling a long furrow. Many trace fossils cross each other (Pl. 2E, arrow). The median groove separates the prominent zones of the ridge which are more or less arcuate in cross-section, where this trace fossil is approximately semi-circular in outline. The lower part between strings is commonly flat or concave upward. Laminae are seldom preserved and generally composite; they could be biserial on the upper side. In fine-grained turbidites of the "marnoso arenacea" and "scisti varicolori" sole expressions of *S. strozzii* (Uchman 1995a, text-fig. 11a) are usually preserved as hypichnia bilobate ridges. Fish teeth are seldom present inside meandering tunnel of *Scolicia* isp. Calcisiltitic turbidites of calcareous-marly unit of the "scisti varicolori" at M. Solare, (middle Eocene P10-P12 zones) (Monaco & Uchman 1999) reveal some well preserved specimens. In the studied areas, *Scolicia* specimens are crossed by bulldozing traces. Different names have been proposed by Seilacher (2007) depending on preservation of meandering scolicids. In the pre-turbidite community composed by hemipelagic mud that settled during the long intervals between turbidite events, a typical scolicid form (e.g. *Scolicia strozzii*) occurring as washed-out hypichnia was named "*Taphrhelminthopsis* preservation".

At the top of turbidites *Scolicia prisca* de Quatrefages has been recovered. It is preserved usually as epichnial trilobate furrow with concave bottom and oblique slopes departing from a median furrow, which show densely-packed transverse ribs, 1 mm thick, perpendicular to the long axis of burrow and slightly bent externally. In the Verghereto marls, at the top of 5 cm thick sandy turbidite bed, a spectacular oucrop 20 m wide reveals hundreds of well preserved *S. prisca* epichnia specimens, from 1.8 to 2.8 cm in diameter (mean 2.4 cm), slightly meandering in shape and crossed by several other trace fossils (e.g. *Subphyllochorda* as *Palaeobullia* preservation, *Glockericknus*). This level represents probably a wonderful example of preserved sea-bottom of a submarine high.

The *Scolicia* group embraces many bilobate-trilobate trace fossils related in Mesozoic and Cenozoic to irregular echinoid (spatangoid) burrows (Smith & Crimes 1983; Seilacher 1986); they are common from shelf throughout deep-water environments since the Tithonian (Tchoumatchenco & Uchman 2001; Monaco *et al.* 2005).

Category: winding.

Stratinomy: hypichnia, endichnia and epichnia as different ichnospecies.

Occurrence: "scisti varicolori" and "scaglia variegata" (mainly Eocene), Macigno, Arenarie di Monte Cervarola and abundant in the "marnoso arenacea" formation (Oligo-Miocene).

Samples: 23 specimens, VA 07, 17, Ma 00, 31, 63, 79, 95, 98, 100, 119, 120, 121, 163, 166, 167, 180, 185, 207, 210, 218, PT 131a-b, SG 131c.

Spiral structures (e.g. *Rotundusichnium, Spirophycus* and *Spirorhaphe*)

Description: some spiral structures have been found in the studied sequences (Pl. 1K, N). Unfortunately their preservation is poor in the Arenarie di Monte Cervarola, "Macigno" and "marnoso arenacea" formations: often only partial rings are preserved at the sole of thick-bedded calcarenites. Therefore, their taxonomic attribution is problematic. Spiral ichnotaxa are grouped by Uchman (1998) in the category of spiral structures, and are typically preserved as hypichnia and epichnia (e.g. *Rotundusichnium*) in flysch deposits. In the studied sections of Arenarie di Monte Cervarola and Macigno units spiral structures are very similar to ichnogenera "*Spirophycus*", *Spirorhaphe* and *Rotundusichnium*.

Two specimens of "*Spirophycus*", respectively identified as "*Spirophycus*" *bicornis* (Sacco) and "*Spirophycus*" isp. have been found in eastern Tuscany; they consist of meandering to spiral whorls, 2-3 cm in diameter and up 30 cm long, slightly knobby exteriorly and forming a close convolute ring in the inner part (Pl. 1K). They resemble some *Nereites* preservations but further investigations are required. Other six specimens are very uncertain, and their attribution to *Spirorhaphe* or to *Rotundusichnium* is very difficult. Two of them resemble *R. zumayensis* (Llarena), since they are typically coiled and inclined towards the centre in the same manner of the specimen figured by Uchman (1998, fig. 89); nevertheless the structures of spirals are lacking or very poorly preserved, and the preservation of the whorls and the loop of the centre in a specimen are similar to *Spirorhaphe* and further analysis is required (Pl. 1N).

Category: spiral.

Stratinomy: hypichnia in massive, thick-bedded sandstones.

Occurrence: Arenarie di Monte Cervarola, Macigno and "marnoso arenacea" (Oligo-Miocene).

Samples: 8 specimens, PT 125, 132, CEV 154, 157, 158, MA 161, 176, 177.

"Spirophycus" Häntzschel 1962

Description, stratinomy, occurrence and samples: see "Spiral structures".

Spirorhaphe Fuchs 1895

Description, stratinomy, occurrence and samples: see "Spiral structures".

Spongeliomorpha De Saporta 1887

Description: this trace fossil appears as a long cylindrical tunnel, 1.2 to 2 cm thick, vertically or horizontally distributed, characterized by sets of longitudinal and oblique, fine, elongate striations recovered on the exterior of burrow casts. A swelling (diameter up to 3.2 cm) has been observed at one end of a sample found in a cm-thick, fine-grained turbidite in the Montecoronaro area (Verghereto), but here elongate striations are seldom preserved. When the presence of striations is uncertain, *Spongeliomorpha* can be mistaken for similar ichnotaxa (e.g. *Granularia*, which in turn is included in *Ophiomorpha*), thus requiring further analysis. In the studied outcrops *S. sublumbricoides* (Azpeitia Moros) occurs as well and reveals short, oblique, irregularly distributed external ridges as illustrated by Uchman (1998, fig. 29).

Category: string-shaped.

Stratinomy: hypichnia at soles of thin-bedded calcarenites.

Occurrence: very abundant in some beds of the "marnoso arenacea" formation (Miocene).

Samples: 3 specimens, MA 86, 195, 206.

Strobilorhaphe Książkiewicz 1968

Description: this uncommon, horizontal trace fossil consists of a central arcuate stem and lateral short, clavate branches. *S.* cf. *glandifer* Książkiewicz has been rarely recovered as hypichnial trace at the sole of fine-grained turbidites of "marnoso arenacea" of Savio Valley, showing often atypical aggregations of globe-shaped bulges. This form closely resembles the ichnospecies illustrated by Uchman (1998, fig. 14) and indicated as breeding structure, maybe produced by polychaetes; it occurs from Ordovician to Eocene (Książkiewicz 1977).

Category: clavate.

Stratinomy: hypichnia in thin-bedded calcarenite.

Occurrence: "marnoso arenacea" formation (Miocene).

Samples: 1 specimen, MA 38.

Subphyllochorda Götzinger & Becker 1932

Description: in accordance with Książkiewicz (1977) and Smith & Crimes (1983), here we consider the ichnogenera *Cardioichnus* and *Subphyllochorda* as separate from the previously described *Scolicia,* although Uchman (1995a, 1998) includes all these forms in the *Scolicia* ichnogenus. Seilacher (2007) defines the "*Subphyllochorda* preservation" as hypichnia at the sole of turbidite beds, within the post-turbidite association. Our studies evidenced that *Subphyllochorda* cannot be clearly considered as a post-turbidite burrow because lamination and the other sedimentary structures referable to the turbidite event are undisturbed by post-depositional burrowing; therefore further studied are needed to better understand the stratinomy of this trace. When it is preserved as epichnia, *Subphyllochorda* appears as a convex winding form, 1-4 cm broad, at the top of thin-bedded (5 cm) sandstones. According to Seilacher (2007) scolicid epichnial meanders are named "*Palaeobullia* preservation". At the Verghereto High (Montecoronaro) many epichnial *Subphyllochorda* (*Palaeobullia* preservation) are composed by bilaterally symmetrical backfill laminae, often curved close the central axis, and composed by strings of sediment, 2-5 mm in diameter. The strings are very similar to those illustrated by Smith & Crimes (1983, fig. 4C), although two parallel ridges are poorly preserved. Many burrows are crossed by other epichnial forms (e.g. *Scolicia prisca*) in the same bed.

Category: winding.

Stratinomy: probabily epichnia at the top of cm-thick sandy turbidites (maybe hypichnia, see text).

Occurrence: "marnoso arenacea" formation (Miocene).

Samples: 7 specimens, MA 98a-d, 166a-c.

Taenidium Heer 1877

Description: this is a typical horizontally-distributed, meniscate trace fossil that occurs as simple, straight to sinuous string, usually unlined, with a fill of meniscus-shaped segments (see D'Alessandro & Bromley 1987). This form, up to 22 mm in diameter, is rare in studied outcrops. It appears usually as hypichnial and endichnial form in mudstones and fine-grained turbidites of "scisti varicolori" of the Trasimeno area (M. Solare, Pl. 1D). Some endichnial meniscate trace fossils are visible in reddish mudstones also of the "Scaglia" of eastern Umbria. A doubtful endichnia specimen has been observed also in thin-bedded turbidites of the "marnoso arenacea" in the Verghereto area.

The unwalled meniscate trace fossils named *Muensteria* Sternberg 1833, display a similar aspect and, according to the Książkiewicz material revision by Uchman (1998), they can be included in *Taenidium* (see also D'Alessandro & Bromley 1987). The term "*Muensteria* preservation" (e.g. meniscous-shaped, pellettoidal semilunae), although still used by Seilacher (2007), is not recommended for further use by the above-mentioned Uchman revision.

Category: winding (meniscate).

Stratinomy: hypichnial and endichnial form in mudstones.

Occurrence: "Scaglia" (mainly Scaglia Rossa and "scaglia variegata"), "scisti varicolori"; doubtful in the "marnoso arenacea" formation.

Samples: 8 specimens, SG 235a-d, VA 236a-c, ?MA236b.

Thalassinoides Ehrenberg 1844

Description: *Thalassinoides* is a facies-crossing, smooth-walled, essentially cylindrical Y- to T-shaped branched trace fossil, extremely abundant in the geological record and produced mainly by crustaceans (Frey *et al.* 1978, 1984; Monaco 2000b; Monaco & Garassino 2001; Monaco & Giannetti 2002). The origin and palaeoenvironmental significance of *Thalassinoides* were summarised by Howard & Frey (1984) and Ekdale (1992). According to Föllmi & Grimm (1990) it is possible that the crustaceans producing *Thalassinoides* may survive to transportation by turbiditic currents and produce burrows under anoxic conditions during a limited numbers of days.

Apart from widespread Mesozoic and Cenozoic occurrences, *Thalassinoides* has been reported from shallow water sediments in the Palaeozoic (e.g. Palmer 1978; Archer & Maples 1984; Sheehan & Schiefelbein 1984). During early Jurassic times, *Thalassinoides suevicus* (Rieth) characterizes also shallow-marine environments, occurring as three-dimensional systems of branched, Y-shaped tunnels of variable diameter enlarged at points of bifurcation (Fürsich & Oschmann 1993; Giannetti & Monaco 2004).

In the studied turbidites this form is predominantly horizontal, more-or-less regularly branched, essentially cylindrical, and dichotomous bifurcations are more common than T-shaped branches as pointed out by Howard and Frey (1984). This ichnotaxon, represented by *T. suevicus*, has been described commonly in the Tertiary flysch deposits (e.g. Istria, Croatia and Slovenia; Tunis & Uchman 1996a). It displays a meniscate backfill and irregular knobby structures (transitional to *Ophiomorpha*), although swellings in some branching points are typical of *Thalassinoides* (Pl. 1J).

In the Scaglia Rossa and "scisti varicolori" formations *T. suevicus* is horizontal or oblique, strongly flattened 10-40 mm in diameter. T-shaped branching is rare, but it may occur together with Y-shaped branching in the same bed. In "scisti varicolori" this form is present in the calcareous-marly and clayey-marly units (middle Eocene, from P10 to P12 Zones), commonly greatly abundant at some horizons (10 specimens/m^2 in the lower part of P12 Zone). A similar ichnodensity occurs in many beds of Scaglia Rossa and "S. variegata" of eastern Umbria. In the turbidites of the "Macigno" and "marnoso arenacea" this trace occurs as typically obliquely oriented endichnia towards hypichnia (Pratomagno, Mandrioli and Città di Castello areas, Pl. 1 and 2J, M). In siliciclastic deposits this ichnogenus is usually replaced by *Ophiomorpha* isp. and *O. rudis* (Pl. 2G - L, N).

Category: branched (horizontal).

Stratinomy: endichnia towards hypichnia and crossichnia (multilayer colonizer) in every bed.

Occurrence: Scaglia Rossa, "scaglia variegata", Scaglia Cinerea, "scisti varicolori", Arenarie di Monte Cervarola, Macigno, "marne di Vicchio", "marnoso arenacea" formations (Eocene to Miocene).

Samples: 10 specimens, SG 231a-b, VA 231c-d, PT 124, 143, 151, MA 50, 70, 219.

Trichichnus Frey 1970

Description: this is a rarely found form, consisting of thin, hair-like (0.5-1.1 mm in width), branched straight to sinuous trace fossils, oriented at various angles with respect to the bedding. Burrow walls are distinct or indistinct, and mostly unlined (Frey & Howard 1970; Fillion & Pickerill 1990). In the examined material of "scisti varicolori" and "marnoso arenacea" *Trichichnus linearis* Frey has been recovered; specimens are mostly 0.7-1.1 mm in diameter, branched with acute angles. The absence of the lining perhaps may be connected with diagenetic processes (Monaco & Uchman 1999). This trace fossil is commonly filled by darker and finer material than the host rock, and frequently impregnated by secondary ferruginous oxides; around the trace fossils a ferruginous, oxidized yellowish halo is present as well (MacBride & Picard 1991).

Category: branched (vertical).

Stratinomy: mainly endichnia in calcareous fine-grained turbidites.

Occurrence: "scisti varicolori" and "marnoso arenacea" (Eocene to Miocene).

Samples: 4 specimens, 230a-d.

Urohelminthoida Sacco 1888

Description: *Urohelminthoida* represents a group of "uniramous meanders" graphoglyptids including several ichnogenera (e.g. *Protopaleodictyon*) which are classified and studied in Northern Apennines and other areas (Sacco 1888; Seilacher 1977b). They occur in many environments, from deep-sea floors (Gaillard 1991) to shallow-waters (extremely rare), from Jurassic to Miocene. In the studied sections *Urohelminthoida* is very common and consists of hypichnial string-sized, tight meanders, in which turning points are angular, and regularly spaced appendages protrude outwardly from turning points. *U. dertonensis* Sacco is the most frequent and typical species in the studied turbidites, where it commonly forms regular meanders, 30-45 mm wide, and show hypichnial strings up to 4 mm in diameter; the appendages are up 60 mm long. *Urohelminthoida* isp. and *U.* cf. *appendiculata* Heer, sampled from the "marnoso arenacea" formation in the Mandrioli Pass occur as well, and these specimens show some similarities with those described in Switzerland (Heer 1877). *U.* cf. *appendiculata* is very rare in the studied flysch and consists of slightly irregular meanders, tight (their distance is two or three times the tunnel diameter) and very wide, with a course becoming convex; appendages are short, parallel to the tunnels. These appendages differ from those of the similarly-shaped *Oscillorhaphe venezoelana*, which displays transverse bars at the turning point (Seilacher 1977b, fig. 8d). Locally, the distinction from *Helminthorhaphe*, which exhibits one order of smooth and very high meanders, may be difficult, but only if turning points and bars are not well exposed (Seilacher 1977b, fig. 6g).

Category: meandering (uniramous).

Stratinomy: hypichnia from muddy to sandy turbidites.

Occurrence: mainly in siliciclastic turbidites of the Arenarie di Monte Cervarola and "marnoso arenacea" formations (usually from Oligocene to Miocene).

Samples: 12 specimens, PT 232a-b, MA 27, 37, 54, 60, 62, 64, 68, 69, 122, 191.

Zoophycos Massalongo 1855

Description: this ichnogenus includes several three-dimensional spreite structures with helicoidal shape, up to 70 cm in diameter, mainly developed in muddy deposits (hemipelagites). Spreite structures are very common and locally well preserved in soft sediments (e.g. "marne di Vicchio" formation of Valsavignone); in plain view they exhibit primary and secondary lamellae (see distribution and detailed description in Olivero & Gaillard 2007). A marginal tube may be arranged in helicoidal spirals and central vertical tunnels sometimes can be preserved. This form has more or less U- or J-shaped protrusive burrows. In the Contessa area (Gubbio) the overall outline is mainly circular to elliptical or lobate (very long lobes) in the limestones of the "Scaglia" (Scaglia Rossa and "scaglia variegata") and "Bisciaro" (Pl. 1G, H). In the Umbrian Apennines the diameter increases progressively from 20-40 cm from the limestones of the Scaglia (mainly at the early Paleogene interval), to the marly deposits of the Bisciaro or "marne di Vicchio" formations (Oligocene-Miocene) where they reach up to 60-100 cm in diameter (Pl. 1G, H). Different ichnogenera and species have been described under the name *Zoophycos*, and recently this ichnogenus has been extensively discussed (Häntzschel 1975; Ekdale & Lewis 1991; Wetzel 1992; Olivero 1996, 2003, 2007 *cum biblio.*; Olivero & Gaillard 1996; Gaillard *et al.* 1999).

Category: helicoidal.

Stratinomy: endichnia to crossichnia mainly in hemipelagites.

Occurrence: in mudstones intercalated with carbonate and siliciclastic turbidites, "scisti varicolori", "marne di Vicchio" and "marnoso arenacea" formations (e.g. M. Solare, Monte Silvestre, Valsavignone area, respectively); very abundant in the Scaglia and Bisciaro formations (Paleogene-Neogene) of Umbrian-Marche Apennines.

Samples: 28 specimens, VA 200a-b; MA 201a-f; SG 202a-d (Scaglia Rossa); 203a-e ("scaglia variegata"); 204a-m (Scaglia Cinerea and Bisciaro).

5. DISCUSSION AND CONCLUSIONS ON STRATINOMIC FEATURES OF TRACE FOSSILS IN TURBIDITE SUB-ENVIRONMENTS OF NORTHERN APENNINES

In turbidites the terms "pre-" and "post-depositional" were introduced by Książkiewicz (1954) to indicate trace fossil preservation. The stratinomic classification in a typical arenaceous bed was introduced by Seilacher (1964) to indicate the different types of preservation and location of the trace fossils compared to the bed itself. According to this scheme, the trace fossils can be termed *full relief*, *epirelief* and *hyporelief*, with the two latter categories being also qualifiable both as positive or negative *semirelief*. Such terminology is particularly useful for turbiditic facies (Seilacher 1977a, 1977b; Monaco & Caracuel 2007; Monaco 2008). The classification of Martinsson (1970) uses groups with a series of prefixes corresponding to the position of the trace fossils compared to the sand bed: *exichnia* (external to the bed), *endichnia* (within the bed), *epichnia* (on the top of the bed), *hypichnia* (at the base of the bed). This latter, more general scheme has been used also by Seilacher (2007) and Savrda (2007) and it is adopted in the present paper, albeit with some modifications and improvements especially directed to facilitate the specialist stratigraphers in the field observation of the sedimentary facies of flysch deposits (Fig. 2). In 317 studied specimens from turbidite and hemipelagite deposits of the Northern Apennines, deposited from Eocene to late Miocene, the preservation varies from exceptional for hypichnia and epichnia, to good for endichnia and moderate or poor for crossichnia and exichnia.

A. Hypichnia dominate among other catagories if we consider the diversity of studied ichnogenera and ichnospecies. Graphoglyptids are largely represented with many ichnogenera and ichnospecies. Other ichnotaxa have been found but in many cases their diversity is very low although their ichnodensity is very high (e.g. *Arthro-*

phycus that represents 80% of the total at sole of some thick-bedded turbidites). Ichnodiversity of hypichnia is poor in massive and thick-bedded high-density turbidites and increases in fine-grained and thin-bedded low-density deposits (mainly F9a-b facies). Pre-depositional traces preserved as hypichnia are represented by simple or complex networks (large to small in size), uniramous and biramous meanders, knob- and plug-shaped forms, spiral and circular structures and many string-shaped burrows. Among large networks, *Paleodictyon* is the most typical, because it may be preserved as an horizontal (often deformed) mesh with vertical shafts in the same sample (*Glenodictyum* and *Ramodictyon, sensu* Seilacher 2007, respectively) and it can be crossed by many string-shaped burrows (e.g. *Spongeliomorpha*). Other typical hypichnia are thin and regular networks (usually not deformed): *P. strozzii, P. majus, P. italicum, P. minimum, P. latum* and *Squamodictyon* (see various types of preservation described by Monaco 2008). Other typical hypichnia are meandering-shaped (uniramous or biramous and others) graphoglyptids and the most frequent ichnogenera are: *Desmograpton, Urohelminthoida*, *Paleomeandron*, *Protopaleodictyon*, *Megagrapton*, *Cosmorhaphe*, and *Helminthorhaphe*. Winding-shaped hypichnia, more or less internally structured, are also very abundant in the studied soles of turbidites and the most representative are: *Helminthopsis, Gordia, Halopoa, Scolicia,* and *Taenidium*. Spiral structures such as *Rotundusichnium, Spirorhaphe* and *Spirophycus* have been found in siliciclastic turbidites of Arenarie di Monte Cervarola and “marnoso arenacea”. Probably also radiate (*Lorenzinia* and small *Glockerichnus*) or knob-shaped (*Parahaentzschelinia* and *Bergaueria*) forms may be considered pre-depositional hypichnia.

B. Endichnia developed within sandy beds and these trace fossils are three-dimensionally distributed to exploit food resources and external nutrients transported with sand directly by turbidity flows (post-depositional trace fossils). Typical endichnia consist in branched tubes that can be straight or sinuous and more or less structured; they have been observed within sandstones close to the hypichnia position: *Ophiomorpha annulata, O. rudis* and *Thalassinoides*. A similar case of endichnia is that of *Palaeophycus* in “scisti varicolori” formation, where it can be observed in calcarenite beds or at the transition between coarse-grained sand to silt (pipe structures, see Seilacher 2007). Muddy endichnia are characterized by simple pellettoidal *Alcyonidiopsis* in mud turbidites of “scisti varicolori” and branched vertical burrows *Chondrites*, *Cladichnus* and *Trichichnus* developing downward in calcilutites and in cm-thick muddy turbidites (e.g. “scisti varicolori”, Scaglia). *Trichichnus* has been recovered also in the fine-grained deposits of “marnoso arenacea” formation. Many types of pustulose biserial *Nereites* in muddy turbidites of the “scisti varicolori” may be considered as endichnia, where it can reach also the epichnia position with a progressive increase in the ichnodensity throughout the top of bed.

C. Epichnia are poor or lacking in siliciclastic facies (F7-F8-F9a of Macigno, Arenarie di Monte Cervarola and “marnoso arenacea”); the meandering epichnial community dominated by *Scolicia prisca* shows a very high ichnodensity in fringe F9b facies of the Verghereto High (Monaco 2008). The high ichnodensity is also observed in the preservational variants of *Nereites* (e.g. *N. missouriensis* and *Neonereites*) which are epichnia at the top of medium-bedded turbidites of “marnoso arenacea” of Città di Castello (with *Thalassinoides*) and in thin-bedded cm-thick turbidites of the “scisti varicolori”. Other epichnia belong to trails which exhibit backfill meniscate structures (e.g. *Taenidium* or *Muensteria*), simple sinuous traces such as *Planolites* (e.g. *P. beverleyensis*), *Subphyllochorda* and radiate forms (e.g. large *Glockerichnus*) which are very common in fringe deposits of Verghereto High. In fine-grained calcareous turbidites of “scisti varicolori” endichnia/epichnia are well developed and *Chondrites*, *Cladichnus* and *Nereites* assemblage appears in reddish colour and ichnodensity increases upwards (Monaco & Caracuel 2007).

D. Exichnia has been rarely found because trace fossils are usually not well preserved in marly deposits between turbidites for compaction due to burial and tectonic processes (e.g. very flat *Thalassinoides suevicus* specimens in hemipelagic mudstones at Monte Solare and partially preserved *Ophiomorpha annulata* specimens in marls at Bagno di Romagna). The preservation is better in those facies in which trace fossils cross more beds; in these cases flask-shaped or car-silencer shaped *Ophiomorpha*-like burrows and *Thalassinoides* develop vertically, horizontally or obliquely in more pelitic beds. They are indicated with the term “crossichnia” (Monaco *et al.* 2007), to describe those trace fossils that correspond to “multilayer colonizers” of Uchman (1995b) and Wetzel & Uchman (1997) (Fig. 2); vertically or obliquely distributed crossichnia are abundant usually in pelitic and arenaceous deposits of lower slope/basin plain, involving more inter-turbidite and turbidite beds: some clay deposits are crossed by *O. rudis* in Montone area, while 50 cm long subquadrate (in transversal section) trace fossil (undetermined), develop in clay deposits of San Sepolcro (G. Giorni, personal comm.). Exichnia are also present in thick hemipelagic deposits of Eocene-Oligocene Scaglia and early Miocene Bisciaro formations (Contessa-Gubbio area and S-E Umbria), preserved as helicoidal or lobate structures up 1 m wide of the *Zoophycos*.

The usefulness of Martinsson stratinomy in deep water turbidites is greater and then easily observable, especially when siliciclastic facies reduce progressively their thickeness with distality along the same basin (e.g. active and inactive lobes in basinal sub-environments, see Ricci Lucchi 1981). In many of the foredeep basins of the northern Apennines here considered (e.g. Inner Basin for the "marnoso arenacea", Ricci Lucchi 1981) the coarse-grained and thicker sands were deposited in active fans along the axis of narrow troughs; externally, these facies progressively turn in to fine-grained and thinner bodies, according to the distribution of the terrigenous supply (also from lateral sources) and to the topography of the sea floor. Sedimentary facies and hypichnia diversification follow the same trend: as indicated by Uchman (1995a) facies distality produced high diversification in some ichnotaxa (e.g. graphogliptids) with a progressive reduction in the number of other ichnotaxa such as *Ophiomorpha* and *Thalassinoides*.

Not only the ichnodiversity but also the ichnodensity of hypichnia is related to sedimentation rates of turbidity regime and physical processes (e.g. bottom currents) that are typical of each sub-environment of a same basin (e.g. the Inner Basin of "marnoso arenacea"). Physical processes influences also the preservation of pre-depositional trace fossils: some washed-out hypichnia are very common under the action of tractive currents (Monaco 2008), while a minor number of washed-out forms (e.g. well cemented crossing hyporelief of *Scolicia strozzii)* are those filled rapidly by sand without traction (some facies of "marnoso arenacea" and "marne di Vicchio" at Verghereto, Mandrioli Pass and Valsavignone). Another aspect concerns the cross-facies burrowers when organisms varies their burrowing strategies following environmental variations of the substrate: in active or inactive lobes, inter-lobes, fringe areas of submarine highs the same ichnotaxon may change their stratinomic position, according to the change of the characteristics of the sediment. Many specimens of *Thalassinoides* (*T. suevicus*) and *Ophiomorpha* (e.g. car silencer-shaped *Ophiomorpha* and *O. rudis*) are hypichnia in thicker beds of active lobes (high sedimentation rates) but are endichnia, endichnia/epichnia (with *Nereites* in a same sample) and crossichnia in thinner and muddy facies of inter-lobes (e.g. lower slope/basin plain in Montone and Città di Castello).

Many other typical hypichnia are sensitive to environmental characteristics of the substrate, such as fodinichnia *Spongeliomopha* and *Protovirgularia,* that cross other trace fossils (e.g. *Paleodictyon hexagonum*) and pre-turbiditic structures, such as mud lineations, induced by pre-turbidite currents on the sea-floor (Monaco 2008). Another aspect is the discontinuous sedimentation that is typical of margins of moulti-source sandy lobes (e.g. in the Arenarie di Monte Cervarola of Cortona area): thicker, massive F6-F8 facies overlay thinner F9 turbidite beds of different colour and composition and hemipelagite mud is very discontinuous (from 50 cm to 300 cm). Here a great abundance of post-depositional *Halopoa* (*Fucusopsis* preservation*)* suggest that these peculiar hypichnia (asterosomids) were preserved as at the sole of turbidites together many spiral structures such as *Spirorhaphe,* while graphoglyptids are very rare (only *Urohelminthoida*).

Synecological relationships between burrowers and related environmental parameters requires a long discussion that is not included in the purposes of this paper; for this reason these topics will be described and discussed in another work.

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