

First documentation of wood borings (*Teredolites* and insect larvae) in Early Pleistocene lower shoreface storm deposits (Orvieto area, central Italy)

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ABSTRACT - Findings of isolated wood clasts (wood branches and/or portions of a tree trunk) in Early Pleistocene deposits within the "Chiani-Tevere" depositional cycle (Orvieto area, central Italy) are described. The specimens show pervasive borings developed parallel to the wood fibers, assigned here to *Teredolites longissimus* Kelly & Bromley, 1984 and doubtfully to *T. clavatus* Leymerie, 1842. Oriented thin section analyses of the grouped or isolated *Teredolites* specimens have shown that the borings vary in shape and diameter from circular to oval or flattened, have a thin lining and are sand-filled. On the exterior surface the characteristic elongated grooves of *Teredolites longissimus* arranged in the direction of the perforation may be observed. Two successive phases of bioerosion are identified: subaerial borings by insect larvae indicate terrestrial activity prior to transport and teredinids indicate a marginal marine environment. The macrofossil assemblages and sedimentological structures suggest storm events in a lower shoreface environment. The ichnological analyses of the boring history combined with the sedimentological data indicate a gradual transition from a fan delta to upper shoreface conditions.

RIASSUNTO - [Prima documentazione di perforazioni di legni (*Teredolites* e larve di insetti) in tempestiti del Pleistocene Inferiore (area di Orvieto, Italia centrale)] - Vengono studiati alcuni macroresti vegetali (rami e porzioni di tronco) rinvenuti entro depositi del Pleistocene Inferiore appartenenti al ciclo deposizionale "Chiani-Tevere" (zona di Orvieto, Italia centrale). I resti presentano numerosissime perforazioni debolmente clavate e allungate ascrivibili all'ichnotaxon *Teredolites longissimus* Kelly & Bromley, 1984, mentre l'altra ichnospecie *T. clavatus* Leymerie, 1842 è di dubbia attribuzione. L'analisi di sezioni sottili orientate ha rivelato che le bioperforazioni variano sia nella forma che nel diametro, presentano un lining sottile ed hanno un riempimento sabbioso. Esternamente sono presenti dei solchi allungati disposti nel verso della perforazione come è tipico di *T. longissimus*. Lo studio ha evidenziato due successive fasi di bioerosione, la prima, in condizioni subaeree, operata forse da larve di insetti, la seconda riferita a teredinidi, in ambiente marino marginale. Successivamente i resti vegetali bioerosi furono accumulati da tempeste in un ambiente di avanspiaggia (forse non superiore a 30-40 m di profondità) con lo sviluppo di concentrazioni gradate a bivalvi e concrezioni diagenetiche.

INTRODUCTION

Marginal marine environments frequently exhibit woodgrounds and log-ground (often as isolated and resedimented wood clasts) that frequently preserve pervasive bivalve boring activity (Savrda et al., 2005; Savrda, 2007). In modern marginal marine environment these woodgrounds are deeply excavated by pholadid and teredinid bivalves and usually are associated with other different shallow traces of soft, firm to hard substrate types. In ancient marginal marine environments woodgrounds rarely contain identifiable ichnofossils other than the ichnotaxon *Teredolites* Leymerie, 1842 (Savrda, 2007). The corresponding ichnofacies is known as *Teredolites* ichnofacies (Bromley et al., 1984; Gingras et al., 2004). Two different ichnospecies usually occur, an elongated form, *Teredolites longissimus* Kelly & Bromley, 1984, and a shorter or clavate form, *T. clavatus* Leymerie, 1842. In the analysis of wood-boring bivalves, Evans (1999) indicates that *T. clavatus* is produced by *Martesiinae* while *T. longissimus* by teredinids and also by xylophagines. This author evidences that boring

morphology can change from perpendicular to the grain of the wood in the case of xylophagines to parallel to the wood-grain for teredinids (Turner, 1967), but the boring morphology alone, mainly in the fossil record, is of little use in distinguishing between these specialist wood-boring groups (Evans, 1999).

The aim of this paper is to describe *Teredolites* and other small borings (probably produced by insect larvae) in isolated wood clasts from lower shoreface deposits of Early Pleistocene of western Umbrian Apennines (Orzalume-Cottano section, Orvieto area, central Italy). Taphonomy has been utilized in order to analyze the preservational features of *Teredolites* in isolated or grouped specimens and external concretions. The lining and the sand fill have been observed in cross sections using the DinoLite microscope camera that allows to observe and photograph a continuous spectrum from 8 to 200 magnifications (Monaco & Checconi, 2010). Ichnological, sedimentological and paleontological features of the sediment including the wood clasts were considered to better characterize the depositional environment (fan delta to lower and upper shoreface).



Fig. 1 - Study area and localization of the Orzalume-Cottano section.

GEOLOGICAL SETTING

The Orzalume-Cottano composite section (Fig. 1) is placed in the Orvieto area (western Umbria, central Italy), at an altitude of about 300 m a.s.l. along the M. Peglia anticline western limb, into the Plio-Pleistocene fill of the Paglia graben, a NW-SE oriented extensional basin (Funicello et al., 1981). The pre-Pliocene rocky substrate is represented by Jurassic to Eocene deposits (mainly carbonates and marls of Umbrian-Marchean units) and Oligocene-Miocene flysch deposits (sandstones and associated facies of Tuscan units) (Fazzini, 1968; Jacobacci et al., 1970; Damiani & Tuscano, 1991; Damiani et al., 1993). According to the new stratigraphic scale of Pliocene-Pleistocene boundary (Gibbard et al., 2010) the study area belongs to the Piacenzian to Quaternary stratigraphic interval and coastal marine and continental deposits widely outcrop in the area. The study section belongs to the Early Pleistocene “Chiani-Tevere” depositional cycle (Gelasian p.p. - Calabrian: Ambrosetti et al., 1987; Girotti & Mancini, 2003; Mancini et al., 2004; Bizzarri, 2006).

THE ORZALUME-COTTANO SECTION

A composite section in the Orzalume-Cottano area has been recognized about between 290 m and 390 m a.s.l. (N 42°43.881, E 12°11.614) and sedimentological and stratigraphic data have been indicated (Fig. 2). Deposits are represented by gravels and sands in the lowermost portion, exposed along two dismissed quarry fronts,

whereas sands dominate the uppermost section. The whole Orzalume-Cottano section leads to a shallow water coastal marine environment, with small river supply, and a main transgressive-regressive trend has been documented.

A detailed taphonomic analysis of the malacofauna is beyond the aims of this note; nevertheless, the preliminary analysis reveals the dominance of well-preserved specimens that exhibit original colours and a low degree of re-elaboration. Thus, most of fossil molluscs are only partially reworked in the same life environment, or subjected to a limited sedimentary transport from the neighbourhood areas; their analyses complete and integrate the paleoenvironmental indications inferred by ichnology and sedimentology. Mainly upon sedimentary features, three main environments have been analysed (Fig. 2): a) fan delta, b) lower and c) upper shoreface.

Fan delta deposits

The basal 35 m are dominated by gravels, with subordinated coarse to very coarse sands. Deposits directly lay on the flysch substrate (Macigno s.l. Auct.) and are made of large boulder matrix-supported gravels, passing upward to cobble clast-supported channelized gravels. The lowermost deposits are barren, and interpreted as alluvial fan deposits. Throughout the following 20 m, cobble to pebble clast supported gravels, still interpreted as river channels, alternate to beachface deposits, represented by coarse sandy levels and parallel cross-stratified gravels (Fig. 2). The fossil content is represented by an oligotypic oyster malacofauna, accompanied by *Lithophaga* borings and serpulids that testifies a coastal marine deposition.

Locally, a richer malacological assemblage, including *Persististrombus coronatus* (Harzhauser & Kronenberg, 2008, with references), Conidae and Cypreidae is documented (Fig. 2). Microfossil assemblages are poor and represented by benthic foraminifers (*Amphistegina* sp., *Elphidium crispum*, *Ammonia beccarii*, *A. parkinsoniana*, *A. taepida*, *Gyroidina altiformis*, *Lobatula lobatula*, *Cancris auriculus*, *Melonis* sp., *Sphaeroidinella* sp.), fish otoliths and bryozoans.

At the top of the portion, channelled bodies with pebble gravels and very coarse sand/granules prevail, with evidences of river current input; however, the occurrence of an assemblage dominated by oligotypic oyster and *Strombidae* in the channel lags still testify a coastal marine deposition. Thus, the basal portion of the section is interpreted as a roughly organized fan delta.

Lower shoreface deposits

Between elevations 325 and 375 m a.s.l., deposits are represented by fine to very fine sands and silty sands, locally weakly to hardly cemented. The sedimentary structures are poorly recognizable, and sands look massive; nevertheless, they show irregularly disposed shell beds made of almost oligotypic bivalves. These beds exhibit taphonomic characters such as abrasion, fragmentation, winnowing of matrix and normal gradation which seem to coincide with the c-case of Kidwell (1991, fig. 5, pag. 278) of episodic deposition and erosion, with high reworking degree. Therefore, they can be better interpreted as tempestites (Fig. 2). In other cases, some shell horizons can be interpreted such as episodic sedimentation with omission and are interpreted as shell

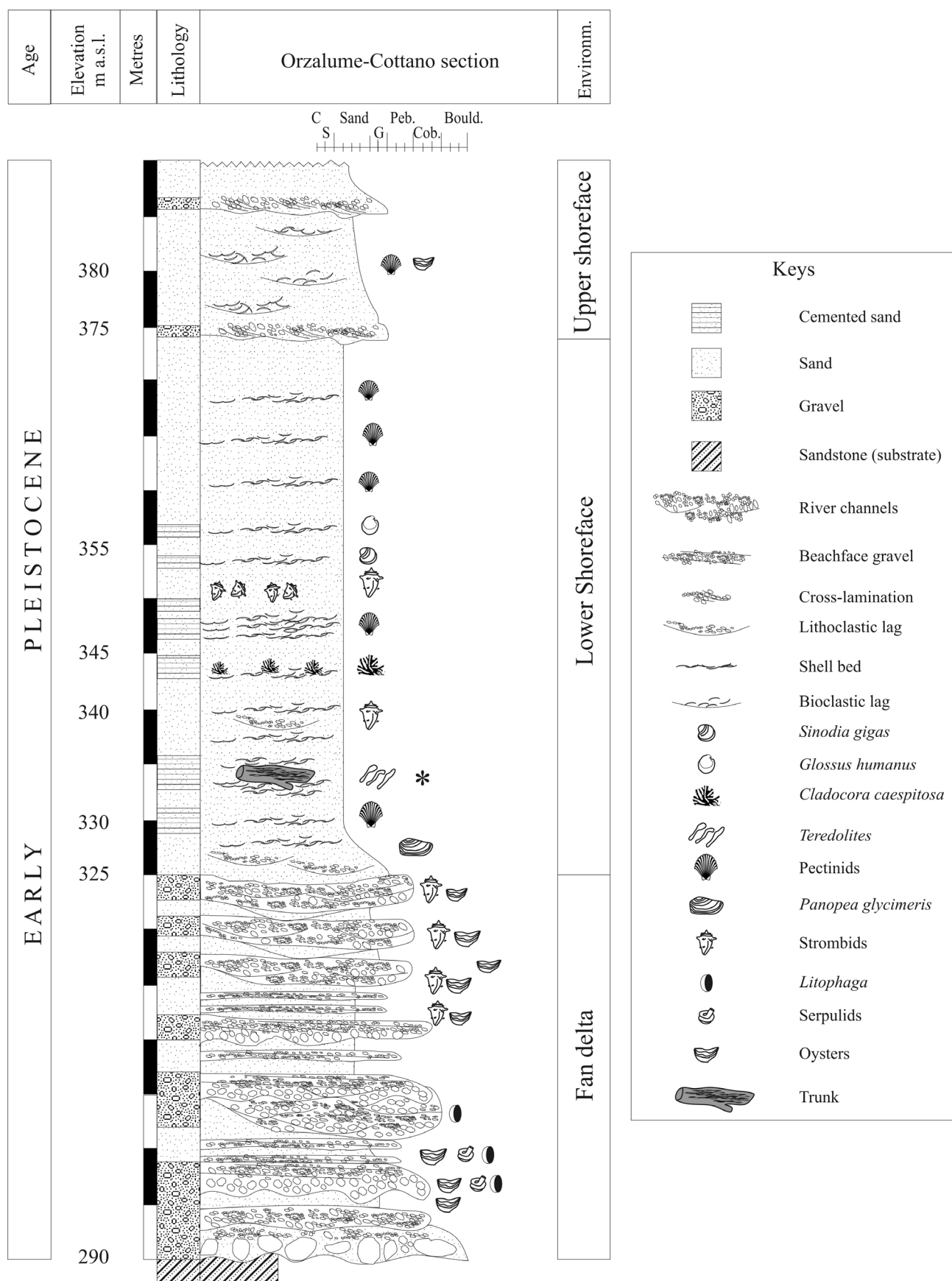


Fig. 2 - Stratigraphic section with macrofossil assemblage and level (asterisk) with isolated wood clast with borings (*Teredolites*). For macrofossil assemblage of trunk see Fig. 3.

pavements (b-case, hiatal accumulation of Kidwell, 1991). Yet, two rich macrofossil assemblages characterize more than the half of deposits, in correspondence of the bioturbated trunk (*Teredolites* trace fossil assemblage) and above it, respectively (Figs 2-3). Microfossil assemblages contain common *Ammonia beccarii*, *A.*

taepida, *A. papillosa*, *Elphidium crispum*, *Lobatula lobatula*, and also rare *Patellina corrugata*, *Melonis padanum*, *Nonionella turgida*, *Gyroidina altiformis*, *Cancris auriculus*, *Bolivina spathulata*, *Bulimina spinata*, *B. marginata*. Planctonic foraminifers are represented by *Globorotalia crassaformis*, *G. menardii*, *Globigerina*

	Rare (1-10)	Common (11-50)	Abundant (>50)
Upper shoreface assemblage		<i>Cerithium</i> sp., <i>Chlamys</i> spp. <i>Pecten</i> spp. <i>Ostrea</i> spp. <i>Glans intermedia</i> (BROCCHI 1814)	<i>Porifera</i> indet. (fragments) <i>Bryozoa</i> indet. (fragments) <i>Hexacorallia</i> indet. (fragments) <i>Echinoidea</i> indet. (fragments)
Lower shoreface assemblage	<i>Aporrhais uttingeriana</i> (RISSE, 1826) <i>Astrea fimbriata</i> (BORSON, 1821) <i>Buccinum corneum</i> LINNEUS, 1758 <i>Ciprecassis pseudocrumena</i> (D'ORBIGNY, 1852) <i>Cymathium distortum</i> (BROCCHI, 1814) <i>Cymathium doderleini</i> (D'ANCONA, 1873) <i>Erato voluta</i> (MONTAGU, 1803) <i>Ficus geometra</i> (BORSON, 1825) <i>Galeodea echinophora</i> (LINNEUS, 1766) <i>Mitra atava</i> (BELLARDI, 1887) <i>Narona</i> (Sveltia) <i>lyrata</i> (BROCCHI, 1814) <i>Rissoina bruguierei</i> (PAYRADEAU, 1826) <i>Schilderia flavicula</i> (LAMARCK, 1810) <i>Strioterebrum reticulare</i> (PECCHIOLOLI in SACCO, 1891) <i>Schilderia utriculata</i> (LAMARCK 1810) <i>Epitonium</i> sp. <i>Jujubinus</i> sp. <i>Hinia</i> sp. <i>Corbula gibba</i> (OLIVI, 1792) <i>Chlamys</i> (<i>Gigantopecten</i>) <i>latissima</i> NEWTON, 1900 <i>Glans intermedia</i> (BROCCHI 1814) <i>Panopea glycymeris</i> (BORN, 1778) <i>Spondylus</i> sp. <i>Cladocora coespitosa</i> (LINNEUS, 1758) <i>Hexacorallia</i> indet. (fragments)	<i>Bolinus brandaris</i> (LAMARCK, 1822) <i>Capulus ungaricus</i> (LINNEUS, 1758) <i>Conus antdiluvianus</i> (BRUGUIERE, 1792) <i>Conus brocchii</i> (BRONN, 1828) <i>Discotectonica pseudopersectiva</i> (BROCCHI, 1814) <i>Distorsio tortuosa</i> (BORSON, 1821) <i>Hexaplex trunculus</i> (MICHELOTTI, 1841) <i>Anadara diluvii</i> (LAMARCK, 1805) <i>Chlamys</i> spp. <i>Chama</i> sp. <i>Glossus humanus</i> (LINNEUS, 1758) <i>Sinodia gigas</i> (LAMARCK, 1818) <i>Pecten jacobaeus</i> (LINNEUS, 1758) <i>Cadulus gadulus</i> (SACCO, 1897)	<i>Murex spinicosta</i> (BRONN, 1831) <i>Nassarius clathratus</i> (BORN, 1788) <i>Natica tigrina</i> (DEFRANCE, 1825) <i>Neverita josephina</i> (RISSE, 1826) <i>Niso eburnea</i> (RISSE, 1826) <i>Ringicula buccinea</i> (BROCCHI, 1814) <i>Persististrombus coronatus</i> (DEFRANCE, 1827) <i>Subula fuscata</i> (BROCCHI, 1814) <i>Xenophora crispa</i> (KONIG, 1825) <i>Aequipten opercularis</i> (LINNEUS, 1758) <i>Chamelea gallina</i> (Linneo, 1758) <i>Spisula subtruncata</i> GRAY, 1837 <i>Tellina nitida</i> (Poli, 1791) <i>Venus multilamella</i> (LAMARCK, 1818) <i>Ditrupe arietina</i> (O. F. MÜLLER, 1776) <i>Bryozoa</i> indet. (fragments) <i>Balanus concavus</i> (DARWIN, 1854)
Trunk assemblage	<i>Bolinus brandaris</i> (LAMARCK, 1822) <i>Conus</i> sp. <i>Gibbula</i> sp. <i>Nassarius pygmaeus</i> (Lamarck 1822) <i>Persististrombus coronatus</i> (Defrance, 1827) <i>Cardium</i> spp.	<i>Bittium reticulatum</i> (DA COSTA, 1778) <i>Cerithium vulgatum</i> (BRUGUIERE, 1792) <i>Chamelea gallina</i> (Linneo, 1758) <i>Corbula gibba</i> (OLIVI, 1792) <i>Glans intermedia</i> (BROCCHI 1814) <i>Tellina nitida</i> (Poli, 1791)	<i>Spisula subtruncata</i> GRAY, 1837
Fan delta assemblage	<i>Conus</i> sp. <i>Persististrombus coronatus</i> (Defrance, 1827) <i>Lithophaga</i> spp. serpulids indet.	<i>Cerithium</i> sp. <i>Schilderia</i> spp. <i>Anadara diluvii</i> (LAMARCK, 1805) <i>Cerastoderma edulis</i> (LINNEUS, 1758) <i>Glycymeris</i> sp. <i>Ostrea lamellosa</i> (BROCCHI 1814) <i>Ostrea edulis</i> (LINNEUS, 1758)	

Fig. 3 - Macrofossil assemblages in the Orzalume-Cottano section.

bulloides, *Globigerinoides ruber*, *G. sacculifer*, *Orbulina universa*. The ostracods *Cyprideis torosa* and *Heterocypris salina* also occur.

Deposits of the intermediate portion are referred to a lower shoreface environment, locally passing to the transition to offshore.

This part of section has a thickness of 15 meter and shows oligotypic levels of molluscs that are shown in Fig. 2. The whole interval is mainly characterized by the fossil record listed in Fig. 3; nevertheless, the malacofauna, dominated by well preserved shell of *Chamelea gallina*, *Spisula subtruncata*, *Tellina nitida*, *Persististrombus coronatus* and *Nassarius pygmaeus* (SFBC sensu Pérès & Picard, 1964) leads to a depth of about 30-40 m, thus still supporting the sedimentological interpretation of a coastal environment. The very good preservation of the shell of molluscs without abrasion and the original colour partially preserved (e.g. *P. coronatus*) indicate a scarce rearrangement or reworking of shells in the same shallow water environment. Furthermore, some specimens are also in position of life (e.g. *Cladocora coespitosa* colonies of about 30 cm in diameter).

An oligotypic assemblage, dominated by *Spisula subtruncata*, *P. coronatus*, *Nassarius pygmaeus*, *Cerithium vulgatum*, *Bittium reticulatum*, *Gibbula fanulum*, is also documented in correspondence of the *Teredolites*-bearing trunk (Fig. 3).

Upper shoreface deposits

The uppermost meters of the section are characterized by coarser deposits, mainly in the coarse sand range. Sediments vary from fine pebble lithoclastic and bioclastic concentrations to roughly organized medium to coarse massive to cross-laminated sands. Both coarse sand and fine gravel reflect the organization of submarine sand bars, with a locally recognizable prevailing landward dipping cross-lamination, and an upper shoreface environment can be inferred (Reading, 1986) (Fig. 2). The microfossil assemblage is dominated by very abundant *Amphistegina lessonii*, *A. radiata*, *Elphidium crispum*, *Lobatula lobatula*, *Planorbulina mediterraneensis*, *P. corrugata*, *Nonion depressulum*, *Canceris auriculus*, *Ammonia parkinsoniana*, *Melonis padanum*; very rare are *Orbulina universa* and *Globigerinoides ruber*.

The nannofossil content of the trunk-bearing sediment allows the attribution to MNN 19 b-c subzones (Rio et al., 1990) and to the base of the Calabrian (*Globorotalia inflata* and *Globigerina cariacensis* foraminifer zones, Colalongo & Sartoni, 1979). However, a Gelasian age for the lower portion cannot be excluded. In fact, the age inferred by some specimens documented in the section is still debated (Malatesta, 1974; Marasti & Raffi, 1976; 1977; Raffi & Marasti, 1982; Raffi et al., 1985, 1989a, 1989b; Raffi, 1986; Raffi & Monegatti, 1993; Monegatti & Raffi, 2001; Harzhauser & Kronenberg, 2008), and this aspect has not been considered here because beyond of the aim of this note. Nevertheless, the common presence of well preserved *P. coronatus* from the base of the section, supports the hypothesis of its surviving in the area through the Gelasian (according to the datum of Harzhauser & Kronenberg, 2008) and since the base of Calabrian.

WOOD BORINGS

The wood borings affect isolated wood stumps and portions of a tree trunks which have been found in the middle part of the Orzalume-Cottano section (Fig. 2). Each elongated wood clast, 10 to 15 cm wide and up to 50 cm long, is embedded in a cemented gray sand. The cemented sand forms a typical carbonate concretion which develops externally to the outer surface of the wood (Pl. 1, fig. 1 upper arrow). It can reach 12 cm in thickness and exhibits many bivalve shells that are usually fragmented and densely-packed (Pl. 1, figs 2-3). Mollusc shells, that are the same of the surrounding sediment of the trunk where *Spisula subtruncata* and *Corbula gibba* dominate, are arranged with a gradation that decreases in size upward (Pl. 1, fig. 4). In many cases the external concretion may be thinner (maximum 5 cm) and shows few and scattered bivalves. Often the shells of molluscs have been dissolved and many holes are present (Pl. 1, fig. 1 lower arrow).

The ichnological analysis evidences two different types of wood borings: the *Teredolites* and the string-like branched forms. In the first case the boring is elongated in the same direction of wood fibers that are arranged in overlapping thin layers from which depart parallel tubes of the *Teredolites* boring specimens (Pl. 1, fig. 3 arrow). In the other boring case, the string-like type, the small tubes are frequently branched and develop obliquely to the wood fibers (Pl. 1, fig. 5 arrow). These wood fibers can be observed as longitudinal impressions in the exterior surface of *Teredolites* specimens, producing long and parallel grooves and strings which are disposed in the verse of boring (Pl. 1, fig. 7 arrow). This means that the boring was growing parallel to the wood fiber, as typical of *Teredolites longissimus* Kelly & Bromley, 1984. In fact, this ichnospecies predominantly develops parallel to the wood grain, having a length/width ratio greater than 5 (Evans, 1999). In the latter boring case, the string-like forms, the inner wall of the wood shows groups of thin trace fossils, 1 mm thick, commonly straight or sinuous, branched and obliquely or parallel arranged respect to the wood grains (Pl. 1, fig. 5). These string-like borings are very abundant in some places, forming concentrations with very high density (up 20 specimens per 10 cm²). Their external shape and distribution resembles that of some thin structures produced by insect larvae on the bark of the wood (see discussion).

The specimens of *Teredolites longissimus* Kelly & Bromley, 1984, are preserved essentially in full relief as grouped or isolated sand-filled tubes, incompletely and variably preserved, each composed of a discrete and thin calcite lining (Pl. 1, fig. 6). Tubes are commonly elongated, usually 7-8 cm long (exceptionally up to 13 cm), sinuous to contorted and densely-packed (Pl. 1, fig. 7). The mean diameter of tubes is 10-12 mm. The clavate shape is developed, although in general it is poorly preserved (Pl. 1, fig. 3 in the centre). The boring lining, 0.5-0.8 mm thick, has been observed with the DinoLite microscope camera (Pl. 1, figs 6, 8-9, arrow); in isolated specimens that have been observed in cross-sectional view, usually the diameter is perfectly circular (diameter = 11 mm, Pl. 1, fig. 8), while in contiguous specimens that

were in contact with each other, the diameter varies from oval to flattened (Pl. 1, fig. 9). Tangential surfaces can be observed at the contact of two different tubes where lining is thinner (Pl. 1, fig. 9 arrow). The fill of tubes consists of a gray, reddish or ochraceous medium to coarse-grained sand, occasionally with small wood remains. Grains of sand fill are quartz, feldspars, lithic rocks, mica flakes and heterogeneous fragments (mainly carbonate and shells). The mud filling has not been recovered (Eberth, 1996).

The presence of the other ichnospecies *T. clavatus* Leymerie, 1842 is doubtful, because the preservation can be very different in several parts of the isolated wood. Large clavate borings occur occasionally with maximum diameter up to 50 mm, showing the same type of lining. It is very difficult to be sure if these borings were predominantly perpendicular to the wood grains (Evans, 1999), because the concentration of specimens is too high (up to 50 specimens per 10 cm²) and a high degree of flattening exists. A detailed description of this clavate ichnotaxon, including the ability to be branched, has been made (Kelly & Bromley, 1984; Savrda & Smith, 1996).

DISCUSSION

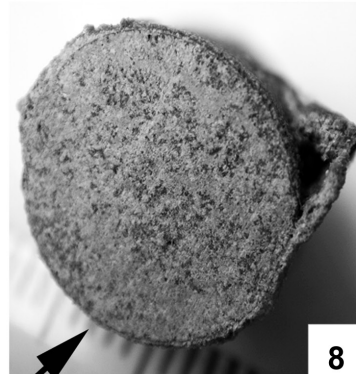
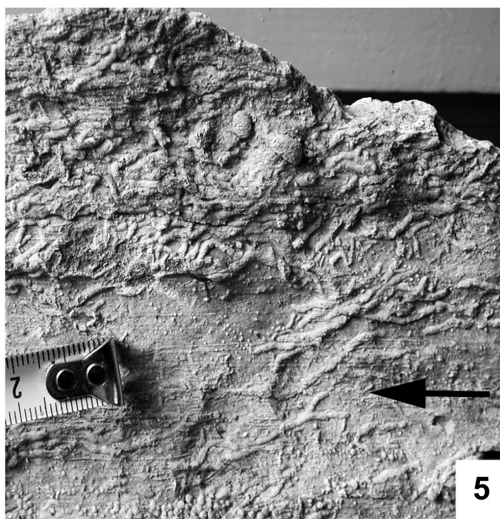
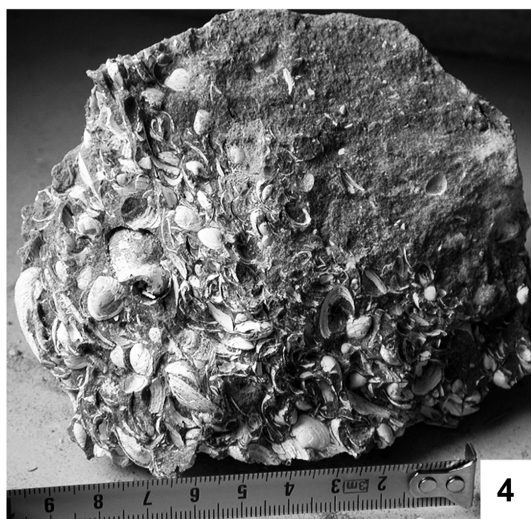
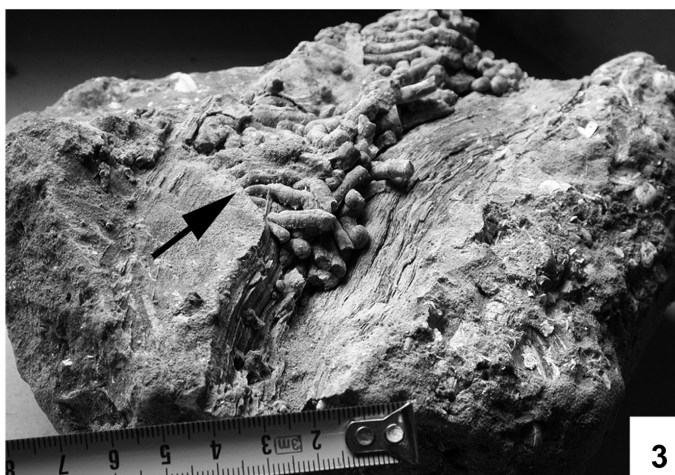
The wood-boring analysis in the Early Pleistocene Orzalume-Cottano section suggests two different stages. During the first stage, the shallow borings of string-like forms were produced in a terrestrial environment. The external shape and distribution of string-like borings resemble that of some thin structures produced on the bark of the wood by insect larvae (Genise & Hazeldine, 1995). These shallow structures resemble to insect larvae burrows similar to *Fuersichnus*-like trace fossils, although *Fuersichnus* has been described more abundantly in the sediment rather than in wood (Hasiotis, 2002). Insect borings in loose sediments of terrestrial settings, not yet lithified, are known in a wide spectrum of shapes and depths (Hasiotis, 2002), but they are unusual within lithified substrates as indicated by Mikulas & Cilek (1998) which analyzed the Holocene castellated sandstones of the Bohemian massif.

After this shallow boring, the second phase occurred with the activity of teredinids producing *Teredolites* holes and sand filling in open tubes of *Teredolites*. It probably occurred prior to the definitive transport in a lower shoreface environment, probably for a storm event. In fact the filling of *Teredolites longissimus* is a sand without shell fragments, that are very abundant externally to tubes. Moreover, many *Teredolites longissimus* specimens show an incomplete calcification of the sand filling and striae of wood fibers tend to reduce in size. The concentrations of mollusc shells that accompanied the isolate wood clasts exhibit a grading upward arrangement and the poor fragmentation of shells seems to confirm a rapid deposition due to a single storm event; yet, it cannot be excluded that the final shell distribution was the result of multiple events induced by storms and shallow water currents. In the Upper Cretaceous of Alberta the assemblage of mud-filled *Teredolites* ichnofossil and oyster lags has been described in high energy environments (Eberth, 1996). Carbonate concretions in the external surface of isolated clasts of Orzalume-Cottano section do not show the typical bivalve boring *Gastrochaenolites* that frequently occurs in coastal rockgrounds (Savrda, 2007), although the availability of bivalves able to create this kind of boring was high in the Pliocene/Pleistocene coastal environments of the Mediterranean area (Caracul et al., 2009). Probably, concretions surrounding the clasts of wood occurred after transport and were due to late diagenesis for the high organic matter content. The lacking of bioerosional processes suggests that cementation occurred in buried sand induced by carbonate-rich pore water circulation. In the Upper Cretaceous of New Zealand, Crampton (1990) indicates that bored fossil wood is abundant in concretions, but to date only one sample yielded shells of the bivalves responsible of the borings. The borings themselves of New Zealand have been identified with the ichnospecies *Teredolites clavatus* Leymerie. In the Orzalume-Cottano section, on the contrary, this ichnospecies is doubtful and bivalves responsible of boring are lacking. Moreover, the very high density and flattening of *Teredolites longissimus* prevents recognition of other ichnospecies. According to Pickerill et al. (2003)

EXPLANATION OF PLATE 1

Boring assemblage in isolated wood clasts, Early Pleistocene Orzalume-Cottano section (Orvieto area).

- Figs 1-3 - Elongated wood clast embedded in a cemented gray sand forming a carbonate concretion which develops externally to the outer surface of the wood (fig. 1, upper arrow). Note holes in fig. 1 (lower arrow) and direction of wood fibers arranged in overlapping thin layers from which depart parallel tubes of *Teredolites longissimus* (fig. 3, arrow).
- Fig. 4 - Bivalve shells, fragmented and densely-packed with a decreasing upward gradation.
- Fig. 5 - Thin borings, 1 mm thick, commonly straight or sinuous, branched (arrow), obliquely or parallel disposed respect to the wood grains.
- Fig. 6 - Calcite lining of *Teredolites* boring with the sand filling, bar = 1 mm.
- Fig. 7 - Group of *Teredolites longissimus* specimens with longitudinal impressions of wood fibers in the exterior surface, producing long and parallel grooves and strings which are disposed in the verse of boring.
- Figs 8-9 - Cross sections of *Teredolites longissimus* where it appears from circular (fig. 8) to oval (fig. 9); note tangential contact at the lining surfaces.



in the Miocene of Grand Bay Formation of the Caribbean (Lesser Antilles) the ichnotaxon *Teredolites* Leymerie, 1842 is only represented by *Teredolites longissimus* Kelly & Bromley, 1984 and occur in allochthonous and isolated specimens showing calcite-lined tubes with a perfect circular diameter. *Teredolites longissimus* is known to be produced in xylic (woody) substrates also in other types of preservations (Kelly & Bromley, 1984). The tubes of Grand Bay Formation may have accumulated in relatively shallow water only to be subsequently resedimented into a deeper water (> 150 m) environment. In the Orzalume-Cottano section sedimentological evidences and the good preservation of mollusc assemblages (Fig. 3) suggest that the degree of resedimentation was lower than in the Caribbean case and wood clasts had a lower level of transport in a lower shoreface environment, not deeper than 30-40 m. The oligotypic assemblage dominated by *Spisula subtruncata*, *P. coronatus*, *Nassarius pygmaeus*, *Cerithium vulgatum*, *Bittium reticulatum*, *Gibbula fanulum* indeed, is typical of lower infralitoral, and it justifies the inferred paleodepth. Basing upon the abundance of *Amphistegina* in the upper shoreface deposits (Bizzarri & Baldanza, 2006), and the recurrence of *P. coronatus* throughout the section, a warm shallow water nearshore environment is documented.

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