Zoophycos-like structures associated with dinosaur tracks in a tidal-flat environment: Lower Jurassic (Southern Alps, Italy)

Andrea BAUCON1 & Marco AVANZINI2*

1DISGAM – Dipartimento di Scienze Geologiche Ambientali e Marine, Università di Trieste, Via E. Weiss, Trieste, Italy
2 Museo Tridentino di Scienze Naturali, Via Calepina, 14, 38100 Trento, Italy
*Corresponding author e-mail: avanzini@mtsn.tn.it

SUMMARY - Zoophycos-like structures associated with dinosaur tracks in a tidal-flat environment: Lower Jurassic (Southern Alps, Italy) - This study reports, for the first time, the occurrence of Zoophycos-like structures in the Lower Jurassic of the Italian Alps (Calcari Grigi Group) through the description of the specimens found in the dinosaur tracksite of Lavini di Marco (Trentino, Southern Alps). The sedimentological features of the layers bearing the Zoophycos-like forms can be related to a coastal tidal-flat environment; data in our possession highlight that dinosaurs and the tracemaker of the Zoophycos-like structures frequented adjacent environments and possibly the same ones. The occurrence of Zoophycos-like structures in peritidal environments possibly represents an important contribution to the evolutionary history of Zoophycos in the Eastern Southern Alps.

1. INTRODUCTION

1.1. Geological and geographical setting

The dinosaur tracksite at Lavini di Marco (Southern Alps) is well known for the abundant dinosaurian ichnofauna (Leonardi & Mietto 2000) (Fig. 1). The dinosaur track bearing layers are attributed to the lower part of the Calcare Grigi Group (Lower Jurassic) (Avanzini et al. 1997). More precisely, the trampled layers are included in the “Peritidal unit” of the Monte Zugna Formation, late Hettangian to Sinemurian in age (Masetti et al. 1998). This stratigraphical unit corresponds to a coastal tidal-flat environment and is characterized by peritidal shallowing-up metrical cycles: each cycle presents an inferior subtidal bed on which an inter-supratidal layer is superimposed (Masetti et al. 1998).

While the dinosaur tracks have been the subject of wide study (Lanzinger & Leonardi 1991; Leonardi & Avanzini 1994; Dalla Vecchia 1994; Avanzini et al. 1997; Leonardi & Mietto 2000) on the other hand non-dinosaurian ichnology has not been discussed, either for Lavini di Marco or for the basal part of the Calcare Grigi Group. Monaco & Giannetti (2001, 2002) and Monaco & Garassino (2001) paid attention exclusively to the upper part of the Group (Rotzo Formation).

1.2. Sedimentological setting

The stratigraphical succession of Lavini di Marco is organized in peritidal sequences characterized by the alternation of mainly subtidal beds (bioclastic and peloidal wackestone; oolitic packstone) with layers attributed to an inter-supratidal environment (wackestone and stromatolitic bindstones with desiccation structures and fenestrae) (Fig. 2).

In this study, a basal cycle, corresponding to the layers named in the Lavini di Marco literature (i.e. Avanzini et al. 1997) 104, 105 and 106, is described (Fig. 2B). Abundant iron oxides concentrated into veins, laminae or globular bodies, fragments of red carbonated mud, small holes filled with silt and sparry calcite, and chemical transformations are indicative of subaerial exposure of these levels (Avanzini et al. 1997).

Layer 104 is constituted of mudstones coarsening upwards to packstone/grainstone, with coated grains and skeletal remains. The depressions present in the upper part of the
layer were filled by laminated mud covered by a crust composed of dolomite, calcite, clays and iron oxides. The topographic characteristics of level 104 are reminiscent of the lateral microkarstification of present day tropical islands. This layer is interpreted (Avanzini et al. 1997) as a representative of a subtidal environment, which came rapidly to subaerial exposure when karstification of the tidal flat occurred.

Layers 105 and 106 constitute a decimetre-scale set (Fig. 2).

Level 105 is an alternance of stromatolitic bands, peloidal grey wackestone and reddish mudstone with a thickness that ranges from 15 mm to 100 mm. Its upper part presents mud-cracks with a diameter of 10-30 up to 50 mm. This level shows a vertical alternance of several emersions and drowning with strong environmental changes in a few centimeters of section. The influence of both marine and fresh water is testified respectively by the presence of the marine alga *Thaumatoporella* and the values of the isotopic ratios ($\delta^{18}O$ from -0.5 to 10/00) and by the absence of typical marine organisms (i.e. foraminifers, brachiopods) and microtextures. Diagenetic and sedimentologic features seem to indicate a prevalence of emersion and a possibly distant coastline. Comparison with present carbonate platforms in a tropical humid climate shows that the lenses of fresh water were ephemeral when level 105 formed (Avanzini et al. 1997).

Level 106 is 100 to 150 mm thick and presents a high lateral variability. Stromatolites and flat pebbles breccias are common. Level 106 was less exposed to subaerial alteration than level 105. It represents sedimentation in brackish pond ($\delta^{18}O$ from +2 to +40/00), emerged bars and shallow pools intercalated.

The whole set consisting of layers 105 and 106 is interpreted (Avanzini et al. 1997) as a representative of a complex inter-supratidal environment.

### 1.3. The trace fossils assemblage

Although the assemblage of trace fossils from Lavini di Marco is in a study stage, we can anticipate that the prevalently subtidal bed 104 bears convex structures ascribed.
to *Thalassinoides* at the basis, while the stratum body appears totally bioturbated. On the upper surface, layer 104 shows several dinosaur footprints (mainly theropods) and various locomotion traces constituted by narrow crests or parallel furrows (they are interpreted as produced by gastropods and, doubtfully, by arthropods – cf. *Pierichnus* in Gaillard et al. 2005).

The inter- supratidal set (layers 105 and 106) maintains a moderately diversified ichnoassociation. On the lower bed junction of each layer, convex branched structures are commonly found. They are comparable with *Thalassinoides*; on the upper layers junctions very similar traces are found preserved as concave burrows. Abundant footprints of *Parabrontopodus Lavinipes* and large di-nosaurs (i.e. *Parabrontopodus Lavinipes*) are common. Several invertebrate trace fossils of the bedset corresponding to layers 105 and 106, have a darker calcareous fill in common. Among the traces highlighted by this peculiar fill, numerous spreite structures are recognized, among which there are structures identifiable with the ichnogenus *Rhizocorallium* and those similar to *Zoophycos*.

2. MORPHOLOGY OF THE ZOOPHYCOS-LIKE SPECIMENS FROM LA VINI DI MARCO

The *Zoophycos*-like structures are concentrated in layers 105 and 106. In planar view, the structures exhibit a spreite with a helicoidal arrangement; the spreite comprises many C- or J-shaped units. Their arrangement typically results in a roughly circular outline shown by the whole structure (Fig. 3A). Some specimens do not fulfill such an outline completely (Fig. 3D, 3F). This fact could be retraced either to preservational or constructional (i.e. the partial development of the structure) mechanisms.

The structures are often highlighted by a filling that is darker than the host rock, analogous to the flat-pebble breccia at times characterizing the top of layers 105 and 106 exposed in dolomitized facies.

The width of the specimens (intended as the distance between the apical point and their external margin) usually varies between 43 and 72 mm. The coiling could be both dextral and sinistral. Locally the trace shows lobate appendages, characterized by a centimetre-scale width; these appendages exhibit a similar development pattern compared to the general coiling of the structure (Fig. 3F). When observed in section the trace consists of a meniscate-like pattern, arranged as an alternation of lamellae, which are light (according to the host sediment) and dark (according to the chromatical/lithological dominance seen in planar view). When it has been possible to determine the contacts between adjacent lamellae clearly, the combined width of a dark and a light one has been measured; the combined width of a dark plus a light lamella is comprised between 0.8 and 1.7 mm. The dark lamellae are often thicker than the light ones, according to an approximate ratio of 1:6. The mean height of the lamellae, corresponding to a single whorl of the trace, ranges between 1.4 and 4 mm. When the structures are examined in polished slabs, the dark lamellae usually have a homogeneous appearance, even if a structure made up of peloids can sometimes be observed (Fig. 3C). When the traces are observed in thin sections, the dark lamellae show a structure supported by calcite peloids (sometimes of skeletal origin) floating in a matrix that contrasts with the host sediment. On the contrary, light lamellae have textural features that reflect those of the host sediment (Fig. 4B).

The above described structures are reminiscent of the ichnogenus *Zoophycos*.

According to Rodriguez-Tovar & Uchman (2004) (after Frey 1970; Häntzschel 1975; Wetzel & Werner 1981; Filion & Pickerill 1984) *Zoophycos* is identified as a spreite structure comprising small, more or less U- or J-shaped, protrusive burrows of variable length and orientation, arranged in helicoid spirals with an overall circular, elliptical or lobate outline; a central vertical tunnel or marginal tube may be present.

According to the general morphology of the studied structures it is possible to exclude ichnotaxonomical correspondences with the morphologically similar ichnogenus *Rhizocorallium*, which is represented by oblique or horizontal U-shaped spreite structures (i.e. Fürsich 1974; Häntzschel 1975; Uchman et al. 2000; Uchman & Gądzicki 2006). In fact, the spreite of *Rhizocorallium* comprises juxtaposed U-shaped units, while the spreite of the Lavini di Marco structures include C-shaped units coiled helically around a fixed extremity of the “C”. This fact results in differing morphologies: *Rhizocorallium* is commonly represented by tongue-shaped burrows (i.e. Fürsich 1974; Uchman et al. 2000), while the Lavini di Marco structures develop a roughly circular outline.

These elements differentiate the above described structures from the ichnogenus *Rhizocorallium*, therefore it is possible to exclude that the here studied structures belong to diagnostically transformed *Rhizocorallium*.

The spreite structures from Lavini di Marco present several diagnostic features analogous with those of the ichnogenus *Zoophycos*. In particular the spreite structure, the helicoidal arrangement and the circular or elliptical outline are common elements of the ichnogenus *Zoophycos* and the Lavini di Marco structures.

Even though the Lavini di Marco spreite structures exhibit a general morphology consistent with the ichnogenus *Zoophycos*, they present considerable differences when they are compared to some representative examples of *Zoophycos* (i.e. Miller & D’Alberto 2001; Bromley & Hanken 2003; Olivero, 2003; Pervesler & Uchman 2004).

In particular, the limited size of the Lavini di Marco spreite structures is the most obvious distinguishing element with regard to the most typical occurrences of *Zoophycos*. In fact, several forms of *Zoophycos* present a markedly larger size with respect to the Lavini di Marco spreite structures (see the specimens described by Miller & D’Alberto 2001;
Fig. 3 - Zoophycos-like specimens and their cross sections. A. Zoophycos-like structure; the superimposed symbols indicate the trace of the section illustrated in figure 3B. B. Polished slab of the specimen illustrated in figure 3A. The arrow points out the area corresponding to figure 3C. C. Detail of the spreite pertaining to the specimen in figures 3A and 3B. D. Zoophycos-like structure; the superimposed symbols mark the trace of the section in figure 3E. E. Polished slab of the specimen illustrated at figure 3D. F. Zoophycos-like structure, field photograph.

Fig. 3 - Esemplari Zoophycos-like e loro sezioni oblique. A. Struttura Zoophycos-like; i simboli indicano la traccia della sezione illustrata in figura 3B. B. Sezione lucida del campione illustrato in figura 3A. La freccia indica l’area che corrisponde alla figura 3C. C. Dettaglio dello spreite del campione nelle figure 3A e 3B. D. Zoophycos-like; i simboli sovrapposti marcano la traccia della sezione in figura 3E. E. Sezione lucida del campione illustrato nella figura 3D. F. Struttura Zoophycos-like, fotografia in affioramento.

Fig. 4 - Zoophycos-like specimens and their cross sections. A. Meniscate structure observed in thin section; the arrows point to the area corresponding to figure 4B. B. Thin section of the structure illustrated in figure 4A (image width: about 2.5 mm; parallel nicols). The superimposed italics mark the spreite constituents (d: dark lamella; l: light lamella) and the sediment not affected by the structure (s: host sediment). C. Spreite examined in polished slab. D. Meniscate structure; the arrow points to the area corresponding to figure 4E. E. Thin section of the specimen at figure 4D (image width: about 2.5 mm; parallel nicols).

Fig. 4 - Strutture Zoophycos-like e loro sezioni oblique. A. Struttura meniscata osservata in sezione sottile; le frecce indicano l’area che corrisponde alla figura 4B. B. Sezioni sottili della struttura illustrata in figura 4A (ampiezza immagine: circa 2.5 mm; nicols paralleli). Le lettere in corsivo indicano le parti diverse dello spreite (d: lamella scura; l: lamella chiara) e il sedimento non coinvolto dalla struttura (s: sedimento ospite). C. Spreite esaminata in sezione lucida. D. La struttura meniscata; la freccia indica l’area che corrisponde alla figura 4E. E. Sezione sottile del campione di figura 4D (ampiezza immagine: circa 2.5 mm; nicols paralleli).
Bromley & Hanken 2003; Olivero 2003; Pervesler & Uchman 2004). The width of the Lavini di Marco spreite structures recalls Spirophyton (i.e. Miller & Johnson 1981; Gaillard et al. 1999), a trace fossil morphologically similar to Zoophycos. Apart from size, the Lavini di Marco structures are not consistent with the basic morphology of Spirophyton, characterized by well-developed vertical growth, a spreite arranged in numerous whorls and an often materialized vertical axis (see Miller & Johnson 1981; Gaillard et al. 1999).

As above mentioned, the circular to elliptical outline is one of the common elements shared by the ichnogenus Zoophycos and the Lavini di Marco spreite structures. Nevertheless, the spreite structures from Lavini di Marco exhibit a roughly circular outline, sometimes partially developed, while most of the typical Zoophycos has a more regular shape and a more complete development of the circular to elliptical geometry (Miller & D’Alberto 2001; Olivero 2003).

For these reasons the spreite structures from Lavini di Marco cannot be assigned with certainty to the ichnogenus Zoophycos, even though the affinities between Zoophycos and the Lavini di Marco forms are significant.

The caution regarding the identification of the Lavini di Marco forms as Zoophycos is also supported by the need of revision proposed for the ichnogenus Zoophycos itself (i.e. Gaillard et al. 1999; Bromley & Hanken 2003): at present day Zoophycos is still a vivid taxonomic problem (see Olivero 2007). In fact, the ichnogenus Zoophycos includes a very broad range of morphological characters (see Olivero & Gaillard 1996; Bromley & Hanken 2003; Löwemark & Schäfer 2003; Olivero 2003; Löwemark et al. 2004) as testified by the large variety of forms known as Zoophycos.

For the above stated reasons the term “Zoophycos-like” is used here to indicate the Lavini di Marco spreite structures.

3. CONSTRUCTIONAL AND BEHAVIORAL INTERPRETATION OF THE ZOOPHYCOS-LIKE STRUCTURES AT LAVINI DI MARCO

The pellets characterizing the dark lamellae show rather uniform features as regards dimensional properties, mineralogical composition and roundness; such sorting, together with the quite rigorous geometrical organization of the lamellae, makes a direct biological cause for the fill of the Zoophycos-like specimens from Lavini di Marco plausible. Thus, it seems very likely that the dark fill displayed by the Zoophycos-like specimens of Lavini di Marco is to be considered as active.

The textural features displayed by the dark fill are comparable with the ones of the dark pebble breccia retraceable at the top of each stratum of the inter-supratidal bed set (layers 105 and 106).

For this reason it could be assumed that the trace-maker has brought darker material from the surface into the deeper part of its burrow.


As previously described, some Zoophycos-like specimens present a roughly circular outline (Fig. 4A), while some others do not completely fulfil such an outline (Fig. 4D, 4F). The latter forms possibly correspond to the partial development of the whole structure which is represented by the roughly circular forms. According to this interpretation, the spreite was constructed by the consecutive creation of C-shaped burrows departing from a common point and following a sub-parallel arrangement with regard to the burrows previously formed (Fig. 5). As the spreite grew, the new-formed burrows gradually increased their size with respect to the previous ones. Since the individual burrows were connected to a central common point, the growing structure revolved and the helical coiling developed. Probably the central common point corresponded to the lower end of a shaft connecting with the seafloor, even if the presence of such a structure can be only inferred.

The above described model has common elements with the one of Olivero & Gaillard (2007) (one opening at the sea

**Fig. 5 - Inferred development of the Zoophycos-like spreite as seen in planar view: four moments of the spreite construction are schematically represented.**

A. A C-shaped burrow is constructed. B. New burrows departed from a common point (arrowed) and maintained a sub-parallel arrangement with regard to the burrows previously formed. Possibly the common point corresponded to the lower end of a shaft connecting with the sea-floor. C. Because the individual burrows were connected to a common point, the growing structure tended to revolve. D. The structure gradually increased its size with the development of helical coiling.
so been noted in the Upper Permian Bellerophon Formation of the Southern Alps, occurring in shallow subtidal environments (Twitchett 1999). Until now, in the Triassic of the Eastern Southern Alps, there is no documented occurrence of shallow Zoophycos, which is although recognized in proximal environments from neighboring areas (Knaust 2004; “Muschelkalk” deposits; Triassic p.p.). Furthermore, recent surveys demonstrated the occurrence of Zoophycos within the lagoonal carbonates of the Rotzo Formation (Calcari Grigi Group, Jurassic p.p.; see Fig. 2).

In the Middle Jurassic, the presence of Zoophycos is not registered in the Eastern Southern Alps, but it is described in pelagic units of Western Southern Alps (Hinnov & Park 1999; Sogno Formation; Middle Jurassic p.p.).

At the Cretaceous-Paleogene transition, Zoophycos becomes common in the pelagic formations of the Eastern Southern Alps (i.e. Luciani & Cobianchi 1999: Scaglia Variegata, Cretaceous p.p.; Miller 2000; Miller & D’Alberto 2001: Scaglia Rossa, Scaglia Cinerea: Cretaceous p.p. - Paleogene). In the Cenozoic of Eastern Southern Alps, Zoophycos occurs in turbidite units of relatively deep sea (Tunis & Uchman 1996: Flysch di Calla, Flysch del Grivio, Flysch di Cormons: Palaeocene p.p. - Eocene p.p.), as it is also observed in the subsequent molassic units of intermediate shelf (Ghibaudo et al. 1996: Arenicula glauconitica di Belluno, Upper Oligocene). Occurrence of proximal Zoophycos is also recorded in shallow marine sands, in the North Alpine Molasse basin (Miocene; Pervesler & Uchman 2004). Based on these observations, it appears that Zoophycos presented a shallowing tendency during the Oligo-Miocene. Zoophycos has also been individuated in slope epipelagic muds, in a Plio-Pleistocene core from the Venice area (Massari et al. 2004).

The relative exiguity of findings requires an analysis with a more detailed resolution and a specific search of Zoophycos across all stratigraphic units of the Eastern Southalpine. Further studies on the ichnotaxonomical status of the Zoophycos-like structures are required to place the Lavini di Marco structures within the mentioned evolutionary history. In particular, it is necessary to verify if the Zoophycos-like structures could be definitively assigned to the ichnogenus Zoophycos. At present, this is not possible, considering either the need of revision proposed for Zoophycos itself (i.e. Glaillard et al. 1999; Bromley & Hanken 2003) or the morphological discrepancies between the Zoophycos-like structures and the typical Zoophycos occurrences (i.e. Miller & D’Alberto 2001; Bromley & Hanken 2003; Olivero 2003; Pervesler & Uchman 2004). Nevertheless, there are significant morphological correspondences between the Zoophycos-like structures and the ichnogenus Zoophycos (as explained above). For these reasons, the Zoophycos-like structures could be placed contextually within the evolutionary history of Zoophycos in the Eastern Southern Alps.

The contribution of the structures from Lavini di Marco to the reconstruction of the evolutionary trend of Zoophycos in the Eastern Southern Alps could result significant. In fact, the Zoophycos-like forms found at Lavini di Marco could represent...
the connecting link between the Palaeozoic Zoophycos (mostly occurring in shallow environments) and the Cretaceous-Cenozoic forms (inhabiting deeper environments), clearly presenting more analogy with the bathymetric pattern of the shallow Palaeozoic forms. Taking into account the aforementioned bathymetric occurrences of the ichnogenus, the evolutionary trend of Zoophycos in the Eastern Southern Alps reveals a gradual displacement from mostly superficial settings (especially in the Palaeozoic) to deep environments (during the Cenozoic). In the Southern Alps, the bathymetric shift of Zoophycos probably occurred at the Lower-Middle Jurassic boundary, between Pliensbachian and Bajocian (see Fig. 6).

Oliviero (2003) reports similar results in the French Subalpine basin, attesting the shift of Zoophycos from shelf to deep basin environments between Toarcian and Bathonian. Bottjer et al. (1988) and Knaust (2004) proposed the global occurrences of the ichnogenus, according to a bathymetric shift of Zoophycos during the Phanerozoic. Neto de Carvalho & Rodrigues (2003) register similar results for Zoophycos in Portugal, confirming a comparable bathymetrical tendency while considering the worldwide occurrences of the ichnogenus.

5. CONCLUSIONS

The study of non-dinosaurian trace fossils at Lavini di Marco enhances the already remarkable qualities of the ichnosite, suggesting the possibility of better asserting the palaeoenvironment frequented by dinosaurs. The ethologic interpretation of the Zoophycos-like structures from Lavini di Marco would suggest a feasible use of these traces in the stratigraphical study of the ichnosite, especially of the analysis of the spreite lamellae. In fact, part of the material constituting the lamellae of the Zoophycos-like specimens would derive from superficial levels, almost entirely obliterated by bioturbation or erosional phenomena. Consequently, the study of the lamellae could highlight variations in the depositional regime, otherwise difficult to notice. The utility of this approach has already been clarified by Savrda (2003) with regards to Zoophycos.

At present, it is not clear if the association of Zoophycos-like forms and dinosaur footprints pertains to the same ichnoecoensis; yet, it is manifest that the tracemaker of Zoophycos-like forms and dinosaurs colonized at least neighbouring peritidal environments, definitively confirming the
superficial nature of the Zoophycos-like structures found at Lavini di Marco.

The preliminary results of the analysis of the Zoophycos-like specimens from Lavini di Marco could also assume a considerable importance in terms of the paleobathymetric trend of Zoophycos in the Eastern Southern Alps, placing the shallow Lavini di Marco forms between the Palaeozoic Zoophycos forms, mostly superficial, and the deep Tertiary ones.

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REFERENCES


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Luciani V. & Cobianchi M., 1999 - The Bonarelli Level and other black shales in the Cenomanian-Turonian of the northeastern Dolomites (Italy): calcareous nanofossil and foraminiferal
Venturini C. (ed.), 1990 - *Field Workshop on Carboniferous to Permian Sequence of the Pramollo-Nassfeld Basin (Carnic Alps)*. Arti Grafiche Friulane, Udine: 120.