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PALAEOENVIRONMENTAL IMPLICATIONS OF *ASTERIACITES LUMBRICALIS* IN THE COSTE DELL'ANGLONE SINEMURIAN DINOSAUR ICHNOSITE (NE ITALY)

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ABSTRACT

The finding of *Asteriacites lumbricalis* in the Lower Jurassic of the Trento carbonate Platform is here integrated with the sedimentological, stratigraphical, and palaeontological data for the Coste dell'Anglone ichnosite in order to better reconstruct its palaeoenvironmental setting. The presence of these traces produced by small ophiuroids support the interpretation, for this geographical sector during the middle-late Sinemurian, of a marginal-marine tidal flat environment. A marginal marine environment is consistent also with the documented existence of sedentary populations of dinosaurs recorded as footprints in the deposits that overlie those preserving *Asteriacites*.

KEY WORDS: Asteriacites lumbricalis; Sinemurian; Trento Platform; dinosaur ichnosite

INTRODUCTION

The Coste dell'Anglone ichnosite is located along the eastern slope of Monte Brento (Dro, Trentino Alto-Adige, NE Italy; Figure 1), in the central-eastern sector of the Southern Alps, slightly north of the Lake Garda. In this site, hundreds of dinosaur tracks, mostly arranged in long trackways, were recognized on a wide surface dipping about 30° SE, representing the flank of a ramp anticline associated with the main E-oriented thrust (Petti et al. 2008, Petti et al. in press).

Immediately below the dinosaur trampled bed, several *Asteriacites lumbricalis* traces were found (see also Bernardi et al. 2010). *Asteriacites* von Schlotheim, 1820 is a well known star-shaped resting trace (cubichnia) that belongs to the *Cruziana* ichnofacies (Seilacher 1964, 1967). In wave-dominated systems this ichnofacies is often present in the region between daily wave base and storm

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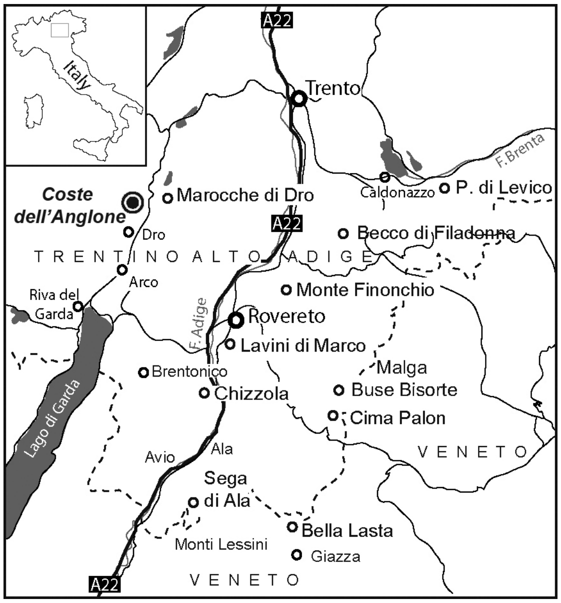

FIGURE 1. Location map of the Coste dell'Anglone ichnosite, Trentino Alto-Adige, NE Italy.

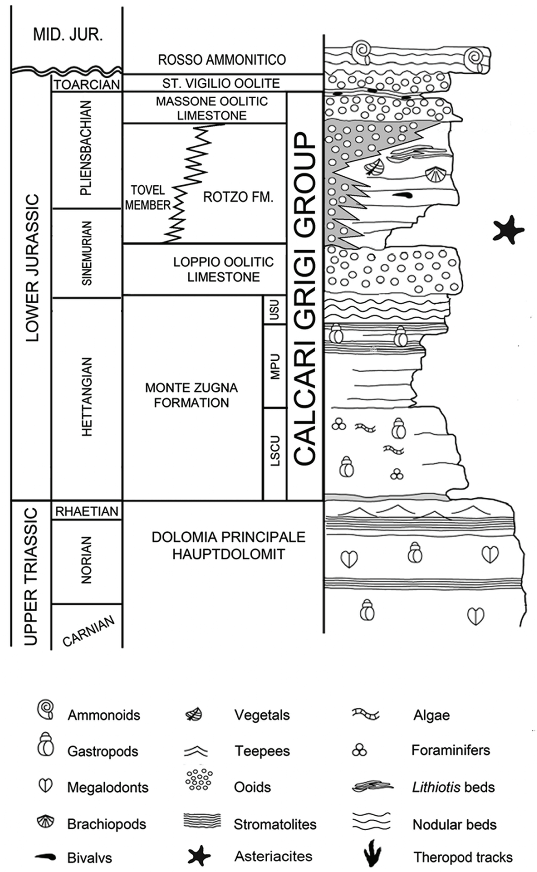

FIGURE 2. Stratigraphical section of the Lower Jurassic deposits at Coste dell'Anglone ichnosite. Trace fossils bearing levels belong to the lower portion of the Rotzo Formation (Sinemurian-Pliensbachian, Calcari Grigi Group).

wave base (Frey and Pemberton 1985, but see Frey et al. 1990) while in tide-dominated environments it may also occur in intertidal positions, grading seaward into the *Skolithos* ichnofacies (see discussion in Mangano and Buatois 2004). *Asteriacites* has a long temporal range extending from Cambrian to recent shallow- to deep-marine facies (see Mikuláš 1992 and references therein). In the Eastern sector of the Southern Alps, *Asteriacites* has been documented several times (e.g., Broglio Loriga et al. 1983, 1990), and its occurrence has in particular been investigated in the study of the Permo-Triassic aftermath (e.g., Twitchett and Wignall 1996; Wilson and Rigby 2000).

Seilacher (1953) suggested that *Asteriacites lumbricalis* was probably made by ophiuroids but most subsequent papers did not provide any discussion about the possible producer of the trace (but see Spencer and Wright 1966; Lawrence 1987; Wilson 1997). The tracemaker was generally intuitively indicated as a member of the Asterozoa without distinguishing between asteroids and ophiuroids (e.g., Santos and Campanha 1970; Brito 1977; Crimes and Jiang 1986). However, Mángano et al. (1999) convincingly showed that an ophiuroid tracemaker is the most reliable interpretation in the majority of cases. Mikuláš (1990) and West and Ward (1990) have also provided evidence of *Asteriacites lumbricalis* preserved with ophiuroids remains.

GEOLOGICAL SETTING

Trace-bearing levels belong to the lower portion of the Rotzo Formation (Sinemurian-Pliensbachian; Calcari Grigi Group, see Avanzini et al. (2007) and references therein; Figure 2) represented in this geographic sector by a shallowing upward sequence composed by cycles, each characterized by the transition from a low energy subtidal unit to high energy subtidal deposits up to inter- and supra-tidal deposits (see Monaco and Giannetti 2002; Giannetti and Monaco 2004).

In the studied section, the whole sedimentary succession is developed through the vertical stacking of cyclic, meter-scale, shallowing-thickening-upward packages showing a characteristic asymmetric profile due to the different weathering profiles of their component lithofacies.

At its base, marking the beginning of the marine transgression, each cycle starts with a decimetre-thick transgressive basal lag comprised of reworked intraclasts and bioclasts and/or intraformational breccias with flat pebbles ripped from the stromatolitic levels at the top of the underlying cycle.

Above this lag, the main part of the subtidal portion of the cycle is alternatively made of oolitic-bioclastic calcarenites that, in some cases, occur as graded storm layers or of grey, peloidal packstone/wackestone. The subtidal parts of the cycles may include gastropod and bivalve lags both in primary position and as reworked, disarticulated valves.

The inter-supratidal, upper portion of each cycle is represented by thin reddish marly levels or sometimes by stromatolitic dolostone that includes a wide range of depositional structures and diagenetic modification produced during subaerial exposures of the sediments, from sheet and polygonal cracks, tepee and birdseye structures to microstalactictic cements, and other products of vadose diagenesis.

Microfossils analysis allowed the recognition of various taxa such as *Paleodasycladus mediterraneus*, *P. fragilis*, *Siphovalvulina* spp., *Pseudopfenderina butterlini*, *Ammobaculites* sp., *Spiraloconus* sp. This microassemblage strongly indicates a middle-late Sinemurian age that seems coherent with the stratigraphical location of the studied levels (Petti et al. 2009b).

SEDIMENTOLOGY AND ICHNOLOGY OF THE TRACE BEARING CYCLE

Here follows a detailed ichnological description of two shallowing upward cycles including both *Asteriacites* and dinosaur traces (Figure 3).

The base of this sedimentary portion is represented by a peloidal mud followed by sandy layers with parallel to slightly irregular upper and lower contacts and internal laminae varying from parallel to undulatory. This heterolitic stratification (*sensu* Damicco and Hardie 1994), or flaser-lenticular bedding (*sensu* Reineck 1960) was considered by Reineck and Wunderlich (1968) as quite common in shallow water carbonate platform deposits. When tidal flats are covered during ebb or flood tides, currents or waves produce irregularly rippled sands and silts. During slack water or calm seas, mud suspended in the water column settles out, burying the ripples to various degrees. The mud compacts and is thus not easily eroded during the next current cycle. Alternatively, as appears in the Coste dell'Anglone dinosaur ichnosite, such interlaminated structures can be produced by the preferential trapping of mud by microbial mats during storm flooding and then deposition of sand as the current wane (Damicco and Hardie 1994). The top of the peritidal cycle shows a 30 cm thick inter- to supra-tidal sequence made of a interlaying of thinly laminated dark peloidal mudstone and reddish millimetre-thick sandy-dolostone layers. The presence of thin stromatolite layers with subaerial exposure evidence, makes reasonable that in our case the tidal flat, after the accumulation of the peloidal mud, became exposed to the subaerial environment with pedogenetic rubefaction, mud cracking, and dolomitisation. Among these finely laminated layers and immediately below the supratidal interval, a monospecific *Asteriacites lumbricalis* assemblage was recognised (Figure 4).

The lower part of the subsequent cycle (deposited in the lower-middle subtidal environment of a carbonate lagoon) is intensely burrowed. Centimetre-sized elliptical spots and vertical tunnels are infilled by peloidal grainstones and mixed skeletal debris. These tubular concentrations may be related to open burrow networks of crustaceans burrowed in a firm substrate (Monaco and Garassino 2001). In other overlying parasequences, burrowing of this basal portion of the cycle is evidenced by turnarounds at nodes and branched tunnels indicating deposit feeding activity by decapod crustaceans (*Thalassinoides* and *Ophiomorpha*). Commonly, cylindrical branches Y to T shaped show diameters up to 5 cm. Mazes in general are regularly tiered, and burrowing can be recognised as a primary factor in the nodularity of this basal part of the cycles.

The middle and upper part of the cycle is much less burrowed. Small trace fossils (0.5 to 1 cm in diameter) include *Chondrites*, *Planolites* and *Skolithos*. These traces are associated to ripple marks and reworked bivalve and brachiopod skeletal fragments. Among taphonomic characters abrasion, reorientation, disarticulation, winnowing, and shelter porosity suggest the dominance of recurrent physical agents on the biological ones (Monaco 1999). These taphonomical features are related to a middle subtidal environment with a shallowing trend from the bottom that, at the top, reaches the normal wave base level and the intertidal/supra-tidal environment.

Vertebrate tracks (an apparent monospecific theropod ichnoassociation) are slightly impressed on the top of the cycle consisting of alternating stromatolitic laminae and dark gray bioclastic grainstone covering a set of meandering shallow tidal channels infilled by coarse grained and imbri-

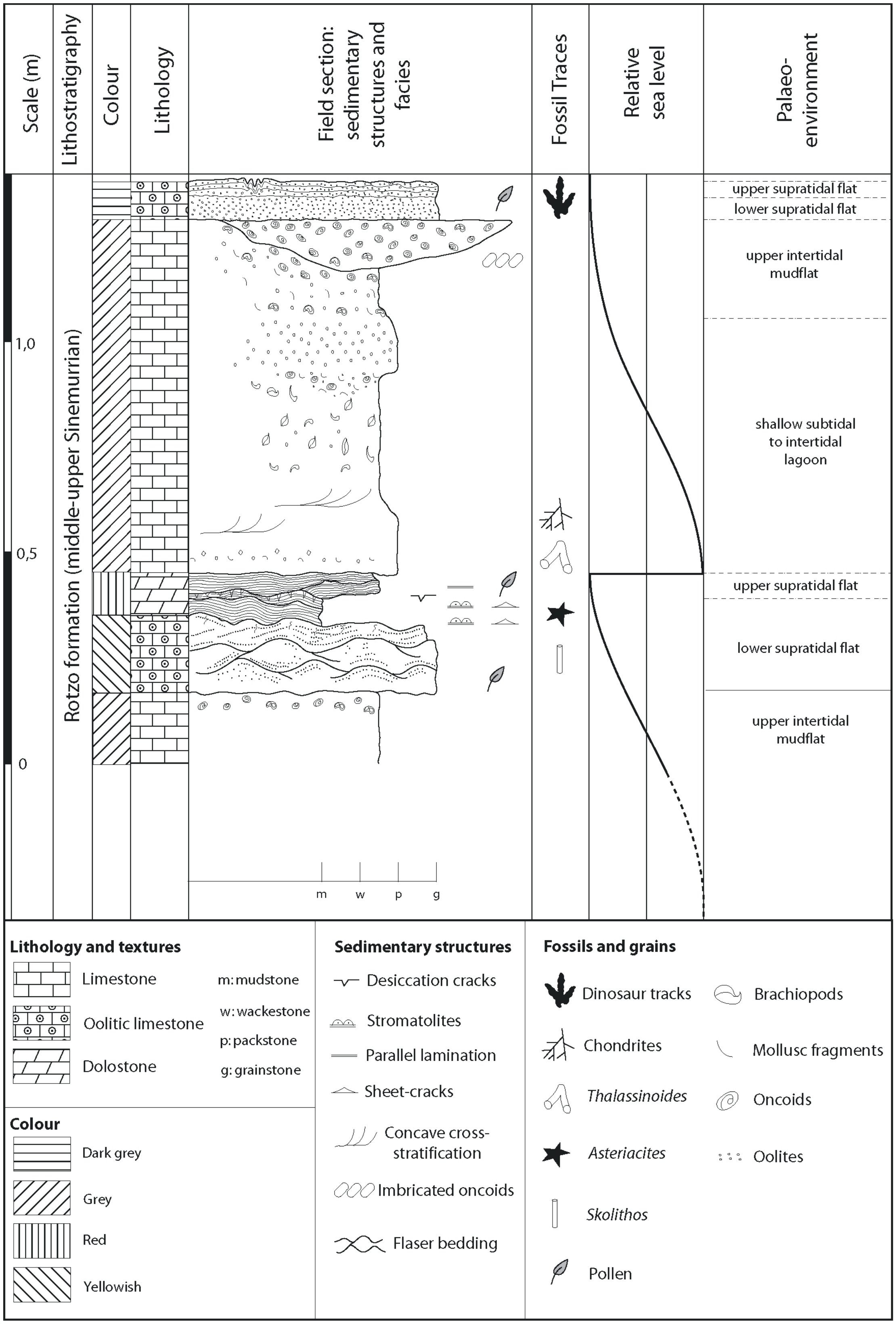

FIGURE 3. The studied section at the Coste dell'Anglone ichnosite is constituted of two shallowing upward cycles including both *Asteriacites lumbricalis* and dinosaur traces.

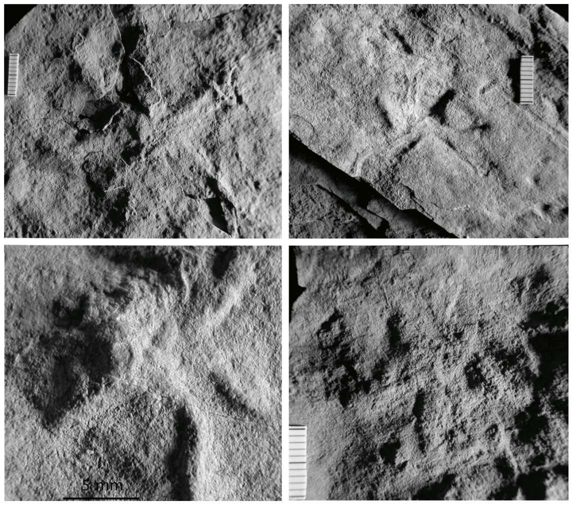

FIGURE 4. Examples of the small sized *Asteriacites lumbricalis* preserved at the Coste dell'Anglone ichnosite. Where not otherwise indicated, scale bar equals 10 mm.

cated oncoidal floatstones/rudtones. They are associated only to a few *Planolites* and locally to irregularly shaped depressions probably related to both biological and physical erosional processes. Similar irregularly shaped depressions have been described by Kvale et al. (2001) on modern intertidal tidal flats. They were interpreted as the destruction of the stabilized algal mats owing to bioturbation processes (e.g., infaunal organism burrows opening on the sediment surface) during the low tide. The result is the erosion or removal of a section of the microbial mat through a combination of current and wave action during a subsequent high tide, forming a shallow and irregular depression on the tidal flat surface.

ASTERIACITES LUMBRICALIS

About 30 star-shaped traces have been analysed, and all specimens resemble the typical morphology of *Asteriacites lumbricalis* (Figure 4). Quality of preservation is highly variable. Most traces are represented by poorly preserved convex hyporeliefs. It is, however, always possible to identify 4-5 rays tapering toward the tip. Rays originate from a central structure (average diameter 4 mm) that in the majority of the specimens is undifferentiated. The most informative traces show morphological details such as delicate transversal or V-shaped striations on the rays. Those are produced by the regular digging action of the tube feet, moving sediment outward from beneath the arms (Seilacher 1953). Locally, a shallow impression is visible in the central area. The few traces preserved as concave epireliefs did not provide any further detail. Trace diameters (arm tip to arm tip) range from 5 to 21 mm with more than half having a diameter of less then 13 mm. The arms are moderately long in relation to the central structure with lengths ranging from 3 to 18 mm. Arm thickness ranges from 1 to 5 mm.

DISCUSSION: PALEOENVIRONMENTAL INTERPRETATION

Integration of sedimentological and ichnological data for the Coste dell'Anglone ichnosite is of particular interest not only for its bearing on the paleogeographic reconstruction of this restricted setting but, more importantly, for its possible contribution to the ongoing debate on the palaeogoeography of the Trento Platform during the Early Jurassic (e.g., Petti et al. 2009a). Since its recognition in the early 1970s, the sedimentary cover of the Southern Alps has been interpreted as one of the best preserved section of the southern continental margin of the Mesozoic Tethys, characterized by a horst and graben structure inherited from rifting closely related to the opening of the central North Atlantic (Castellarin and Picotti 1990; Castellarin et al. 1992). The rifting phase took place in the Late Triassic and the Early Jurassic and produced high-standing blocks separated by troughs. All of the western sector of the margin (Piedmont and Lombardy) rapidly drowned in the Early Liassic whereas in the eastern part, some sectors kept their shallow water sedimentation conditions. These are, from east to west, the Friuli Platform, a carbonate platform that persisted from the Jurassic until the Cretaceous and the Trento Platform drowned at the end of Early Jurassic, when evolved into a pelagic plateau with condensed sedimentation during the Late Jurassic. These platforms have been pulled apart by a pelagic basin formed during the Hettangian (Belluno Basin). The Trento Platform covers a wide area in northeastern Italy, extending north-south from Verona to Bolzano. Westward the Trento Platform is separated from the Lombardian basin by the “Garda escarpment” fault system, which was active during the Jurassic and Cretaceous. The prolongation of the platform to the south-west has been hypothesized through the integrated analysis of surface and subsurface data (see Masetti et al. 2006).

The thick Calcari Grigi Group (Hettangian-Pliensbachian) corresponds to the Early Jurassic shallow-water sedimentation phase of the Trento Platform. In the last 15 years the search for dino-

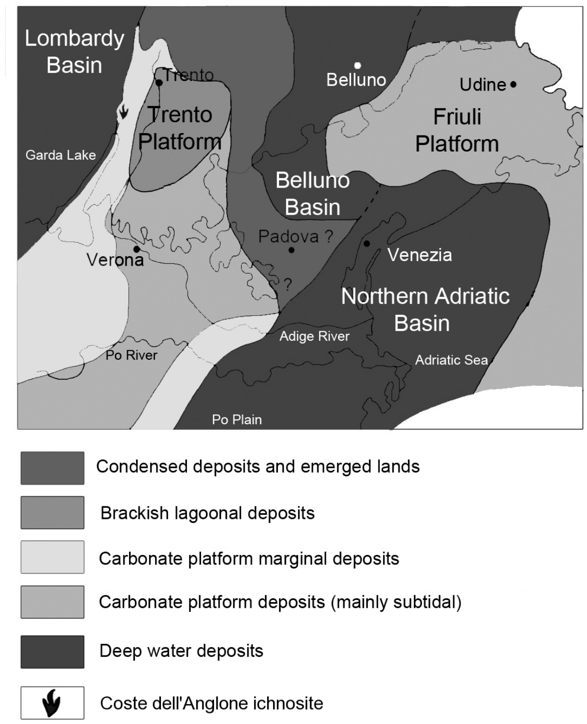

FIGURE 5. Palaeogeographical setting of the considered sector during the Sinemurian (Early Jurassic). High-standing blocks (Trento and Friuli platforms) are separated by troughs (Belluno and Northern Adriatic basins). The Coste dell'Anglone ichnosite was located on the on the sandy barrier complex that separates the open sea (Lombardy basin) from the Trento carbonate platform.

saur tracksites on the Lower Jurassic Trento Platform, led to the discovery of several sites scattered across an area of about 1,500 km^2. The continuity of dinosaur occurrence on the Trento Platform in the Hettangian-Sinemurian interval suggests a stable link of the Southern Alps carbonate tidal flats with emerged and vegetated lands and with freshwater supplies, but the localization of these lands or of wide "continental bridges" is still unresolved.

The numerous sedimentological and stratigraphical works carried out on the Calcari Grigi Group allowed to finely describe its paleoenviromental setting during the Early Jurassic (see Avanzini et al. 2006 for a review of the unit). Particularly the Rotzo Formation has always been interpreted as a shallow subtidal platform environment, with gently inclined depositional ramp and inner lagoon bordered by ooolitic shoals.

The Coste dell'Anglone ichnosite was located on the margin of this lagoon, more exactly on the sandy barrier complex that separates the open sea toward the west (Lombardy basin) from the lagoon and the inner carbonate platform toward the East (Figure 5). In this environment the flora was dominated by pioneer plants (such as Cheirolepidiacea) that lived neighboring the coasts favoring semi-arid environments (Petti et al. 2009b).

The recovery of the *Asteriacites* ichnoassemblage offers the possibility to better define this paleoenvironment. *Asteriacites* is recorded in marginal-marine, tidal-flat facies and is generally considered as indicative of fully oxygenated (Müller 1980; Mikuláš 1992; Twitchett and Wignall 1996) and clear waters (Kilbourne et al. 1998; see also Kesling and Le Vasseur 1971 and Mikuláš 1990, 1992). Facies analysis, indicating sedimentation in sand, mixed sand-mud, and intertidal flats (i.e., channel and pond subenvironments) is consistent with this suggestion. Sedimentary structures are indicative of shallow water tidal environment, and the observed heterolitic stratification indicates the presence of steady flows at low current velocities. The occurrence of dinosaur tracks and other supratidal markers (mud cracks, sheet crack, oxidized shells, reddish film of soils) provide evidences for repeated subaerial exposures of this sector considered up to now as fully subtidal.

Asteriacites has been also shown to be common in brackish-water conditions (Mángano et al. 1999). This is consistent with the possible presence of a fresh water source in a not too far area that would have been necessary to sustain the existence of the sedentary populations of dinosaurs documented in the Coste dell'Anglone site. Present data, however, are insufficient to test this hypothesis.

Here presented data are consistent with the interpretations of Bosellini and Broglio Loriga (1971) and Masetti et al. (1998) that envisaged a lagoon-barrier island complex scenario for this unit during the Sinemurian with a subtidal ramp gently inclined to the west and an intertidal-supratidal barrier island complex, trending approximately N-S, now corresponding to Mt. Brento-Mt. Biaina and Mt. Baldo chains (ramp-lagoonal model).

CONCLUSIONS

The finding of *Asteriacites lumbricalis* in the Coste dell'Anglone Lower Jurassic site is integrated within the paleoenvironmental contextualization of the area. This ophiuroid trace can be considered indicative of a tidal environment with fully oxygenated and clear waters. Here we suggest that during the upper Sinemurian, this area of the Trento Platform was occupied by marginal-marine, tidalflat embayments with ponds and channels. This interpretation is consistent also with the existence of sedentary populations of dinosaurs recorded as footprints in the deposits that directly overlie those preserving *Asteriacites*.

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