Rivista Italiana di Paleontologia e Stratigrafia	volume 113	no. 1	pp. 139-148	March 2007

SHORT NOTE - NOTA BREVE

A NEW DINOSAUR TRACKSITE IN THE LATE ALBIAN OF ISTRIA, CROATIA

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Received: August 22, 2006; accepted: January 9, 2007

Key words: Dinosaur footprints, theropods, late Albian, Istria, ADCP

Abstract. A new site with dinosaur footprints has been found in the upper Albian sediments of Istria, Croatia. The site was discovered near the city of Pula, at the Zlatne Stijene locality. The carbonate succession of the Zlatne Stijene locality is characterized by thin bedded limestones deposited in peritidal and foreshore environments. The microfossil assemblage found at the site indicates a late Albian age. One clearly distinguishable footprint and four indeterminate rounded tracks were discovered at the investigated outcrop. The footprint is tridactyl and belongs to a medium-sized bipedal theropod dinosaur of approximately 3 meter in length. Regarding dimensions and morphology it is closely related to the other late Albian theropod footprints from the Adriatic-Dinaridic carbonate platform (ADCP). The Zlatne Stijene locality fits with the *Brontopodus* ichnofacies concept.

Riassunto. Una nuova località con impronte di dinosauri è stata rinvenuta in sedimenti del Albiano superiore dell'Istria, presso la città di Pola nella località di Zlatne Stijene. La successione carbonatica del sito è caratterizzata da calcari sottilmente stratificati deposti in ambiente peritidale e di spiaggia esterna. L'associazione di microfossili rinvenuta indica un'età albiana superiore. Sono state scoperte un'impronta chiaramente riconoscibile e quattro tracce arrotondate indeterminabili. L'impronta è tridattila ed appartiene ad un dinosauro teropode bipede di media grandezza, lungo circa tre metri. Le dimensioni e la morfologia sono strettamente confrontabili con altre impronte di teropodi dell'Albiano superiore della piattaforma Adriatico-Dinarica (ADCP). La località di Zlatne Stijene rientra nello schema della ichnofacies a *Brontopodus*.

Introduction

The late Albian is the age that bears the most abundant record of dinosaur presence on the Adriatic-Dinaridic carbonate platform (ADCP). There are nearly a dozen sites with dinosaur footprints in Istria which were found in the sediments that crop out along the shore in the upper Albian sediments of the so-called West Istrian anticline. These sediments belong to the 3rd Istrian megasequence (upper Albian - upper Santonian; Velić et al. 2003). The late Albian dinosaur ichnocoenoses from Istria consists of theropod, sauropod and ornithopod footprints found at different localities. Theropod footprints are the most common. They are found in upper Albian sediments at the Puntižela (Dalla Vecchia & Tarlao 2000), Lanterna (Dalla Vecchia et al. 1993), Solaris (Dalla Vecchia & Tarlao 2000) and Veli Brijun (Ploče and Kamik/Plješivac sites: Polšak 1965; Velić & Tišljar 1987; Dalla Vecchia et al. 2002; Mezga & Bajraktarević 2004) localities. The new site was discovered near the city of Pula, at the Zlatne Stijene locality (Fig. 1). The GPS coordinates of the site are N 44°50'45", E 13°50'08". The outcrop is situated at the sea shore and during the stormy weather it is in direct contact with the sea water (Fig. 2). The discovery of dinosaur footprints in Albian rocks along the Zlatne Stijene coast was already mentioned earlier by the late B. Godec (Gogala & Pavlovec 1978). Whether his find represents the same site as the new discovered locality remains unclear, because B. Godec died in 1976.

Depositional environments and microfossil assemblage

Istria belongs to the northwestern part of the ADCP. It is predominantly constituted of carbonate deposits ranging in age from late Middle Jurassic to

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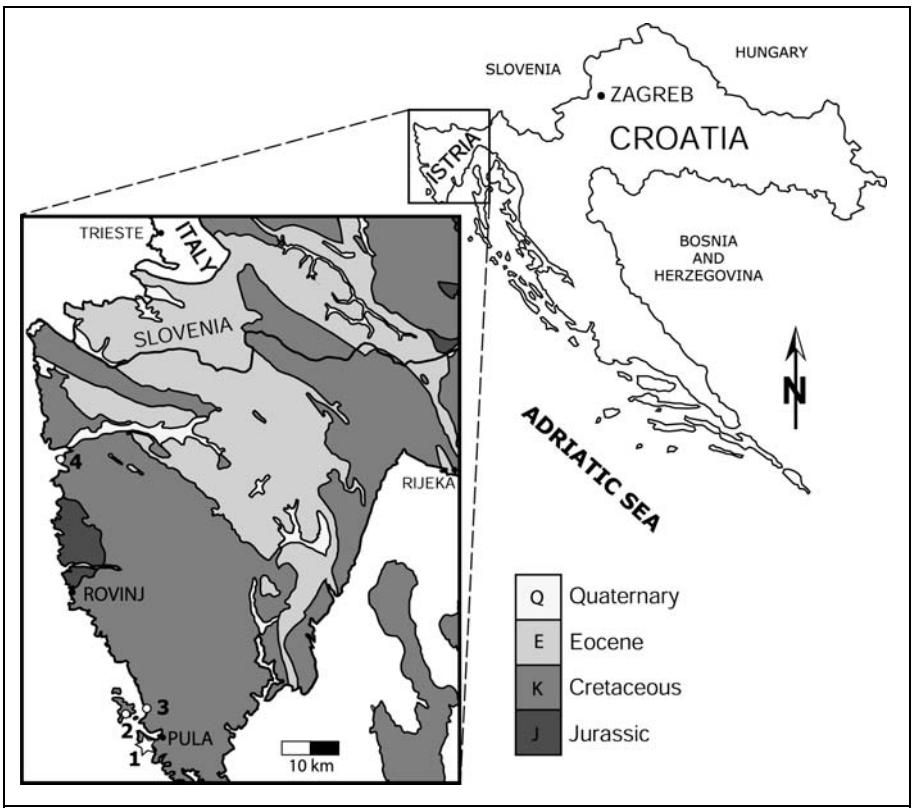

Fig. 1 - Geologic and geographic position of the Zlatne Stijene and the other late Albian locality in Istria. 1 - Zlatne Stijene; 2 - Kamik/Plješivac, Ploče; 3 - Puntižela; 4 - Solaris I and II, Lanterna.

Fig. 2 - Panoramic view of Zlatne Stijene locality (arrow mark the position of the track-bearing layer).

Eocene and to a lesser extent of Eocene siliciclastic rocks, flysch and calcareous breccia, and Quaternary terra rossa and loess (Velić et al. 1995; 2003). The depositional succession of Istria can be divided into five sedimentary units or megasequences divided by important discontinuities – emersion surfaces of different duration (Velić et al. 1995; Vlahović et al. 2005). These megasequences are: 1) Bathonian – lowermost Kimmeridgian; 2) upper Tithonian – lower/upper Aptian; 3) upper Albian – upper Santonian; 4) Eocene; 5) Quaternary.

The investigated area is situated in a succession of late lower Cretaceous deposits, which are part of the third transgressive – regressive megasequence, upper Albian – upper Santonian in age, which is very thick and very variable facies succession. Several larger sedimentary units can be separated, each characterized by

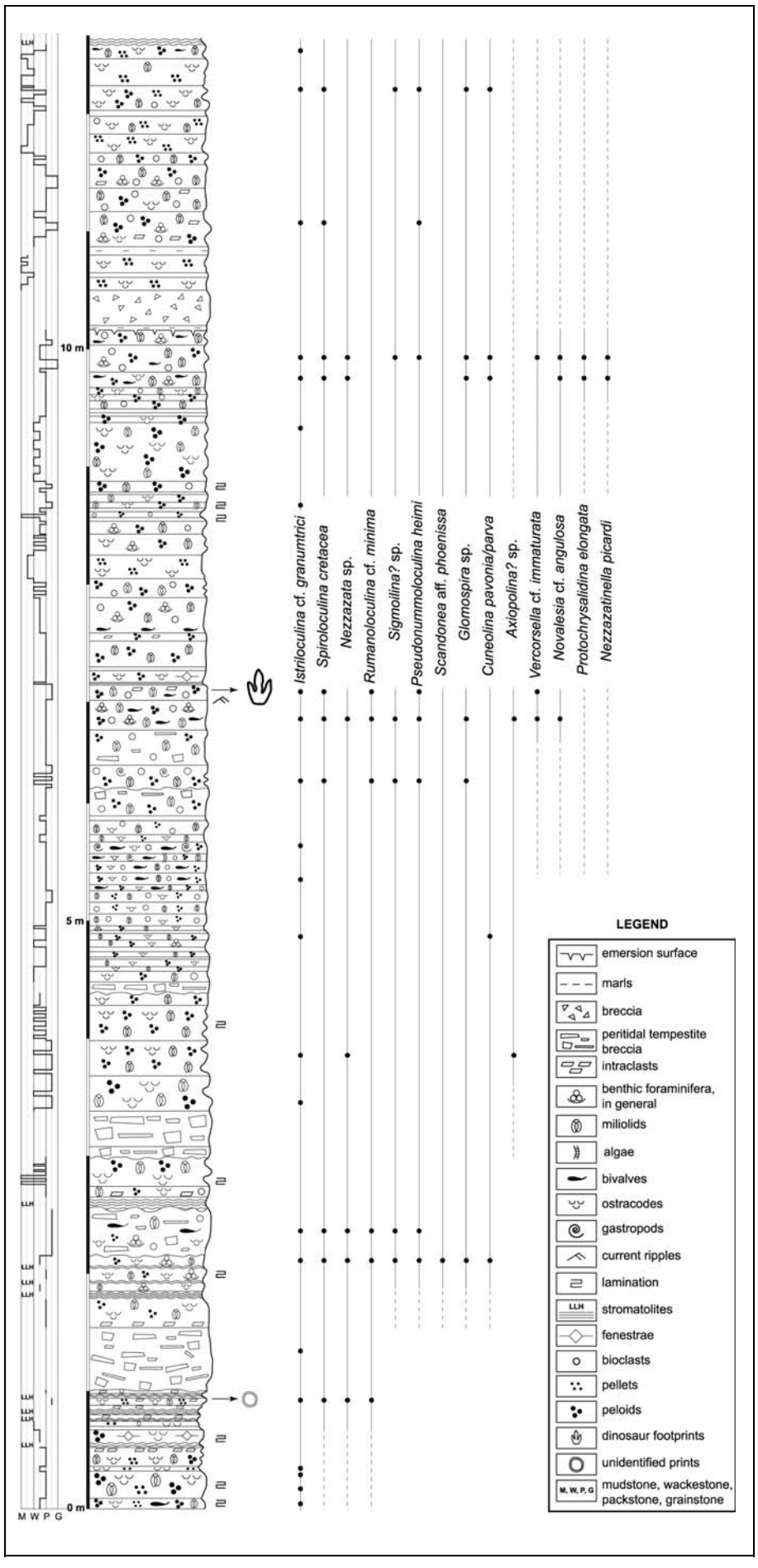

Fig. 3 - Detailed lithological column with microfossil assemblage (benthic foraminifera) in the Upper Albian of the Zlatne Stijene locality.

relatively similar sedimentary conditions and environments (Tišljar et al. 1998; Velić et al. 2003; Vlahović et al. 2003). These are: 1) a peritidal and foreshore sedimentary system during the middle and late Albian; 2) differentiation of the sedimentary systems (lateral and vertical facies variations; from peritidal and barrier bars to the offshore-transition zone) during the Vraconian and Cenomanian; 3) a drowned platform system during the youngest Cenomanian and early Turonian; 4) a shallow-water sedimentary system during late Turonian, Coniacian and Santonian. The explored outcrop belongs to the upper part of the first sedimentary unit which is characterized by a thick sequence of thin bedded (5-20 cm) grainy limestones deposited in peritidal (with common shallowing – upward cycles) and foreshore environments in the late Albian.

The whole surface of the outcrop is largely eroded due to sea water abrasion but also due to human activity. The upper Albian carbonate succession of Zlatne Stijene locality (Fig. 3) is characterized by thin bedded limestones (Fig. 4A), usually peloidal wackestones to peloidal packstone/grainstones (Fig. 5A), and laminated peloidal wackestone/packstones with ostracodes, miliolids and benthic foraminifera as the first member of shallowing – upward cycles (Fig. 3). Sporadic peloidal wackestone/packstones with LLH stromatolites (Fig. 5B) are recog-

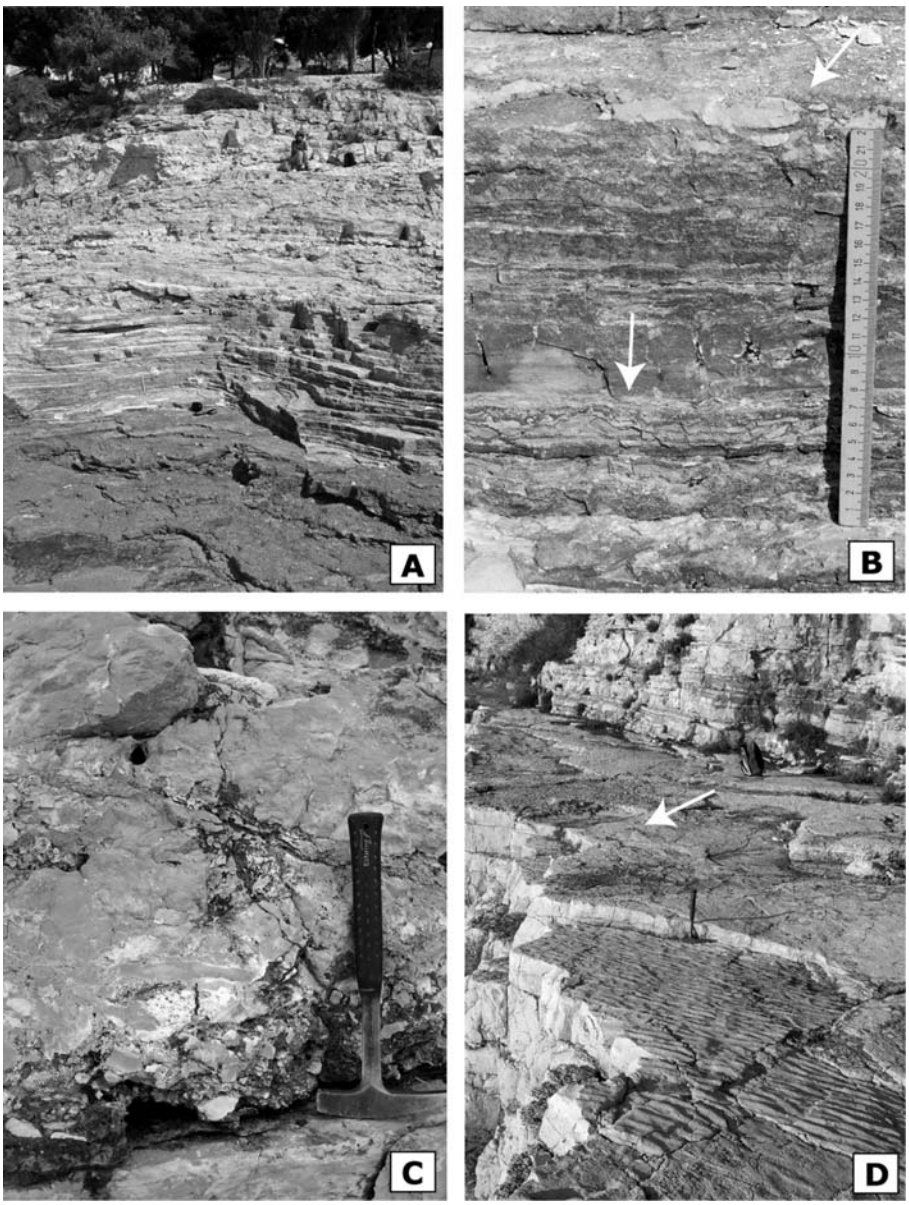

Fig. 4 - A) Thin bedded limestones of the lower part of the Zlatne Stijene succession. B) Peritidal tempestite breccia (marked with arrows) in the lower part of the Zlatne Stijene succession. C) Emersion breccia in the upper part of the Zlatne Stijene succession. D) Current ripple marks in the layer just below the trackbearing horizon (arrow indicate the position of the footprint).

nized especially in the lower part of the Zlatne Stijene succession. The also present intraformational breccias are probably formed in peritidal environments during severe storms (peritidal tempestite breccia; Fig. 4B). Stromatolitic laminae or LLH stromatolites as well as intraformational peritidal breccia or erosional breccia (Fig. 4C) represent the end member of shallowing-upward cycles. Just below the trackbearing layer there is a peloidal-bioclastic packstone/grainstone layer with current ripple marks (Fig. 4D). The same sediment type, which is typical for shallow subtidal deposits, also forms the layer in which the footprint is preserved. Above the trackbearing horizon there are several layers of distinctively recrystallized peloidal wackestone/packstones with geopetal infill (Fig. 5C), fenestrae and dissolution vugs filled with drusy calcite cement (Fig. 5D). Together with the footprint, these sedimentological features prove short exposure of these layers to meteoric conditions.

The age of the upper Albian deposits in Istria was usually determined by the presence of index fossils; the so called "primitive" orbitolinids [e.g. "*Valdanchella*" *dercourti* Decrouez & Moullade, *Neoiraquia insolita* (Decrouez & Moullade)] accompanied by other benthic foraminifera like: *Cuneolina pavonia* D'Orbigny, *Pseudonummoloculina heimi* (Bonet), *Nezzazatinella picardi* (Henson), *Protochrysalidina elongata* Luperto Sinni etc. Although the "primitive" orbitolinids were not found in the Zlatne Stijene succession, the microfossil assemblage composed of *Protochrysalidina elongata* (Figs. 5E, 5F), *Pseudonummoloculina heimi* (Fig. 5G), *Istriloculina* cf. *granumtrici* Neagu, *Rumanoloculina* cf. *minima* (Tappan), *Spiroloculina cretacea* Reuss, *Sigmoilina*? sp. (Fig. 5H), *Axiopolina*? sp. (Fig. 5I), *Scandonea* aff. *phoenissa*

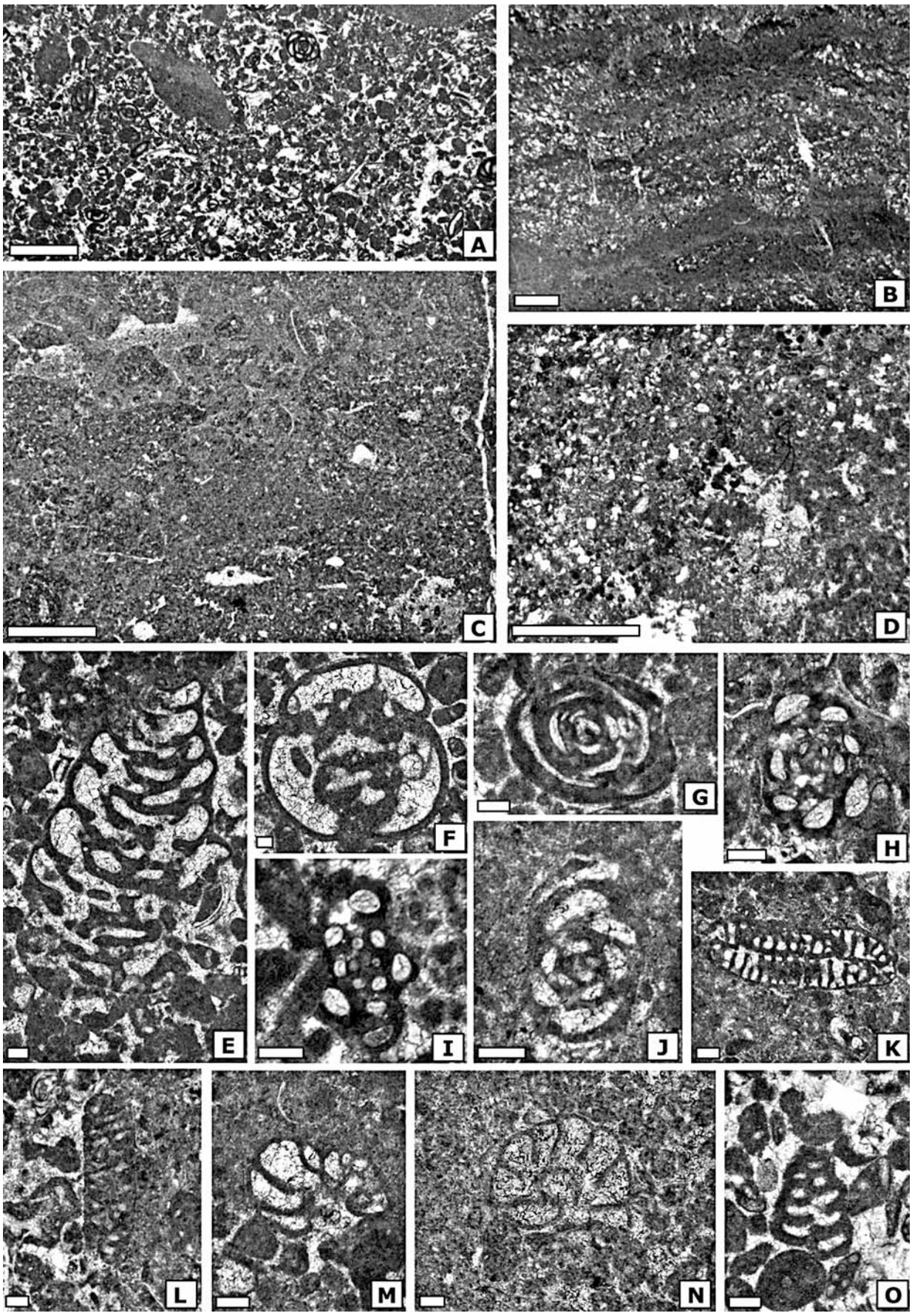

Fig. 5 - A) Peloidal packstone/grainstone with miliolids. B) Stromatolitic laminae. C) Peloidal wackestone/packstone with dissolution enlarged voids with geopetal infill. D) Peloidal wackestone/packstone with dissolution vugs filled with drusy calcite. E) *Protochrysalidina elongata* Luperto Sinni; subaxial section. F) *Protochrysalidina elongata* Luperto Sinni; transversal section. G) *Pseudonummoloculina heimi* (Bonet); oblique section. H) *Sigmoilina*? sp.; oblique section. I) *Axiopolina*? sp.; oblique section. J) *Scandonea* aff. *phoenissa* Saint-Marc; oblique section. K) *Cuneolina pavonia/parva*; transversal section. L) *Cuneolina pavonia/parva*; oblique radial section. M) *Nezzazatinella picardi* (Henson); oblique axial section. N) *Nezzazatinella picardi* (Henson); oblique section. O) *Novalesia* cf. *angulosa* Magniez; oblique axial section. Scale bar in Figs. 5A – D = 1 mm; in Figs. 5E – O = 0.1 mm.

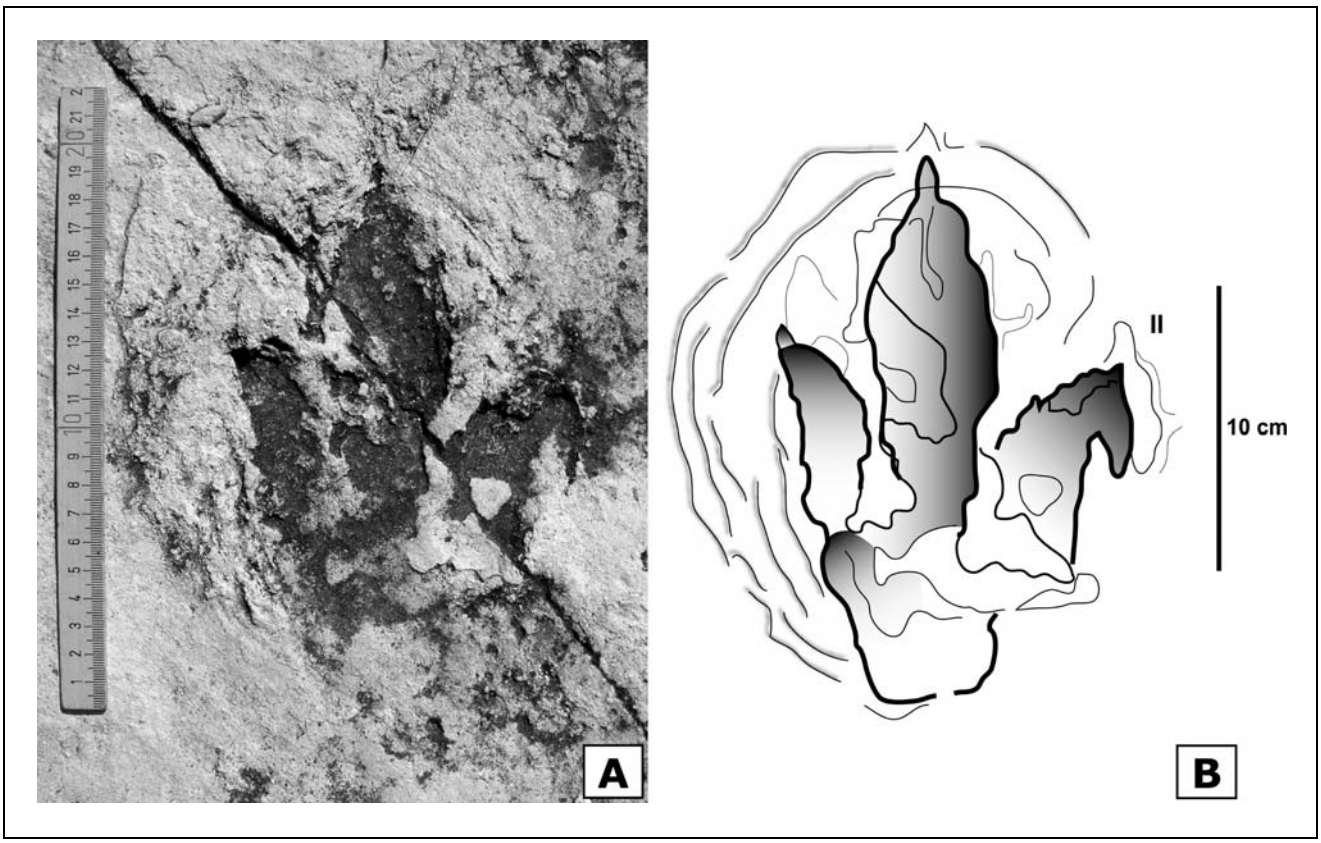

Fig. 6 - A) Theropod footprint from Zlatne Stijene locality. B) Interpretative drawing of theropod footprint from Zlatne Stijene locality; heavy line represents the outline of the print, the light one represents deformation of the print caused by mud collapse.

Saint-Marc (Fig. 5J), *Glomospira* sp., *Cuneolina pavonia/parva* (Figs. 5K, 5L), *Nezzazata* sp., *Nezzazatinella picardi* (Figs. 5M, 5N), *Vercorsella* cf. *immaturata* He and *Novalesia* cf. *angulosa* Magniez (Fig. 5O) indicates a late Albian age.

Ichnology

Dinosaur footprints

Only one clearly distinguishable footprint has been found on the investigated outcrop. There are no visible trackways. The footprint is tridactyl, mesaxonic, longer than wide (Figs. 6A, 6B). The whole state of preservation is not ideal; the print is quite eroded and affected by carbonate dissolution due to the sea's proximity. It is preserved as an imprint (epichnia or negative epirelief). On the middle (III) and left digit (IV) there are conspicuous V-shaped claw impressions. The length of the footprints was measured from the anterior to the posterior part of the print along the digit III axis, and the width was measured as a maximum width perpendicular to the length between the tips of digits II and IV. The measures were taken only of the inner part of the prints (excluding the expulsion rim). The footprint is 195 mm long and 120 mm wide with long and slender digits and straight digit axes. The middle digit (III) is the largest one (115 mm long and 40 mm wide) while the other two are of similar dimensions; the left digit (IV) is 70 mm long and 20 mm wide and the right one (digit II) measures 70 mm in length and 30 mm in width. The right digit (II) is somewhat detached from the other two and separated from the middle one by a pronounced bulge which could indicate that this digit is digit II. It is also less well preserved than the other two digits. The left digit (IV) continues posteriorly into the 'heel' impression without interruption. The digits are widest in their middle part and become narrower proximally and distally. The angle that the axis of right digit closes with the axis of the middle digit (32°) is larger than the one between the axis of the middle and the left digit (15°). Total divarication between the outer digits (II and IV) is 47°. Around the footprint, especially its left side, there is a clearly pronounced expulsion rim, which resulted from the placing of the foot in the wet mud. Inside this rim, there are also clearly visible concentric grooves which probably formed due to cracking under pressure ('load cracks'). The footprint could be interpreted as a true track rather than undertrack although it is relatively shallow (1-1.5 cm), when compared to its size, which means that the sediment was rather solid and firm, with a resistance to imprinting. The heel print and the hallux impression are not visible. Regarding the position of the digit II, which is represented by a right digit, it is concluded that this print represents the

track of the left foot. The more prominent rim around the left side of the print could indicate that the dinosaur walked by leaning its foot more on the outer side (if the interpretation of this print as a left track is correct). On the basis of the claw marks or pointed distal end of digital prints, relatively slender digit impressions, total divarication between the outer digits and generally longer than wide footprint, it is concluded that this print belongs to a medium-sized bipedal theropod dinosaur.

The question arises, why there are no other footprints on the trackbearing layer. Beside the fact that the exposed trackbearing area is very small (about 10 m^2), and it is partly covered with thin overlaying sediments, the surface of the trackbearing layer is heavy obliterated by erosion and karstification which strongly influenced footprint recognition. It is possible that this footprint is a part of trackway which could be tracked below the overlying layer. Although there are some interesting shapes around the described footprint which could resemble the form of a tridactyl footprint (Fig. 7), they lack the basic elements on which the dinosaur footprint is defined (clear morphology and outlines, expulsion rim etc.) and we are hesitant to proclaim them as the footprints.

Indeterminate prints

5.2 meters below the trackbearing horizon intriguing rounded depressions occur on the upper bedding plane of a 7 cm thick layer (Fig. 8A). They form shapes of an almost perfect circle and are only a centimeter deep. There are four such depressions; three of them are 20-25 cm in diameter and the fourth has a diameter of 9 cm. It does not seem that they form any kind of trackway, although in one case a smaller depression seems to be related to the larger one (Fig. 8B). The bottoms of the depressions are fully flattened and no diagnostic morphological features could be observed. There are no pronounced expulsion rims around them

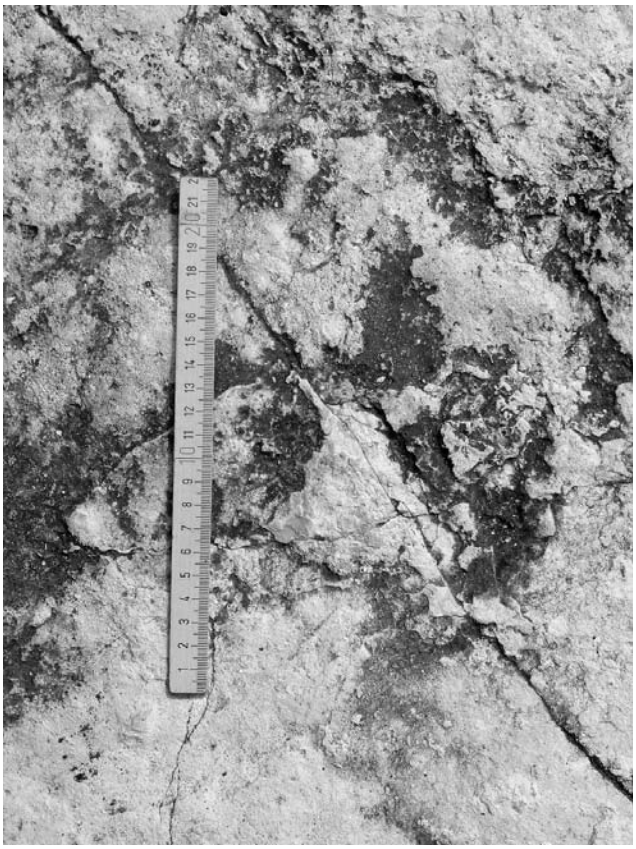

Fig. 7 - Possible tridactyl footprint found 15 cm in front of the described footprint.

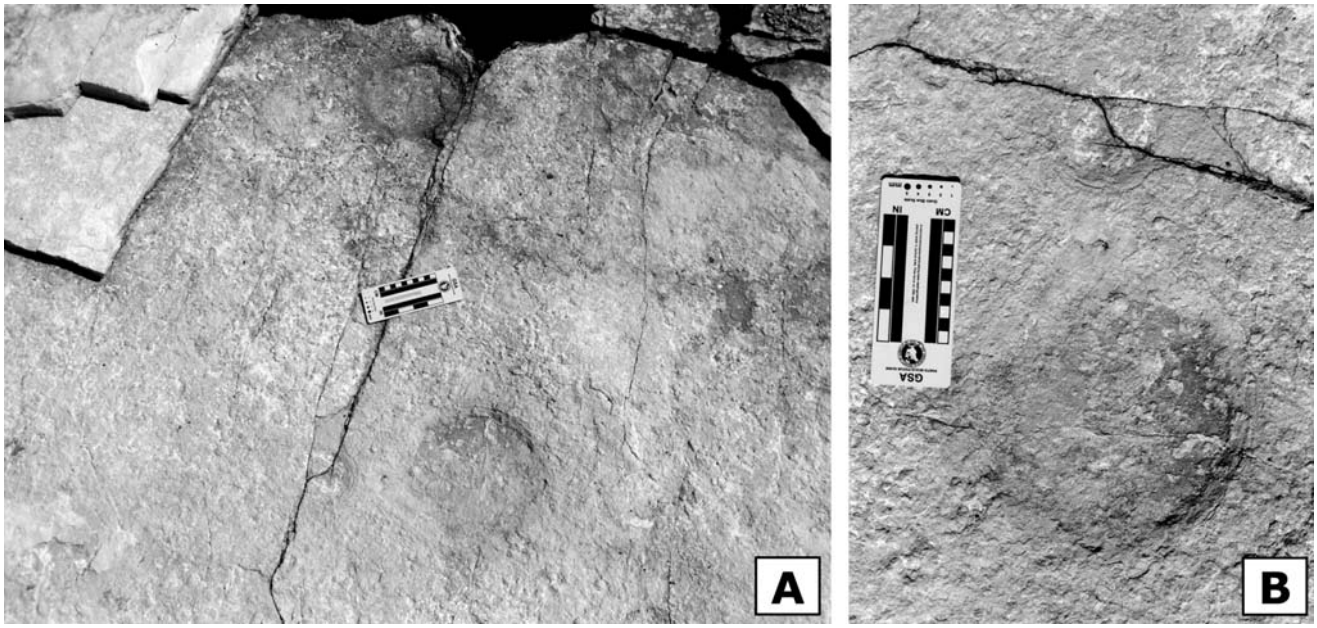

Fig. 8 - A) Indeterminate prints found a few meters below the trackbearing horizon. B) A pair of undeterminable prints from Zlatne Stijene locality.

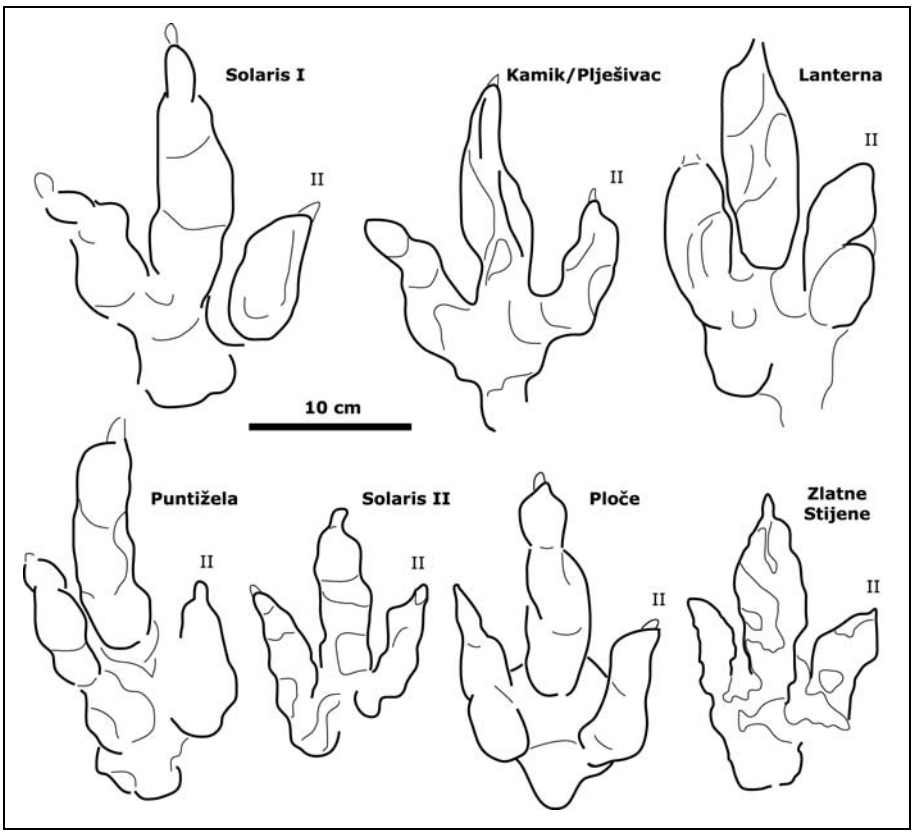

Fig. 9 - Interpretative drawing of theropod footprints from Late Albian localities in Istria compared to the new discovered footprint at Zlatne Stijene locality. II indicates the position of digit II. **Lanterna** track redrawn from Dalla Vecchia et al. (1993); **Puntižela** redrawn from Dalla Vecchia & Tarlao (2000).

which would imply that they were formed under the pressure of animal feet but there are some visible concentric grooves (Fig. 8B). The sediment which forms this layer is a peloidal packstone deposited in a low-energy subtidal environment.

Discussion

The footprint from the Zlatne Stijene locality closely resembles the other late Albian theropod footprints found in Istria (Figs. 1, 9) due to its morphology and dimensions. Comparison of their dimensions (see Tab. 1) shows the close similarity in footprint length of Zlatne Stijene print to the Solaris I site (Dalla Vecchia & Tarlao 2000), FW/FL ratio to Solaris II site (Dalla Vecchia & Tarlao 2000) and total divarication to Solaris I site. Regarding the overall morphology, the Zlatne Stijene footprint shows general similarity to all the other theropod footprints from late Albian of Istria except to the footprints from the Kamik/Plješivac site (Dalla Vecchia et al. 2002; Mezga & Bajraktarević 2004). Those prints have much greater total divarication and FW/FL ratios. The Puntižela (Dalla Vecchia & Tarlao 2000) and Ploče (Dalla Vecchia et al. 2002; Mezga & Bajraktarević 2004) footprints also differ from the Zlatne Stijene track in having more slender and elongated digits. The Solaris II footprints have somewhat smaller dimensions and total divarication, the digits are V-shaped but their overall morphology is similar. However, the closest morphological relation is between the Zlatne Stijene footprint and the Solaris I and Lanterna (Dalla Vecchia et al. 1993) footprints in having the middle digit widest in its middle part and become narrower proximally and distally. Regarding dimensions and morphology the Zlatne Stijene footprint would be most closely related to the Solaris I footprints, which were interpreted as medium-sized theropod footprints (Dalla Vecchia & Tarlao 2000). However, we must bear in mind the bad shape of preservation that could cause some misinterpretation. Since there are no skeletal remains of theropod dinosaurs from Adriatic-Dinaridic carbonate platform so far, the identity of the Zlatne Stijene trackmaker could be only assumed, regarding the skeletal finds of small to mid-sized theropods from the nearby areas (southern Europe and Africa). These remains include *Genusaurus sisteronis* Accarie et al. from Middle Albian of southern France and *Scipionyx samniticus* Dal Sasso & Signore from lower Albian of Italy. However, there are numerous remains of large theropods from the Albian of Europe and Africa (Weishampel et al. 2004). It would be difficult to assign the Zlatne Stijene footprint to any particular dinosaur genus, especially because the late Albian theropod footprints found on the ADCP represent the only evidence of mid-sized theropods in this region.

LOCALITY	FL	FW	FW/FL	A II–III	A III–IV	TD
Puntižela	19		0.60	22	24	46
Ploče	20.13	13.9	0.68			41.6
Plješivac	18.6	13.6	0.73			72.8
Solaris I	19.69		0.64	21.7	22.5	44.2
Solaris II	18.16		0.61	18.1	20.7	38.8
Lanterna	21.75	13	0.57	16.6	17.6	34.2
ZLATNE STIJENE	**19.5**	**12**	**0.62**	**32**	**15**	**47**

Tab. 1 - Comparison of theropod footprint parameters from Late Albian localities in Istria. Data compiled from Dalla Vecchia et al. (1993, 2002); Dalla Vecchia & Tarlao (2000); Mezga & Bajraktarević (2004).
Key to abbreviations: FL - footprint length; FW - footprint width; A II-III - angle between digits II and III; A III-IV - angle between digits III and IV; TD - total divarication. FL and FW are in cm; A II-III, A III-IV and TD in degrees. All measurements are average, except Zlatne Stijene locality.

The hip height of the Zlatne Stijene theropod was predicted using the Thulborn's ratios for small theropods (4.5FL; Thulborn 1990). Based on footprint length, the calculated hip height of this theropod was 0.88 m. Applying this value to the skeleton of small theropod dinosaur indicates the length of the animal at approximately 3 m.

The problem arises with the identification of the circular depressions which were found below the trackbearing layer. What could form those depressions? Were they caused by activity of some animal, do they represent some kind of sedimentological feature or are they the result of karstification processes? They could be interpreted as the undertracks of some animal but there are no footprints in the succession of thinly bedded upper layers, and no emersion hiatuses between them. They most probably represent the original upper-bedding plane texture. Concentric grooves around them (Fig. 8B) were probably formed due to cracking under the pressure ('load cracks'). Regarding the morphology and depositional environment it could be presumed that these unusual depressions represent the tracks of some kind of animal. It is, however, difficult to ascertain do they represent the resting traces (*Cubichnia*) or were they produced during animal activity like walking or swimming.

The late Albian dinosaur ichnocoenoses from Istria is constituted of theropod, sauropod and ornithopod footprints found at different localities. These ichnocoenoses represent the *Brontopodus* ichnofacies concept (Dalla Vecchia 1998; Mezga & Bajraktarević 2004). The *Brontopodus* ichnofacies is characteristic of carbonate platform environment and is dominated by sauropod tracks accompanied with large theropod footprints (Lockley et al. 1994). Although the Zlatne Stijene site represents shallow carbonate platform environment as well as the other Istrian late Albian locality, the dominant tracks in these ichnocoenoses are the small to medium theropods. Sauropod footprints have been found at just one site (Dalla Vecchia & Tarlao 2000), but there are also ornithopod footprints at one locality (Dalla Vecchia et al. 2002; Mezga & Bajraktarević 2004). Although the depositional environment of the late Albian site in Istria is in agreement with the *Brontopodus* ichnofacies concept, the composition of the ichnocoenoses differs from it. But this could also be due to the relatively small outcrops and track samples.

Conclusion

A new site with the dinosaur footprints has been found in the upper Albian sediments of Istria. The site was discovered near the city of Pula, at the Zlatne Stijene locality. The carbonate succession at the Zlatne Stijene locality is similar to other upper Albian localities in Istria. It is characterized by thin-bedded limestones deposited in peritidal and foreshore environments. The microfossil assemblage found at the site indicates a late Albian age. One clearly distinguishable footprint has been found at the investigated outcrop. The footprint is tridactyl and belongs to a medium-sized bipedal theropod dinosaur approximately 3 meter in length. Regarding dimensions and morphology it is closely related to the other late Albian theropod footprints from the Adriatic-Dinaridic carbonate platform. Five meters below the trackbearing horizon four undeterminable rounded prints were found, most probably representing the animal tracks. This new locality, similar to the other late Albian localities in Istria, resembles the *Brontopodus* ichnofacies concept (Lockley et al. 1994).

Acknowledgments. This article is dedicated to the late Božidar Godec, the great admirer of Istrian fossils. The research was supported by a grant from the Ministry of Science, Education and Sport of the Republic of Croatia (project no. 0119402 and 0119400) and 'SCOPES 2001-2003, Joint Research Project' sponsored by Swiss National Science Foundation. We would like to thank M. Pavletić for the help during the field work and G. Mikša for the thin section photomicrographs. Thanks to M. Lockley for his review of the manuscript and useful suggestions and M. Gaetani for his editorial work.

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