Rivista Italiana di Paleontologia e Stratigrafia	volume 112	no. 3	pp. 435-445	November 2006

A NEW DINOSAUR TRACKSITE IN THE CENOMANIAN OF ISTRIA, CROATIA

ALEKSANDAR MEZGA [1], GIORGIO TUNIS [2], ALAN MORO [1], ALCEO TARLAO [3], VLASTA ĆOSOVIĆ [1] & DAMIR BUCKOVIĆ [1]

Received: May 2nd, 2006; accepted: July 13, 2006

Key words: Dinosaur footprints, sauropods, Late Cenomanian, Istria, Adriatic-Dinaridic carbonate platform.

Abstract. The new locality with dinosaur footprints has been discovered in the port of Karigador village in Istria. The site is situated in peritidal limestones of late Cenomanian age. The track-bearing horizon is bioclastic wackestone-packstone deposited in a subtidal environment. A single trackway which consist of 28 pairs of footprints and a group of 4 track pairs was registered at the site. Trackways belong to quadrupedal dinosaurs and are assigned to sauropods. Oval-circular shaped footprints represent the pedal prints and horseshoe-semicircular shaped ones represent the manus prints. The trackway is of narrow-gauge type with outwardly rotated manus and pedal prints. The average length of the pedal prints is 33 cm what indicates the length of the individual of app. 10 m. The preferred gait of the individual was a normal walk, taking normal strides with a speed of around 3 km/h. The trackmaker was a non-titanosaurian sauropod. Together with the other late Cenomanian sauropod localities in Istria (Fenoliga and Ladin Gaj), the Karigador site represents an example of sauropod tracks in a carbonate platform environment which can be assigned to *Brontopodus* ichnofacies.

Riassunto. È stata scoperta una nuova località con impronte di dinosauro nel porto del villaggio di Karigador in Istria. Il sito si trova entro calcari peritidali di età Cenomaniano superiore e lo strato che contiene le tracce è costituito da wackestone-packstone bioclastici, deposti in ambiente subtidale. Oltre ad una singola pista, che consiste di 28 paia di impronte, nel sito è stato ugualmente osservato un gruppo di 4 paia di impronte. Le tracce appartengono ad un dinosauro quadrupede e sono riferite ad un sauropode. Impronte di forma oval-circolare rappresentano l'impronta del pes, mentre le impronte semicircolari a ferro di cavallo rappresentano quelle della manus. La traccia è di tipo a passo stretto con manus e pes ruotati verso l'esterno. La lunghezza media dell'impronta del pes è di 33 cm, che indicherebbe una lunghezza dell'individuo di circa 10 m. L'andatura preferita dell'individuo era quella di una marcia normale, ad una velocità media di circa 3 km/h. Il responsabile delle tracce era un sauropode non titanosauro. Unitamente alle altre località a sauropodi del Cenomaniano superiore dell'Istria (Fenoliga e Ladin Gaj), il sito di Karigador rappresenta un esempio di piste di sauropode situate in ambiente di piattaforma carbonatica, che può venir attribuito alla ichnofacies a *Brontopodus*.

Introduction

The late Cenomanian is the age that bears abundant evidence of dinosaur activity on the Adriatic-Dinaridic carbonate platform (ADCP). The carbonates of this Mesozoic platform today crop out along the eastern margin of the Adriatic Sea including the area of today's Istrian peninsula. So far, there are four sites with dinosaur footprints in the late Cenomanian rocks of Istria. The largest site is on the Fenoliga islet in southern Istria where an ichnocoenosis including theropod and sauropod tracks was discovered (Gogala 1975; Leghissa & Leonardi 1990; Mezga & Bajraktarević 1999; Dalla Vecchia et al. 2001). On the nearby Grakalovac promontory some faintly preserved theropod tracks were found (Dalla Vecchia et al. 2001). In northwestern Istria there are two localities, one with theropod tracks in the village of Lovrečica (Dalla Vecchia et al. 2001), and one with sauropod footprints inside the Ladin Gaj autocamp (Dalla Vecchia et al. 2001). Two clearly recognizable sauropod trackways were registered at these four localities, one at the Fenoliga islet and one at the Ladin Gaj autocamp.

Here we report the discovery of the new site with dinosaur footprints in northwestern Istria. The locality is situated at the port of Karigador village (Fig. 1), along its coast. We refer to this site as the Karigador locality,

1 Department of Geology and Paleontology, Faculty of Science, University of Zagreb, Horvatovac 102a, 10 000 Zagreb, Croatia. E-mail: amezga@geol.pmf.hr.
2 Dipartimento di Scienze Geologiche, Ambientali e Marine, Università di Trieste, Via Weiss 2, 34127 Trieste, Italy.
3 Museo Paleontologico Cittadino di Monfalcone, Via Valentinis 134, 34134 Monfalcone, Italy

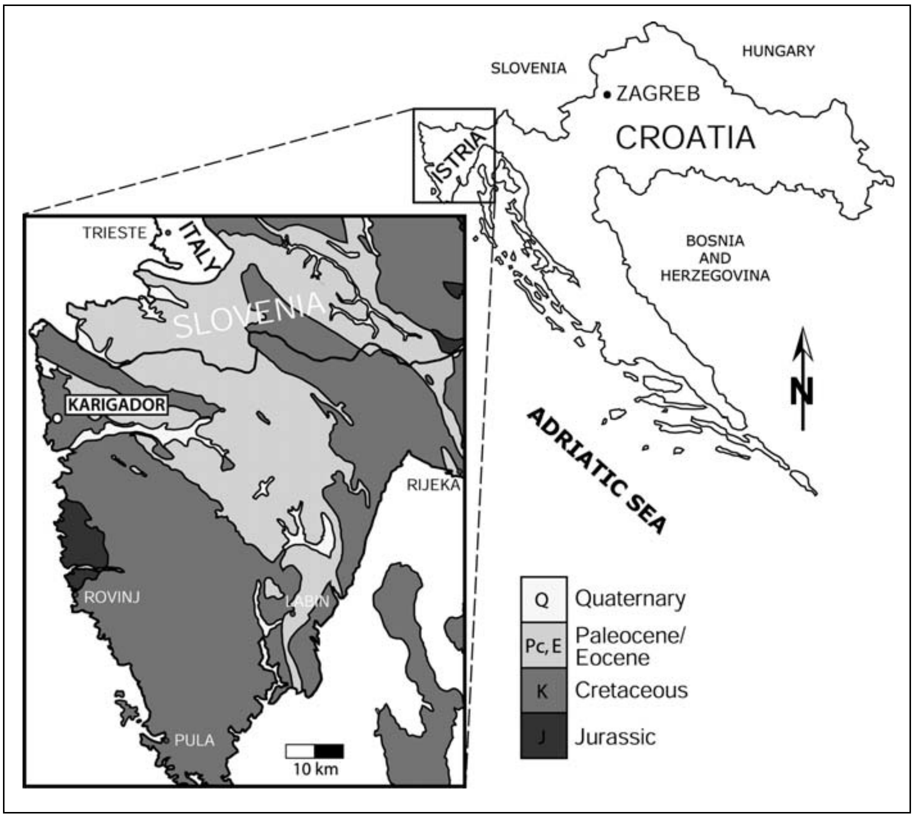


Fig. 1 - Geologic and geographic position of the new dinosaur tracksite in Istria.

although Dalla Vecchia et al. (2001) referred to the site at the 'Ladin Gaj' autocamp as the 'Karigador' site. It would be more proper to call this new site 'Karigador' because it is situated right in the port of the village, whereas the site discovered by Dalla Vecchia et al. (2001) is situated in the nearby 'Ladin Gaj' autocamp.

Geological setting

Istria belongs to the northwestern part of the ADCP. It was mainly formed by shallow water carbonates with a stratigraphic range from the Middle Jurassic to Eocene (Velić et al. 1995), and to a lesser extent by Eocene siliciclastic rocks, flysch and calcareous breccias. The depositional succession of Istria can be divided into five sedimentary units or megasequences separated by important discontinuities – emersion surfaces of different duration (Tišljar et al. 1998; Vlahović et al. 2005). Those megasequences are: (1) Bathonian - lowermost Kimmeridgian; (2) upper Tithonian - lower/upper Aptian; (3) upper Albian - upper Santonian; (4) Eocene; and (5) Quaternary.

The investigated area is situated in Cenomanian deposits belonging to the third transgressive – regressive megasequence upper Albian – upper Santonian which is characterized by a drowned platform depositional system at the end of the Cenomanian and the beginning of the Turonian (Velić et al. 1995). The Karigador section is situated within the port of Karigador, approximately 20 m westward from the pier (Fig. 2). It is a 2.23 m thick succession of mud-supported limestones. The lower boundary of the succession, as well as the footprint bearing layer, is covered by the sea and their investigation is possible only during low tide periods. Limestones are sub horizontally orientated, dipping 5° towards N-NW.

Investigated limestones consist of foraminiferal-peloidal wackstone-packstones, radiolitid floatstones and intertidal laminites (Fig. 3). Within the floatstones, beside radiolitids, a few *Chondrodonta* shells are observed. They represent a part of shallowing-upward cycle which consists of subtidal unit B, with wackestone-

Fig. 2 - Panoramic view of the Karigador locality.

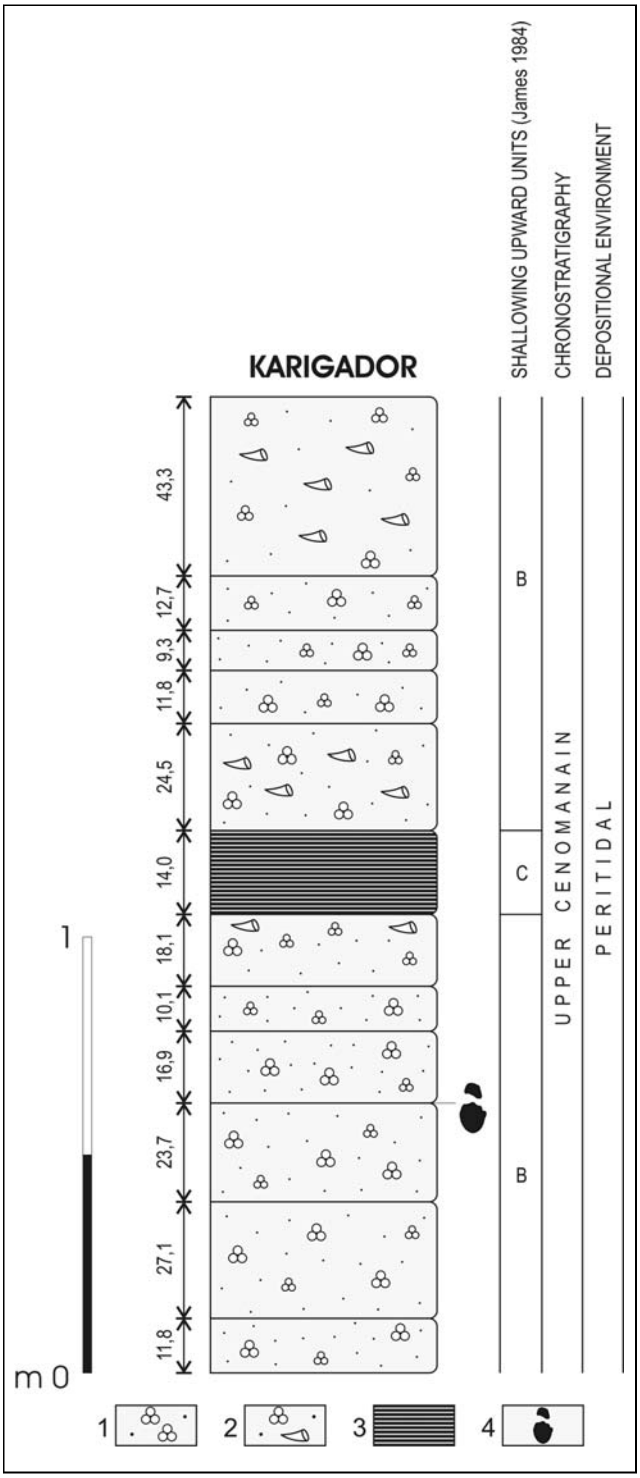


Fig. 3 - Lithological column of the Karigador site. 1 - benthic foraminifers; 2 - rudist shells; 3 - intertidal laminites; 4 - dinosaur footprints.

packstone-floatstone, and intertidal unit C with intertidal laminites (James 1984). The lower boundary of the cycles is covered by the sea. Dinosaur footprints are preserved on the upper bedding plane of the subtidal foraminiferal-peloidal wackestone-packstone. The distance between the dinosaur footprint bearing layer and the top of the intertidal laminites is 58 cm. In thin sections, within mud matrix, beside pellets and peloids, benthic foraminifers are present. The microfossil community consists of *Chrysalidina gradata* d'Orbigny, *Broeckina (Pastrikella) balcanica* Cherchi, Radoičić & Schroeder, *Cuneolina* sp., *Nezzazata* sp. and miliolids (Figs. 4A, 4B). Algae *Thaumatoporella parvovesiculifera* (Raineri) and *Aeolisaccus kotori* Radoičić are also present. According to the microfossil assemblage, the age of these limestones can be determined as late Cenomanian.

Based on the structures, textures as well as the microfossil assemblage, typical for upper Cenomanian shallow water deposits on Istrian peninsula (Dalla Vecchia et al. 2001; Vlahović et al. 2005), the depositional environment can be determined as a proximal peritidal carbonate platform.

Ichnology

The measurements of the footprints were taken as follows: the length of the footprints was measured from the anterior to the posterior part of the print along its axis and the width was measured as a maximum width perpendicular to the length. In prints with pronounced expulsion rims the measures were taken only of the inner part of the prints (excluding the expulsion rims). The depth of the footprints was measured in the center of the prints (also excluding the height of the expulsion rims). In prints without the expulsion rims the measures were taken from the edge of the depression margin. The measurements of the footprints without expulsion rims should be regarded with caution due to the erosion and corrosion of the sediment, so the possibility of extramorphological (sedimentological) exaggeration of measurements can not be excluded.

The track association from the Karigador site includes one preserved trackway composed of 28 pairs of footprints and a single group of 4 pairs of prints (Figs. 5, 6). Although it appears that these four prints belong to the main trackway, their arrangement is different with respect to the prints in the trackway. On the basis of their morphological characteristics and the age of sediments as well, there is no doubt that the footprints belong to dinosaurs. The footprints are preserved as imprints (epichnia or negative epirelief). There were two different types of footprints discovered at the site; larger circular-elliptic ones and smaller semicircular, horseshoe-shaped ones. Given that both types of print occur in the same trackway, it is obvious that they belong to the same animal. Around some of the footprints, an expulsion rim is visible, representing compressed waterlogged sediment squeezed from the print by the weight of the dinosaur. Such rims are usually more prominent than the footprints themselves and they prevent

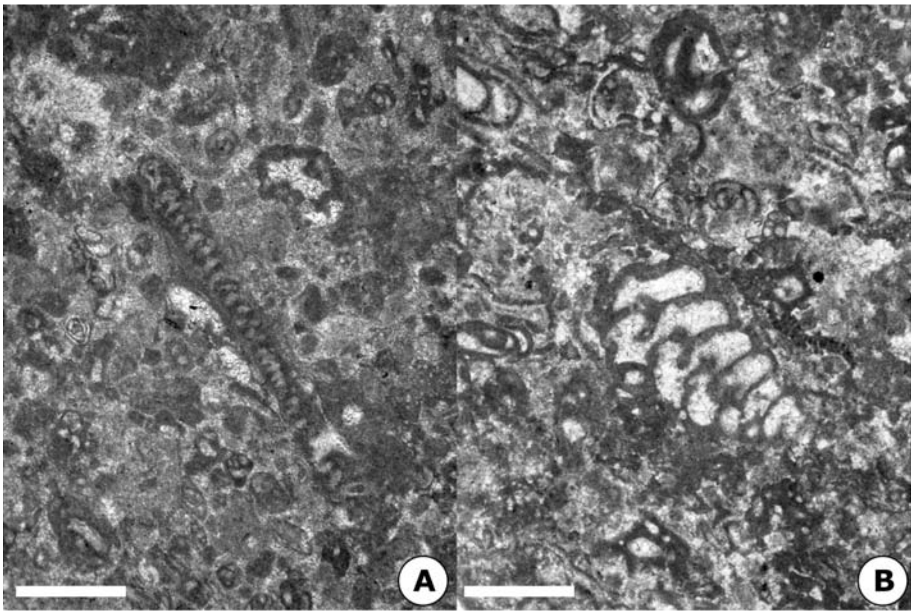


Fig. 4 - (A) Axial section of *Broeckina (Pastrikella) balcanica* Cherchi, Radoičić & Schroeder from the investigated locality. (B) Axial section of *Chrysalidina gradata* d'Orbigny from the investigated locality. Scale bar = 0.5 mm.

the prints from being obliterated by erosion. The arrangement of the footprints in the trackway and differences in the size and shape clearly indicate that the trackways were left by quadrupedal animals. The smaller semicircular footprints represent the manus prints and the larger circular ones the pes prints (Figs. 7A, 7B). The footprints are attributed to sauropod dinosaurs on the basis of their morphology i.e. oval-circle shape of the pedal prints and horseshoe-semicircular shape of the manus prints (Fig. 8). The difference in size and shape of the manus-pes prints is a result of the different anatomy of the sauropod front and hind feet. The margin of the footprints is, in most cases, clearly discernable because of the expulsion rims around the prints. It could also be observed that the rims are more prominent at one side of the print, which could be a result of the different weight distribution on the sediment. The manus prints have the more prominent rims along the anterior side while on the pes prints the expulsion rims are more prominent posteromedially. Expulsion rims around the manus prints are generally more prominent than those of the pes prints. All of the footprints have been severely obliterated by sea water erosion and corrosion. This is not surprising considering the fact that the outcrop is only exposed during the winter low-tide. The measured parameters of the footprints are given in the Table 1. The state of footprint preservation is far from ideal; in fact it is difficult to find a footprint with clearly pronounced morphology where the digit impressions are also recognizable.

Manus prints are semicircular to semilunate in shape, wider than long, with clear outward rotation (from the trackway midline). The length of the manus ranges from 13 to 25 cm with average of 17.6 cm. The manus width ranges from 18 to 28 cm averaging 22.8 cm. In most cases the manus prints are wider than long because of the collapse of the footprint margin which occurs anteroposteriorly, causing manus deformation along its length. Due to bad preservation of the Karigador prints it is difficult to recognize the probable impressions of individual digits, but on some of them the impression of the manus digit could be faintly visible (Fig. 8; prints no. 10, 18) and it gives the manus prints the characteristically horseshoe shape. However, this feature is not observable on all of the manus prints (see Figs. 8, 9A print no. 17) and could also be caused by the mud collapse during foot extraction from the substrate. Pes prints are oval or elliptical in shape, anteroposteriorly elongated with a somewhat narrower 'heel' impression and, on some of them, a wider anterior region. They are also rotated from the trackway midline. The length of the pes prints range from 27 to 41 cm with an average of 33 cm while their widths range from 22 to 32.5 cm averaging 25.5 cm. None of the pedal prints reveals clearly visible digit impressions. The heteropody is not pronounced, the ratio between the manus-pes areas is 1/2 to 1/3 (Fig. 8).

The parameters of the trackway are given in Table 2. The orientation of the trackway is 110°. The trackway is of the narrow-gauge type where the internal trackway width rarely exceeds 10 cm and it often has negative values (see Tab. 2 and Fig. 5, compare to fig. 1 in Lockley et al. 1994a). The footprints in the trackway are rotated outwardly, from the trackway midline (Fig. 9A). The reason why we are hesitant to ascribe the footprints no. 1-4 (Figs. 5, 9B) to the main trackway is their arrangement with respect to the trackway midline. If we suppose that print no. 1 is a left, no. 2 a right and no. 3 a left footprint, then the position of the no. 2 manus would be extremely inward rotated which is op-

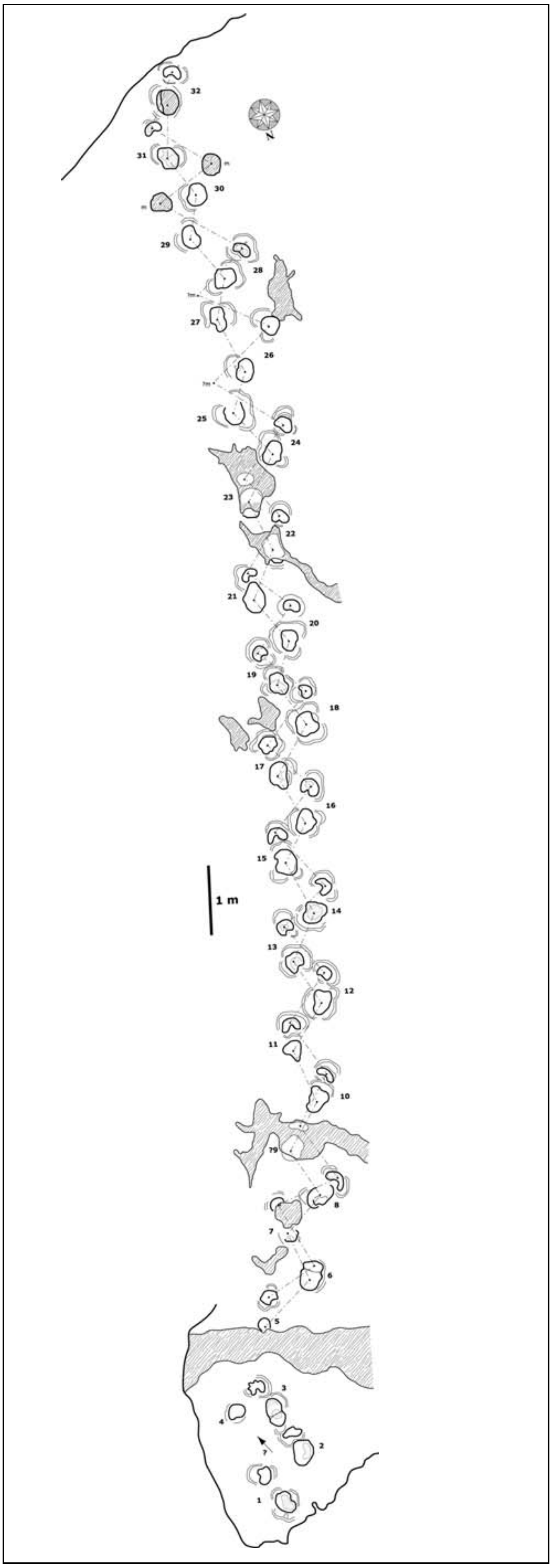


Fig. 5 - Drawing of the dinosaur trackway from Karigador locality.

posite to the already mentioned outwardly rotation of the manus in the whole trackway. There is also a print (no. 4) which does not fit in the trackway scenario. A possible explanation could be that the prints (nos. 1-4) form a separate trackway with a trackway orientation of 70°, where prints no. 1 and 3 represent the left, and prints no. 2 and 4 the right footprints.

Discussion

The size of the Karigador tracks is relatively small when compared to the other Cretaceous sauropod ichnites (e.g. Lockley & Hunt 1995; Lockley & Meyer 1999). With an average pes length of 33 cm they are some of the smallest sauropod tracks known. The dimension of the sauropod dinosaur which left them is calculated using both the hip height and glenoacetabular distance estimates. The hip height was predicted using Alexander's (4FL; 1989) and Thulborn's (5.9FL; 1990) ratios. Applying the obtained values to the skeleton of *Apatosaurus* (as a non-titanosaurian sauropod), the length of 8.3 and 12.2 m respectively, was calculated. Measuring the glenoacetabular distance (according to Thulborn 1990) and applying it to the same skeleton, a length of 13.5 m was obtained. Such discrepancies among the obtained values express the still variable methods of estimating the size of the trackmaker. What can be concluded on the basis of those calculations is that the trackmaker of Karigador was a small sauropod approximately 10 m in length.

The speed of Karigador sauropod was estimated using the Alexander's formula $v = 0.25g^{0.5} \times SL^{1.67} \times h^{-1.17}$ (Alexander 1976). The average speed is around 3 km/h which reflects the typical walking speed of sauropods. The average walking speed (AWS) was calculated using the formula $v=1.675h^{0.129}$ (Thulborn 1990) and compared to the data from Table 10.3 from Thulborn (1990). This parameter indicates whether the dinosaurs walked slower or faster than some predicted speed. The AWS is 3.14 km/h which is slower than predicted speed for sauropods (3.45-3.67), but it is in agreement with calculated speed. The relationship between stride length and footprint length (SL/FL) as well as stride length and hip height (SL/h) was also calculated (Tab. 2). The average ratio of SL/FL for the Karigador sauropod is 3.82 which is significantly lower than the values (7-8) obtained by Thulborn (1990). The SL/h ratio is 0.95, similar to the value (0.93) predicted by Thulborn (1990) for the quadrupedal dinosaurs (mainly sauropods). Regarding these facts it could be concluded that the Karigador sauropod walked by taking normal strides i.e. its preferred gait was a normal walk.

What could be said about the identity of the trackmaker? When compared to the other Late Cretac-

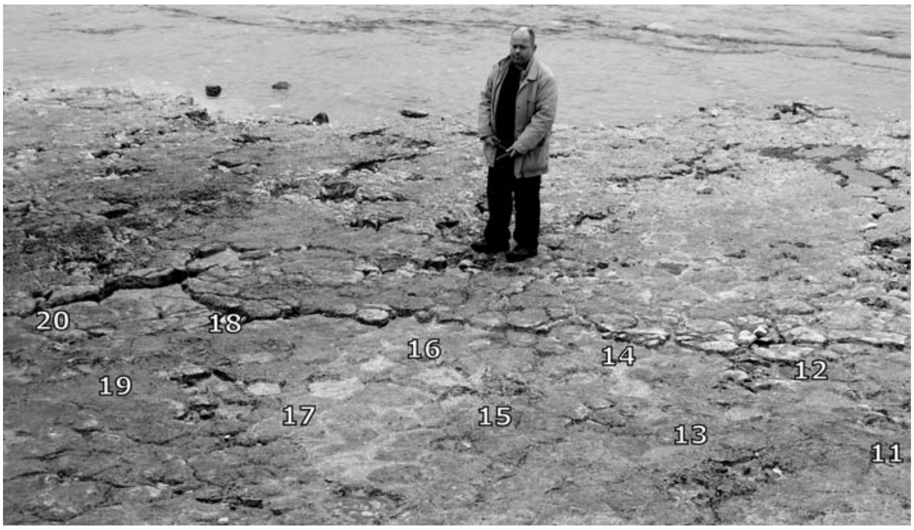


Fig. 6 - The main belt of the Karigador trackway from footprint no. 11 to footprint no. 20.

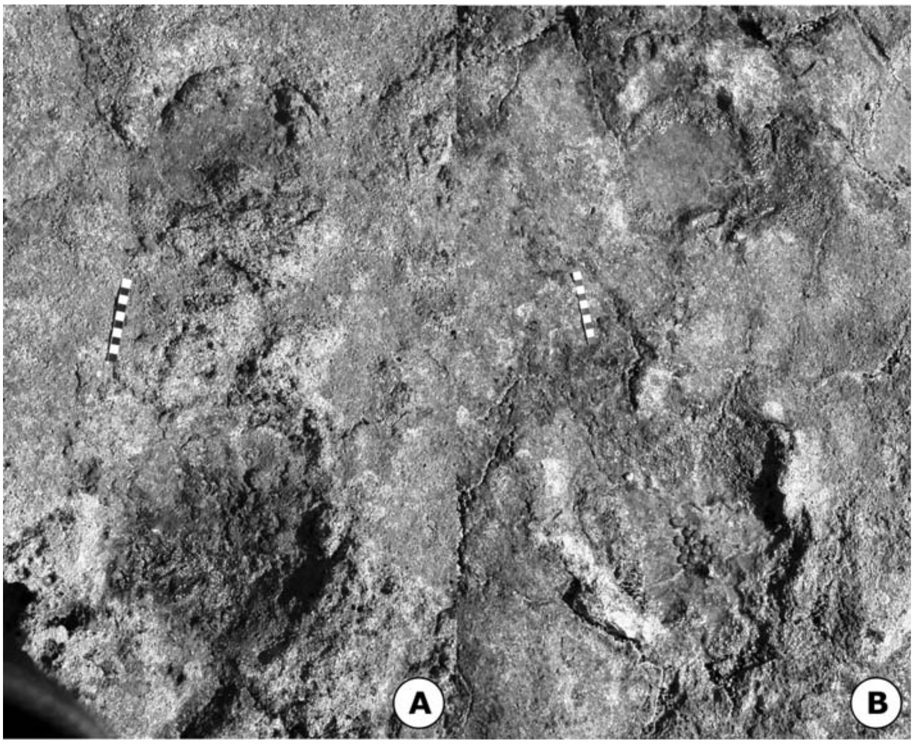


Fig. 7 - (A) A pair of manus-pes prints no. 19. (B) A pair of manus-pes prints no. 13.

eous footprints found at other world localities (e.g., Farlow et al. 1989; Lockley et al. 1994a; Lockley & Meyer 1999) it could be concluded that the state of preservation of the Karigador tracks is rather poor, so it is difficult to ascertain some crucial morphological characters which could related them to some of the existing ichnogenera. Due to heavy erosion the Karigador footprints lack the distinctive morphologic features which could be used for taxonomic interpretation. However, the narrow-gauge type of trackway and outwardly rotated manus are characteristic of the sauropod ichnogenus *Parabrontopodus* (Lockley et al. 1994a; Lockley & Meyer 1999). *Parabrontopodus* manus prints are wider than long, semicircular in shape, significantly smaller in size than the pes prints and they lack clearly visible digit impressions (Lockley et al. 1994a). *Parabrontopodus* pes prints are longer than wide with longer axis orientated outwardly from the trackway midline (Lockley et al. 1994a). The Karigador footprints have the above mentioned features, but they lack an important characteristic of *Parabrontopodus*; the strong pronounced heteropody. The heteropody in Karigador tracks is more similar to that observed in *Brontopodus* types of footprints (Lockley et al. 1994a), but *Brontopodus* has larger size, manus print as wide as long, and large pedal claw marks (Farlow et al. 1989). Therefore, we are hesitant to assign the Karigador tracks to either of these ichnogenera.

FOOTPRINT	ML	MW	PL	PW	MD	PD	direction	h
1	21	18	31	22	4.5	4.5	54	124
2	12.5	26.5	35.5	28	4.5	4	58	142
3	18	23	37	23	3	4	58	148
4					4			
5	22	25.5			4	3.5	94	
6						4		
7						4	65	
8	16	28	35.5	26	4	4		142
9					2		136	
10	13	27	33.5	26	4	2	113	134
11	17	24	28	25.5	3	3	90	112
12	13.5	20	34	24.5	4	4	107	136
13	18.5	21	28	26	4	4	76	112
14	17	22	33	28	3	3.5	114	132
15	19.5	25	36	27.5	4	4	83	144
16	21	24	32.5	27.5	3	4	108	130
17	22	25	36	24	4	4	75	144
18	18	19	32	29.5	2.5	4	90	128
19	20	20	29	22	2	4	74	116
20	14	20	27	22.5	2	4.5	105	108
21	15	20	41	26		3.5	71	164
22	15	20			4		108	
23						4		
24	17	23	33.5	26	2	4.5	115	134
25			34	27		4	72	136
26	25	25	30	24	4	4	119	120
27			35	22.5		4.5	76	140
28	14.5	23.5	34	26.5	3.5	3.5	120	136
29			32	22.5		4		128
30			29	24.5		4		116
31			31	25		4	72	124
32			39	32.5	2.5		109	156
	17.60	**22.83**	**33.06**	**25.54**	**3.37**	**3.89**		**132.24**

Tab. 1 - Measurements of the footprints on the Karigador locality.
Key to abbreviations (also for Tab. 2): ML – manus length, MW – manus width, PL – pes length, PW – pes width, MD – manus depth, PD – pes depth, h – hip height, ETW – external trackway width, ITW – internal trackway width, A – pace angulation, GAD – glenoacetabular distance, v – velocity, AWS – average walking speed, SL/FL – stride length/footprint length ratio, SL/h – stride length/hip height ratio. All dimensions in cm. Direction and pace angulation in degrees. Bold numbers are averages

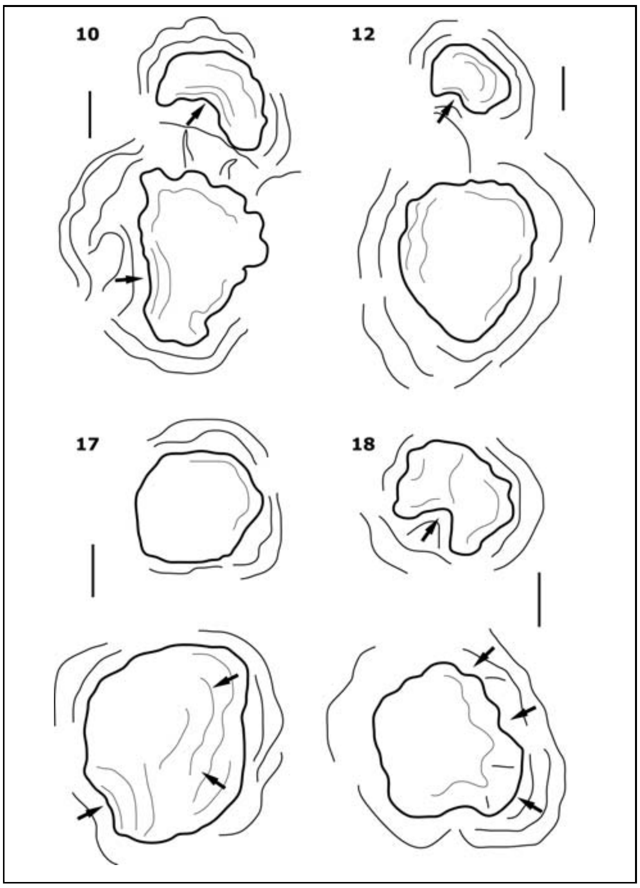


Fig. 8 - Interpretative drawing of some manus-pes footprint pairs from the Karigador site. Arrows indicate direction of mud collapse. Solid line = 10 cm. 10, 12, 17 and 18 are footprint numbers.

Cenomanian sauropod track records on the ADCP include localities on the Fenoliga islet and 'Ladin Gaj' autocamp (Dalla Vecchia 1994; Mezga & Bajraktarević 1999; Dalla Vecchia et al. 2001). When compared to them, Karigador footprints show slightly smaller dimensions (Tab. 3). The pace angulation of Karigador tracks more closely resembles that of the Ladin Gaj than the Fenoliga footprints and SL/FL is similar in all three localities (Mezga & Bajraktarević 1999; Dalla Vecchia et al. 2001). A pronounced outward rotation is characteristic of the Karigador and the Ladin Gaj tracks and strong heteropody is not typical of tracks from any of the three sites. The Karigador and the Ladin Gaj trackways are of narrow-gauge type whereas the Fenoliga trackways show medium to wide-gauge character (Fig. 10; Mezga & Bajraktarevic 1999; Dalla Vecchia et al. 2001). The slow walking gait was similar in all localities (Mezga & Bajraktarević 1999; Dalla Vecchia et al. 2001). Regarding morphology of the footprints from these three localities (Fig. 11), they all show the same basic shapes and characteristics. The Karigador footprints are more similar to those of the Ladin Gaj site than to Fenoliga, regarding the aforementioned features. It is another example of ADCP sauropod tracks found in the carbonate platform environments. Although the Karigador tracks are of narrow-gauge type, they could be assigned to the *Brontopodus* ichnofacies sensu Lockley et al. (1994b). This ichnofacies was named by a wide-gauge ichnotaxon, but it is characterized by recur-

FOOTPRINT	pace	stride	PA	ETW	ITW	GAD	v (m/s)	v (km/h)	AWS	SL/FL	SL/h
1–2	78			65	0						
7–8	70										
10–11	78										
11–12	76										
12–13	70			61	8						
13–14	76			62	2						
14–15	81										
15–16	64			60.5	0						
16–17	75				5						
17–18	78										
18–19	69										
19–20	62			43	–4						
20–21	75			67	18						
21–22	87										
24–25	77										
25–26	60										
26–27	80										
27–28	58			48	–3						
28–29	72			55	0						
29–30	60										
30–31	68										
31–32	68										
	72.00			**57.69**							
5–7		142									
11–13		122	111							4.35	1.08
13–15		138	121				1	3.6		4.31	1.07
15–17		119	116							3.30	0.82
17–19		125	110							3.90	0.96
19–21		120	119							3.42	0.85
25–27		128					0.8	2.88		3.71	0.92
27–29		116								3.46	0.86
29–31		114	126							3.61	0.90
8–10		134								3.94	0.97
10–12		135	118							3.97	1.00
12–14		126	117							3.76	0.94
14–16		125	117							3.78	0.95
16–18		133	115							4.15	1.03
18–20		120	121							4.06	1.01
20–22		122								4.51	1.12
22–24		124								3.70	0.92
24–26		118	114				0.76	2.74		3.68	0.92
26–28		130								4.06	1.01
28–30		118	125							3.74	0.93
30–32		121								3.55	0.88
		125.24	**117.69**				**0.85**	**3.07**	3.14	**3.85**	**0.96**
P7–M13						170					
P11–M14						167					
P12–M15						168					
P13–M16						173					
P14–M17						165					
P15–M18						172					
P16–M19						171					
P17–M20						165					
P18–M21						158					
P19–M22						159					
						166.80					

Tab. 2 - Measurements of the trackway at the Karigador locality. For abbreviations, see Tab. 1.

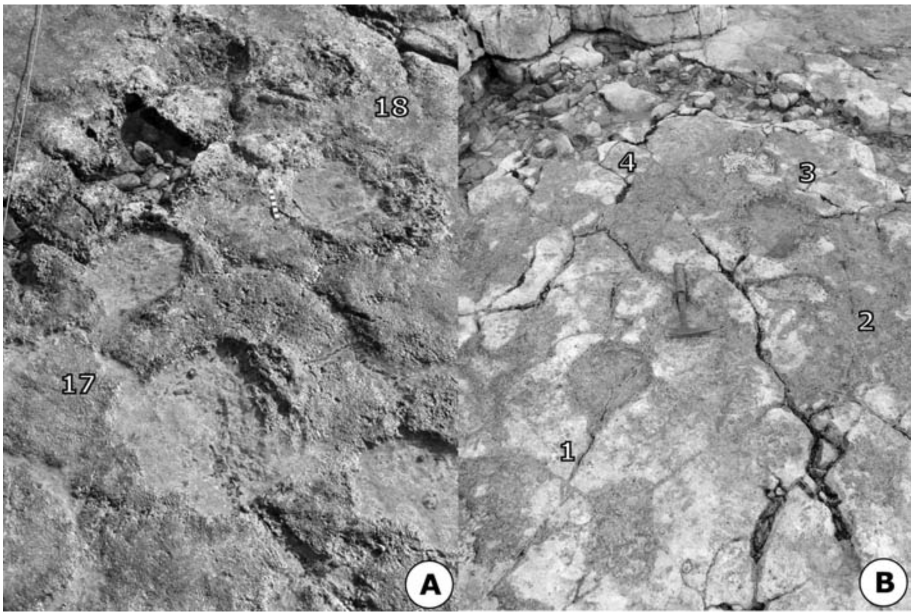
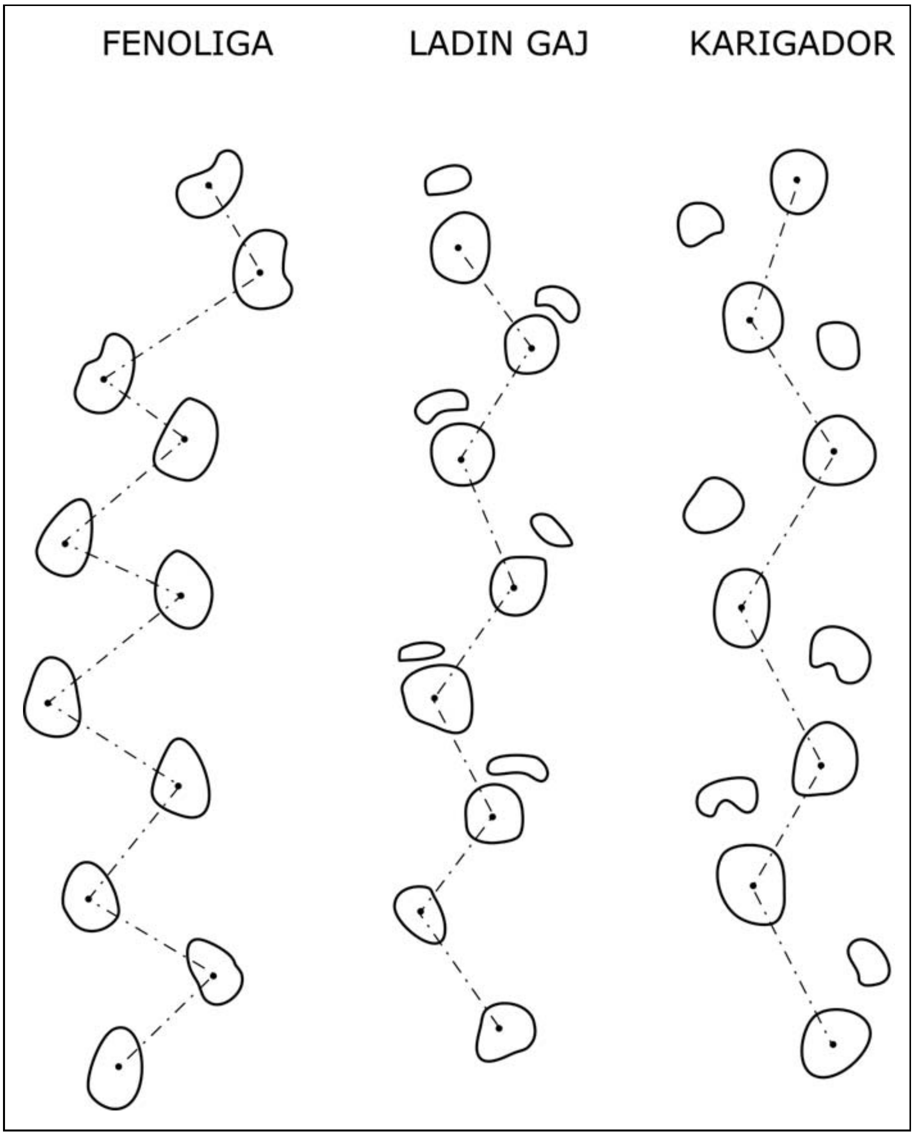


Fig. 9 - (A) Segment of the sauropod trackway from Karigador site with footprints no. 17 and 18. (B) Footprints no. 1 - 4 from Karigador locality.

Fig. 10 - Comparison between the sauropod trackways from Fenoliga, Ladin Gaj and Karigador localities.



	FENOLIGA	LADIN GAJ	KARIGADOR
PL	31–40	32–40	33
PW	20–31	33	25.5
ML	14.5–19.5	15–20	17.5
MW	20.5–23.5	24–29	23
A	98	115.5	117.5
SL/FL	3.30–3.80	3.20–3.25	3.82
AWS	3.22	3.22	3.14
GAD		163	167

Tab. 3 - Comparison of footprint parameters from Karigador, Ladin Gaj and Fenoliga localities. Data compiled from Mezga & Bajraktarević (1999) and Dalla Vecchia et al. (2001). For abbreviations, see Tab. 1.

rent sauropod footprint ichnocoenosis in carbonate facies related to carbonate platform environments (Lockley et al. 1994b).

Regarding the fact that the Karigador trackway is of narrow-gauge type, it could be concluded that the sauropod which left those footprints was presumably not of the titanosaurian type (Farlow et al. 1989; Lockley et al. 1994a; Wilson & Carrano 1999). However, wide-gauge trackways are less pronounced in smaller trackways suggesting that even among wide-gauge sauropods, juveniles may have been narrow gauge (Lockley et al. 2002). This may also be the case for the Karigador tracks, but there are no larger (adult) sauropod tracks found on ADCP in the Cenomanian. The find of narrow-gauge sauropods in Late Cretaceous of ADCP (Karigador and Ladin Gaj sites) could be significant with respect to the fact that the Late Cretaceous is dominated by wide-gauge sauropod trackways (Lockley et al. 1994c; Wilson & Carrano 1999). The late Cenomanian of ADCP is the geological youngest known record of narrow-gauge trackways. The non-titanosaurian sauropods which lived during the Cenomanian period on the Europe or African continent are poorly known. They include only undetermined African finds of cf. *Dicraeosaurus* sp. from the Early Cenomanian of Marsa Matruh and *Dicraeosauridae* indet. from the Albian-Cenomanian of Wadi Milk (Weishampel et al. 2004). There are no non-titanosaurian sauropods known from Europe during the Late Cretaceous (Weishampel

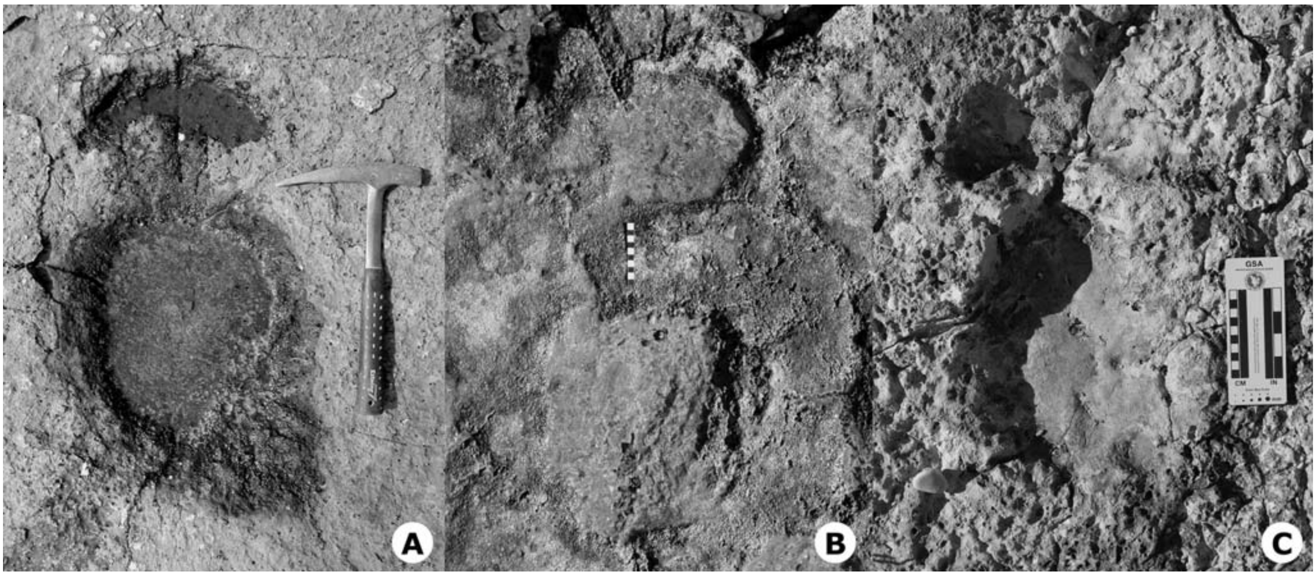


Fig. 11 - Sauropod footprints from Ladin Gaj (A), Karigador (B) and Fenoliga (C) localities.

et al. 2004). This might favor the interpretation of the trackways as those of juvenile titanosaurs. However, it should be noted that there are also mid-Cretaceous genera of diplodocoid sauropods from Africa which include *Rebbachisaurus* and *Nigersaurus* from the Albian (Weishampel et al. 2004). If the Karigador and Ladin Gaj trackmakers are considered as non-titanosaurian (or even diplodocoid), this could be an indication of their African rather than their European origin. The connection of the ADCP with other continents has often been questioned in recent studies (e.g. Dalla Vecchia 2002; Vlahović et al. 2005) and there is general agreement of its connection with the African continent until, at least, Barremian times. Was this connection still present in the Cenomanian or did the ADCP became isolated (Dalla Vecchia et al. 2001; Dalla Vecchia 2002) during the mid-Cretaceous? This is still not fully understood, especially regarding the new finds, not only in Istria but also in the other parts of ADCP (island of Hvar; Mezga, pers. obs.).

Conclusion

A new locality with dinosaur footprints has been discovered at the port of Karigador village in Istria. The site is situated in peritidal limestones of late Cenomanian age. The trackbearing horizon is a bioclastic wackestone-packstone deposited in a subtidal environment. A single trackway which consist of 28 pairs of footprints and a group of 4 track pairs was recognized at the outcrop. The trackways belong to quadrupedal dinosaurs and are assigned to sauropods. Oval-circular shaped footprints represent the pedal prints and horseshoe-semicircular shaped ones represent the manus prints. The trackway is small and of narrow-gauge type with outwardly rotated manus and pedal prints. An average length of the pedal prints is 33 cm which indicates the estimated length of the individual of app. 10 m. The preferred gait of the individual was a normal walk, taking normal strides with a speed of around 3 km/h. The trackmaker may have been a non-titanosaurian sauropod that produced narrow-gauge type of trackway though a small titanosaurid trackway can not be discounted. Together with the other Upper Cenomanian sauropod localities in Istria (Fenoliga and Ladin Gaj), the Karigador site represents an example of sauropod tracks in a carbonate platform environment which could be assigned to the *Brontopodus* ichnofacies (Lockley et al. 1994b).

Acknowledgments. This work was supported by a grant from the Ministry of Science, Education and Sport of the Republic of Croatia, project no. 0119402. We would like to thank R. Koščal for the drawing of the lithological column and G. Mikša for the thin section photomicrographs. We thank M. Lockley and H. Haubold for their reviews of the manuscript and useful suggestions and M. Gaetani for his editorial work. Thanks to Blanka Cvetko Tešović for her patience and good will.

REFERENCES

Alexander R.McN. (1976) - Estimates of speeds of dinosaurs. *Nature*, 261: 129-130, London.

Alexander R.McN. (1989) - Dynamics of dinosaurs and other extinct giants. V. of 167 pp. Columbia University Press, New York.

Dalla Vecchia F.M. (1994) - Jurassic and Cretaceous sauropod evidence in the Mesozoic carbonate platform of the southern Alps and Dinarids. *Gaia*, 10: 65-73, Lisbon.

Dalla Vecchia F.M. (2002) - Cretaceous dinosaurs in the Adriatic-Dinaric Carbonate Platform (Italy and Croatia): paleoenvironmental implications and paleogeographical hypotheses. *Mem. Soc. Geol. It.*, 57: 89-100, Roma.

Dalla Vecchia F.M., Tarlao A., Tunis G. & Venturini S. (2001) - Dinosaur track sites in the upper Cenomanian (Late Cretaceous) of the Istrian peninsula (Croatia). *Boll. Soc. Paleont. It.*, 40 (1): 25-54, Modena.

Farlow J.O., Pittman J.G., Hawthorne J.M. (1989) - *Brontopodus birdi*, Lower Cretaceous Sauropod Footprints from the U.S. Gulf Coastal Plain. In: Gillette D.D. & Lockley M.G. (eds) - Dinosaur Tracks and Traces: 371-394, Cambridge University Press, Cambridge.

Gogala M. (1975) - Sledi iz davnine na jugu Istre. *Proteus*, 37: 229-232, Ljubljana.

James N.P. (1984) - Shallowing upward sequences in carbonates. In: Walker, R.G. (ed.) - Facies models: 213-228, Geological Association of Canada, Toronto.

Leghissa S. & Leonardi G. (1990) - Una pista di sauropode scoperta nei calcari cenomaniani dell'Istria. Centro di Cultura Giuliano-Dalmata: 30 pp, Milano.

Lockley M.G., Farlow J.O. & Meyer C.A. (1994a) - *Brontopodus* and *Parabrontopodus* ichnogen. nov. and the significance of wide- and narrow-gauge sauropod trackways. *Gaia*, 10: 135-145, Lisbon.

Lockley M. G., Hunt A. P. & Meyer C. A. (1994b) - Vertebrate tracks and the Ichnofacies Concept: implication for paleoecology and palichnostratigraphy. In: Donovan, S. (ed.) - The Paleobiology of Trace Fossils: 241-268, Wiley & Sons, New York

Lockley M. G., Meyer C. A., Hunt A. P. & Lucas, S.G. (1994c) - The distribution of sauropod tracks and trackmakers. *Gaia*, 10: 233-249, Lisbon.

Lockley M.G. & Hunt A.P. (1995) - Dinosaur tracks and other fossil footprints of the western United States. V. of 360 pp. Columbia University Press.

Lockley M. G. & Meyer C. A. (1999) - Dinosaur Tracks and other fossil footprints of Europe. V. of 323 pp. Columbia University Press, New York.

Lockley M.G., Wright J., White D., Matsukawa M., Jianjun L., Lu F. & Hong L. (2002) - The first sauropod trackways from China. *Cretaceous Research*, 23: 363-381, Dorset.

Mezga A. & Bajraktarević Z. (1999) - Cenomanian dinosaur tracks on the islet of Fenoliga in southern Istria, Croatia. *Cretaceous Research*, 20: 735-746, Dorset.

Tišljar J., Vlahović I., Velić I., Matičec D. & Robson J. (1998) - Carbonate facies evolution from the Late Albian to Middle Cenomanian in southern Istria (Croatia): Influence of synsedimentary tectonics and extensive organic carbonate production. *Facies*, 38: 137-152, Erlangen.

Thulborn R. A. (1990) - Dinosaur tracks. V. of 410 pp. Chapman and Hall, London.

Velić I., Tišljar J., Matičec D. & Vlahović I. (1995) - A review of the Geology of Istria. In: Vlahović I. and Velić I. (eds.) - Excursion Guide-Book of the First Croatian Geological Congress: 21-30, Institute of Geology, Zagreb.

Vlahović I., Tišljar J., Velić I. & Matičec D. (2005) - Evolution of the Adriatic Carbonate Platform: Palaeogeography, main events and depositional dynamics. *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 220 (3): 333-360, Amsterdam.

Weishampel D.B., Barrett P.M., Coria R.A., Le Loeuff J., Xing X., Xijin Z., Sahni A., Gomani E.M.P. & Noto C.R. (2004) - Dinosaurian distribution. In: Weishampel, D.B., Dodson P. and Osmolska H. (eds) - The Dinosauria, 2nd ed.: 517-606, University of California Press, Berkeley.

Wilson J.A. & Carrano M.T. (1999) - Titanosaurs and the origin of "wide-gauge" trackways: a biomechanical and systematic perspective on sauropod locomotion. *Paleobiology*, 25 (2): 252-267, Lawrence.