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Atreipus-like footprints and their co-occurrence with *Evazoum* from the upper Carnian (Tuvalian) of Trentino-Alto Adige

Simone D'ORAZI PORCHETTI[1*], Umberto NICOSIA[1], Paolo MIETTO[2], Fabio Massimo PETTI[1,3] & Marco AVANZINI[3]

[1]Dipartimento di Scienze della Terra, Sapienza Università di Roma, P.le Aldo Moro 5, 00185 Roma, Italy
[2]Dipartimento di Geoscienze, Università di Padova, Via Giotto 1, 35122 Padova, Italy
[3]Museo Tridentino di Scienze Naturali, Via Calepina 14, 38100 Trento, Italy
[*]Corresponding author e-mail: *simone.dorazi@uniroma1.it*

SUMMARY - Atreipus-*like footprints and their co-occurrence with* Evazoum *from the upper Carnian (Tuvalian) of Trentino-Alto Adige* - A new Tuvalian (Carnian) tetrapod ichnocoenosis is described from Trentino-Alto Adige (Northeastern Italy). The outcrop has yielded *Atreipus*-like and *Evazoum*-like footprints along with grallatorids and crurotarsan ichnites. *Atreipus* appears for the first time in the Italian ichnologic record while *Evazoum* co-occurs with *Atreipus* uniquely in this outcrop. The ichnocoenosis gives new insights on the palaeogeographic distribution and biochronologic significance of *Atreipus* and *Evazoum*.

RIASSUNTO - *Orme* Atreipus-*like e loro compresenza con* Evazoum *dal Carnico superiore (Tuvalico) del Trentino-Alto Adige* - Viene descritta una nuova icnocenosi a tetrapodi dal Tuvalico del Trentino-Alto Adige (Italia Nordorientale). L'affioramento ha restituito orme tipo *Atreipus* e tipo *Evazoum* assieme a impronte grallatoridi e di crurotarsi. *Atreipus* compare per la prima volta nel record icnologico italiano, mentre *Evazoum* si trova in associazione con *Atreipus* esclusivamente in questo affioramento. L'icnocenosi fornisce nuove informazioni sul significato biocronologico e sulla distribuzione paleogeografica di *Atreipus* e *Evazoum*.

Key words: *Atreipus*, *Evazoum*, Tuvalian, Travenanzes Fm., Trentino, Italy
Parole chiave: *Atreipus*, *Evazoum*, Tuvalico, Formazione di Travenanzes, Trentino, Italia

1. INTRODUCTION

On April 2004 several archosaur footprints have been discovered by one of the authors (M.A.) near the ruins of the XII century San Gottardo Castle (formerly known as Corona di Mezo), above the Mezzocorona village, about 18 km North of Trento (Trentino-Alto Adige) (Fig. 1). The analysis revealed at least 50 footprints referred to crurotarsans, dinosauriforms and dinosaurs preserved on three main carbonate layers. This paper focuses on the description of the dinosauriform and dinosaur footprints.

2. GEOLOGY

The Adige Valley represents the central sector of the eastern Southern Alps. Several stratigraphical units are present here, referable to the 3rd-order depositional sequences deposited during the Triassic.

Near the town of Mezzocorona, in the Middle Adige Valley, the first three of the four Carnian depositional sequences (Car1-4 *sensu* De Zanche *et al.* 1993) are missing due to the erosion that defines the Sequence Boundary of Car4 in the late Carnian (Tuvalian). This unconformity corresponds to the top of the Sciliar Fm., Anisian-Ladinian *p.p.* in age (De Zanche & Mietto 1988).

The Anisian-Ladinian unconformity at San Gottardo Castle is overlain by white-grey aphanitic to silty dolostones with beds of reddish or greenish shales (Fig. 2, left), assigned to the Travenanzes Formation (= upper portion of the "Raibl Beds" *Auct*.) (Neri *et al.* 2005).

This lithofacies might be interpreted as a marginal marine environment interested sometimes by input of detritical sediments, accompanied also by open marine, albeit shallow, sedimentation. This shallow lagoonal deposition has been affected by periodical subaerial exposure marked by an increase in birdseyes levels, mudcrack surfaces and archosaur footprints. Higher in the sequence, the disappearance of shale beds shows that the clastic input was replaced definitively by deposition of subtidal and peritidal primary dolostones.

A correlation of the upper Carnian deposits along the Adige Valley shows a strong lateral variation typical of transitional and coastal environment with interfingering between terminal fan/flood plain and a shallow lagoonal environment with periodic input of continental detritic sediments

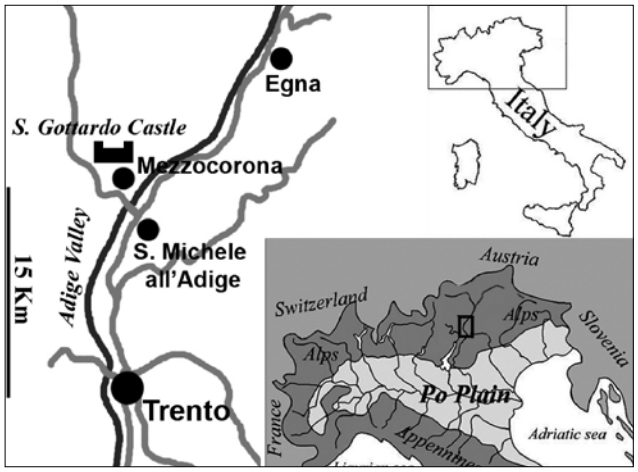

Fig. 1 - Location of the new outcrop.
Fig. 1 - Ubicazione del nuovo affioramento.

(Gennaro 2007). Later, the continental input ended and the climate became progressively dryer until evaporites were deposited in the upper part of the southern (Po Plain) sections. At the same time, shallow marine conditions prevailed in to the north. Higher up, the Travenanzes Formation gradually passes into the Dolomia Principale/Hauptdolomit, and only the disappearance of shale beds may be used to define a lithostratigraphic boundary between these two formations.

2.1. Age of Travenanzes Formation

Samples of black and grey shales from the lowermost part of the Travenanzes Formation have yielded a remarkable amount of organic matter, mainly composed of amorphous material, spores and pollen (Gennaro 2007). The spores and pollen taxa identified in the samples are listed in table 1, in which taxa are grouped into paleotaxa (Playford & Dettmann 1965).

According to Roghi (2004), the recorded pollen associations belong to the *Granuloperculatipollis rudis* assemblage, characterized by Circumpolles *Partitisporites quadruplicis* and *Granuloperculatipollis rudis.* This latter species always occurs with the "long range" (Roghi 2004) elements *Enzonalasporites vigens, Pseudoenzonalasporites summus, Camerosporites secatus* and *Duplicisporites verrucosus*. Except for *Partitisporites quadruplicis*, all the other five species have been found in the collected samples, often with the bryophyte *Ricciisporites tuberculatus* (Tab. 1). This association indicates a Tuvalian age.

3. MATERIAL

The exposed layers are lower surfaces and occur as overhangs (Fig. 2, right) where footprints are preserved as convex hyporeliefs. The surfaces, from the base to the top, are labelled with letters A, B and C.

On the surface of the lowermost layer (Fig. 3a) a thick mud-cracking is preserved; layer A has yielded at least four footprints. Layer B (Fig. 3b) is little exposed and has yielded two tridactyl footprints and few scattered round marks. This level crops out with a small slab just few meters away

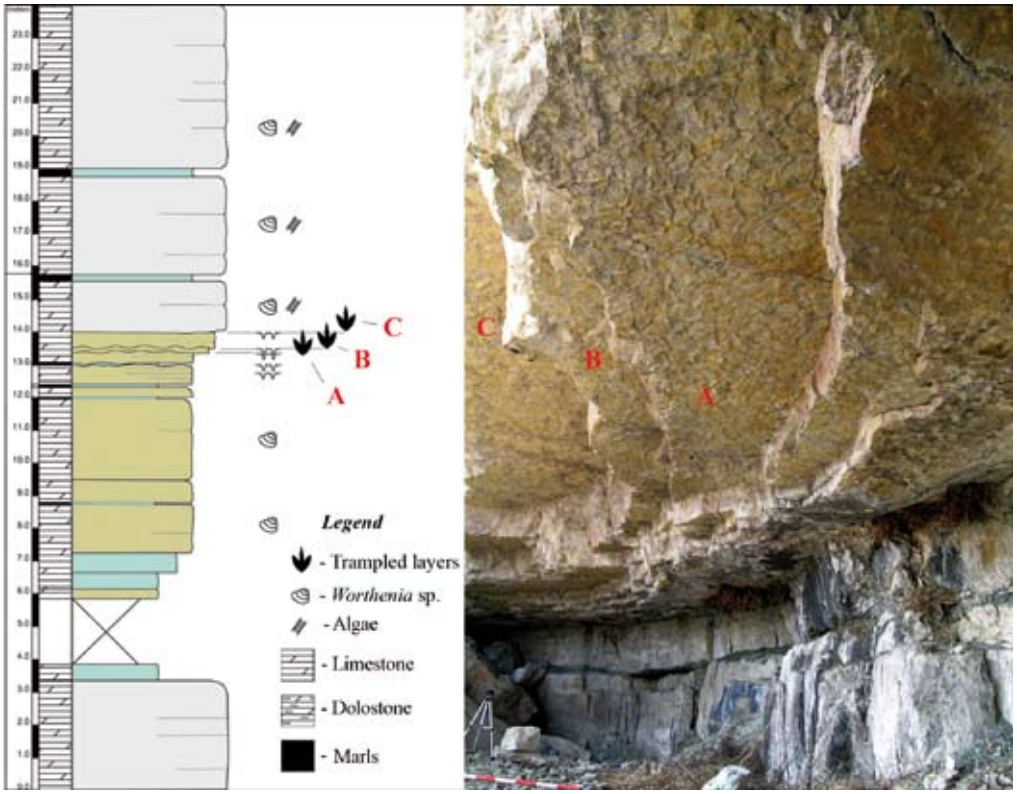

Fig. 2 - Log of the section (left) with footprint bearing beds (metric scale on the left side) and close-up (right) of the trampled layers (small pole for scale, bottom left).
Fig. 2 - Sezione colonnare (sinistra) con indicazione dei livelli ad impronte (scala metrica sul lato sinistro) e particolare dei livelli ad impronte (palina per riferimento, in basso a sinistra)

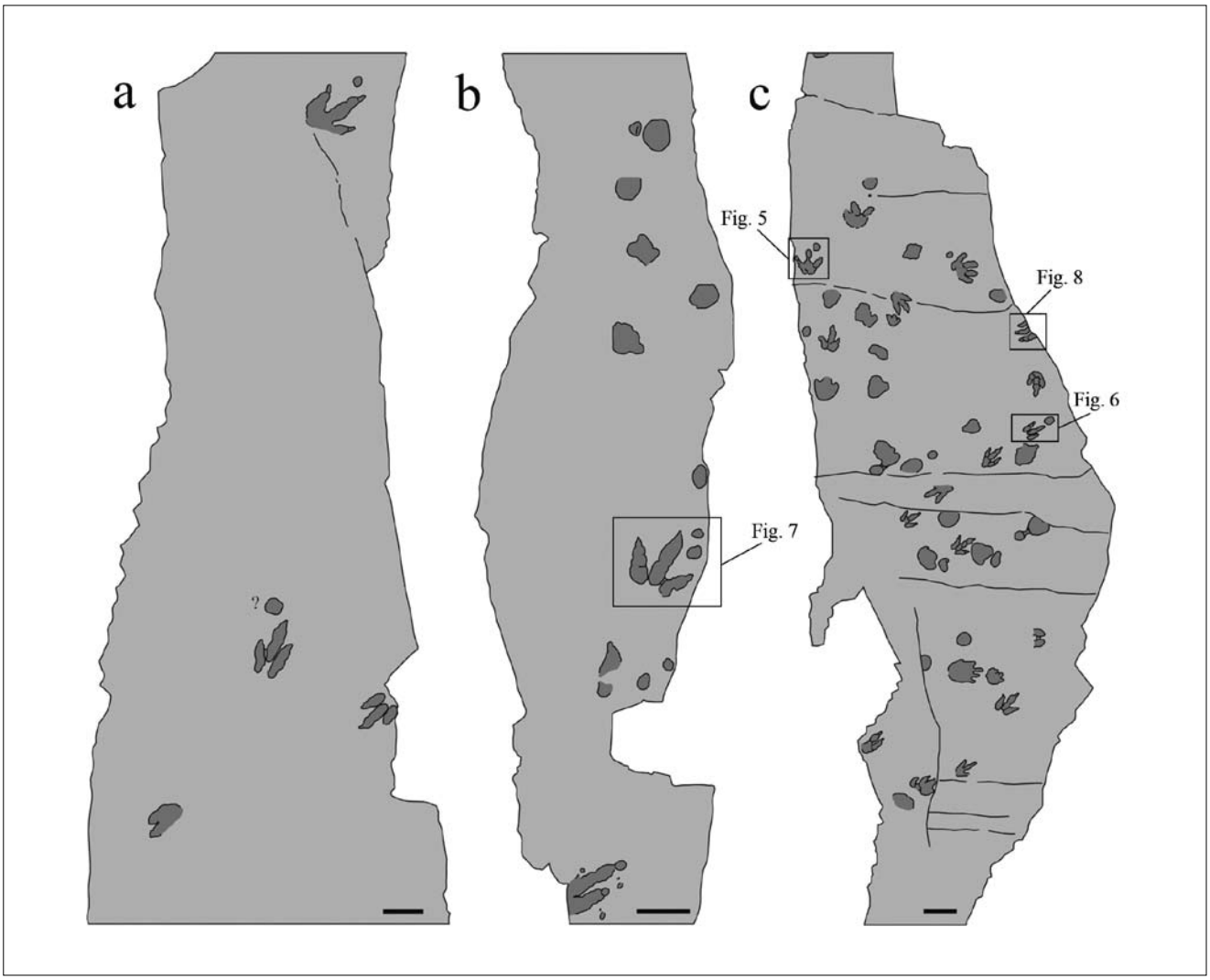

Fig. 3 - a. Map of the surfaces A, b. B and c. C. Scale bar 10 cm in a. and b., 20 cm in c.
Fig. 3 - a. Rilievo delle superfici A, b. B e c. C. Scala 10 cm in a. e b., 20 cm in c.

from the main layer; both the surfaces have a well preserved mud-crack net.

More than 40 footprints have been observed on the uppermost bed (Fig. 3c). About 14 footprints are tridactyl in some cases associated with smaller round prints, along with poorly preserved chirotheroid tracks. At least three morphotypes have been observed at the Mezzocorona locality.

3.1. Tridactyl and tetradactyl footprints

3.1.1. Grallator isp.

A first morph is represented by tridactyl footprints (Fig. 4) that have the posterior end of digit IV pulled back in comparison to digit II (foot length: 16 cm, foot width: 11 cm); as a consequence, the posterior margin of these tracks is slightly asymmetric. Digit III is dominant respect to digit II and IV and the footprint is clearly mesaxonic. This set of characters suggests an attribution to *Grallator* isp.

3.1.2. Atreipus-like

Other tridactyl footprints have indeed a much more symmetric posterior margin. These tracks are associated to small round marks, lying close to the tip of digit III of the pes. These small round prints are here interpreted as manus prints (Fig. 5). A clear difference in the divarication and relative length of digits has been observed in this latter record, where a "slender-" (Fig. 6) (foot length: 14 cm, foot width: 8 cm, manus length: ?4 cm) and a "robust-form" (Fig. 7) (foot length: 14 cm, foot width 13.8 cm, manus length: ?7 cm) can be therefore separated. The "robust" form is stouter and more massive, respect to a slim and lighter "slender-form"; this standing, the presence of a manus print is the most characterizing feature. Comparisons of this record with known ichnotaxa highlighted its likeness with *Atreipus*, a tulip-shaped, symmetric footmark, associated to a tri- or, in some cases, tetradactyl handprint. Although some author have questioned the ichnotaxonomic validity of *Atreipus* (see Weems

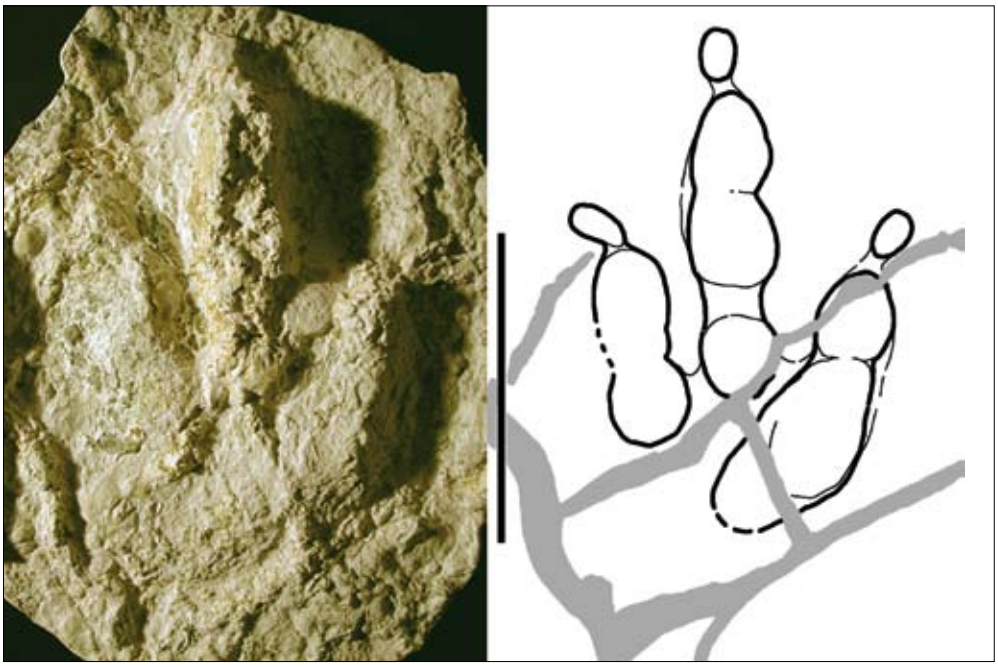

Fig. 4 - Photograph and interpretative drawing of the most representative specimen referred to *Grallator* isp. Scale bar 10 cm.
Fig. 4 - Fotografia e disegno interpretativo dell'esemplare più rappresentativo attribuito a Grallator *isp. Scala 10 cm.*

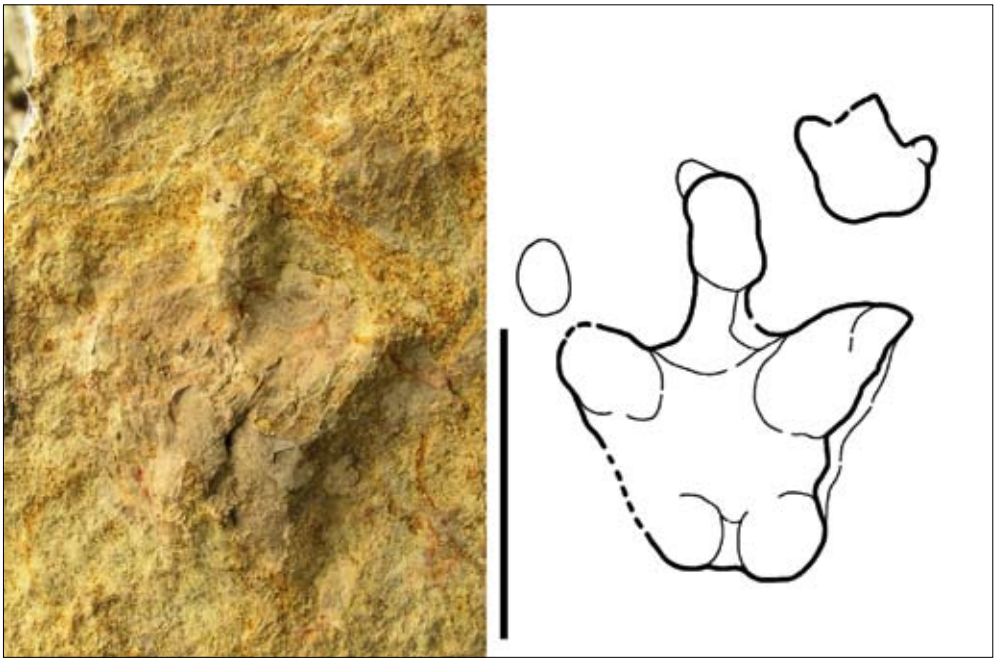

Fig. 5 - Photograph and interpretative drawing of an *Atreipus*-like specimen. Scale bar 10 cm.
Fig. 5 - Fotografia e disegno interpretativo di un esemplare tipo Atreipus. *Scala 10 cm.*

1992; Weems & Kimmel 1993), this taxon is here considered to be defined by a peculiar and constant set of characters and according to Safran & Rainforth (2004) is clearly distinct from *Grallator*. Some minor variations are related to the overall dimension of the specimens (see Lockley & Hunt 1995) and to digit divarication. Although the composite type specimens as drawn by Olsen & Baird (1986) show little digit divarication, some material from the Newark Supergroup (see Olsen & Baird 1986: 67) has digits as splayed as the Mezzocorona "robust-form" material. A larger variation in digit spreading is at least more common in the European material (Demathieu & Gand 1972a, 1972b, 1973, 1981a, 1981b; Courel & Demathieu 2000; Gand & Demathieu 2005). The Mezzocorona material shows close affinities with the early Tuvalian tridactyl tracks from the Deep River Basin succession (Pekin Formation; North Carolina, USA; Olsen & Huber 1998: fig. 10), characterized by similar size, proportions and digit divarication.

3.1.3. Evazoum isp.

Bed B and C have also yielded two footprints (Fig. 8) preserving digits II, III and IV. All digits are slightly bent inward and digit III is just a little longer than digits II and IV

(foot length: 13.5 cm, foot width: 12.7 cm). The shape is unlike the classic *Grallator*, where digits are straight and digit III is largely dominant. The specimens from Mezzocorona show indeed the features of *Evazoum* and they are therefore ascribed to this ichnotaxon.

Evazoum Nicosia & Loi, 2003 has been erected on well

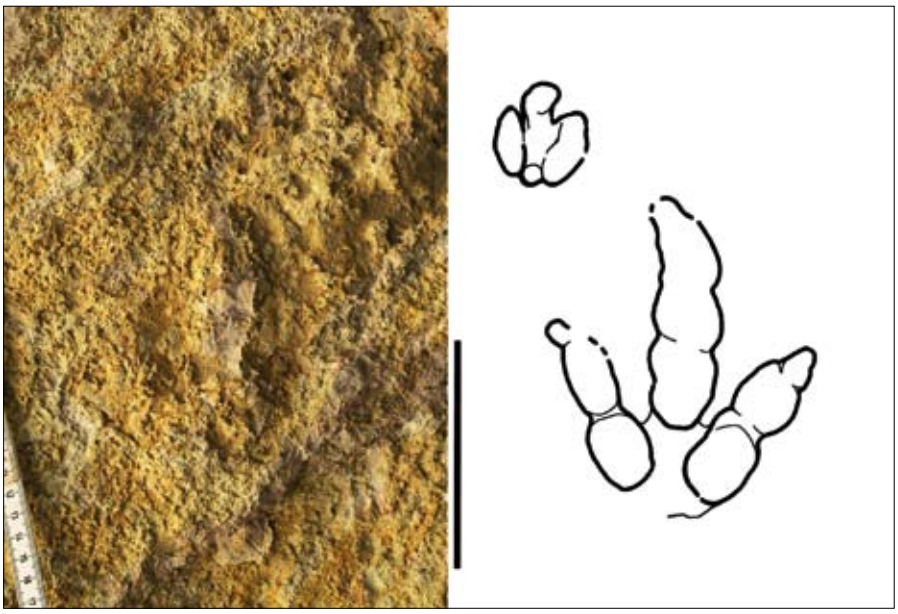

Fig. 6 - Specimen referred to *Atreipus*, in the "slender -form", photograph and interpretative drawing. Scale bar 10 cm.
Fig. 6 - Esemplare riferito ad Atreipus*, "forma gracile", foto e disegno interpretativo. Scala 10 cm.*

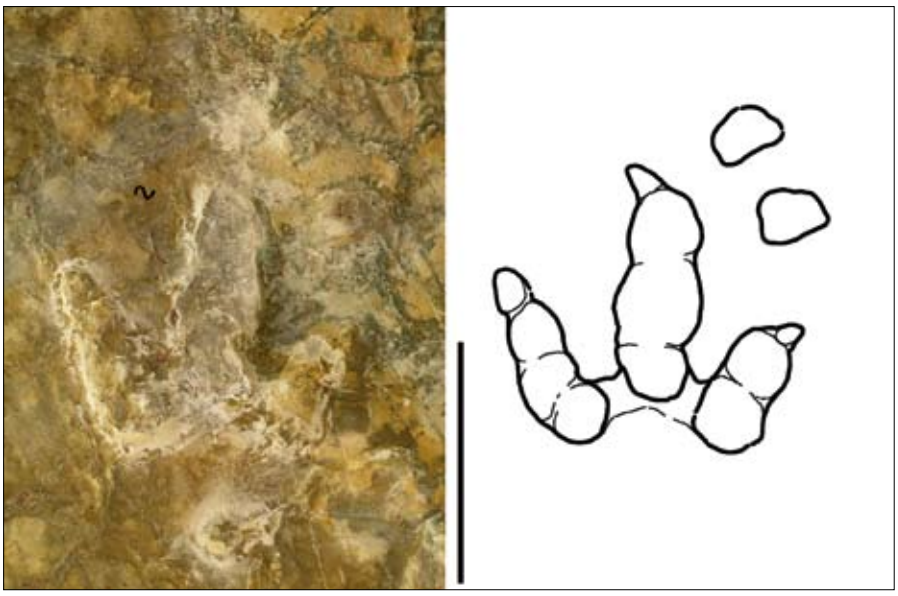

Fig. 7 - Specimen referred to *Atreipus*, in the "robust -form", photograph and interpretative drawing; arrows indicate manus prints. Scale bar 10 cm.
Fig. 7 - Esemplare riferito ad Atreipus*, "forma robusta", foto e disegno interpretativo. Frecce ad indicare le tracce di manus. Scala 10 cm.*

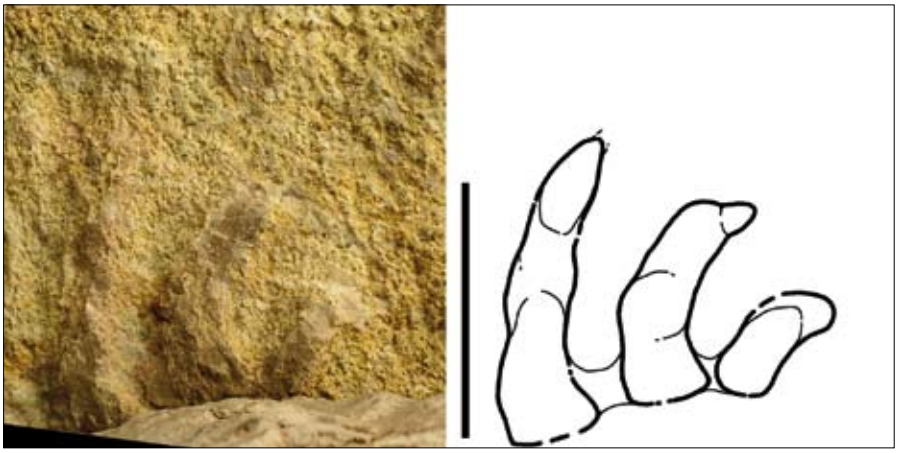

Fig. 8 - Photograph and interpretative drawing of *Evazoum* isp. from the San Gottardo Castle. Scale bar 10 cm.
Fig. 8 - Foto e disegno interpretativo di Evazoum *isp. dal Castello di San Gottardo. Scala 10 cm.*

preserved material from the Late Triassic Monte Marcello Formation (Lerici, north western Italy) and referred to a light-build biped sauropodomorph. Nicosia & Loi (2003) stated how the diagnosis of the new ichnogenus should include several other Late Triassic tracks from Europe and North America, referred either to *Kalosauropus* (Lockley & Meyer 2000) or to *Pseudotetrasauropus* (Lockley & Hunt 1995; D'Orazi Porchetti & Nicosia 2007). However, all of the approaches to this material were informal until the work of Lockley *et al.* (2006), who referred to as *Evazoum* many small bipedal and tetradactyl specimens. All the *Evazoum*-like footprints are functionally tetradactyl, with four digits oriented forward; digit III is dominant while digit II and IV are slightly shorter, footprints length being generally below 30 cm. Digits can be more or less splayed, and are generally slightly bent inward. Usually, *Evazoum* has lateral digits (III-IV) deeply impressed, with a weight-bearing role of digit I strongly reduced. This pattern is testified by feeble and partial marks (when present) of digit I. Digit II shows, in some specimens, a high degree of shortening associated with an enlargement of its proximal half. The pad beneath digit IV is here reinterpreted as the covering of a metatarso-phalangeal joint (see Nicosia & Loi 2003 for a different interpretation). *Evazoum*-like footprints are clearly digitigrade (*sensu* Carrano 1997) (Fig. 9).

Nonetheless, Klein *et al.* (2006) and Klein & Haubold (2007), consider several specimens of *Evazoum* as sediment-biased morphs, and assigned some to badly preserved *Brachychirotherium*. However, there are no trackways in which this transition (Klein *et al.* 2006: 247, fig. 8) can be shown. Where both morphotypes (Klein *et al.* 2006: fig. 4L) are preserved close to each other, showing the same quality of anatomical details, a similar preservation clarifies a neat separation between these two morphotypes, one biped and tetradactyl (*Evazoum*), the other quadruped and pentadactyl (*Brachychirotherium*).

3.2. *Remarks on* Atreipus *and* Evazoum *and their distribution*

Along with more common tridactyl footprints here referred to *Grallator* and quadruped tracks of likely crurotarsan origin, this ichnocoenosis has yielded two remarkable features, *Atreipus* and *Evazoum*.

The ichnotaxon *Atreipus* has been erected on material found in large samples from several localities of North American east coast (Newark Supergroup), as well as in the Hansbacher Sandstone (*A. metzneri*) of the German Middle Keuper (Olsen & Baird 1986).

The age of *Atreipus*, as defined by Olsen & Baird (1986), is restricted to the Late Triassic (Carnian-Norian). Lockley & Hunt (1995) referred several large footprints from the Lake Powell (Chinle Group, Utah) to *Atreipus*. *Atreipus* has also been mentioned from other localities in Utah (Chinle Group, Four miles Canyon; Gierliński 1995). However, many other tridactyl footprints associated to manus impressions have been hitherto described from the Middle and the Upper Triassic of France, even if in most cases these records have been ascribed to *Coelurosaurichnus* or to *Anchisauripus* (Courel & Demathieu 2000; Gand *et al.* 2005). Gand & Demathieu (2005: 744) stated "Quoi qu'il en soit, d'ores et déjà, l'usage d'*Atreipus* pour nommer les couples pied-main de *C. grancieri* et de *C. perriauxi* impose que sa répartition verticale [...],

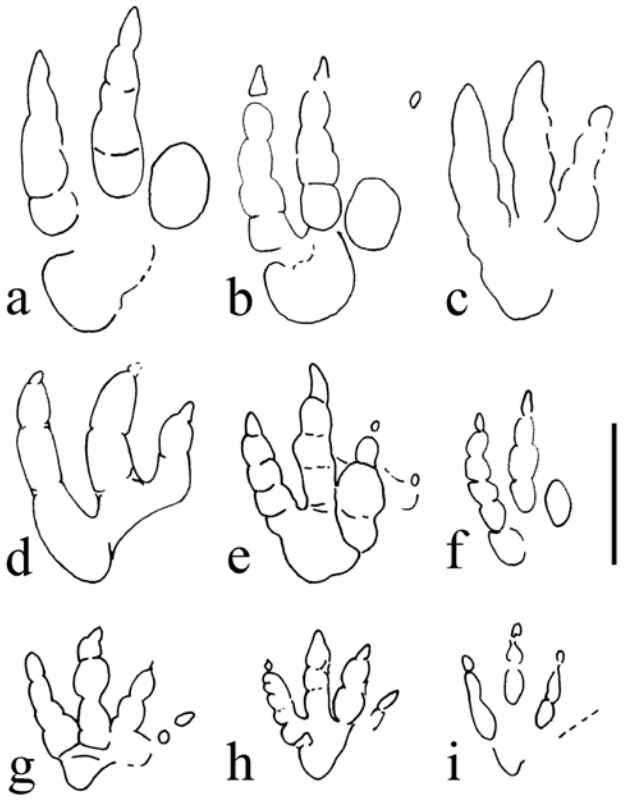

Fig. 9 - Most representative footprints types considered here as *Evazoum.* a. CU MWC 153.6 (from Lockley *et al.* 2006) ; b. CU MWC 153.3 (from Lockley *et al.* 2006); c. P-14152 (from Lockley *et al.* 2006); d. specimen from San Gottardo Castle (this work); e. SMNS 81826 (from Haderer 2004); f. CU MWC 153.8 (from Lockley *et al.* 2006); g. specimen from Mesa Redonda, New Mexico (unnumbered) (from Hunt *et al.* 1993); h. holotype of *E. sirigui* (from Nicosia & Loi 2003); i. Sheep Pen Sandstone (from Lockley *et al.* 1993). All specimens redrawn and oriented with digit IV on the left, scale bar 10 cm. Institutional Abbreviations, CU-MWC: joint of University of Colorado at Denver, Dinosaur Tracks Museum (Denver), and Museum of Western Colorado; SMNS: Staatliches Museum für Naturkunde Stuttgart (Germany).

Fig. 9 - Esemplari più rappresentativi riferiti ad Evazoum. *a. CU MWC 153.6 (da Lockley* et al. *2006); b. CU MWC 153.3 (da Lockley* et al. *2006); c. P-14152 (da Lockley* et al. *2006); d. esemplare dal Castello di San Gottardo (questo lavoro); e. SMNS 81826 (da Haderer 2004); f. CU MWC 153.8 (da Lockley* et al. *2006); g. esemplare da Mesa Redonda, New Mexico (non numerato) (da Hunt* et al. *1993); h. olotipo di* E. sirigui *(da Nicosia & Loi 2003); i. Sheep Pen Sandstone (da Lockley* et al. *1993). Tutti gli esemplari ridisegnati ed orientati con il dito IV a sinistra, scala 10 cm. Sigle delle istituzioni, CU-MWC: University of Colorado at Denver, Dinosaur Tracks Museum (Denver), e Museum of Western Colorado; SMNS: Staatliches Museum für Naturkunde Stuttgart (Germania).*

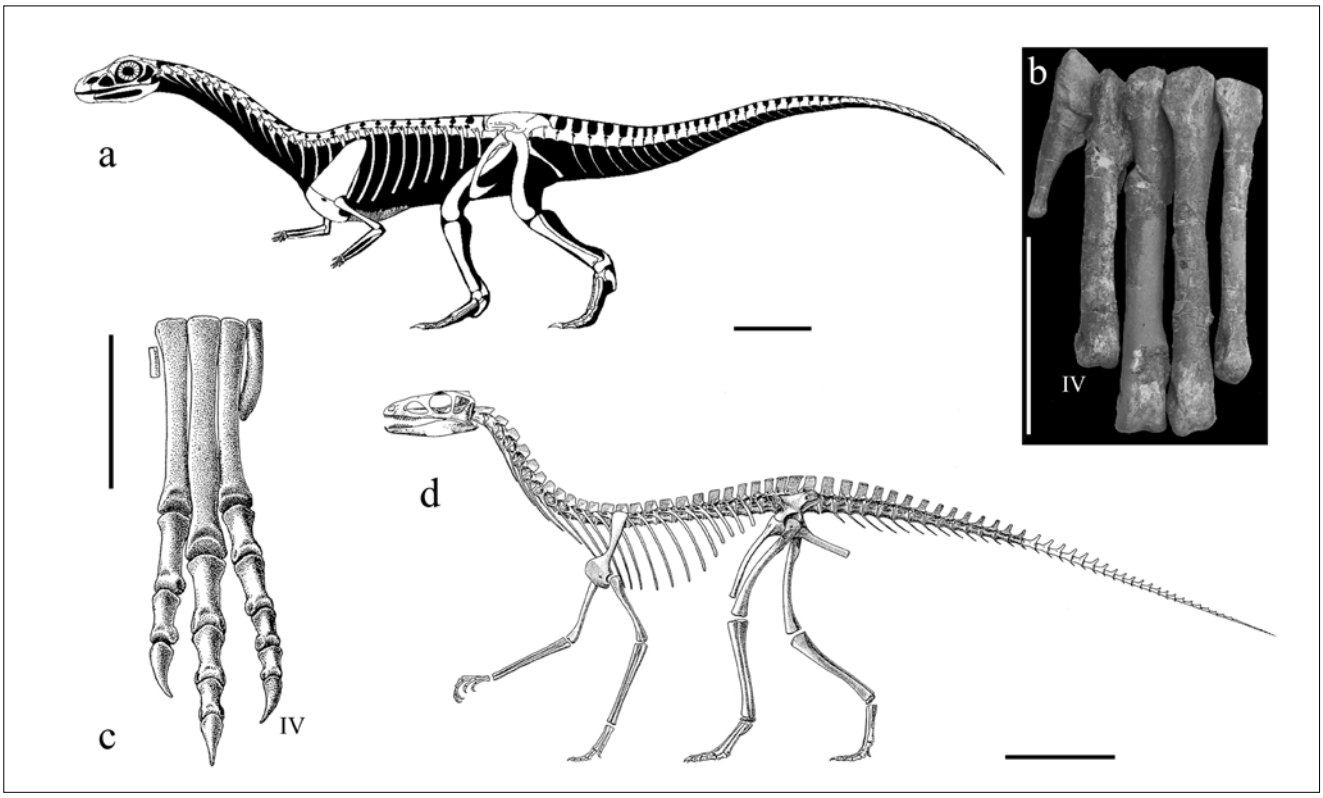

Fig. 10 - Zoological affinities for *Evazoum* and *Atreipus*. a. Skeletal reconstruction and b. right metatarsals of *Effigia okeeffeae* Nesbitt 2007. Left autopodium (c) and body restoration (d) of *Silesaurus opolensis* Dzik 2003. Scale bar 25 cm in a. and d.; 5 cm in b. and c.
Fig. 10 - Potenziali corrispettivi zoologici per Evazoum *ed* Atreipus*. a. Ricostruzione scheletrica e b. metatarsali destri di* Effigia okeeffeae *Nesbitt 2007. Autopodio sinistro (c) e ricostruzione (d) di Silesaurus opolensis Dzik 2003. Scala 25 cm in a. e d.; 5 cm in b. e c.*

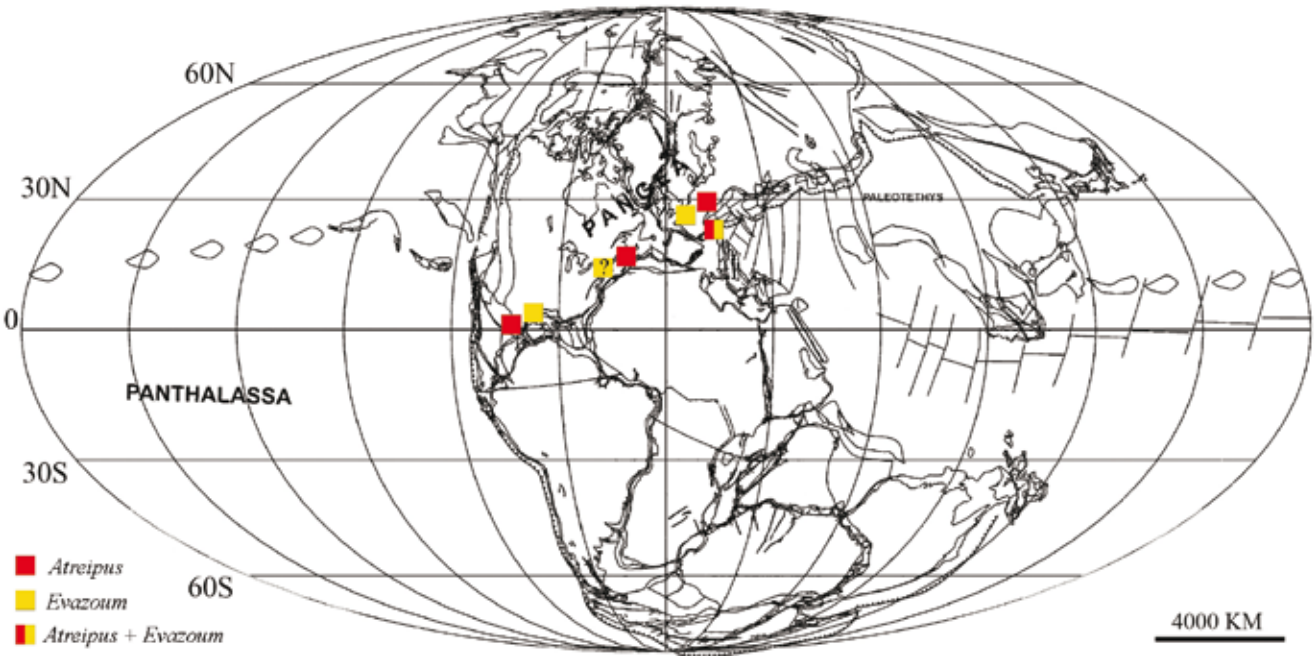

Fig. 11 - Paleogeographic map showing the occurrences of *Atreipus* and *Evazoum* in the Late Triassic (Carnian, 224 My). Red: *Atreipus*, yellow: *Evazoum*; red/yellow: co-occurrence of *Atreipus* and *Evazoum* in the same outcrop (map from Golonka 2007, modified).
Fig. 11 - Mappa paleogeografica mostrante la distribuzione di Atreipus *ed* Evazoum *nel Triassico Superiore (Carnico, 224 Ma). Rosso:* Atreipus*, giallo:* Evazoum*; rosso/giallo: associazione di* Atreipus *e* Evazoum *nello stesso affioramento (mappa da Golonka 2007, modificata).*

Tab. 1 - Synopsis of the pollen data.
Tab. 1 - Sinopsi dei dati pollinici.

SPORES	APICULATI	*Spiritisporites spirabilis* Sheuring, 1970 *Baculatisporites* sp. N. 1
	CAVATOMONOLETES	*Aratrisporites scabratus* Klaus, 1960 *Aratrisporites* sp. *Granulatisporites* sp.
POLLEN	MONOSACCITES	*Enzonalasporites vigens* Leschik, 1956 *Patinasporits densus* Leschik, 1956 emend. Sheuring, 1970 *Pseudoenzonalasporites summus* Sheuring, 1970
	CIRCUMPOLLES	*Paracirculina quadruplicis* Sheuring, 1970 *Camerosporites secatus* Leschik, 1956 emend. Scheuring 1978 *Duplicisporites verrucosus* Leschik, 1956 emend. Scheuring 1978 *Duplicisporites granulatus* Leschik, 1956 emend. Scheuring 1970 *Granuloperculatipollis rudis* (Venkatachala and Gòczàn, 1964) emend. Scheuring, in Mostler *et. al.* 1978
	POLYPLICATES	*Brodispora* sp.
	ALETES	*Ricciisporites* cf. *R. tuberculatus* Lundblad, 1954

Tab. 2 - Stratigraphic occurrences of *Atreipus* and *Evazoum* sorted by formation.
Tab. 2 - Distribuzione stratigrafica di Atreipus *ed* Evazoum*, selezionata per formazioni.*

	America		Europe		
	Eastern North America	Western N. America	France*	Germany	Italy
Atreipus	Passaic Formation[1]; Gettysburg Formation[1]; Cow Branch Formation[1]; Wolfville Formation[1]; Lokatong Formation[1]	Chinle Formation[3]	Ensemble gréso-dolomitique gris [EGDG] Grès inférieurs[4] ; Formation des «Grès inférieurs»[5] ;	Hassberge Formation[6]; Steigerwald Formation[6]; Stuttgart Formation[1]; Benk Formation[6]	Travenanzes Formation[8]
Evazoum	?Wolfville Formation[2]; ?Passaic Formation[2]	Chinle Formation[2]		Löwenstein Formation[7]	Travenanzes Formation[8]; Monte Marcello Formation[9]

* See text for the ichnotaxonomic interpretation of the French material.
[1] Olsen & Baird 1986; [2] Lockley *et al.* 2006; [3] Lockley & Hunt 1995; [4] Gand *et al.* 2005; [5] Gand & Demathieu 2005; [6] Haubold & Klein 2000; [7] Haderer 2004; [8] This work; [9] Nicosia & Loi 2003

comprenne en plus, la période Anisien supérieur-Ladinien inférieur". According to Gand & Demathieu (2005), the specimens from the upper Ladinian and lower Anisian of France are here considered as *Atreipus* isp., pending however a formal assignment of the material.

The German record of *Atreipus* is summarized in Haubold & Klein (2000), and spans from the Middle to the Late Triassic. Claims of possible *Atreipus* from the Early Jurassic of Poland (Gierliński & Niedźwienski 2002) are doubtful; the latest *Atreipus* is considered here older than the Triassic-Jurassic boundary (see also Szajna & Hartline 2003).

Evazoum (*sensu* Lockley *et al.* 2006) has been recognized in North America (Farlow & Lockley 1993; Lockley *et al.* 1993; Lockley & Hunt 1995; Hunt *et al.* 2000; Lockley *et al.* 2000; Gaston *et al.* 2003; Klein *et al.* 2006; Lockley *et al.* 2004) and Europe (Lockley *et al.* 1996). A couple of tracks described by Haderer (2004: figs 1, 2g, 2h, 3g, 3h) from the Stubensendstein of Germany (Staatliches Museum für Naturkunde Stuttgart, SMNS 81826) and referred to a prosauropod trackmaker are ascribed here to *Evazoum* (see Tab. 2 for a summary).

Olsen & Baird (1986) considered *Atreipus* a possible basal ornithischian footprint, not excluding however a dinosauriform origin for this ichnite. This ichnogenus has been regarded as ornithischian by Haubold (1986) who later opted for a dinosauriform origin (Haubold & Klein 2000). Carrano & Wilson (2001) proposed a synapomorphy based assignment of *Atreipus* to the dinosauriforms, while Irmis *et al.* (2007a) and Nesbitt *et al.* (2007) consider an unambiguous attribution either to dinosauriform or ornithischian as not constrained by the skeletal record. *Atreipus* is here interpreted as a probable dinosauriform ichnite (Fig. 10c, d), with an early occurrence in Middle Triassic strata.

Evazoum has been originally regarded (Nicosia & Loi 2003) as a prosauropod (*sensu* Galton & Upchurch 2004) footprint; however recent findings (Nesbitt 2007) of biped crurotarsan with a high degree of convergence in foot morphology with sauropodomorph imply a more cautious attribution, and therefore a crurotarsan origin cannot be excluded (Fig. 10a, b). From a paleogeographic point of view, the distribution of *Atreipus* and *Evazoum* on a Late Triassic Pangea (Golonka 2007) map shows that both ichnogenera are limited between 0° and 30° paleolatitudes N (Fig. 11).

4. CONCLUSIONS

Atreipus-like footprints appear for the first time in the Italian ichnologic record and occur together with *Evazoum*.

According to Gand & Demathieu (2005) the statigraphic distribution of *Atreipus* as originally defined must be regarded in the light of new data, in particular of European material currently assigned to different ichnospecies (e.g.: *Coelurosaurichnus perriauxi*, *C. grancieri*).

The occurrences of these ichnogenera have been analyzed in the frame of the Late Triassic paleogeography, showing a distribution restricted between the equator and the 30° North. Noteworthy, the distribution of *Atreipus* and *Evazoum* is in accordance with the tropical and para-tropical climatic boundary proposed by Scotese (2000) during the Upper Triassic; however, sampling is still limited and new discoveries can possibly enlarge this distribution.

The key role of Late Triassic records in the understanding of the first phase of dinosaur radiation is remarkably enhanced by the new discovery. The co-occurrence at the Mezzocorona ichnosite of dinosauriforms, dinosaurs and non-dinosaurian archosaurs is in accordance with the most recent view of non abrupt substitution (Irmis *et al.* 2007b) of dinosaur fauna over more archaic ones.

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