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TWO NEW ICHNOSITES FROM THE PERMO-TRIASSIC OF CARNIC ALPS (FRIULI VENEZIA GIULIA, NE ITALY)

DUE NUOVI ICNOSITI DAL PERMO-TRIASSICO DELLE ALPI
CARNICHE (FRIULI VENEZIA GIULIA, ITALIA NORDORIENTALE)

Riassunto breve - Vengono segnalati due nuovi icnositi dalle Alpi Carniche del Friuli Venezia Giulia (Italia Nordorientale). Il sito di Valdajer (Ligosullo), all'interno dei depositi Permiani della Arenaria di Val Gardena, conserva impronte riferibili all'icnogenere *Pachypes* le cui grandi impronte vengono così per la prima volta segnalate in Friuli. Il secondo sito è quello di Pierabech (Forni Avoltri), dove un masso proveniente dai livelli della Formazione di Werfen conserva alcune depressioni che potrebbero esser riferite a tracce di seminuoto di una grande tetrapode; non si può comunque escludere che si tratti di strutture sedimentarie di origine inorganica. Se si tratta di impronte esse rappresentano l'inattesa testimonianza di grandi tetrapodi nel Triassico inferiore, immediatamente successivi alla grande estinzione di massa del passaggio Permiano/Triassico.

Parole chiave: Impronte di vertebrati, *Pachypes*, Permo-Triassico, Arenaria di Val Gardena, Formazione di Werfen, Alpi Carniche.

Abstract - Two new vertebrate ichnosites are reported from the Carnic Alps of Friuli, NE Italy. The Valdajer (Ligosullo) site occurs in the Upper Permian Arenarie di Val Gardena and it preserves tracks referred to the large-sized ichnogenus *Pachypes* that is reported for the first time in Friuli. A boulder from the Werfen Formation near Pierabech (Forni Avoltri) preserves depressions that could be half-swim tracks of a large tetrapod; however, it cannot be excluded that they are inorganic sedimentological structures. If they are actual footprints, they would represent the unexpected record of a large-bodied tetrapod in the Lower Triassic just after the catastrophic mass extinction at the Permian/Triassic boundary.

Key-words: Vertebrate footprints, *Pachypes*, Permo-Triassic, Arenaria di Val Gardena, Formazione di Werfen, Carnic Alps.

Introduction

The first report of vertebrate fossil tracks from Friuli Venezia Giulia Autonomous Region (Northeastern Italy) dates back to 1986, when P. Mietto and G. Muscio described two tetrapod footprints from the Upper Carboniferous (Pennsylvanian) of the Carnic Alps (Udine Province). Since then, several other tetrapod ichnofossils have been discovered and published, including material of great scientific interest like the tracks and nests in the Carnian (Upper Triassic) of Dogna Valley (DALLA VECCHIA 1996; AVANZINI et al. 2007), the dinosaur footprints from the Norian-Rhaetian of the western Carnic Alps (DALLA VECCHIA & MIETTO 1997; DALLA VECCHIA 2006; MARZOLA & DALLA VECCHIA in press), the dinosaur footprints from the Lower Cretaceous of the Cansiglio Plateau (DALLA VECCHIA & VENTURINI 1995; DALLA VECCHIA 1999), and mammalian trackways from the Neogene of the Osoppo hill (DALLA VECCHIA & RUSTIONI 1996).

The record of Palaeozoic and Mesozoic vertebrates tracks is rich also in the close areas of Veneto and Trentino-Alto Adige Regions (for a recent review see NICOSIA et al. 2005 and DALLA VECCHIA 2013), which share with Friuli Venezia Giulia a similar geological history.

Two further ichnosites added in the last years, both from the Carnic Alps in the Udine Province and from the Permo-Triassic sequence, are the object of this note.

Valdajer locality (Ligosullo Municipality)

In 2011, Mario Cuder, retired teacher living in Tolmezzo, informed the Museo Friulano di Storia Naturale in Udine about the presence of probable vertebrates footprints in an outcrop located near the castle of Valdajer in the territory of the Ligosullo Municipality (Fig. 1). The footprints were mapped in autumn 2012 by two of the authors (FMDV and GM).



Fig. 1 - Location of the finding sites.
- Posizione della località di rinvenimento.

Geology and age

The footprints-bearing outcrop is located along the road that goes up from the castle of Valdajer to the Casera Valdajer locality, at an altitude of about 1340 m above sea level, just passed the crossroads towards Casera Cuesta Robbia Alta locality, on the left side of the road. The section (Fig. 2) is a little more than 1,5 m thick and it is made mainly of reddish pelite. It belongs to the Arenaria di Val Gardena (Val Gardena Sandstone Formation) that is 40 to 240 metres thick in Friuli, it is referred to the Upper Permian, and originated in a continental environment (VENTURINI 2006).

During the Late Permian, the present day area of the Carnic Alps as well as most of the Southern Alps was an extended continental plain under a hot-dry climate and crossed by ephemeral rivers carrying sediments from northern reliefs. Lagunar and shallow marine environments existed to south east in Friuli; a slow transgression gradually brought them to the north leading to the deposition of the Formazione a Bellerophon (Bellerophon Formation) in Carnia at the end of the Permian (VENTURINI 1986, 2006).

Bedding is 30° dipping to South; it is lens-like and discontinuous. Whitish dolomite caliches with a diameter ranging one to six centimetres are present into the pelite; they are scattered or concentrated in horizons (Fig. 3b). Carbonate horizons just a few centimetres thick are rarer. Two pelite levels with scattered caliches about 20-25 cm below the track-bearing surface show mud-cracking in their upper surface (Fig. 3a). The polygons measure 5-10 centimetres in diameter and the cracks are filled up with reddish pelite. The tracks

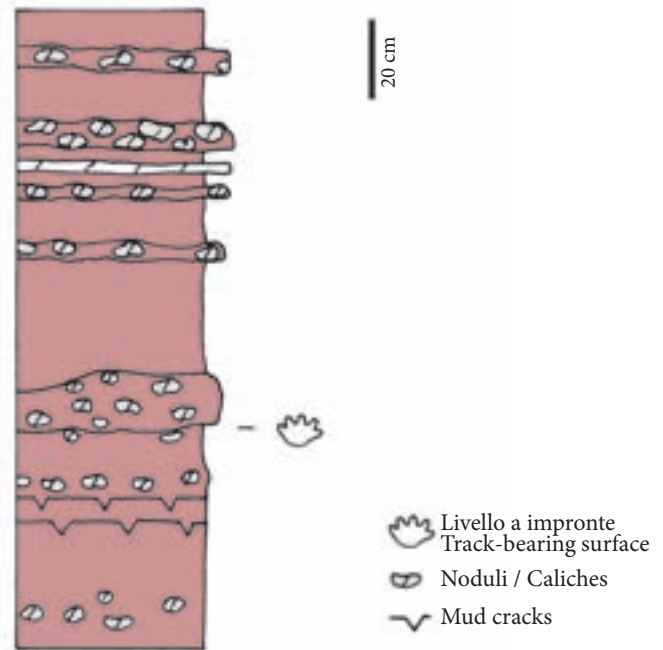


Fig. 2 - The stratigraphic column of the Valdajer locality. Levels rich in caliches are protruding; in white the carbonate horizon.
- Colonna stratigrafica del sito di Valdajer. Sono evidenziati i livelli ricchi di noduli, e, in bianco, quello carbonatico.



Fig. 3 - Sedimentary structures in the stratigraphic section of the Valdajer locality. a) mud cracks; b) caliches. The scale bar is centimetric.
- Strutture sedimentarie nella sezione di valdajer. a) mud cracks; b) caliches. la scala è centimetrica.

are preserved on an irregular upper bedding surface of a bed made of reddish pelite containing some carbonate nodules.

The section belongs to the lower part of the Formation (VENTURINI 2006) where carbonate nodules are particularly abundant.

The trackway

Five tracks could be identified in the outcrop and they were mapped (Figs 4-5). The northern and eastern parts of the track-bearing surface were still covered by debris and moss when we mapped the site. Later, cleaning of the surface for the realization of its mould revealed a further track in the upper (northern) part of the surface, which is not reported in Fig. 5b.

Probably the tracks continue into the rock wall and they could be exposed removing the covering beds.

Another possible track, partial and similar to the five here described, occurs a few metres apart in another small outcrop, probably exposing the same surface (G.M., pers. obs.).

The five tracks are in a bad condition of preservation because of the weathering of the surface and the intimate breakage of the pelite in small and loose fragments caused by tectonics. They are essentially shallow and irregular depressions surrounded by a low expulsion rim. Apparently they are aligned in two rows (three in one row and two in the other) with a N-S direction (Fig. 5b). They are interpreted as a trackway of a quadrupedal trackmaker made of three consecutive pedal prints, two consecutive of one pes (the right in Fig. 5b) and one of

the other, with the manus print associated to the first prints of each pes.

The depressions have a roughly subrectangular outline, with an irregular edge. Their main axis, which corresponds to the width of the tracks, is quite similar in the five tracks, ranging between 21 and 22.5 centimetres. They are much wider than long (the width/length ratio of the manus print is 1.35-1.50, while the ratio of the pedal print is 1.67-1.73). The depressions identified as the manus prints are just a little smaller than the pedal prints: the ratio between the width of the manus print and that of the pes is 0.93. The foot morphology is not well defined and digital prints are not recognizable for sure, but trackmaker's digits were undoubtedly short. The expulsion rim is shallow but broad.

The manual prints occur in front of the pedal ones at a distance of 32.5 cm on the presumed right side and 37.5 cm on the left (measured from the centre of the depression). The outer and inner widths of the trackway are significant, respectively 78 cm and 30-35 cm. The pace angulation of the pes is quite low (76°), the pace is 60 and 69 cm, and the stride is only 79.5 cm.

Discussion

The available information suggests that the trackmaker was a large quadrupedal tetrapod with a wide body and a manus almost as broad as the pes and with short digits, which was moving slowly but without dragging the belly and the tail.

The size and morphology of the tracks (wider than long, manus nearly as large as pes and with short



Fig. 4 - The outcrop with the track-bearing surface of the Valdajer locality. For the scale bar see fig. 5.
- L'affioramento di Valdajer con la superficie interessata dalle piste. Per la scala vedi fig. 5.

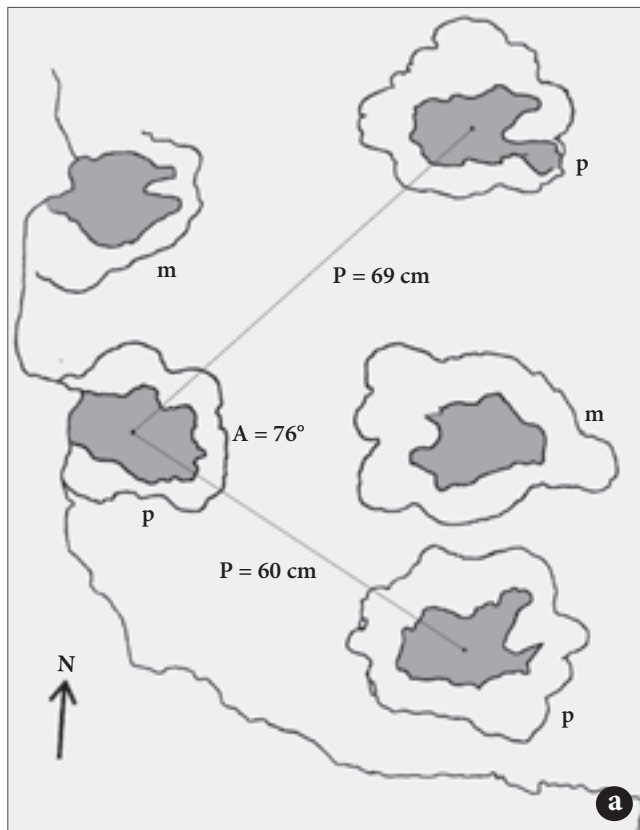


Fig. 5 - The track-bearing surface of the Valdaj locality; a) map, abbreviations: A = pace angulation, m = manus print, p = pes print, P = pace; b) photograph, scale bar = 100 mm.

- La superficie con le piste di Valdaj; a) mappa, legenda: A = angolo del passo, m = impronta della zampa anteriore (manus), p = impronta della zampa posteriore (pes), P = passo; b) fotografia, scala = 100 mm.



digital prints), the trackway parameters, and the stratigraphic provenance are compatible with just one Permian ichnogenus: *Pachypes* (see HAUBOLD 1971; AVANZINI et al. 2001; VALENTINI et al. 2008, 2009). The ichnospecies *P. dolomiticus* LEONARDI, CONTI, LEONARDI, MARIOTTI & NICOSIA, 1975 is reported from the Arenaria di Val Gardena of the Bletterbach gorge (Redagno/Redein, Alto Adige/Südtirol; LEONARDI et al., 1975), Seceda Mt. (Ortisei, Alto Adige/Südtirol), and Recoaro (Vicenza Province; MIETTO 1981). According to NICOSIA et al. (2005, p. 47), it was found in all Upper Permian ichnosites of the Southern Alps and it is the most characteristic ichnotaxon of the Upper Permian ichnoassociation. No other ichnogenus with similar size and trackway parameters is known in the Permian of Southern Alps.

Pachypes is ascribed to the pareiasaurs (VALENTINI et al. 2008, 2009), a group of large-bodied anapsid amniotes typical of the Middle-Upper Permian that some paleontologists once considered as strictly related to chelonians (e.g., LEE 1997). They were heavy quadrupeds characterized by a stocky body up to three metres long,

with massive limbs and short digits. Their skeletal remains were found mainly in South Africa and Russia, but also in other African countries (Zambia, Tanzania, Niger and Morocco), Brazil, China, and Europe (Scotland and Germany).

Pierabech locality (Forni Avoltri Municipality)

In summer 2012, Carlo Gervasi, priest of San Marco church in Udine, reported to the Museo Friulano di Storia Naturale the presence of a large boulder with presumed vertebrate tracks located at 1058 m above sea level on the right bank of Avanza Brook, just upstream of its confluence with Degano Torrent near Pierabech (Fig. 1).

Geology and age

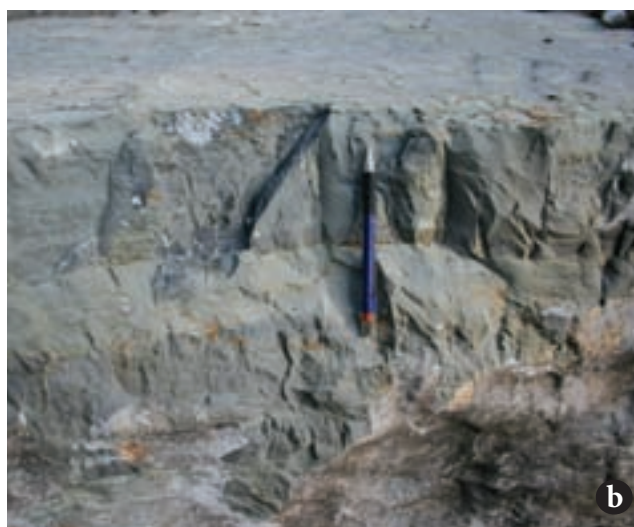
The boulder has the form of an irregular parallelepiped and measures about 200 cm to 155 cm and it is 50 cm



Fig. 6 - The track-bearing boulder in the bed of the Avanza Brook.
- *Il masso con le impronte nell'alveo del Rio Avanza.*



Fig. 7 - Detail of the bedding (a) and lamination (b) in the boulder of the Pierabeck locality.
- *Particolare della stratificazione (a) e della laminazione (b) nel masso di Pierabeck.*



thick (Fig. 6). It is part of a thick limestone bed; because of its shape and rounded edges, it probably has been subject to a transport along the brook, although limited, in addition to a possible displacement by the people working to restore the brook bed. The hydrographic basin of the Avanza Brook is not very extended, thus the block probably comes from an outcrop that is relatively close to the place it is now.

The boulder is made up of gray calcilutite with a very low percentage of phyllosilicatic minerals scattered in the carbonate matrix, which originated a greenish film on the weathered surfaces. Flattened mica particles of the size of silt are also visible, especially on the upper bedding surface. The upper portion of the boulder as exposed (about 15 cm on a total of 50 cm) seems to be barely laminated (with plane-parallel lamination; Fig. 7). The surface bearing the presumed tracks is flat, slightly wavy and it has a parallel fracture on the short side of the block, about two cm wide, originated after the depression. The surface shows a dense network of conjugated fractures (angles between planes range 70°-110°), related to tectonic stress on a consolidated mass.

A thin (millimeter-thick) calcite film locally removed by weathering covers all the previous structures.

Only Palaeozoic and Triassic formations crop out in the basin of the Avanza Brook and close surroundings. The Palaeozoic units include Devonian-Silurian meta-limestones and marbles, the Conglomerato di Sesto (Sesto Conglomerate; ?Middle-Upper Permian), the Arenaria di Val Gardena (Upper Permian), and the Formazione a Bellerophon (uppermost Permian). The Triassic units include the Formazione di Werfen (Werfen Formation; Lower Triassic, Induan and Olenekian), the Dolomia del Serla inferiore (Lower Serla Formation; Anisian) and the Formazione del Serla superiore (Upper Serla Formation; Anisian, cfr. Popera Dolostone) (VENTURINI et al. 2001; VENTURINI 2009).

Considering the characteristics of the lithostratigraphic units listed above, the lithotypes that are most similar to that of the boulder occur in some members of the Werfen Formation, namely the Membro di Siusi (Siusi Member), the Oolite a Gasteropodi (Gastropod Oolite), and the Membro di Val Badia (Val Badia Member). The last one crops out in more distant areas not in the



Fig. 8 - Limestone bed in the Werfen Formation, cropping out 200 m south of the boulder, close to Pierabech summer camp. The lithology is similar to that one of the boulder.

- *Calcari della Formazione di Werfen, simili a quelli del masso di Pierabech, affioranti circa 200 m a sud, presso la colonia estiva.*

hydrographic basin of the Avanza Brook, while the other two crop out in stratigraphic order along the right slope of the Avanza Brook just south of Pierabech. Thick limestone beds made of gray calcilutite alternated to both pelite horizons and coarse bioclastic levels (Fig. 8) crops out in that setting. The depositional environment of those limestone intercalations was subtidal but shallow in a carbonate platform setting, periodically swinging to intertidal conditions.

The tracks

The upper exposed surface of the boulder preserves a sequence of 11 aligned depressions with a kidney or sausage outline (Figs 9-10). The row of depression is about 1.6 m long.

The sequence has a group of three parallel and close to each other depressions about 10 cm long at its extremities; depressions are diagonally arranged compared to the alignment. Other five single depression with a similar morphology and diagonal arrangement occur in between those two sets of depressions. The described sequence ends with a group of three depressions similar to the first one (Fig. 9). Each depression is deeper along the convex side, the maximum depth being about a centimetre and has a slightly raised edge. Their length ranges 5-10 cm.

Discussion

The sequence of tracks is certainly not comparable to a “normal” trackway of a walking tetrapod, both bipedal and quadrupedal. Its irregularity and incompleteness as well as the morphology of the depressions suggest that, if made of vertebrate traces, it represents a half-swim trackway (see LOCKLEY & MEYER 2000, p. 177) i.e., a series of footprints left by an animal swimming in shallow water and touching occasionally the bottom, in this specific case sometimes with three fingers, sometimes just with one finger or with the medial or lateral margin of the foot. In half-swim trackways, the digital prints are typically parallel in each footprint and are less than the actual digital count, often three for pentadactyl feet. Numerous examples of this kind of trackways have been reported in literature (cfr. COOMBS 1980; LOCKLEY & MEYER 2000; AVANZINI et al 2005; EZQUERRA et al. 2007). In the case of the tracks of Pierabech, given the footprints size, it could be a quite large tetrapod.

The characteristics of the sedimentary environment of the Membro di Siusi and the Oolite a Gasteropodi are compatible with this hypothesis. Although the presence of tetrapod tracks in the Werfen Formation of Friuli is dubious (DALLA VECCHIA 2013), they are documented in the close Veneto and Trentino Alto Adige/Südtirol (LEONARDI 1968; MIETTO 1986; CONTI et al. 2000; NICOSIA et al. 2005) although they are rare. They are mostly referable to the ichnogenus *Rhynchosauroides* MAIDWELL 1911 and include also half-swim tracks, although of small-sized reptiles (NICOSIA et al. 2005).

Another possibility is that the depressions were produced by a dragged object on the tidal flat by tidal or other currents. The process can be easily observed on the tidal flats of the northern Adriatic sea. A pebble of coherent mud laying on the surface of the muddy sand of intertidal part of the flat is an obstacle to the tidal current; the turbulence created by the obstacle produces a depression all around the lee side until the inertia is overwhelmed by tidal current or the mixed action of tidal current, currents forced by strong winds and the wave action, and the object is removed



Fig. 9 - The presumed tracks. Left: photograph (not taken perpendicular to the surface); right: drawing based on the photograph. Scale bar = 100 mm.
 - *Le possibili impronte di Pierabeck. A sinistra: una fotografia (la ripresa non è perpendicolare alla superficie); a destra: il disegno basato sulle fotografie. Scala di riferimento = 10 cm.*



Fig. 11 - Sedimentary structures created by the tide current in the tidal flat of Grado (Adriatic Sea, Gorizia Province).
 - *Strutture sedimentarie create dalle correnti di marea nella piana tidale di Grado (Gorizia, Mare Adriatico).*



Fig. 10- Detail of one of the presumed tracks. Scale bar = 10 cm.
 - *Dettaglio di una delle possibili impronte. Scala di riferimento = 10 cm.*

depositing again after a limited transport. The process repeats and the object is moved away again. With this phenomenon repeated several times, the final result is a series of crescent-like depressions in a row in direction of the stream and with the object at an end of the series (Fig. 11).

Another possibility is that the depressions are marks produced by an object rolling at the sea bottom, for example an ammonoid shell (see BARTHEL et al 1994; LANDMAN & COBBAN 2007). Ammonoids are relatively common in the Werfen Formation (VENTURINI 2006).

Conclusions

The new two localities increase the ichnological record of Friuli. *Pachypes* is reported for the first time in the Region and it is the first unambiguous ichnofossil of a vertebrate from the Permian of Friuli; it shows that large tetrapods lived locally in the continental plains where the Arenaria di Val Gardena was depositing. The traces from Pierabech locality, if half-swim tracks of an animal and not inorganic sedimentological features, would represent the unexpected record of a large-bodied tetrapod in the Lower Triassic just after the catastrophic mass extinction at the Permian/Triassic boundary.

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