



The Carboniferous tetrapod ichnoassociation from Italy

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ABSTRACT - The tetrapod footprints from the Carboniferous (Pennsylvanian) of Italy come from the upper Moscovian San Giorgio Formation of Sardinia and the lower Gzhelian Corona Formation of the Carnian Alps. They include exclusively anamniote tracks: the ichnogenera *Batrachichnus* and *Limnopus* and tetrapod tracks indet. similar to *Matthewichnus*. The occurrence of anamniote tracks may have a marked palaeoecological significance, since these tetrapods were tied to water for reproduction. These tracks represent the oldest record of tetrapods from Italy (either from trace fossils or skeletons) and the oldest Italian record of these ichnogenera. Despite the fragmentary material and the few known localities, the Pennsylvanian of Italy has a noteworthy potential for further prospecting, because of the relatively good preservation and the stratigraphy of the track-bearing formations. The Italian ichnoassociation could be the key for the understanding of the *Notalacerta* and *Dromopus* footprint biochrons in the Carboniferous of W Europe, which is less extensively known than the North American record.

Keywords: tetrapod footprints; vertebrate tracks; Carboniferous; Pennsylvanian; Italy.

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1. INTRODUCTION

The tetrapod footprints from the Carboniferous of Italy are known since the eighties of the twentieth century (Fondi, 1980; Mietto et al., 1986). The tracks known from the San Giorgio Formation of Sardinia are of late Moscovian age and constitute the oldest record of tetrapod tracks from Italy (Marchetti et al., 2018). The tracks known from the Corona Formation of the Carnian Alps are of early Gzhelian age and include the oldest record of tetrapod tracks from the Southern Alps (Marchetti et al., 2019a). Despite the few occurrences and the low diversity, the Carboniferous (Pennsylvanian) tetrapod ichnoassociation from Italy deserves attention because of the scarce tetrapod footprint record from the Carboniferous of W Europe and the non-occurrence of tetrapod skeletons of this age from Italy. The purpose of this contribution is to provide a review of the tetrapod footprint record from the Carboniferous of Italy as understood from the most recent literature, in order to highlight new insights and possible directions of further prospecting.

2. GEOLOGICAL SETTING AND STRATIGRAPHY OF SAN GIORGIO BASIN

The Carboniferous San Giorgio Basin is located in southwestern Sardinia (Iglesiente sub-region), about 2 km SW from Iglesias (Fig. 1). The fluvio-lacustrine succession of the San Giorgio Formation (about 40 m thick) discordantly lies on the Variscan basement (Cocozza, 1967; Carmignani et al., 2012) and currently is badly exposed and covered by deposits of the aborted Campo Pisano Pb-Zn mine. The most continuous succession crops out along the waterway drain cut, excavated near the mine dump that modifies the San Giorgio river path (Del Rio and Pittau, 2004).

Several studies were published between the end of the 19th and the beginning of the 20th century (e.g. Gambera, 1897a, 1897b; Arcangeli, 1901; Merlo, 1911; Testa, 1914; Novarese, 1917; Novarese and Taricco, 1923; Oosterban, 1936), but the most accurate description of the fluvio-lacustrine successions was proposed only during the 60s by Cocozza (1967). Recently, other new studies have provided useful sedimentological and palaeontological

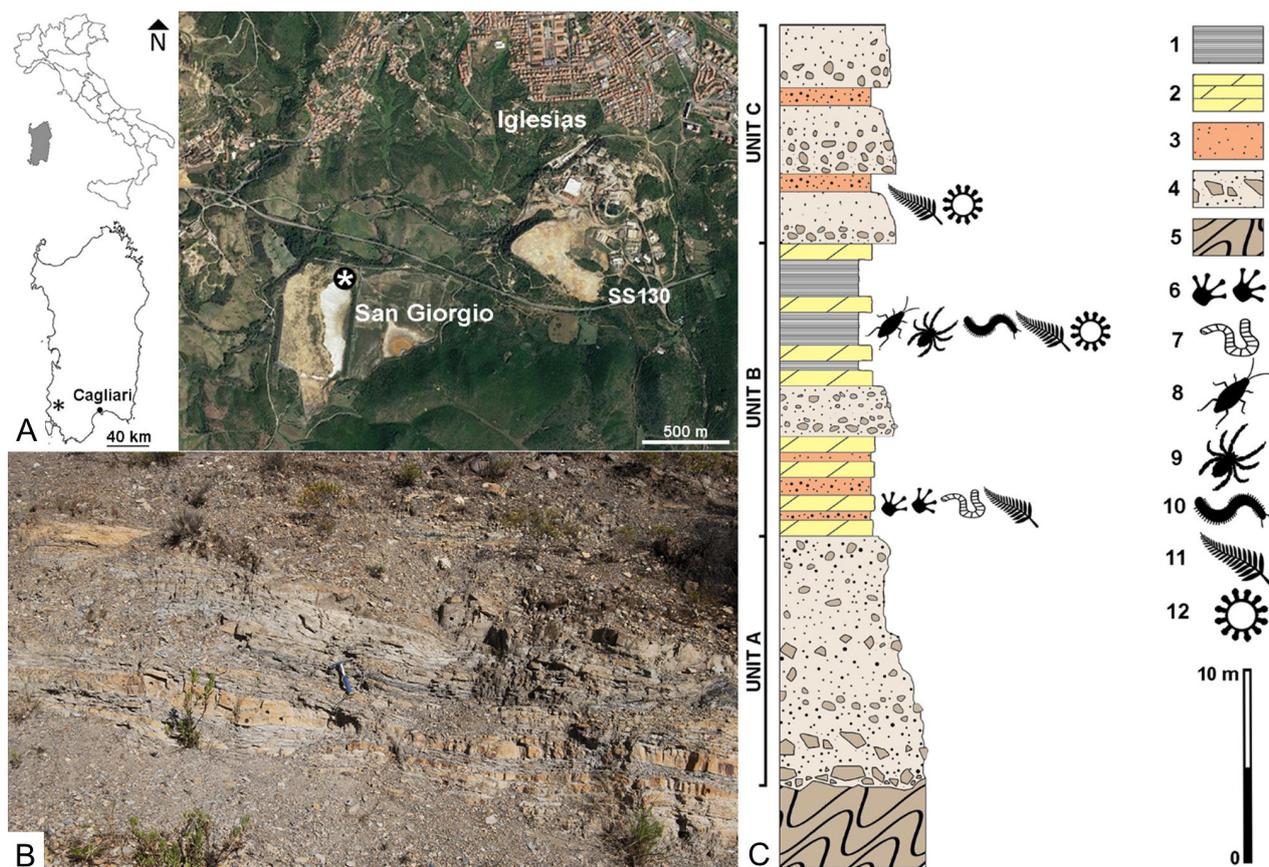


Fig. 1 - Geological setting of the San Giorgio Basin, Sardinia. A) Location of the Carboniferous San Giorgio Basin; B) Unit B of the San Giorgio Formation, trace fossil locality of Nicosia et al. (2004); C) Synthetic stratigraphic column of the San Giorgio Formation and its informal units: 1, carbon-rich clays; 2, dolostones; 3, sandstones; 4, heterometric breccias and conglomerates; 5, Variscan basement; 6, tetrapod footprints; 7, invertebrate traces; 8, undetermined blattoid; 9, *Anthracomartus voelkelianus*; 10, *Arthropleura* sp.; 11, macroflora; 12, microflora.

data (e.g. Benedetti et al., 2002; Del Rio et al., 2002; Barca and Costamagna, 2003; Conti et al., 2004; Nicosia et al., 2004; Pillola et al., 2004; Selden and Pillola, 2009; Cleal et al., 2016; Marchetti et al., 2018).

Del Rio et al. (2002) divided the San Giorgio Formation succession into three units from the bottom to the top (Fig. 1): Unit A: heterolithic breccias, made up of polygenic, angular clasts (mainly Cambrian limestones and dolostones), with grey dolomitic cement (thickness 0-13 m); Unit B: yellow-grey dolostones, with local lenticular conglomerate bodies and minute well-bedded breccias with dolomitic cement, grading to platy dolomites, dolomitic siltstones, and carbon-rich clays, usually finely laminated, capped by massive sandstones (thickness 6-15 m); Unit C: mainly made up of polygenic heterolithic conglomerates, interfingering with sandy, flat, lenticular deposits, with local concentrations of plant remains and *Calamites* trunks in life position (thickness 6-11 m).

As regards the age of the succession, Novarese (1917) and Novarese and Taricco (1923) suggested an Autunian age based on the palaeoflora. Coccozza (1967) described several plant taxa and proposed an attribution to the late Stephanian. This age was confirmed by subsequent

studies on the sporomorph assemblages (Del Rio, 1973). Recently, Cleal et al. (2016) proposed a late Moscovian age based on the macroflora. In 1980, Fondi assigned a late Westphalian (D) age on the basis of the tetrapod footprints from the lower portion of Unit B. The author assigned these footprints to the ichnotaxon *Salichnium* (*Saurichnites*) *heringi*, after comparison with Saxonian ichnoassociations (central-eastern Germany). The taxonomic and biostratigraphic meaning of the material assigned to *Salichnium* by Fondi (1980) was recently revised by Marchetti et al. (2018) and it is no longer strictly indicative of a Westphalian D age (Haubold, 1996; Voigt, 2012). Furthermore, Marchetti et al. (2018) described the ichnoassociation of the lower portion of the Unit B and reported the following vertebrate and invertebrate ichnotaxa: *Batrachichnus salamandroides*, *Diplichnites* isp., *Cochlichnus anguineus*, *Treptichnus bifurcus* and *Treptichnus* isp. The only body fossils reported in the succession are represented by arthropod remains found in the upper part of Unit B: an undetermined blattoid wing, the mostly complete trigonotarbid arachnid *Anthracomartus voelkelianus* and an incomplete tergite of *Arthropleura* (Benedetti et al., 2002; Selden and Pillola, 2009).

3. THE SAN GIORGIO BASIN VERTEBRATE ICHNOASSOCIATION

3.1. HISTORICAL OVERVIEW

The first mention of vertebrate tracks from the Carboniferous of Italy is by Fondi (1980), who described in detail a specimen from Unit B of the San Giorgio Formation, previously found by his colleague Francesco Leone of the University of Cagliari, nearby the locality Casa Tagliani. Fondi (1980) assigned this material to *Salichnum heringi* (Geinitz, 1885) and compared the material with other occurrences of this ichnotaxon in German outcrops of Westphalian D age. More than 20 years later, new prospecting in the same locality resulted in the discovery of several new specimens with vertebrate and invertebrate trace fossils (Nicosia et al., 2004; Pillola et al., 2004). Notably, these works described other morphotypes different from the tracks assigned to *Salichnum heringi* by Fondi (1980). All this material was comprehensively restudied and described by Marchetti et al. (2018). These authors re-assigned *Salichnum heringi* to tetrapod track indet., noting a similarity of this material with the ichnogenus *Matthewichnus*. Moreover, several specimens were assigned to *Batrachichnus salamandroides*. This was the first description of the ichnogenus *Batrachichnus* from the Carboniferous of Italy. Marchetti et al. (2018) also described invertebrate

traces and hypothesised the alternation of three different palaeoenvironments (submerged, transitional and emerged) based on the association of trace fossils and on their morphological preservation.

3.2. ICHNOASSOCIATION STRUCTURE

The ichnoassociation includes the ichnospecies *Batrachichnus salamandroides* and tetrapod tracks indet. similar to *Matthewichnus*. *Batrachichnus salamandroides* (Fig. 2) is the most common morphotype from the San Giorgio Formation. It includes small-sized (*pes* length 0.5-1.5 cm) trackways, incomplete step cycles, isolated *pes-manus* couples and isolated *pes* and *manus* imprints (specimens MDLCA 23111, 23113, 23114, 23116, 23119, 23120; Museo Sardo di Geologia e Paleontologia Domenico Lovisato, Cagliari). This material was assigned to *B. salamandroides* by Marchetti et al. (2018), but some of these specimens had been previously described, although not classified, by Nicosia et al. (2004) and Pillola et al. (2004). *Batrachichnus* is considered a small (*pes* length <2 cm) track of temnospondyl anamniotes (Haubold, 1996).

The specimen MDLCA 3257 (described by Fondi, 1980) includes two trackways preserved in concave epirelief, perpendicular to each other, characterised by small tracks (*pes* length of about 1 cm), low pace angulation, secondary *pes-manus* overstepping and digit imprints commonly ending in parallel drag marks (Fig. 3). It has been recently

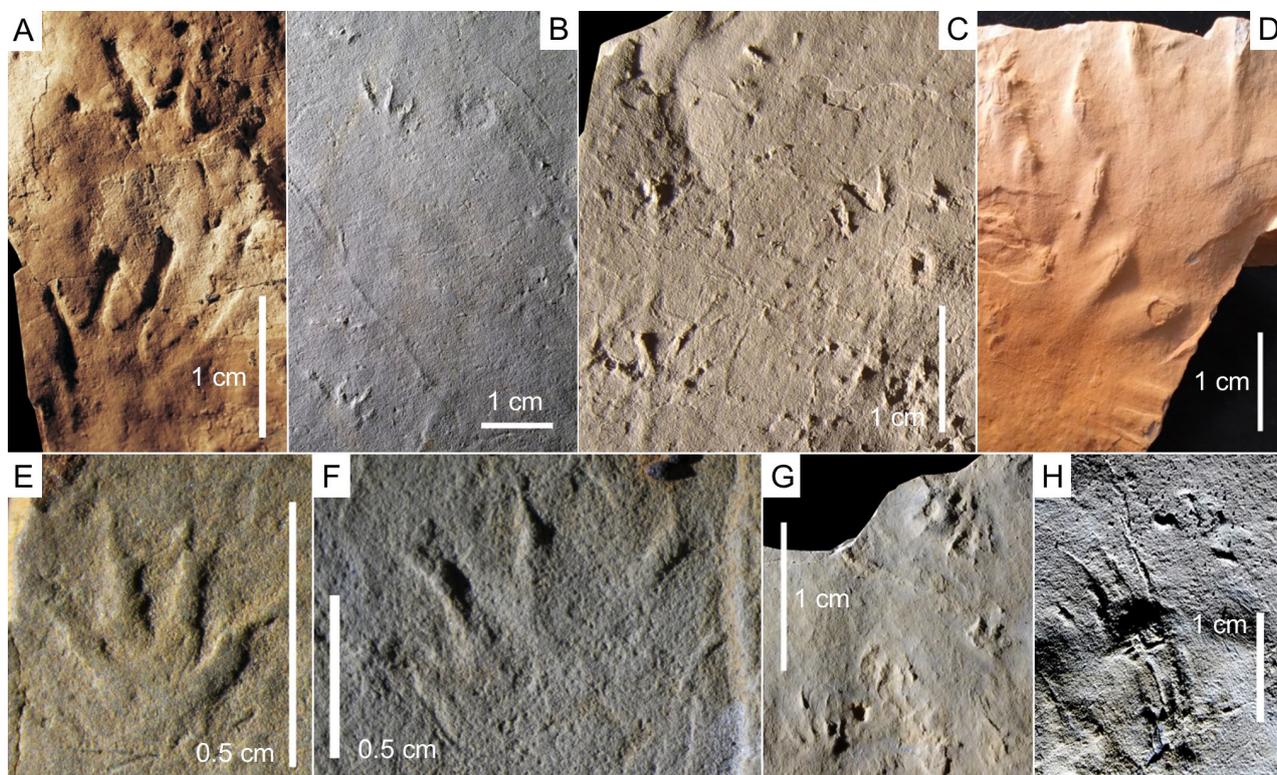


Fig. 2 - Tetrapod footprints from the San Giorgio Formation. Small temnospondyl tracks, ichnospecies *Batrachichnus salamandroides*. A) MDLCA 23116. *Pes-manus* couple, concave epirelief. B) MDLCA 23111. Trackway, convex hyporelief. C) MDLCA 23119. Incomplete step cycle, convex hyporelief. D) MDLCA Superimposed isolated tracks, convex hyporelief. E) MDLCA 23113. *manus* imprint, convex hyporelief. F) MDLCA 23114. *Pes* imprint, convex hyporelief. G) MDLCA 23121. Isolated tracks and parallel digit drag marks, convex hyporelief. H) MDLCA 23120. Isolated *manus* imprint and *pes-manus* couple showing parallel digit drag marks, convex hyporelief.

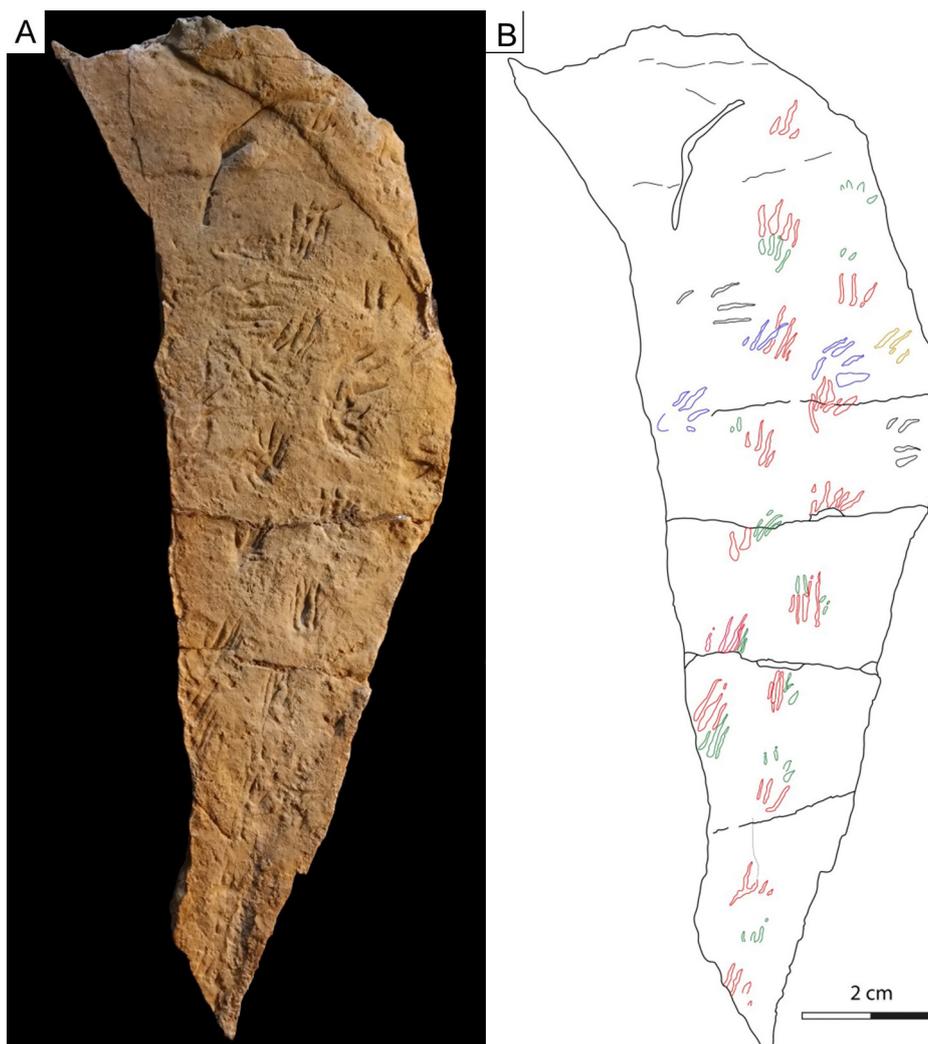


Fig. 3 - Tetrapod footprints from the San Giorgio Formation. Undetermined tetrapod footprints, specimen MDLCA 3257 (Fondi, 1980). A. Concave epirelief. B. Interpretive drawing. Note the main trackway and other incomplete step cycles disposed perpendicularly to the trace. Note the common overstep of the *pes* on the *manus* and the low pace angulation compared to the glenoacetabular distance in the main trackway.

re-analysed by Marchetti et al. (2018) and assigned to tetrapod tracks indet., showing some similarities to *Matthewichnus*. The trackmakers were probably small lepospondyl anamniotes.

The tetrapod ichnoassociation is not diverse, although some specimens show a good morphological preservation *sensu* Marchetti et al. (2019b). The tetrapod traces are constituted exclusively by small anamniote tracks and parallel digit drag marks (possible swimming traces), which generally indicate the presence of persisting water sources. This ichnoassociation includes the earliest occurrence of *Batrachichnus* from Italy, known also from the Cisuralian and possibly the Lopingian (Marchetti, 2016; Marchetti et al., 2019c). However, the ichnofaunal composition is not sufficient to provide more precise biostratigraphic data, because of the long stratigraphic range of *Batrachichnus*, which occurred within all the footprint biochrons of the Carboniferous (e.g. Fillmore et al., 2012). The tetrapod footprints from San Giorgio are

the oldest known from Italy (Marchetti et al., 2018) and are dated as late Moscovian (Cleal et al., 2016).

4. GEOLOGICAL SETTING AND STRATIGRAPHY OF CARNIAN ALPS

The oldest vertebrate trace fossils from the Southern Alps come from a thick succession known as the Pontebba Supergroup (305-295 Ma, Venturini, 2006), which outcrops extensively along the Carnian Alps of Friuli along the border with Austria, especially in the areas around the Lanza and Pramollo passes (between Paularo, Moggio Udinese and Pontebba). During the late Carboniferous, this area was near the palaeoequator (4°N) and was characterised by a wet and warm climate. Here, between the Mississippian and the Pennsylvanian, the Hercynian orogenesis generated a mountain chain known as “palaeocarnic” that, in a relatively short time, was eroded. The late Carboniferous palaeoenvironment

was conditioned by the tectonic development of three basins: the Forni Avoltri, Pramollo and Tarvisio basins. The Pramollo Basin contains the most extensive and thickest rock sequence, including about 2000 m of sediments accumulated during about 40 Ma (Venturini, 1983, 1991; Massari et al., 1991). The Pramollo Group of the Pramollo Basin is constituted - in stratigraphic order - by the Meledis, Pizzul, Corona, Auernig and Carnizza formations. The Pramollo Group is characterised by mixed continental-marine deposits, that in its upper part form recognisable depositional cycles linked to glacial and interglacial intervals (Venturini, 2006).

The only two footprints found so far come from the Corona Formation (late Carboniferous, early Gzhelian) (Fig. 4). It is a 300 m-thick succession, characterised by alternating quartz conglomerates, sandstones and mudstones. The conglomerates are coarse infillings of distributary channels in a deltaic environment (Venturini, 2006). The tetrapod footprints, described by Mietto et al. (1986), were impressed in the soft and fine-grained sediments of the deltaic plain crossed by distributary channels which, during episodic flooding, covered the surrounding areas with silt and sand. The abundant clastic sediment brought by streams was provided by the erosion of the Hercynian Chain. The fine-grained sandstones and mudstones are rich with plant remains and debris, occasionally forming coal. The thick vegetation that covered the swampy emerged areas was constituted mostly by horsetails (including forms 15 m high, such as *Calamites*) and lycopsids (even bigger), but in higher and drier areas grew mostly ferns, seed ferns (Pteridosperms) and cordaitales (e.g. Ronchi et al., 2012).

5. THE CARNIAN ALPS VERTEBRATE ICHNOASSOCIATION

5.1. HISTORICAL OVERVIEW

The discovery of tetrapod trace fossils in the Carnian Alps and Prealps started with the finding, in the 1980s, of

two isolated footprints from the late Carboniferous of the Pramollo-Lanza area. This was followed by the finding of several trace fossils of archosauromorphs, dinosaurs and mammals in younger units (Dalla Vecchia, 2013).

The first report of vertebrate footprints from the Carboniferous of the Southern Alps is that of Mietto et al. (1986), who described two relatively large, incomplete and isolated tracks from the Monte Corona Formation, localities Monte Auernig (Passo Pramollo) and Val Dolce (Passo di Lanza).

One of these footprints was found by Corrado Venturini in the Passo di Pramollo area (Pontebba) on a fallen block of silty sandstone along the trail that connects Passo Porta, Monte Auernig and Monte Corona. The specimen is now held by the Museo Friulano di Storia Naturale di Udine (MFSN 1808) (Fig. 5A). The trace fossil is preserved in convex hyporelief, and is 4.9 cm long and 3.8 cm wide. It consists of three, possibly four digits. According to Mietto et al. (1986), it is a partial footprint, probably deformed because of lateral sliding, of a right and semi-plantigrade *manus* which preserved the imprints of digits III-V and possibly also of digit II. Digit IV is the longest, digit V is the shortest (if we do not consider the dubious digit II trace). The digit imprints are short and wide, the imprints of digits IV and III are slightly medially curved. No claw marks were observed.

Mietto et al. (1986) refer this trace to basal tetrapods (“labyrinthodont amphibians”) based on general appearance, the lack of claw marks and because of the “functional prevalence” of digit IV. The most similar ichnogenus has been considered *Hylopus*; the main difference would be in the occurrence - in this ichnogenus - of a narrower imprint of digit IV. Therefore, the specimen from Pramollo has been referred by these authors to *Hylopus cf. hardingi* (otherwise known from the Mississippian of Nova Scotia; Marchetti et al., 2019b). An alternative interpretation is that this would have been a very deformed track of *Notalacerta*, fitting because of geologic age, but quite dissimilar in morphology (e.g.

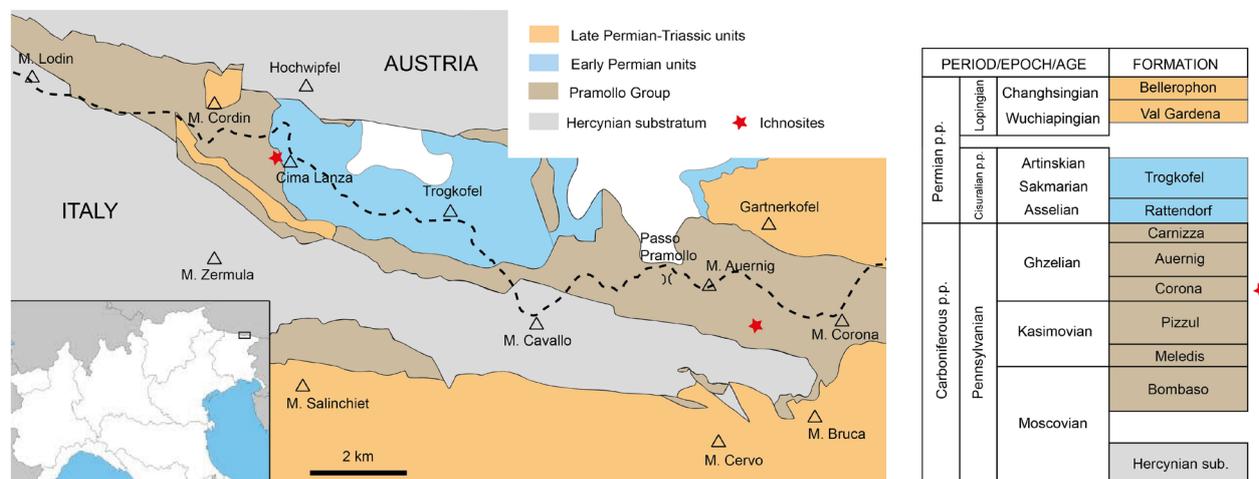


Fig. 4 - Geological setting of the Pramollo Basin and Corona Formation, Carnian Alps.

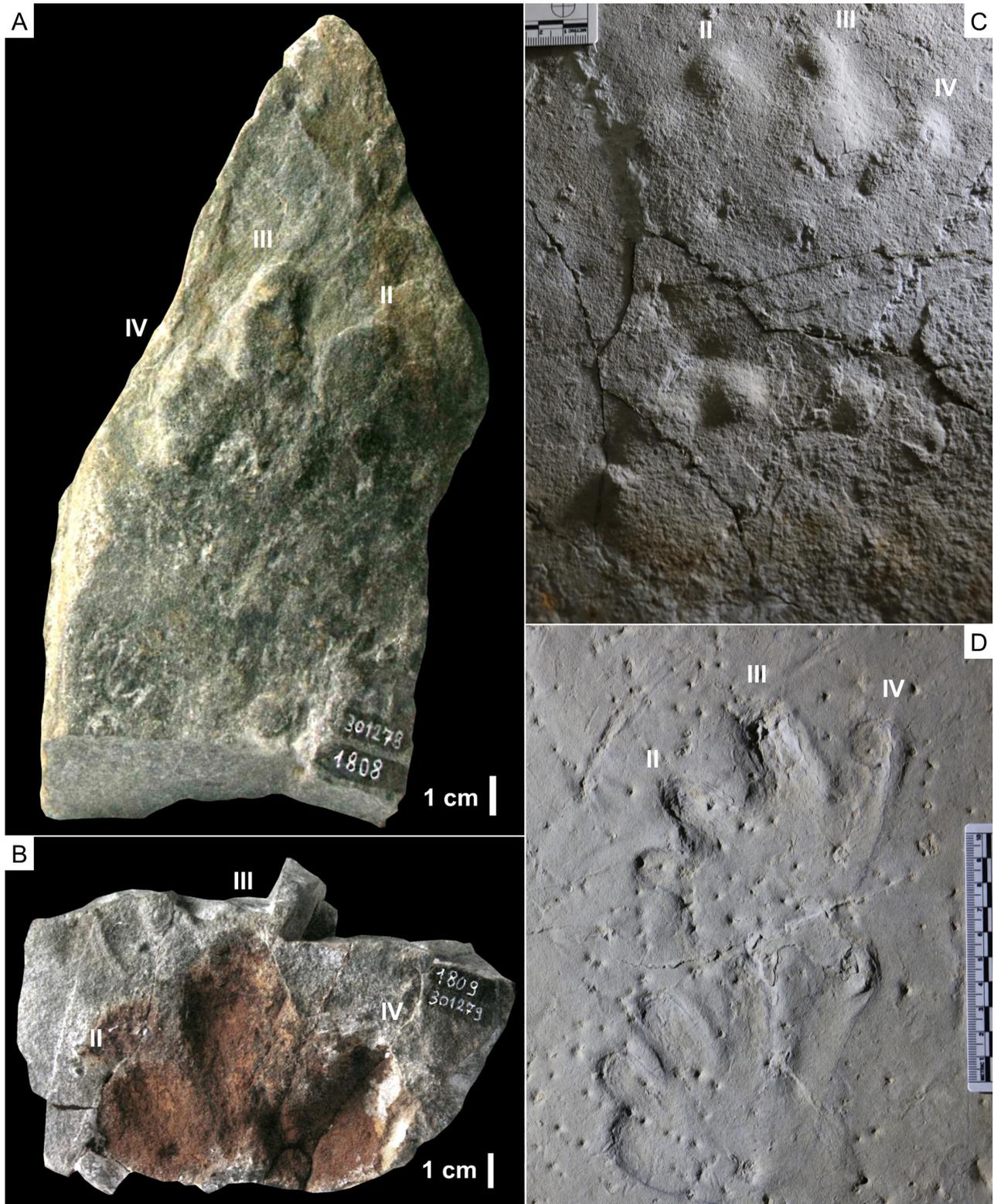


Fig. 5 - Tetrapod footprints from the Corona Formation, Pramollo Group (A-B) and more completely-preserved tracks from Kansas (C-D). Large temnospondyl tracks, ichnogenus *Limnopus*. A) MFSN 1808. *Limnopus* isp. Partial right *manus* imprint, with impression of digits II-IV, convex hyporelief. B) MFSN 1809. ?*Limnopus* isp. Partial right *manus* imprint, with impression of digits II-IV, concave epirelief. C) YPM 488-2. *Limnopus* isp. Left *pes-manus* couple, convex hyporelief. D) YPM 488-2. Right *pes-manus* couple, concave epirelief. YPM = Yale Peabody Museum, New Haven, Connecticut.

Lagnaoui et al., 2014; Marchetti et al., 2019b). Marchetti et al. (2019a) considered this partial track to be an incomplete right tetradactyl *manus* showing only digits

II-IV and re-assigned this footprint to *Limnopus* isp.

The second footprint comes from the Val Dolce area (Passo di Lanza). According to Romano Azzola, who

discovered the specimen, this footprint was paired to a second footprint that was placed 20 cm in front of it and that was narrower and with longer digit imprints. Unfortunately, this second footprint was lost and not documented. The collected footprint (MFSN 1809) (Fig. 5B) is a natural mould about 6 cm long and about 7.5 cm wide. According to Mietto et al. (1986) it could be an imprint of a right *manus*, whereas the lost footprint could be that of a *pes*. It was assigned to ?*Limnopus*. The uncertainties come from the ambiguous preservation of the proximal part of the footprint. Mietto et al. (1986) proposed also an alternative interpretation, although less likely: it could be the incomplete imprint of a synapsid amniote.

5.2. ICHNOASSOCIATION STRUCTURE

The ichnoassociation currently includes the ichnogenus *Limnopus*. Specimen MFSN 1808 (Fig. 5A) includes a relatively large, ectaxonic, isolated track with three clear digit impressions. The digit imprints are short, thick, distally curved inwards and end in rounded terminations. These were interpreted as digits III-V imprints and assigned to *Hylopus cf. hardingi* by Mietto et al. (1986). Nevertheless, the digit imprints of *Hylopus hardingi* Dawson, 1863 are significantly longer, slenderer and characterised by a more marked medial-lateral increase of digit length compared to MFSN 1808. Also, the digit divergence between the two longest digits of the *manus* is higher in *Hylopus* than in this specimen (e.g. Lagnaoui et al., 2014; Marchetti et al., 2019b). Moreover, Gzhelian occurrences of *Hylopus* are unknown so far (e.g. Schneider et al., 2019). Because of morphology, proportions, arrangement and size, the digit imprints of MFSN 1808 have been interpreted as the digit II-

IV imprints of a left *manus* footprint of *Limnopus* by Marchetti et al. (2019c). In fact, this partial track is almost identical to the lateral part (considering only digits II-IV) of complete large *Limnopus manus* tracks from the Pennsylvanian of Kansas, originally described by Marsh (1894) as *Allopus* or *Baropus* and later synonymised with *Limnopus* by Haubold (2000) (Fig. 5 C,D). Specimen MFSN 1809 (Fig. 5B) includes a poorly-preserved, partially impressed, ectaxonic track with three short and thick digit impressions, assigned to ?*Limnopus* by Mietto et al. (1986). *Limnopus* is considered a relatively large (*pes* length >2 cm) track of temnospondyl anamniotes (Haubold, 1996).

The tetrapod ichnoassociation is very fragmentary, not diverse and it is constituted exclusively by large anamniote tracks. A specimen (MFSN 1808) shows a relatively good morphological preservation *sensu* Marchetti et al. (2019b). This ichnoassociation, which has an early Gzhelian age (e.g. Venturini, 2006), includes the earliest occurrence of *Limnopus* from Italy, which is also known from the Cisuralian (e.g. Marchetti et al., 2013). However, the ichnofaunal composition is not sufficient to provide more precise biostratigraphic data, because of the long stratigraphic range of *Limnopus* (e.g. Schneider et al., 2019). It is likely that the tetrapod trace fossils were much more abundant in the “Permo-Carbonifero Pontebbano” than these few findings seem to suggest.

6. CONCLUSIONS AND PERSPECTIVES

The tetrapod ichnoassociation from the Carboniferous (Pennsylvanian) of Italy includes the ichnogenera *Batrachichnus*, *Limnopus* and tetrapod tracks indet. similar to *Matthewichnus* (Fig. 6). All these footprints

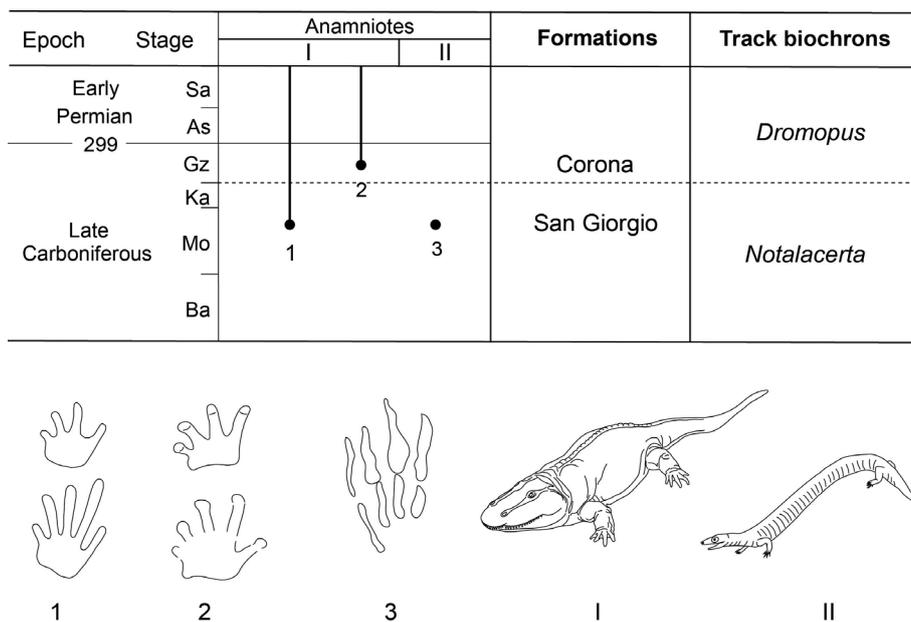


Fig. 6 - Stratigraphic distribution and inferred trackmakers of the Carboniferous tracks from Italy. 1, *Batrachichnus*; 2, *Limnopus*; 3 Undetermined tetrapod tracks; I, temnospondyl anamniotes; II, lepospondyl anamniotes.

have been attributed to anamniote producers. The only occurrence of anamniotes may have a marked palaeoecological significance, since these animals were tied to water for reproduction. Nevertheless, further material is necessary to correctly infer the tetrapod palaeoecology of the track-bearing units.

The San Giorgio tetrapod ichnoassociation, dated as late Moscovian (Cleal et al., 2016), is the oldest known from Italy and includes the oldest record of *Batrachichnus* from Italy. This ichnoassociation should belong to the *Notalacerta* tetrapod footprint biochron, nevertheless more findings are needed to provide useful biostratigraphic data. The Carnian Alps tetrapod ichnoassociation, dated as early Gzhelian (Venturini, 2006) includes the oldest occurrence of *Limnopus* from Italy. Also, these footprints are remarkable because of the large track size. The ichnoassociation from the Carnian Alps should belong to the *Dromopus* tetrapod footprint biochron, nevertheless more findings are needed to provide useful biostratigraphic data.

In the end, the tetrapod footprints and ichnosites from the Pennsylvanian of Italy are few and fragmentary, consistently with the tetrapod footprint record from the Carboniferous of W Europe (e.g. Haubold, 1996). Nevertheless, the morphological preservation is relatively good, and the stratigraphy of the San Giorgio and Corona formations suggests that these tetrapod ichnoassociations would be key for the understanding of the *Notalacerta* and the *Dromopus* tetrapod footprint biochrons in W Europe. In fact, these biochrons presently are based mostly on North American occurrences (e.g. Fillmore et al., 2012).

Moreover, since these tetrapod footprints represent the oldest tetrapod occurrences from Italy, considering either the track and the skeleton record, new data would help to better understand the tetrapod evolution within these area during this time span. This includes the effects of the supposed Kasimovian revolution of the tetrapod record and the beginning of the Autunian biotas (e.g. Schneider et al., 2019).

Further prospecting should concentrate on the fine-grained lithofacies of the San Giorgio and Corona formations, and new areas yielding abundant plant remains and other continental fossils should be explored (e.g. Ronchi et al., 2012).

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