



## Triassic tetrapod ichnofossils from Italy: the state of the art

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**ABSTRACT** - We provide here the most complete census of the Italian Triassic tetrapod ichnosites ever published based on an extensive literature review, integrated with previously unpublished data. Most ichnosites are located in the Southern Alps but track-bearing localities are also described in the Western Alps, in Northern Apennines, Maritime Alps and in Sardinia. The chronostratigraphic distribution of the tetrapod footprints can be framed in two macro-sets of ichnoassociations. A first set ranges from the upper Lower Triassic (Olenekian) to the Middle Triassic (upper Anisian, Illyrian) where ichnoassociations are dominated by lizard-like footprints (e.g. *Rhynchosauroides* isp.), with gradual increase through time of footprints referable to archosauriforms (e.g. chirotheriid footprints). After a hiatus extending up to the basal part of the Carnian (basal Julian), a second set of ichnoassociations spreads the whole Upper Triassic. This second set is dominated initially by chirotheriid footprints but, it shows a shift to dinosaur footprints dominance in correspondence with the abrupt global climate perturbation of the Carnian Pluvial Episode.

**Keywords:** ichnology; tetrapod footprints; Triassic; Southern Alps; Western Alps; Northern Apennines; Italy.

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### 1. INTRODUCTION

The first Triassic tetrapod footprints discovered from the Italian territory were reported from Monte Pisano in northern Tuscany. They were first documented by Tommasi (1886) and later described by Fucini (1915, 1936), Huene (1940, 1941) and finally revised by Rau and Tongiorgi (1974 a,b) and Tongiorgi (1980) who dated them to the early Carnian.

Triassic footprints are known from the Southern Alps since the first decade of the 20<sup>th</sup> century when Julius Pia found the first specimens in the upper Anisian of the Braies/Prags Dolomites (locality Lapadures, Flatschkofel, Col Valacia). Later, the material was studied by Abel (1926), who established the new ichnospecies *Rhynchosauroides tirolicus* Abel, 1926.

P. Leonardi (1968) reported the first footprints from the Lower Triassic Werfen Formation of the western

Dolomites. In 1973, tracks from the same area, originally described by Abel were studied by R. Brandner (Bechstädt and Brandner, 1970; Brandner, 1973) and identified as coming from equivalent stratigraphic units of the Recoaro area in the Vicentinian Prealps.

The unexpected discovery of dinosaur footprints in the Upper Triassic Dolomia Principale (Main Dolomite or Hauptdolomit of German authors) of the Dolomites in 1985 (Mietto, 1988) paved the way for the massive discovery of tetrapod (mainly dinosaur) footprints in the Mesozoic carbonate platforms, practically along the entire Italian peninsula (Avanzini et al., 2000; Nicosia et al., 2005). The first discovery of tetrapod footprints in the Dolomia Principale of the Carnic Prealps (Friulian Dolomites) dates to 1994 (Dalla Vecchia and Mietto, 1997).

Extensive research undertaken in the last 40 years led to the discovery of numerous vertebrate tracks and

Tab. 1 - Summary table of the Early Triassic Italian ichnosites.

ichnosite	Geographical area	Region/ Province	Municipality	3 <sup>th</sup> order sequence	Lithostratigraphy	Age	Ichnotaxonomy/ attribution	Main references	Repository
Contrada Maltaure	Vicentinian Prealps	Veneto Vicenza	Recoaro T.	O1 1	Werfen Fm Campil Mb.	early Olenekian	Rhynchosauroides isp. R. schochardti R. aff. palmatus	Avanzini and Mietto (2008a)	MCD
Mount Pic (Bulla)	Western Dolomites	Trentino A.A. Bolzano a.p.	Ortisei	O1 1	Werfen Fm Campil Mb.	early Olenekian	Archosauriformes ?	Leonardi P. (1968) Conti et al. (2000) Petti et al. (2013)	MGP-FE
Venegia	Western Dolomites	Trentino A.A. Trento a.p.	Moena	O1 1	Werfen Fm Campil Mb.	early Olenekian	Archosauriformes ?	Leonardi P. (1968) Conti et al. (2000) Petti et al. (2013)	MGP-FE
Furcia Rossa	Western Dolomites	Veneto Belluno	Falcade	O1 1	Werfen Fm. Campil Mb.	early Olenekian	Capitosauroides cf. bernburgensis	Avanzini and Mietto (2008a)	MCV
Lusia Pass	Western Dolomites	Trentino A.A. Trento a.p.	Predazzo	O1 1	Werfen Fm. Campil Mb.	early Olenekian	Rhynchosauroides isp.		MGP-PD
Butterloch Gorge	Western Dolomites	Trentino A.A. Bolzano a.p.	Aldino	O1 1	Werfen Fm. Campil Mb.	early Olenekian	Rhynchosauroides isp.	Conti et al. (2000)	MSN-VE
Studena	Canal del Ferro	Friuli V.G. a.r. Udine	Pontebba	O1 1	Werfen Fm. Campil Mb.	early Olenekian	?chirotheriid or not biogenic	Conti et al. (2000) Dalla Vecchia (2008, 2013) Petti et al. (2013)	MFST-UD
Pierabech	Carnic Alps	Friuli V.G. a.r. Udine	Forni Avoltri	O1 1	Werfen Fm. Siusi Mb. ?	early Olenekian	possibly half-swim tracks of a large tetrapod	Dalla Vecchia et al. (2013) Dalla Vecchia (2013)	in a square of Forni Avoltri
Gattera	Vicentinian Prealps	Veneto Vicenza	Recoaro T.	O1 2	Werfen Fm M. Naro Breccia	late Olenekian	R. schochardti	Mietto (1986) Avanzini and Mietto (2008a) Petti et al. (2013)	MGP-PD
Contrada Rossi	Vicentinian Prealps	Veneto Vicenza	Schio	O1 2	Werfen Fm M. Naro Breccia	late Olenekian	Rhynchosauroides isp.		MGP-PD
Firmalin Brook	Adige Valley Basin	Trentino A.A. Bolzano a.p.	Appiano	O1 2	Werfen Fm.	late Olenekian	semi-swimming tetrapod		MUSE-TN
Gardetta Plateau	Western Alps	Piedmont Cuneo	Canosio	undef.	"semelle silicieuse"	early Triassic	Archosauriformes	Petti et al. 2020	in situ

tracksites initially in the Southern Alps, then in the northern Apennines, in the Maritime and Western Alps and finally in Sardinia (Conti et al., 2000; Avanzini et al., 2001; Nicosia et al., 2005; Avanzini and Mietto, 2008a; Citton et al., 2020). Tetrapod footprints are now known in these regions from the lower Carboniferous to the Lower Cretaceous and have been pivotal in several palaeoenvironmental, palaeogeographic and biochronological studies (Conti et al., 1997, 2000; Avanzini et al., 2001; Avanzini and Mietto, 2005; Petti et al., 2013).

Integrated data from ammonoids, conodonts, pollens and sequence stratigraphy allows to define a high resolution chronostratigraphic framework for the Triassic succession of the Southern Alps (De Zanche et al., 1993; Mietto and Manfrin, 1995; Gianolla et al., 1998, 2018; Neri et al., 2007; Stefani et al., 2010), this has been used to date the footprint levels with an unusual resolution for terrestrial ichnofossils (Avanzini and Mietto, 2005, 2008a; Petti et al., 2013). Otherwise, tetrapod ichnoassociation documented from Anisian successions became important

because of their excellent state of preservation and the broad vertical distribution of the footprint-bearing levels (Avanzini and Neri, 1998; Avanzini, 1999; Avanzini et al., 2001). The almost continuous succession of tetrapod footprints in the upper Carnian-Norian/Rhaetian of the Southern Alps was also recently used to reconstruct macroevolutionary trends in reptile evolution (Bernardi et al., 2018).

## 2. OBJECTIVES OF THE PAPER

This paper provides an updated catalogue of the Italian Triassic tetrapod palaeoichnology. This work completes and expands the two previous databases published by Avanzini and Mietto (2005) and Petti et al. (2013). In additions to the data available from the bibliography, new data are also reported. Not all the track-bearing formations outcrop evenly, with some ichnoassociation more represented than other, and, in addition, not all the sites or formations have been studied with the same detail. These facts lead to what may look like an

unbalanced report of data, which, however, reflects the actual situation of the ichnological studies in the Italian Triassic.

For the purpose of this paper, the stratigraphic and nomenclatural complexity of the Triassic lithostratigraphy has been resolved by attributing each tetrapod ichnosite to a 3<sup>th</sup> order depositional sequence, following the framework by Gianolla et al. (1998) and its recent updates (Neri et al., 2007; Stefani et al., 2010; Dal Corso et al., 2015, 2018; Gattolin et al., 2015; Caggiati et al., 2018; Gianolla et al., 2018). Footprint descriptions follow the terminology used in Leonardi (1987). All the ichnosites and the track attributions are listed in tables 1-3.

The following acronyms have been used in the text: FL=footprint length; FW=footprint width; SB=sequence boundary; PCM-Auronzo di Cadore=Palazzo Corte Metto Museum, Auronzo di Cadore (Belluno); MSN-Bolzano/Bozen=Natural History Museum of Alto Adige, Bolzano/Bozen; MC-Calci=Natural History Museum of Calci - Unipi (Pisa); MGP-Ferrara=Geo-Palaeontological Museum, Ferrara University; MGP-Padova=Geology and Palaeontology Museum, Padua University; MSN-Firenze=Natural History Museum, Florence University; MLC-Lerici=Geo-Palaeontological Museum of Lerici Castle (La Spezia); DISTA-Pavia=Department of the Earth and Environmental Sciences, Pavia University; MGD-Predazzo=Geological Museum of Dolomites, Predazzo (Trento); MUST-Roma=Earth Science Museum, University "La Sapienza", Rome; MCC-Selva di Cadore="Vittorino Cazzetta" Civic Museum of Selva di Cadore (Belluno); MUSE-Trento=MUSE Science Museum of Trento; MFSN-Udine=Friulian Museum of Natural History, Udine; MCD-Valdagno="Domenico Dal Lago" Civic Museum of Valdagno (Vicenza); and MSN-Venezia=Museum of Natural History, Venice.

### 3. GEOLOGICAL SETTING

The majority of Italian Triassic ichnosites are located in the Southern Alps. For this reason, and because of the particularly complex stratigraphical context of the Southern Alps, we describe only this area in the general geological setting. Geological and stratigraphical information of tracksites located in other regions are given at the beginning of the relative paragraph.

The Southern Alps are a south-verging fold-and-thrust belt of the Alpine Chain (Castellarin and Cantelli, 2000; Doglioni and Carminati, 2008; Carminati et al., 2010; Handy et al., 2010). They consist of a well-preserved Mesozoic passive continental margin inverted during the Alpine orogeny (Fig. 1). The eastern sector, particularly the area between the Adige and the Piave rivers, is less deformed and documents one of the most spectacular and comprehensive Triassic successions in the World (Gianolla et al., 2009). The reduced tectonic deformation, together with a sedimentary succession framed within a high-resolution bio-chronostratigraphic framework, allowed a detailed reconstruction of the spatial and

temporal evolution of the depositional systems (De Zanche et al., 1993; Gianolla et al., 1998, 2018). The relationship between carbonate, mixed and terrigenous systems, representing continental to marginal marine and deep water settings and the presence of an impressive zircon U-Pb geochronological framework, ranging from the middle Anisian to the uppermost Ladinian interval (Brack et al., 1996, 2007; Mietto et al., 2012a; Wotzlav et al., 2018; Storck et al., 2019, 2020), have made this area a worldwide reference for the Middle Triassic (Fig. 2).

During late Permian and Early Triassic, the Southern Alps were an embayment of the Tethys Ocean, and the rock record testifies a widespread shallow water sedimentation. The Lower Triassic is characterised by a mixed terrigenous-carbonate succession grouped into the Werfen Formation (Posenato, 2019). This formation is traditionally subdivided into nine members (Bosellini, 1968; Farabegoli et al., 1977; Broglio Loriga et al., 1983; Neri et al., 2007) more or less traceable from Lombardy to the Julian Alps, and organised in four main transgressive-regressive cycles (In 1, In 2, Ol 1 and Ol 2) locally bounded by emersion surfaces and supratidal intervals (Neri et al., 2007; Posenato, 2019). The Werfen Formation records low bathymetric gradients, dipping eastwards and north-eastwards (Bosellini, 1968; Farabegoli and Viel, 1982; Broglio Loriga et al., 1983, 1990) and documents a period of almost constant subsidence and environmental homogeneity modulated only by sea level fluctuations (Stefani et al., 2010). This layer-cake stratigraphy continues in the lower Anisian with the development of a regional-scale shallow water carbonate platform characterised by large tidal flats laterally grading into evaporitic deposits (Lower Serla Dolomite/Lusnizza member). This depositional phase was followed by a rapid change in subsidence rate linked to increased tectonic activity that terminated the flat topography and started to differentiate the area in blocks (large horsts and grabens related to local uplift and strong subsidence) with complex evolution (Assereto et al., 1977; Gianolla et al., 1998; Bosellini et al., 2003; Neri et al., 2007).

The Anisian succession is organised into three depositional sequences (An 2-An 4) bounded landward by subaerial unconformities, each followed by (1) a continental conglomerate (e.g. Piz da Peres, Voltago and Richthofen conglomerates), (2) shallow-water terrigenous-carbonate deposits (e.g. Gracilis Formation and Recoaro Limestone), (3) shallow water carbonate platforms and mounds (e.g. Monte Rite, Upper Serla, Contrin formations). These depositional sequences can be traced from shallow areas into more basinal setting, (4) where the relative deep-water sedimentation is recorded by the Dont, Bivera and Ambata formations. During the late Anisian an abrupt increase in subsidence (An5 depositional sequence), associated with a strong sea level rise (Gianolla et al., 1998), led to a marked retreat of the coastline (during Triassic times the emergent lands were placed towards the present-day Po Plain). This transgression was associated to a change from low-

Tab. 2 - Summary table of the Middle Triassic Italian ichnosites.

ichnosite	Geographical area	Region/Province	Municipality	3th order sequence	Lithostratigraphy	Age	Ichnotaxonomy/attribution	Main references	Repository
Pregantale Valley	Vicentinian Prealps	Veneto Vicenza	Recoaro T.	An 2	Gracilis Fm.	early Anisian Bithynian	? Dinosauromorpha	Avanzini and Mietto (2008a)	MGP-PD
Pregantale Valley	Vicentinian Prealps	Veneto Vicenza	Recoaro T.	An 3	Voltzia Beds	middle Anisian Pelsonian	<i>Rhynchosauroides</i> sp. <i>Parasynaptichnium</i> sp. <i>P. gracilis?</i> <i>Sphingopus</i> sp.	Avanzini and Mietto (2008a) Avanzini and Mietto (2008a) Mietto (1987) Avanzini and Mietto (2008a) Petti et al. (2013)	MGP-PD MGP-PD MCD MGP-PD
Mount Marzola	Valsugana	Trentino A.A. Trento a.p.	Trento	An 3	Voltzia Beds	middle Anisian Pelsonian	<i>Procolophonichnium</i> sp.	Petti et al. (2013)	MUSE-TN
Urban Brook	Adige Valley Basin	Trentino A.A. Trento a.p.	Ruffrè	An 3	Voltago Cgm.	middle Anisian Pelsonian	<i>Rhynchosauroides tirolicus</i> <i>Isochirotherium delicatum</i> <i>Synaptichnium pseudosuchoides</i> <i>Chirotherium</i> sp.? <i>Sphingopus</i> sp.	Avanzini and Mietto (2008a) Petti et al. (2013)	MUSE-TN
Mount Ozol	Adige Valley Basin	Trentino A.A. Trento a.p.	Ruffrè	An 3	Voltago Cgm.	middle Anisian Pelsonian	<i>Rhynchosauroides</i> sp. <i>Chirotheriids</i>		MUSE-TN
Bad Gfrill	Adige Valley Basin	Trentino A.A. Bolzano a.p.	Terlano	An 3	Voltago Cgm. Giovo Fm.	middle Anisian Pelsonian	<i>Procolophonichnium</i> sp. <i>Rhynchosauroides</i> sp. <i>Rhynchosauroides tirolicus</i> <i>Synaptichnium</i> sp. <i>S. pseudosuchoides</i> <i>S. diabloense</i> <i>S. cf. cameromense</i> <i>Chirotherium</i> sp. <i>C. barthii</i> <i>Rotodactylus</i> sp.	Avanzini and Valdiserri (2004) Valdiserri and Avanzini (2007) Avanzini and Mietto (2008a) Valdiserri et al. (2009) Petti et al. (2013)	
Senale	Adige Valley Basin	Trentino A.A. Bolzano a.p.	Senale San Felice	An 3	Voltago Cgm.	middle Anisian Pelsonian	<i>Rhynchosauroides tirolicus</i>	Avanzini and Renesto (2002)	MUSE-TN
Palade Pass/Gampepass	Adige Valley Basin	Trentino A.A. Bolzano a.p.	Lana	An 3	Voltago Cgm.	middle Anisian Pelsonian	<i>Procolophonichnium</i> sp. <i>Rhynchosauroides</i> sp. <i>R. tirolicus</i> <i>Brachychotherium</i> sp. <i>Isochirotherium delicatum</i> <i>Parasynaptichnium gracilis</i> <i>Synaptichnium</i> sp. <i>Chirotherium</i> sp. <i>Rotodactylus</i> sp.	Avanzini and Neri (1998) Avanzini (1999) Avanzini and Renesto (2002) Avanzini and Mietto (2008a) Petti et al. (2013)	MUSE-TN
Appiano	Adige Valley Basin	Trentino A.A. Bolzano a.p.	Appiano	An 3	Voltago Cgm. Giovo Fm	middle Anisian Pelsonian	<i>Rhynchosauroides tirolicus</i> <i>R. cf. rectipes</i> <i>Chirotheriids</i>	Avanzini and Mietto (2008a)	MUSE-TN MGP-PD

Tab. 2 - ...Continued

ichnosite	Geographical area	Region/Province	Municipality	3th order sequence	Lithostratigraphy	Age	Ichnotaxonomy/attribution	Main references	Repository
Mount Macaion	Adige Valley Basin	Trentino A.A. Bolzano a.p.	Appiano	An 3	Voltago Cgm.	middle Anisian Pelsonian	<i>Rhynchosauroides</i> isp.		MUSE-TN
Cortaccia	Adige Valley Basin	Trentino A.A. Bolzano a.p.	Appiano	An 3	Voltago Cgm. Giovo Fm.	middle Anisian Pelsonian	<i>Rhynchosauroides</i> isp. <i>Chirotheriids</i> <i>Rotodactylus</i> isp.		MUSE-TN
Roverè della Luna	Adige Valley Basin	Trentino A.A. Trento a.p.	Roverè della Luna	An 3	Voltago Cgm. Giovo Fm.	middle Anisian Pelsonian	<i>Rhynchosauroides</i> isp. <i>Chirotheriids</i> <i>Rotodactylus</i> isp.		MUSE-TN
San Floriano	Adige Valley Basin	Trentino A.A. Bolzano a.p.	Egna	An 3	Voltago Cgm. Giovo Fm.	middle Anisian Pelsonian	<i>Rhynchosauroides</i> isp. <i>Chirotheriid</i> <i>Rotodactylus</i> isp.		MUSE-TN
Ville di Giovo	Adige Valley Basin	Trentino A.A. Trento a.p.	Giovo	An 3	Voltago Cgm. Giovo Fm.	middle Anisian Pelsonian	<i>Rhynchosauroides</i> isp. <i>Chirotheriids</i> <i>Rotodactylus</i> isp.		MUSE-TN
San Michele all'Adige	Adige Valley Basin	Trentino A.A. Trento a.p.	San Michele all'Adige	An 3	Voltago Cgm. Giovo Fm.	middle Anisian Pelsonian	<i>Rhynchosauroides</i> isp. <i>Chirotheriids</i> <i>Rotodactylus</i> isp.		MUSE-TN
Mount Cernera	Eastern Dolomites	Veneto Belluno	Selva di Cadore	An 3	Voltago Cgm.	middle Anisian Pelsonian	<i>Rhynchosauroides</i> isp.	Avanzini and Mietto (2008a)	MGP-PD
Creme Valley	Vicentinian Prealps	Veneto Vicenza	Recoaro T.	An 4	Tretto Cgm.	middle Anisian Illyrian	<i>Procolophonichnium</i> isp. <i>Rhynchosauroides tirolicus</i> <i>Brachychirotherium</i> af. <i>Parvum</i> <i>Chirotherium barthii</i> <i>Rotodactylus rothi</i> <i>Rotodactylus lucasi</i>	Avanzini and Mietto (2008a)	MCD
Ometto	Adige Valley Basin	Trentino A.A. Trento a.p.	Vallarsa	An 4	Richthofen Cgm.	middle Anisian Illyrian	<i>Procolophonichnium</i> isp. <i>Rhynchosauroides</i> isp. <i>Brachychirotherium</i> isp. <i>Chirotherium</i> isp. <i>Rotodactylus</i> isp.	Todesco and Bernardi (2011)	MUSE-TN
Gerlano Valley	Adige Valley Basin	Trentino A.A. Trento a.p.	Vallarsa	An 4	Richthofen Cgm.	middle Anisian Illyrian	<i>Procolophonichnium</i> isp. <i>Rhynchosauroides</i> isp. <i>Brachychirotherium</i> isp. <i>Chirotherium</i> isp. <i>Rotodactylus</i> isp.	Todesco and Bernardi (2011) Petti et al. (2013)	MUSE-TN
Ronchi Valley	Adige Valley Basin	Trentino A.A. Trento a.p.	Vallarsa	An 4	Richthofen Cgm.	middle Anisian Illyrian	<i>Rhynchosauroides</i> isp. ? <i>Chirotherium</i> isp.	Petti et al. (2013)	MUSE-TN

Tab. 2 - ...Continued

ichnosite	Geographical area	Region/Province	Municipality	3th order sequence	Lithostratigraphy	Age	Ichnotaxonomy/attribution	Main references	Repository
Inferno Brook	Adige Valley Basin	Trentino A.A. Bolzano a.p.	Termeno	An 4	Richthofen Cgm.	middle Anisian Illyrian	<i>Isochirotherium infernense</i> <i>I. cf. marshalli</i>	Avanzini and Leonardi (2002)	MUSE-TN <i>in situ</i>
Fiorentina Valley	Eastern Dolomites	Veneto Belluno	Selva di Cadore	An 4	Richthofen Cgm. Morbiac Lms.	middle Anisian Illyrian	<i>Rhynchosauroides tirolicus</i> <i>R. peabody</i> <i>Rotodactylus</i> isp..	Avanzini and Renesto (2002) Avanzini and Mietto (2008a) Petti et al. (2013)	MGP-PD
Ruaz Brook	Eastern Dolomites	Veneto Belluno	Liminallongo	An 4	Richthofen Cgm. Morbiac Lms.	middle Anisian Illyrian	<i>Rhynchosauroides</i> isp. <i>Rhynchosauroides tirolicus</i>	Avanzini and Mietto (2008a)	MGP-PD
Duron Valley	Western Dolomites	Trentino A.A. Trento a.p.	Campitello di Fassa	An 4	Morbiac Lms.	middle Anisian Illyrian	<i>Rhynchosauroides tirolicus</i> <i>Brachychotherium</i> isp. <i>Isochirotherium delicatum</i> <i>Chirotherium barthii</i>	Avanzini et al. (2007b) Todisco et al (2008a) Petti et al. (2013)	MGD
Crepa di Socorda	Western Dolomites	Trentino A.A. Trento a.p.	Pozza di Fassa	An 4	Morbiac Lms.	middle Anisian Illyrian	<i>Procolophonichnium</i> isp. <i>Rhynchosauroides</i> isp. <i>Brachychotherium</i> isp.	MUSE-TN	
Piz da Peres	Northern Dolomites	Trentino A.A. Bolzano a.p.	Valdaora	An 4	Richthofen Cgm.	middle Anisian Illyrian	<i>Procolophonichnium</i> isp. <i>Rhynchosauroides tirolicus</i> <i>Isochirotherium delicatum</i> <i>Brachychotherium</i> isp. <i>B. aff. parvum</i> <i>Chirotherium</i> cf. <i>rex</i> <i>Sphingopus ladinicus</i>	Avanzini and Mietto (2008a) Todisco et al (2008b) Avanzini and Wächter (2012) Petti et al. (2013)	MSN-BZ MUSE-TN MGP-PD
Mirtilli Hill	Sappada area	Friuli V.G. a.r. Udine	Sappada	An 4	Richthofen Cgm.	middle Anisian Illyrian	<i>Rhynchosauroides</i> isp..	Venturini et al (2009)	unknown
Ponte di Nava	Western Liguria	Liguria Savona	Ormea	O 2-An 2	Casa Valmarecchia Pelite Fm	late Olenekian to early Anisian	<i>Chirotherium</i> isp..	Santi et al. (2005)	<i>in situ</i>
Capo Caccia promontory	Sardinia	Sardinia Sassari	Alghero	An 2-An 4	Cala Viola Sandstones	Anisian	<i>Rhynchosauroides</i> isp. <i>Rotodactylus</i> isp..	Cifton et al. (2020)	<i>in situ</i>

Tab. 3 - Summary table of the Late Triassic Italian ichnosesites.

ichnosite	Geographical area	Region/Province	Municipality	3th order sequence	Lithostratigraphy	Age	Ichnotaxonomy/contribution	Main references	Repository
Mount Coldai	Western Dolomites	Veneto Belluno	Selva di Cadore	Car 1	Cassian Dolomite 2	early Carnian Julian	? <i>Synapsid</i>		in situ
Busa dei Cavai	Western Dolomites	Veneto Belluno	Selva di Cadore	Car 1	Cassian Dolomite 2	early Carnian Julian	Chirotheriid	Mietto et al. (2012a) Bernardi et al. (2018)	in situ
Mout Averau	Western Dolomites	Veneto Belluno	Cortina d'Ampezzo	Car 1	Cassian Dolomite 2	early Carnian Julian	Undefined tetrapod	Mietto et al. (2012a)	in situ
Zone	Brescian Prealps	Lombardy Brescia	Zone	Car 1	Val Sabbia Sandstones	early Carnian Julian	<i>Brachychirotherium</i> isp. <i>B. thuringiacum</i>	Petti et al. (2009)	in situ
Giau Fork	Eastern Dolomites	Veneto Belluno	Cortina d'Ampezzo	Car 2	Heiligkreuz Fm.	Carnian Julian-Tuvallian	Theropods		MCC
Lastoi di Formin	Eastern Dolomites	Veneto Belluno	Cortina d'Ampezzo	Car 2	Heiligkreuz Fm.	Carnian Julian-Tuvallian	Sauropodomorphs	Mietto et al. (2012a) Bernardi et al. (2018)	in situ
Vare di Giau	Eastern Dolomites	Veneto Belluno	Cortina d'Ampezzo	Car 2	Heiligkreuz Fm.	Carnian Julian-Tuvallian	Tetrasauropus isp.	Mietto et al. (2012a) Bernardi et al. (2018)	in situ
Forada Fork	Eastern Dolomites	Veneto Belluno	Cortina d'Ampezzo	Car 2	Heiligkreuz Fm.	Carnian Julian-Tuvallian	swimming tetrapods ?	Mietto et al. (2012)	in situ
Mount Settsass	Western Dolomites	Trentino A.A. Bolzano a.p.	San Cassiano	Car 2	Heiligkreuz Fm.	Carnian Julian-Tuvallian	Archosauriformes	Mietto et al. (2012a) Dalla Vecchia (2013)	in situ
Mount Sasso della Croce	Western Dolomites	Trentino A.A. Bolzano a.p.	Badia	Car 2	Heiligkreuz Fm.	Carnian Julian-Tuvallian	Theropods	Mietto et al. (2012a) Bernardi et al. (2018)	MUSE-TN
Mount Roen	Adige Valley Basin	Trentino A.A. Bolzano a.p.	Termeno	Car 3	Travenanzes Fm.	Late Carnian Tuvallian	<i>Eubrontes</i> isp.	Avanzini et al. (2010) Bernardi et al. (2013)	in situ
Mostizzolo	Adige Valley Basin	Trentino A.A. Trento a.p.	Cles	Car 3	Travenanzes Fm.	Late Carnian Tuvallian	<i>Brachychirotherium eyermani</i> <i>Eubrontes</i> isp.	Bernardi et al. (2013) Bernardi et al. (2018)	MUSE-TN
Gottardo Castle	Adige Valley Basin	Trentino A.A. Trento a.p.	Mezzocorona	Car 3	Travenanzes Fm.	Late Carnian Tuvallian	<i>Grallator</i> isp. <i>Atreipus</i> isp. <i>Evazoum</i> isp.	D'Orazi and Porchetti et al. (2008) Bernardi et al. (2018)	in situ
Vela Brook	Adige Valley Basin	Trentino A.A. Trento a.p.	Mezzocorona	Car 3	Travenanzes Fm.	Late Carnian Tuvallian	Theropods		in situ

Tab. 3 - ...Continued

ichnosite	Geographical area	Region/Province	Municipality	3th order sequence	Lithostratigraphy	Age	Ichnotaxonomy/attribution	Main references	Repository
Dogna Valley	Julian Alps	Friuli V.G. a.r. Udine	Dogna	Car 3	Dolomia Principale Monticello Mb. of the Dolomia Principale	Late Carnian Tuvallian	Chirotheriid and nesting site	Dalla Vecchia (1996 a,b, 2008) Roghi and Dalla Vecchia (1997) Avanzini et al. (2007) Dalla Vecchia (2013)	MFSN-UD in situ
Mount Pelmetto	Eastern Dolomites	Veneto Belluno	Val di Zoldo	Car 3	Dolomia Principale	late Carnian Tuvallian	<i>Brachychotherium</i> isp. <i>Grallator</i> isp. <i>Eubrontes</i> isp.	Mietto (1988, 1990, 1992) Mietto and Dalla Vecchia (1998) Mietto et al. (2012a) Dalla Vecchia (2013) Bernardi et al. (2018)	in situ MCC
Pegolera Valley	Eastern Dolomites	Veneto Belluno	Agordo	Car 3	Dolomia Principale	late Carnian Tuvallian	<i>Archosauriformes</i> <i>Sauropodomorphs</i>	Belvedere et al. (2008c) Mietto et al. (2012a) Bernardi et al. (2018)	in situ
Piz Ciavazes	Western Dolomites	Trentino A.A. Trento a.p.	Canazei	Car 3	Dolomia Principale	Carnian-Norian Tuvallian-Lacian	<i>Sauropodomorphs</i>		in situ
Strada delle Gallerie	Vicentian Prealps	Veneto Vicenza	Valli del Pasubio	No 1	Dolomia Principale	middle Norian Alautian	<i>Pseudotetrasaurus</i> isp. <i>Evazoum</i> isp. <i>Grallator</i> isp. <i>Eubrontes</i> isp.? <i>Atreipus</i> isp.	Belvedere et al. (2008 a,b) Mietto et al. (2012a) Dalla Vecchia (2013)	in situ
Livinal del Bus	Eastern Dolomites	Veneto Belluno	Val di Zoldo	undef. No	Dolomia Principale	Late Triassic	? <i>Atreipus</i> isp.	Belvedere et al. (2008 a,b) Mietto et al. (2012a) Dalla Vecchia (2013)	in situ
Mount Civetta	Eastern Dolomites	Veneto Belluno	Alleghe	undef. No	Dolomia Principale	Late Triassic	? Theropods	Dalla Vecchia (1995, 2013)	in situ
Ruina del Giau	Eastern Dolomites	Veneto Belluno	Val di Zoldo	undef. No	Dolomia Principale	Late Triassic	Undefined tetrapod	Mietto et al. (2012a)	in situ
Nuvolau Fork	Eastern Dolomites	Veneto Belluno	Cortina d'Ampezzo	undef. No	Dolomia Principale	Late Triassic	Theropods		in situ
Tre Cime di Lavaredo	Northern Dolomites	Veneto Belluno	Auronzo di Cadore	undef. No	Dolomia Principale	Late Triassic	<i>Grallator</i> isp. <i>Eubrontes</i> isp.	Mietto (1992) Mietto et al. (2012a) Dalla Vecchia (2013)	in situ
Puez Plateau	Western Dolomites	Trentino A.A. Trento a.p.	Corvara in Badia	undef. No	Dolomia Principale	Late Triassic	?Theropods	Leonardi and Avanzini (1994) Leonardi G. (2000)	MUSE-TN
Casera Cjasevent	Carnic Prealps	Friuli V.G. a.r. Pordenone	Claut	undef. No	Dolomia Principale	Norian-Rhaetian	<i>Eubrontes</i> -size class	Dalla Vecchia and Mietto (1998) Dalla Vecchia (2013)	in situ

Tab. 3 - ...Continued

ichnosite	Geographical area	Region/Province	Municipality	3th order sequence	Lithostratigraphy	Age	Ichnotaxonomy/attribution	Main references	Repository
Ciol de la Fratta	Carnic Prealps	Friuli V.G. a.r. Pordenone	Claut	undef. No	Dolomia Principale	Norian-Rhaetian	<i>Anchisauripus</i> -size class ?basal sauropodomorph track ?Chirotheriid	Dalla Vecchia and Mietto (1998) Dalla Vecchia (2013)	in situ
Ciolòn Brook	Carnic Prealps	Friuli V.G. a.r. Pordenone	Claut	undef. No	Dolomia Principale	Norian-Rhaetian	<i>Grallator</i> -size class <i>Anchisauripus</i> -size class <i>Eubrontes/Anchisauripus</i> -size class	Marzola and Dalla Vecchia (2014) Dalla Vecchia (2013)	in situ
Pregoane Mountain Pass	Carnic Prealps	Friuli V.G. a.r. Pordenone	Claut	undef. No	Dolomia Principale	Norian-Rhaetian	Undefined/?non biogenic structure	Dalla Vecchia and Mietto (1998) Dalla Vecchia (2013)	in situ
Settimana Valley (6 boulders)	Carnic Prealps	Friuli V.G. a.r. Pordenone	Claut	undef. No	Dolomia Principale	Norian-Rhaetian	<i>Grallator</i> -size class <i>Anchisauripus</i> -size class <i>Eubrontes</i> -size class	Marzola and Dalla Vecchia (2014) Dalla Vecchia (2013)	in situ
Scandoler Valley	Carnic Prealps	Friuli V.G. a.r. Pordenone	Cimolais	undef. No	Dolomia Principale	Norian-Rhaetian	?basal sauropodomorph trackway	Dalla Vecchia and Mietto (1998) Dalla Vecchia (2013)	destroyed
Torrent Pezzeda	Carnic Prealps	Friuli V.G. a.r. Pordenone	Cimolais	undef. No	Dolomia Principale	Norian-Rhaetian	<i>Anchisauripus</i> -size class	Marzola & Dalla Vecchia 2014 Dalla Vecchia (2013)	in situ
Ciol del Tramontin	Carnic Prealps	Friuli V.G. a.r. Pordenone	Cimolais	undef. No	Dolomia Principale	Norian-Rhaetian	<i>Anchisauripus</i> -size class	Dalla Vecchia and Mietto (1998) Dalla Vecchia (2013)	in situ
Susaibes Brook	Carnic Prealps	Friuli V.G. a.r. Pordenone	Andreis	undef. No	Dolomia Principale	Norian-Rhaetian	<i>Anchisauripus</i> -size class? <i>Tetrasauropus</i> isp. Chirotheriid	Dalla Vecchia and Mietto (1998) Dalla Vecchia (2013)	in situ
Lerici	Northern Apennines	Liguria La Spezia	Lerici	undefined	Montemarcello Fm	late Triassic? Tuvallian	<i>Anomoepus</i> isp. <i>Evazoum sirigui</i>	Sirigu Nicosia (1996) Nicosia and Loi (2003)	in situ
Mounts Pisani	Northern Apennines	Toscana Pisa-Lucca	Agnano-Calci	undefined	Quarziti di M. Serra Fm. Scisti Verdi Mb - Quarziti Viola Zonate Mb	? Middle Triassic ? Anisian? Late Triassic ? Late Carnian	<i>Rhynchosauroides</i> isp. <i>Chirotherium</i> isp. <i>Synaptichnium</i> isp. <i>Rotodactylus</i> isp.? <i>Parasynaptichnium</i> isp.? <i>Grallator</i> isp.	Fucini (1915, 1936) Huene (1940, 1941) Rau and Tongiorgi (1974b) Leonardi and Lockley (1995) Sirigu and Tongiorgi (1996) Avanzini (2010)	MSN-FIMC

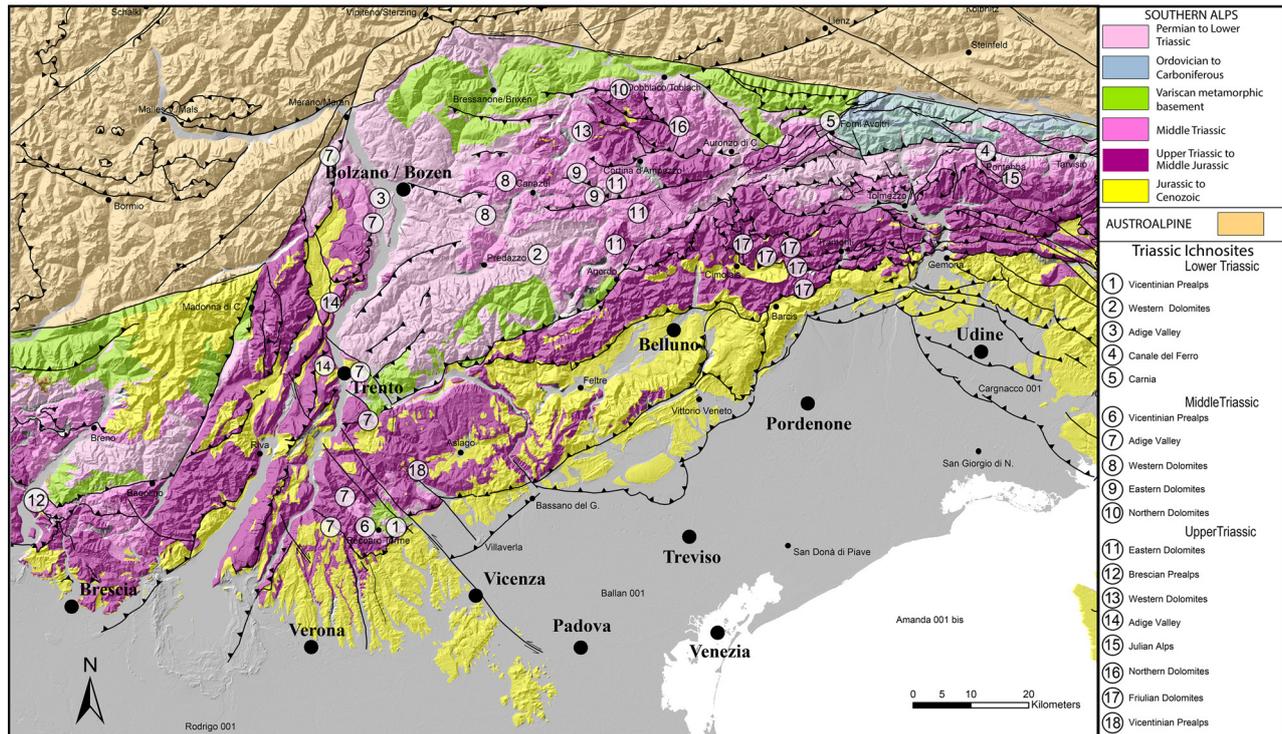


Fig. 1 - Geological sketch map of the Southern Alps with general indication of the sites with Triassic tetrapod footprints.

relief carbonate banks and inner ramps to high-relief isolated carbonate platforms (Sciliar Formation, Spitz Limestone) and an important reduction of continental and marginal marine environments. At that time, the palaeogeography was characterised by a large number of small islands (Bosellini, 1984, 1989; Brack et al., 2007; Stefani et al., 2010; Marangon et al., 2011; Renesto et al., 2020), sometimes drowned (Brack et al., 2007; Stefani et al., 2010; Franceschi et al., 2020) and surrounded by deep basins (e.g. Buchenstein Formation/Nodosus Limestone). Around the Anisian-Ladinian boundary the subsidence rate slowed down, the basin depocenter shifted to the east (because of low subsidence in the western sector) and carbonate platforms started to prograde laterally. The Middle Triassic of the Southern Alps region was also characterised by intense volcanism. Widespread evidence for volcanic activity is recorded in the upper Anisian deposits (Cros and Houel, 1983; Gianolla, 1992; Wotzlav et al., 2018; Storck et al., 2019, 2020). Acid volcanism is documented in several tephra layers and volcanoclastics in the basinal deposits, and locally with subaerial volcanism as in the Vicentinian Prealps, Julian Alps and in some wells in the Po Plain. During the late Ladinian widespread mafic magmatism occurred in several parts of the eastern Southern Alps (Assereto et al., 1977; Viel, 1979; Bosellini et al., 1982; Castellarin et al., 1988; Abbas et al., 2018; Lustrino et al., 2019). This short-lived magmatic event was characterised by strong localised tectonic activity, intrusions, large effusions of lavas above shallow water carbonates, impressive amount of pillow lavas and volcanoclastics into the basins and local accumulation of

megabreccia and chaotic mass-flow (Fernazza Formation). During this time the sedimentation was characterized by siliciclastic and/or mixed carbonate-terrestrial deposits while, in shallow water areas, carbonate production prevailed (La 1 depositional sequence). The upper Ladinian and Carnian are characterized by the erosion of volcanic areas and the progradation of the southern siliciclastic shoreline (Wengen Formation). During late Ladinian to early Carnian times (La 2-Car 1 depositional sequences), the subsidence rate decreased resulting in a general shallowing of the basins. The palaeogeography was consequently characterized by large emerged areas to the south-southwest (Adige Valley; Vicentinian Prealps; Western Dolomites), bounded by attached and isolated carbonate platforms (Cassian Dolomite) in the northeastern Southern Alps. The regressive trend culminated in the late early Carnian (Car 2 depositional sequence), with a strong northeastward shift of the coastline and complete flattening of the palaeotopography matched with a climatically-driven increase in siliciclastic sediment supply into the basins and concomitant demise of the microbial carbonate platforms (Breda et al., 2009; Gattolin et al., 2015). This climatic perturbation, known as Carnian Pluvial Episode (CPE), is a phase of climate change (from arid to markedly humid conditions) recorded worldwide in the Carnian stratigraphic successions that had a strong impact on marine and terrestrial ecosystems (Bosellini et al., 2003; Preto et al., 2010, 2019; Dal Corso et al., 2012, 2015, 2018; Bernardi et al., 2018). In the Southern Alps, it is recorded by the Heiligkreuz Formation and equivalent units (Fig.

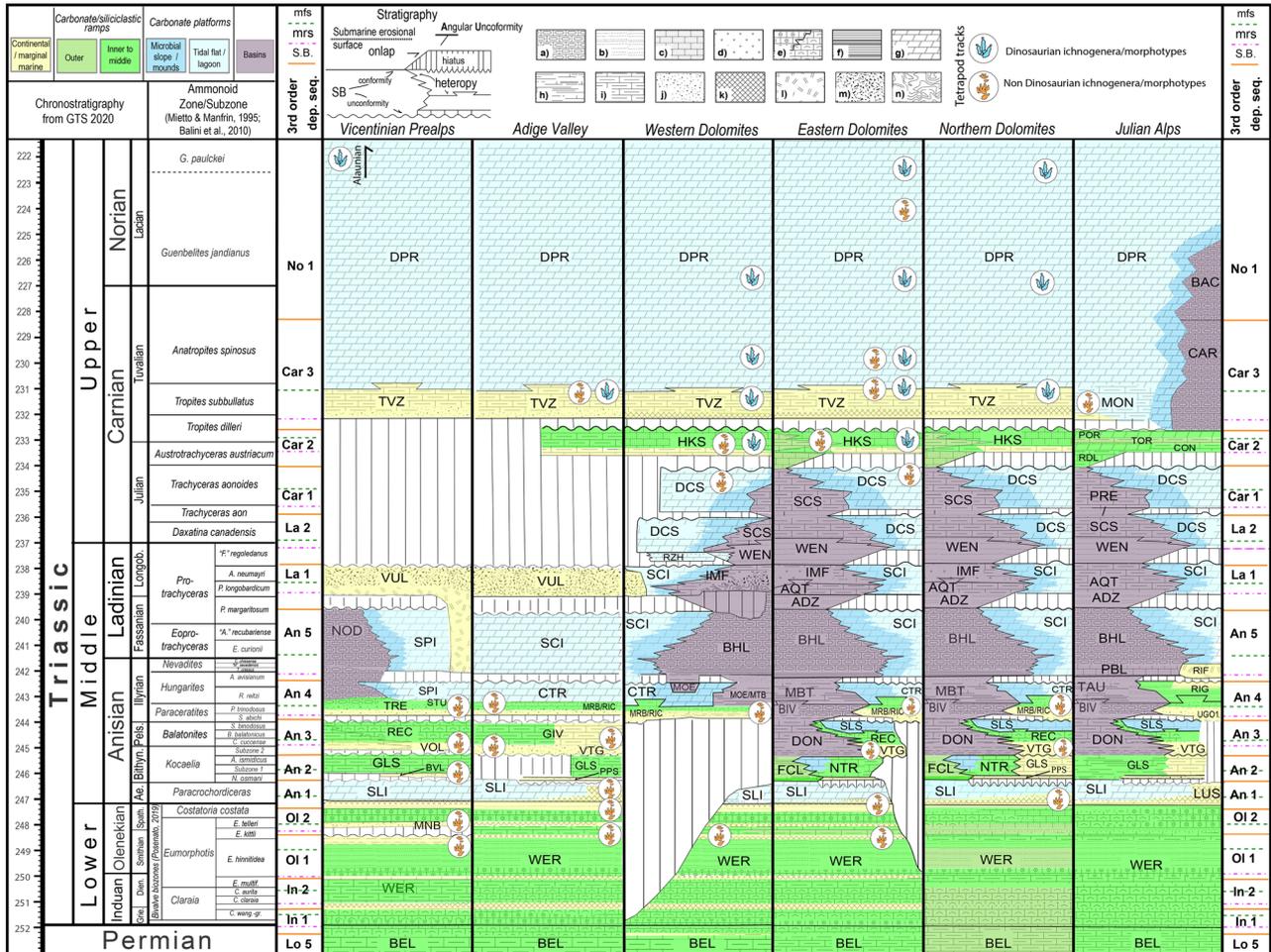


Fig. 2 - Schematic bio-chrono-stratigraphic scheme of the Middle-Upper Triassic succession of the eastern Southern Alps with discussed ichnosites. Lithostratigraphic abbreviations: ADZ: Zoppè Sandstone; AQT: Aquatona Formation; BAC: Bača Dolomite; BEL: Bellerophon Formation; BHL: Buchenstein/Livinalongo Formation; BIV: Biviera Formation; BVL: Breccia della Val Leogra; CAR: Carnitza Formation; CON: Conzen Formation; CTR: Contrin Formation; DCS: Cassian Dolomite; DON: Dont Formation; DPR: Dolomia Principale; FCL: Coll'Alto dark Limestones; GIV: Giovo Formation; GLS: Gracilis Formation; HKS: Heiligkreuz Formation; IMF: Fernazza Formation; LUS: Lusnizza member; MBT: Ambata Formation; MNA: Moena Formation; MON: Monticello Member of the Dolomia Principale; MNB: Monte Naro Breccia; MRB/RIC: Richthofen Conglomerate and Morbiac Limestone; NOD: Nodosus Limestone; NTR: Monte Rite Formation; PBL: Pontebba limestone; POR: Portella dolomite; PPS: Piz da Peres Conglomerate; PRE: Predil Limestone; RDL: Rio del Lago Formation; REC: Recoaro Limestone; RIF: Rio Freddo vulcanites; SCI: Sciliar Formation; SCS: San Cassiano Formation; SLI: Lower Serla Dolomite; SLS Upper Serla Formation; SLU: San Lucano member; SPI: Spitz Limestone; STU: Sturia limestone; TAU: Aupa turbidites; TOR: Tor Formation; TRE: Tretto conglomerate; TVZ: Travenanzes Formation; VBM: Val Badia member; VOL: Voltzia Beds; VTG: Voltgo Conglomerate; VUL: Volcanics; WEN: Wengen Formation; WER: Werfen Formation. Lithologies: a) cherty limestone; b) sandstone; c) sandy limestone; d) volcanics and volcanoclastics; e) oolitic-bioclastic limestone; f) black platy limestone or dolostone, black shale; g) dolostone; h) marlstone, claystone and shale; i) marly limestone; j) conglomerate; k) evaporites; l) tuffs, pyroclastics; m) lava, pillow-lava-pillow breccia; n) chaotic interval. Modified after Gianolla et al. (1998, 2010, 2018).

2). After the flattening of the palaeotopography and the return to arid conditions (Travenanzes Formation), a new transgression prompted the deposition of the thick peritidal succession of the Dolomia Principale (Bosellini and Hardie, 1988; Caggiati et al., 2018), which records a huge regional carbonate platform that extended for hundreds of kilometres from north to south and east to west. From then on, widespread carbonate platforms characterised the Southern Alps for several million years, from the late Carnian to (at least) the Early Jurassic (Trento Platform) or to the Eocene (Friuli Platform).

Based on this chrono-stratigraphical framework we provide an overview of tetrapod ichnoassociations discovered from the Triassic successions of Italy.

#### 4. LOWER TRIASSIC TETRAPOD FOOTPRINTS FROM SOUTHERN AND WESTERN ALPS

In the Southern Alps, the Lower Triassic is represented only by the Werfen and Servino formations that are composed of shallow marine deposits representing the beginning of the Triassic transgression in the western

Tethys. The Werfen Formation was subdivided in several transgressive-regressive sedimentary cycles (Pisa et al., 1978; Broglio Loriga et al., 1983, 1990; Neri and Posenato, 1988; Posenato, 2019), which have been successively reinterpreted as third order depositional sequences (De Zanche et al., 1993; Gianolla et al., 1998; Neri et al., 2007).

Tetrapod footprints are rare in the Werfen Formation, occurring only in its middle-upper part (Avanzini et al., 2001; Avanzini and Mietto, 2008a; Petti et al., 2013).

#### 4.1. OL 1 DEPOSITIONAL SEQUENCE (LOWER OLENEKIAN)

In the Southern Alps, the sequence boundary (SB) of the sequence Ol 1 lies at the base of the Gastropod Oolite Member (uppermost Dienerian) at the sharp transition between supratidal and subtidal deposits. The overlying Campil Member, mostly Smithian in age (Posenato, 2019), is composed of red, laminated siltstones and sandstones with an upward increasing sand content and wave influence; the uppermost part is characterised by a supratidal interval where rare tetrapod footprints are documented (Avanzini and Mietto, 2008a).

##### 4.1.1. Recoaro area (Vicentinian Prealps, Veneto Region)

Three slabs of reddish micaceous siltstone from the Campil Member were collected in the locality Contrada Maltaure (Recoaro Terme Municipality, Vicenza Province) from the Rotolon Valley west of Recoaro Terme. The slabs, (acronymized OG/MA51, OG/MA50 and OG/MA55) and stored at the MCD-Valdagno were reported by Avanzini and Mietto (2008a) who recognized *Rhynchosauroides* isp., *Rhynchosauroides schochardti* (Rühle von Lilienstern, 1939) and *Rhynchosauroides* aff. *palmatus*.

##### 4.1.2. Western Dolomites (Trento and Bolzano Autonomous Provinces and Veneto Region)

Leonardi (1968) reported the first tetrapod footprints from the Werfen Formation of the Dolomites. They are two isolated footprints collected in the debris from the Mount Pic near Bulla/Pufels (Ortisei/St. Ulrich Municipality, Bolzano/Bozen Autonomous Province,) and from the Campil Member of Venegia in Travignolo Valley (Moena Municipality, Trento Autonomous Province). These specimens, never studied in detail, are housed in the MGP-Ferrara and, according to Conti et al. (2000), refer to “reptiles” of modest size, perhaps archosauriforms.

Footprints imprinted on ripple marks were collected in the locality Furcia Rossa from north of San Pellegrino Pass (Falcade Municipality, Belluno Province) in grey-greenish silty-marls facies probably from the Campil Member (sample MVE.1). These footprints, referred to *Capitosauroides* cf. *bernburgensis* by Avanzini and Mietto (2008a), are now showcased in the MCC-Selva di Cadore.

A small slab of reddish siltstone probably coming from the Campil Member with an incomplete footprint

referable to *Rhynchosauroides* isp. was collected in the debris near Lusia Pass (Predazzo Municipality, Trento Autonomous Province), south of San Pellegrino Pass (P. Mietto, pers. obs.), and is now kept in the MGP-Padova.

Conti et al. (2000) reported the presence of a slab from the Werfen Formation with footprints attributed to *Rhynchosauroides* isp. from the Butterloch Gorge (Aldino/Aldein Municipality, Bolzano/Bozen Autonomous Province) and now stored in the MSN-Venezia (sample FB/BU48).

##### 4.1.3. Canal del Ferro (Northern Friuli, Friuli Venezia Giulia Autonomous Region)

Conti et al. (2000) mentioned a slab with several small depressions found from the Werfen Formation near Studena (Pontebba Municipality, Udine Province). These authors described the impressions as overlapping trackways made of mesaxonic footprints possibly referable to “primitive archosaurs”. The slab (plausibly coming from the Campil Member) was later figured by Dalla Vecchia (2008), who noted that only one footprint (about 4 cm long) has a defined outline and resembles a small chirotheriid *pes* impression, although with only four digital prints. Later, Dalla Vecchia (2013) expressed doubts about the biogenic nature of the depressions, suggesting that even the tetradactyl footprint may be a random combination of small depressions of inorganic origin. The slab, with inventory number MFSN 19374, is stored at the MSFN-Udine.

##### 4.1.4. Carnia (Northern Friuli, Friuli Venezia Giulia Autonomous Region)

Dalla Vecchia (2013) and Dalla Vecchia et al. (2013) described a large boulder located at the right bank of the Avanza Brook near Pierabech (Forni Avoltri Municipality, Udine Province). The boulder is made up of gray-greenish calcilutite and comes from the Werfen Formation, probably from the Siusi Member or the Gastropod Oolite Member (Dalla Vecchia et al., 2013). The exposed bed surface preserves a ~1.6 m-long sequence of 11 aligned depressions with a kidney or sausage outline ranging from 5 to 10 cm in length. This sequence terminates both sides with a set of three depressions that are parallel and close to each other, deeper along their convex side, and arranged diagonally with respect the alignment (Dalla Vecchia et al., 2013, Fig. 9). According to Dalla Vecchia et al. (2013), they could be half-swim tracks of a large tetrapod, or impressions of an object dragged or rolled on the substrate by tidal or other currents. If they were footprints, they would represent a rare record of a large-bodied tetrapod in the Alpine Lower Triassic. The boulder is now exhibited in a square of the town of Forni Avoltri.

#### 4.2. OL 2 DEPOSITIONAL SEQUENCE (UPPER OLENEKIAN)

In the eastern Southern Alps, the SB of the depositional sequence Ol 2 is placed at the sharp contact between the sandstones and siltstones of the Campil Member and

the supratidal marly dolomites of the basal Val Badia Member. Locally (Vicentian Prealps), the boundary coincides with a marked subaerial unconformity (Broglia Loriga et al., 1990).

#### 4.2.1. Recoaro area (Vicentian Prealps, Veneto Region)

In the Recoaro area, the SB corresponds to the erosional base of the Mt. Naro Breccia (Gianolla et al., 1998), which is a fluvial deposit consisting of mainly crystalline metamorphic clasts grading upward into the Cencenighe Member (De Zanche and Farabegoli, 1981).

A single footprint (sample FM/VR22) from the locality Gattera in Ricchelere Valley (Recoaro Terme Municipality, Vicenza Province) was referred by Mietto (1986) to *Rhynchosauroides cf. schochardti*. Avanzini and Mietto (2008a) confirmed this attribution, but without open nomenclature (Fig. 3a). The specimen, which was collected in the debris, comes from red-purple and micaceous siltstones referred by Mietto (1986) to the alluvial fine-grained facies of the Mt. Naro Breccia and is kept at the MGP-Padova.

An isolated footprint collected in a bed with the same facies of the Mt. Naro Breccia cropping out near the base of the stratigraphic section of Contrada Rossi locality (De Zanche et al., 1980) in the Tretto area (Schio Municipality, Vicenza Province, Veneto Region), belongs to *Rhynchosauroides* sp. (P. Mietto, pers. obs.). The footprint is now stored in the MGP-Padova.

#### 4.2.2. Adige Valley Basin (Trento and Bolzano Autonomous Provinces)

A slab of grey siltstone with the partial impressions produced by a tetrapod moving in semi-swimming conditions was collected in debris in the Firmalin Brook (Appiano/Eppan Municipality, Bolzano/Bozen Autonomous Province) east of the village (M. Avanzini, pers. obs.). The slab is kept in the MUSE-Trento.

### 4.3. LOWER TRIASSIC TETRAPOD FOOTPRINTS FROM THE WESTERN ALPS (BRIANÇONNAIS DOMAIN)

#### 4.3.1. Gardetta Plateau (Piedmont Region, Cuneo Province, Canosio Municipality)

A new tetrapod tracksite was found in the Lower Triassic siliciclastic deposits of the Briançonnais units, cropping out between the Gardetta Plateau and Preit glacial valley (Western Alps, Piedmont Region).

Tracks are preserved as concave epirelief on a steep bedding plane belonging to the “semelle silicieuse”, usually referred to the Upper Permian-Lower Triassic interval for their stratigraphic position. The track-bearing layer is made up of cross-bedded quartz-arenite and quartz-siltstone with ripple marks, that record a fluvial to mudflat depositional environments. Although the absence of reliable biostratigraphic constraints does not allow an accurate geochronological attribution, they

are usually referred to the Lower Triassic.

The Gardetta ichnosite, currently under study by a team from the University of Turin, Muse of Trento and Sapienza of Rome, is characterised by archosauriform footprints (Petti et al., 2020) representing the first record of terrestrial tetrapods in the Briançonnais domain of the Western Alps and expanding the record of archosauriform footprints in the Lower Triassic of Central Europe (Romano et al., 2020).

### 5. MIDDLE TRIASSIC (ANISIAN) TETRAPOD FOOTPRINTS FROM THE SOUTHERN ALPS

Unlike the Lower Triassic, the Anisian has yielded abundant documentation of tetrapod footprints from the Southern Alps, sometimes with well-preserved specimens. The ichnites are found through nearly the entire Anisian missing in the uppermost part and in the overlying Ladinian. This is due to one of the most relevant eustatic transgressive event (TST of An 5 depositional sequence) of the whole Triassic (De Zanche et al., 1993; Gianolla and Jacquin, 1998; Stefani et al., 2010). However, the recent discovery of a skeleton of a small terrestrial reptile from the Buchenstein Formation (upper Anisian-lowermost upper Ladinian) does not exclude the future discovery of footprints even in this stratigraphic interval, possibly in carbonate platform environments (Renesto et al., 2020).

#### 5.1. AN 2 DEPOSITIONAL SEQUENCE (BITHYNIAN)

A subaerial erosional surface at the top of the Lower Serla Dolomite marks the SB of the sequence An 2. In the Braies/Prags area, as well in other sectors of the eastern southern Alps, the SB is underlain by the Piz da Peres Conglomerate (De Zanche et al., 1992), which coincides with a paraconformity between the Lower Serla Dolomite and fine-grained siliciclastics at the base of the Gracilis Formation or its corresponding units. In the Recoaro area, in Valsugana and near Trento, this unconformity is emphasised by the superimposition of the Val Leogra Breccia (De Zanche and Mietto, 1989) on the Lower Serla Dolomite (Gianolla et al., 1998).

#### 5.1.1. Recoaro area (Vicentian Prealps, Veneto Region)

In the Recoaro area, the Gracilis Formation mostly consists of slightly undulated, often nodular and bioturbated wackestone, marls and calcisiltites locally interlayered with gypsum (De Zanche and Mietto, 1989; De Zanche et al., 1993). Only one specimen (sample PM/VP26), now stored at the MGP-Padova, was found in Pregantale Valley south of Recoaro Terme (Vicenza Province). It is an isolated, tridactyl and mesaxonid footprint impressed by a digitigrade foot with a short and backward-directed digit IV. The footprint, which is 35 mm long and 36 mm wide and has an interdigital angle II-IV of 61°, looks like the convex hyporelief of a right pes and has been referred by Avanzini and Mietto (2008a) to a possible dinosauro-morph tracemaker (Fig. 3b).

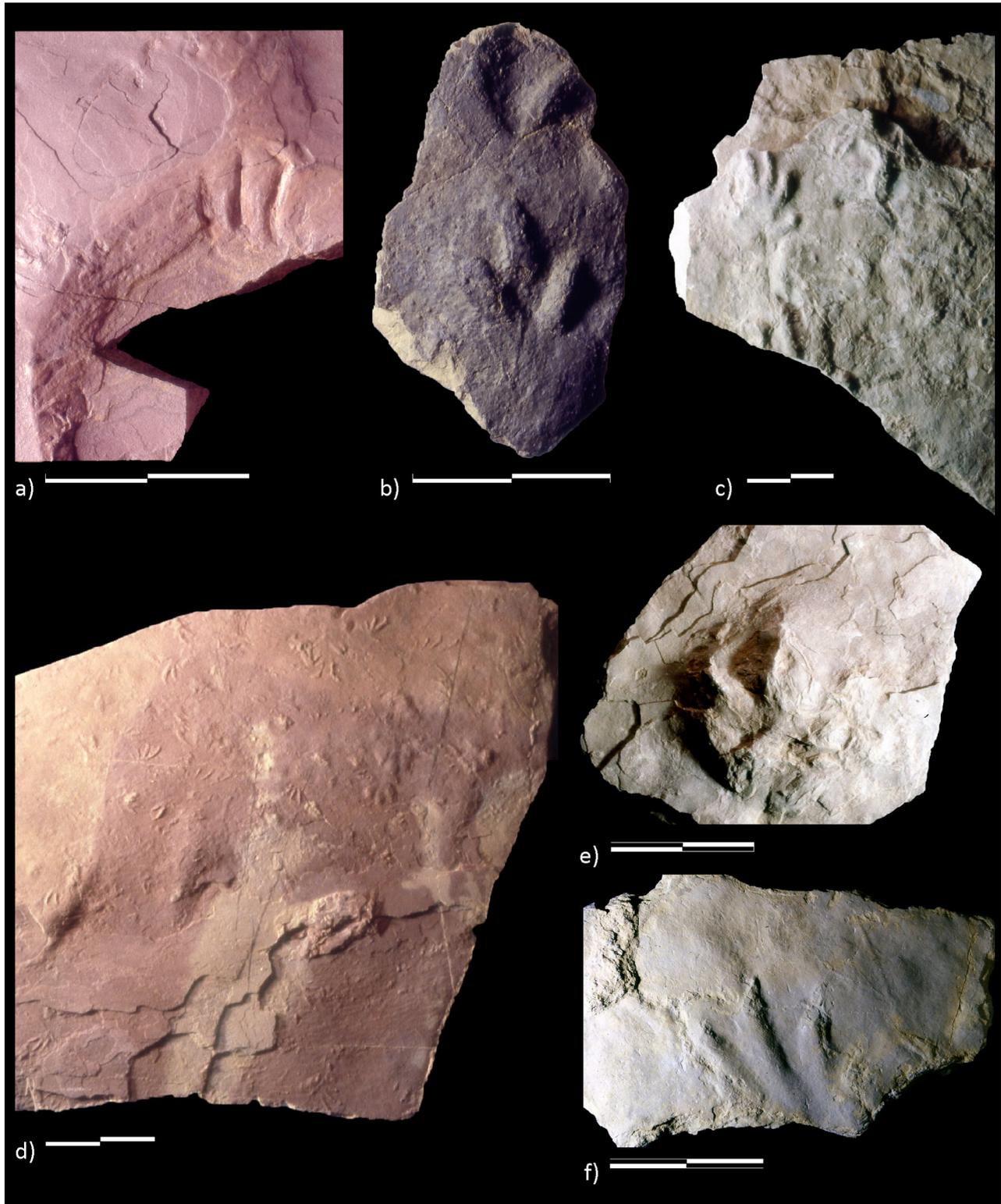


Fig. 3 - Lower and Middle Triassic tetrapod footprints from the 3rd Depositional Sequence Ol 2 (Olenekian), An 2 (Bithynian), An 3 (Bithynian-Pelsonian) and An 4 (Illyrian) from the Recoaro area (Vicentinian Prealps, Veneto Region). a) *Rhynchosauroides schochardti*, specimen FM/VR22, Monte Naro Breccia of Werfen Fm., Gattera, scale bar: 5 cm; b) 'Dinosauromorpha', specimen MP/VR26, Gracilis Fm., Pregantale Valley, scale bar: 5 cm; c) *Parasynaptichnium gracilis*, type-material specimen OG/VP24, left manus and partial left pes, Voltzia Beds, Pregantale Valley, scale bar: 10 cm; d) *Rhynchosauroides tirolicus* and *Brachychirotherium* aff. *parvum sensu* Brandner, 1973, slab OG/VG66, Tretto Conglomerate, Creme Valley, scale bar: 10 cm; e) *Chirotherium barthii*, specimen OG/VC76b, Creme Valley, scale bar: 10 cm; f) *Parasynaptichnium gracilis*, type-material specimen AR/VP23, left pes, Voltzia Beds, Pregantale Valley, scale bar: 10 cm.

## 5.2. AN 3 DEPOSITIONAL SEQUENCE (BITHYNIAN- PELSONIAN)

In the eastern part of the Southern Alps, the SB of the sequence An 3 is placed at the erosional surface at the base of the Voltago Conglomerate or at the karst surface at the top of carbonate platform (Monte Rite Formation) (De Zanche et al., 1993). In the Recoaro area, the boundary corresponds to an abrupt facies change between the Gracilis Formation and the overlying continental Voltzia Beds (Barbieri et al., 1980). In the Dolomites, above the Voltago Conglomerate the sequence continues with the Recoaro Limestone (Balatonites ammonoid Zone, Pelsonian) and the Upper Serla Dolomites or, in the Recoaro area, with the Recoaro Limestone (Gianolla et al., 1998).

### 5.2.1. Recoaro area (Vicentinian Prealps, Veneto Region)

In the Voltzia Beds of the Pregantale Valley, two slabs with footprints preserved as convex hyporeliefs were collected in the debris. The first slab (AR/VP23), is made up of yellowish laminated siltstone, with a slightly wavy surface and bears a partial footprint of a left *pes*, preserving only the traces of digits I-IV (Fig. 3f). The second slab (OG/VP24) is made up of silty, laminated and hazel-gray limestone (Fig. 3c). The lower surface of this slab bears a set of convex hyporeliefs consisting of a well-preserved left *manus* impression and a left *pes* impression of which only traces of the extremities of the digits II-V are preserved. These footprints are the type material of *Parasynaptichnium gracilis* Mietto, 1987, an ichnotaxon that was referred to a medium-sized quadrupedal "archosaur". The tracks are clearly mesaxonic, especially the *pes* imprints. The *manus* impression is typically chirotheriid in shape, with a divergent digit V respect to digits I-IV, low interdigital angles and a poorly preserved digit I. The digit impressions of the *manus* are curved inwards and have pointed apices, except for the digit V impression which has a rounded end. The *manus-pes* distance is 18 cm. The *pes* impression is slender, with long digit traces that are curved medially. The interdigital angles have a relatively low value, while the angle IV-V (although the digit V impression is partially visible and only in one of the two slabs) is very low (<10°). This is the main character to distinguish *Parasynaptichnium gracilis* from the similar and coeval *Chirotherium barthii* Kaup, 1835. In fact, in *C. barthii* the digit V impression is rotated outwards and the interdigital angle IV-V has a much higher value (>40°). The general shape of the *pes*, hypothesized by Mietto (1987) on an incomplete footprint, has been later fully confirmed by the findings from the Adige Valley (Palade Pass/Gampenpass) and the Voltago Conglomerate (Avanzini and Mietto, 2008a). The same authors examined other material from the Voltzia Beds (equivalent to the Voltago Conglomerate) of the Pregantale Valley: two *pes* prints preserved as convex hyporeliefs (samples OG/VP27 and 32) are referred to *Parasynaptichnium gracilis*, the latter

with the well-impressed digit V. Finally, the museum MCD-Valdagno hosts: 1) a possible *manus-pes* pair referable to *Rhynchosauroides* isp. (sample OG/VP31), 2) a poorly impressed footprint doubtfully ascribed to *Parasynaptichnium* isp., and 3) a footprint (OG/VP34), representing a convex hyporeliefs of a left, mesaxonic and digitigrade *pes* with dinosauiromorph appearance, perhaps attributable to *Sphingopus* isp.

### 5.2.2. Valsugana (Southern Trentino, Trento Autonomous Province)

Some footprints come from the Voltzia Beds outcropping along the eastern side of Mount Marzola (Trento Municipality). The ichnoassociation includes small tracks belonging to an apparently oligotypic fauna in which the only ichnogenus represented is, most probably, *Procolophonichnium* Nopcsa, 1923 (M. Avanzini, pers. obs.). The footprints are kept in the MUSE-Trento.

### 5.2.3. Adige Valley Basin (Trento and Bolzano Autonomous Provinces)

The basal silty levels of the Voltago Conglomerate in the upper Non Valley, along the riverbed of the Urban Brook (Ruffrè Municipality, Trento Autonomous Province), nearby Senale-San Felice (Unsere Liebe Frau im Walde-St. Felix), yielded numerous tetrapod footprints (Avanzini and Mietto, 2008a, 2008b) referable to *Rhynchosauroides tirolicus*, *Isochirotherium delicatum* Courel and Demathieu, 1976, *Synaptichnium pseudosuchooides* Nopcsa, 1923 (Figs. 4 d-e), *Chirotherium* isp., and cf. *Sphingopus* isp. (Fig. 4g) (the material is stored at MUSE-Trento).

The same trampled layers were recognized on the eastern flank of the Mount Ozol (Revò Municipality, Trento Autonomous Province). In this locality, several *Rhynchosauroides* and some poorly preserved chirotheriid footprints were discovered (M. Avanzini, pers. obs.). The footprints are kept in the MUSE-Trento.

Several footprints come from the basal inter-supratidal layers of a mixed carbonate siliciclastic unit (Givo Formation) of Pelsonian (middle Anisian) age (Avanzini et al., 2007a) nearby the town of Bad Gfrill (Tesimo Municipality, Bolzano-Bozen Autonomous Province) (Avanzini and Valdiserri, 2004; Valdiserri and Avanzini, 2007; Avanzini and Mietto, 2008b; Valdiserri et al., 2009). This ichnofauna is dominated by the ichnogenus *Rhynchosauroides* (65% of all the recovered footprints) (Fig. 4l) which, together with the ichnospecies *R. tirolicus*, represent the 35% of all the lizard-like footprints. Other tracks correspond to the ichnogenus *Rotodactylus* Peabody, 1948 (Fig. 4f), *Synaptichnium* Nopcsa, 1923 (*S. pseudosuchooides* Nopcsa, 1923), *S. diabloense* Peabody, 1948 and *Synaptichnium* cf. *S. cameronense* (Fig. 4h), *Chirotherium* Kaup, 1835 (*C. barthii*) and *Procolophonichnium*. Many other tracks are at present unidentified. All the footprints are housed in the MUSE-Trento.

The diversity of the ichnoassociation corresponds to the expected faunal composition of this time in

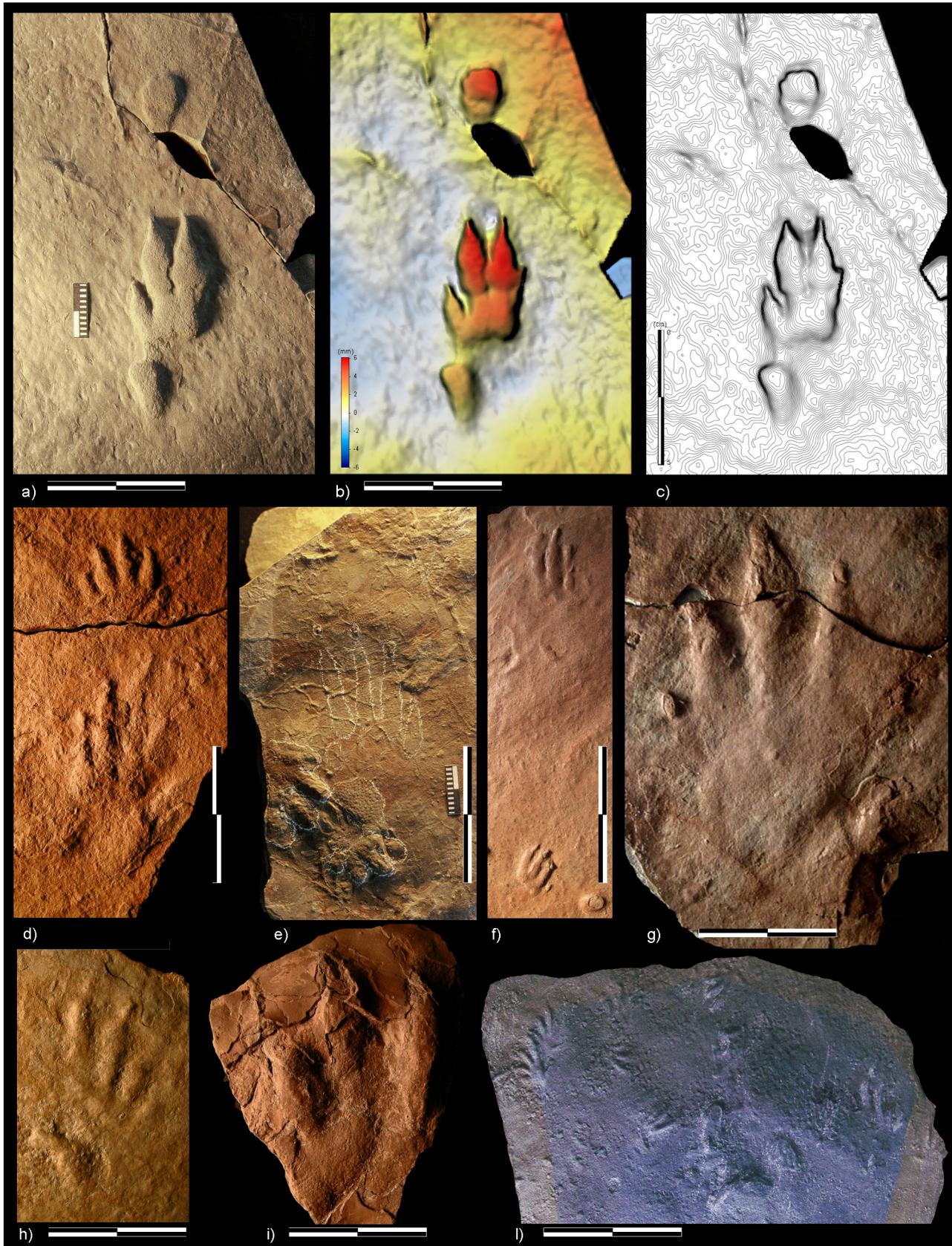


Fig. 4 - Middle Triassic (Anisian) tetrapod footprints from the 3<sup>rd</sup> Depositional Sequence An 3 (Bithynian-Pelsonian) of Adige Valley Basin (Trento and Bolzano/Bozen Autonomous Provinces). a-c) *Isochirotherium delicatum*, Palade Pass/Gampenpass (Bolzano/Bozen); d) *Synaptichnium pseudosuchooides*, Urban Brook (Ruffrè, Trento); e) *Synaptichnium pseudosuchooides* with skin impressions Rio Urban; f) *Rotodactylus* isp., Bad Gfrill (Bolzano/Bozen); g) cf. *Spingopus* isp., Urban Brook; h) *Synaptichnium* cf. *S. cameronense*, Bad Gfrill; i) *Parasynaptichnium gracilis*, Palade Pass/Gampenpass; l) *Rhynchosauroides* isp.; all scale bars: 5 cm.

Southern Alps (Avanzini and Mietto, 2008a). The *Rhynchosauroides*-dominated ichnofauna at Bad Gfrill could be related to the marine influenced tidal flat deposits (*Rhynchosauroides* ichnofacies *sensu* Diedrich, 2002), and seems to represent an intermediate stage between the chirotheriid-dominated siliciclastic continental facies of the Buntsandstein and the *Rhynchosauroides*-dominated carbonate tidal flat of the Middle Triassic Muschelkalk (Mujal et al., 2018).

Well-preserved footprints were found near Palade Pass/Gampenpass in the upper Non Valley (Lana Municipality, Bolzano-Bozen Autonomous Province). The trampled layers consist of red, grey and yellow sandy to marly dolostone and marly sandstone that probably reflect a transitional continental to marine palaeoenvironment characterised by coastal delta mouth bars formed under relatively arid conditions (Avanzini and Neri, 1998; Avanzini, 1999). The most abundant ichnoassociation occurs on a dark red siltstone layer coated by a submillimetre-thick drape of yellow shale, which is located stratigraphically close to the Voltago Conglomerate and Recoaro Limestone (or equivalent) transition (upper Pelsonian).

The footprints are referable to the ichnogenera *Rhynchosauroides* (*R. tirolicus*), *Rotodactylus*, *Brachychirotherium* Beurlen, 1950, *Isochirotherium* Haubold, 1971 (*I. delicatum* Courel and Demathieu, 1976: Fig. 4 a-c), *Parasynaptichnium* (*P. gracilis*: Fig. 4i), *Procolophonichnium*, *Synaptichnium* and *Chirotherium* (Avanzini and Neri, 1998). Many footprints display skin impressions, depicting the arrangement of the scales. The most complete tracks are assigned to *Synaptichnium* isp. where the scale imprints show that the epidermis morphology differed from that observed on chirotheriids tracks (Avanzini, 1999, 2000; Avanzini and Mietto, 2008a, 2008b).

Several well-preserved *Isochirotherium delicatum* footprints have been found on a single bedding plane and on a surface <2 m<sup>2</sup> wide. The footprints indicate a possible social behaviour, probably sampling a same local population (Avanzini and Lockley, 2002). Using footprint length as an arbitrary proxy of age, seven age intervals have been obtained, allowing the construction of an age pyramid structure (Avanzini and Lockley, 2002). Tracks can be differentiated into two groups distinguishable by the L/W ratio, interdigital divarication angles and long axis-cross axis intersection angles. Both groups are represented by similar numbers of individuals, perhaps indicating a balanced population structure (i.e. similar numbers of males and females). The growth curve suggests that growth is rapid in the juvenile stages and decelerates into adulthood, which is presumably reached at sexual maturity. Although it is not possible to affirm with certainty the reason for the differentiation into two groups, it seems most parsimonious to suggest sexual dimorphism, possibly with the female tracks being relatively long and slender and the male tracks being relatively short and stout (Avanzini and Lockley, 2002).

All the footprints are housed in the MUSE-Trento.

In the same formation and area (Non Valley), Avanzini and Renesto (2002) found *R. tirolicus* also near the locality Senale/Unsere Liebe Frau im Walde (Senale-San Felice Municipality, Bolzano-Bozen Autonomous Province). All footprints are housed in the MUSE-Trento.

Near to the Appiano/Eppan Municipality (Bolzano-Bozen Autonomous Province), to the west of the town, three slabs of micaceous siltite from the fine-grained facies of the Voltago Conglomerate have been collected. One slab bears various footprints the best of which are referable to *Rhynchosauroides tirolicus*. *Rhynchosauroides* cf. *rectipes* has been recognized in the other two slabs. One of these latter slabs preserves two *manus-pes* couples, not in succession, characterized by curved *pes* digits (Avanzini and Mietto, 2008a).

From the debris marly facies that characterize the basal part of the Giovo Formation, come two samples that bear some poorly impressed digitigrade tracks and a possible convex hyporelief footprint, of probable chirotheriid affinity. All the samples from Appiano/Eppan, are stored in the MGP-Padova.

Along the base of the walls of Mount Macaion (Appiano/Eppan Municipality, Bolzano-Bozen Autonomous Province) between Tisens and Magrè, numerous sites with imprints of tetrapods have been identified (M. Avanzini, pers. obs.). The stratigraphic levels always lie in the upper part of the Voltago Conglomerate. The most common footprints are assigned to *Rhynchosauroides*. The collected footprints are kept in the MUSE-Trento.

Several other ichnosites were discovered in other places where the Voltago Conglomerate and the uppermost basal part of the Giovo Formation (and equivalent units) crop out (M. Avanzini, pers. obs.). The main localities are Cortaccia (Bolzano Autonomous Province) and Roverè della Luna (Trento Autonomous Province) on the right side of the Adige Valley and San Floriano (Egna/Neumarkt, Bolzano Autonomous Province), at the base of Mount Cislone, on the opposite side of the valley. More trampled levels are present in Cembra Valley (Ville di Giovo, Trento) and San Michele all'Adige (Trento). The ichnofaunas are monotonous and consist almost exclusively of *Rhynchosauroides*, with rare *Rotodactylus* and small unclassifiable chirotheriid footprints. All the collected footprints are kept in the MUSE-Trento.

#### 5.2.4. Eastern Dolomites (Veneto Region)

A small slab of hazelnut-coloured micaceous siltite referable to the fine-grained facies of the Voltago Conglomerate was collected at Mount Cernerà (Selva di Cadore Municipality, Belluno Province). It bears a small footprint (sample PM/CE42), now stored at MGP-Padova, that Avanzini and Mietto (2008a) reported as *Rhynchosauroides* isp.

#### 5.3. AN 4 DEPOSITIONAL SEQUENCE (ILLYRIAN)

In parts of the Dolomites and in the Recoaro area, the SB of the sequence An 4 corresponds to a strong subaerial

erosional surface. This well-defined unconformity is placed at the base of conglomerate-sandy-silty lithozones (Richthofen Conglomerate or Tretto Conglomerate in the Recoaro area) and deeply erodes Anisian, Lower Triassic and Permian units (Bosellini, 1968; Assereto et al., 1977; Farabegoli et al., 1977; Pisa et al., 1978; De Zanche et al., 1992, 1993). Locally (Villaverla 1 A.G.I.P. well) the SB coincides with an angular unconformity on the pre-Permian metamorphic basement (Gianolla et al., 1998). In basinal areas, the correlative conformity is placed at the sharp increase in siliciclastics in the uppermost Dont Formation and is dated to *S. abichi* Subzone (*Paraceratites* Zone, lower Illyrian). In the shelf areas, the succession evolves to the lagoonal Morbiac Limestones (Sturia Beds in Recoaro area) and then to the carbonate platforms (Contrin Formation and Monte Spitz Limestone).

### 5.3.1. Recoaro area (Vicentinian Prealps, Veneto Region)

Brandner (1973) was the first to report the presence of tetrapod footprints in the fine-grained facies of the Tretto Conglomerate in the Recoaro area. Subsequently, twenty slabs of fine reddish and micaceous siltite were found in the upper Creme Valley, south of Recoaro Terme (Vicenza Province), at the base of an about 10-m-thick section of the Recoaro Limestone, at the top of which the Tretto Conglomerate crops out. Unfortunately, the outcrop was affected by a landslide, thus the specimens studied by Avanzini and Mietto (2008a) were collected in the debris. All the recovered slabs are kept at the MCD-Valdagno (Mietto, 1995, 1999a).

Almost all of the slabs bear imprints of the *pes*, *manus*, and *manus-pes* couples, either isolated or in succession. They are either concave epireliefs or convex hyporeliefs and can be referred to *Rhynchosauroides tirolicus*. In some samples the footprints are as well-preserved as to show scale impressions from the palm and sometimes also in the digits, as noted by Avanzini and Renesto (2002). The slab OG/VC72, in addition to isolated footprints and trackways of *R. tirolicus*, exhibits a succession of *manus-pes* couple referable to *Rotodactylus rathi* Demathieu, 1971. The slabs OG/VC65 and 68 bear *manus-pes* couple referable to *Rotodactylus lucasi* Demathieu and Gand, 1973. The slab OG/VC73 is truly spectacular: it preserves multiple and complete couples of *R. tirolicus*, an isolated footprint of *R. lucasi* and a not well-impressed track, but referable to *Procolophonichnium* isp. Isolated footprints possibly referable to the latter ichnotaxon, are also preserved on the slab OG/VC70. One of the most beautiful slabs (OG/VC66) is now exhibited in the Valdagno Museum (Fig. 3d); in addition to the usual *R. tirolicus* footprints, it contains a perfect *manus-pes* couple as convex hyporelief, which is attributed to *Brachychirotherium* aff. *parvum* (*sensu* Brandner, 1973). Finally, two counterpart slabs (GG/VC76a and b) exhibit, in concave epirelief and convex hyporelief respectively, a large *manus* print of *Chirotherium barthii* (Fig. 3e).

### 5.3.2. Adige Valley Basin (Trento and Bolzano/Bozen Autonomous Provinces)

Todesco and Bernardi (2011) reported rich ichnoassociations in various levels within the basal part of the Richthofen Conglomerate cropping out near the village of Ometto and along the Gerlano Valley, a side valley of the Vallarsa (Trento Autonomous Province). Footprints are preserved within silty-sandy beds originated in fan-delta environments. In these localities, the retrieved ichnodiversity is remarkably high, with at least five ichnotaxa documented: *Procolophonichnium* (Fig. 8 f,g), *Rhynchosauroides*, *Rotodactylus*, *Brachychirotherium* and *Chirotherium* (Fig. 5 d-f). The ichnoassociation presents the classical Southern Alpine Anisian composition with “archosauromorph” and “lepidosauromorph” tracks being dominant. A similar, although much less diverse association (*Rhynchosauroides* and cf. *Chirotherium*) was recently discovered few kilometres south to the Vallarsa sites, at the topmost Ronchi Valley (Vallarsa Municipality, Trento Autonomous Province) (M. Bernardi and M. Avanzini, pers. obs.). The collected ichnites are stored at the MUSE-Trento.

A group of large tracks has been found in outcrops of the Morbiac Limestone on the western side of the Adige Valley above Termeno/Tramin an der Weinstraße, a few kilometres south of Bolzano/Bozen (Avanzini and Leonardi, 2002). Most of these tracks are concentrated on the same layer, which crops out along Inferno Brook (Bolzano/Bozen Autonomous Province), at the base of Mount Roen. The footprints are preserved as natural casts (convex hyporeliefs) at the base of a level of a bioclastic yellowish-grey packstone. The underlying layer, fragmented by mud cracks, is made up of thin layers of marl and siltstone with plant fossil remains. Some large *Isochirotherium* footprints with a peculiar shortened morphology led to the definition of the ichnospecies (Avanzini and Leonardi, 2002). Comparison suggests that the Termeno ichnospecies could represent a form of *Isochirotherium* similar to *Isochirotherium marshalli* Peabody, 1948 but being shorter and more robust (L/W ratio of 1.43) and with a smaller and slender digit V. The footprints were left *in situ*. The unique collected sample is stored at the MUSE-Trento (Fig. 5 a-c).

### 5.3.3. Eastern Dolomites (Veneto Region)

The Contrin Formation crops out along the road that shortly before Caprile leads directly to Selva di Cadore, going up the Fiorentina Valley (Selva di Cadore Municipality, Belluno Province), a few meters beyond the bridge that crosses the brook, on the right. During the roadworks made in 1986, the stratigraphic succession below the Contrin Formation was exposed (De Zanche et al., 1993; Gianolla et al., 1998; Neri et al., 2007). Below the road outcropped at least 10 m of laminated arenites and siltstones, mainly reddish in colour, referable to the fine-grained facies of the Richthofen Conglomerate. This succession is followed, up to roadside, of about three m of grey marly limestones alternating with varicoloured

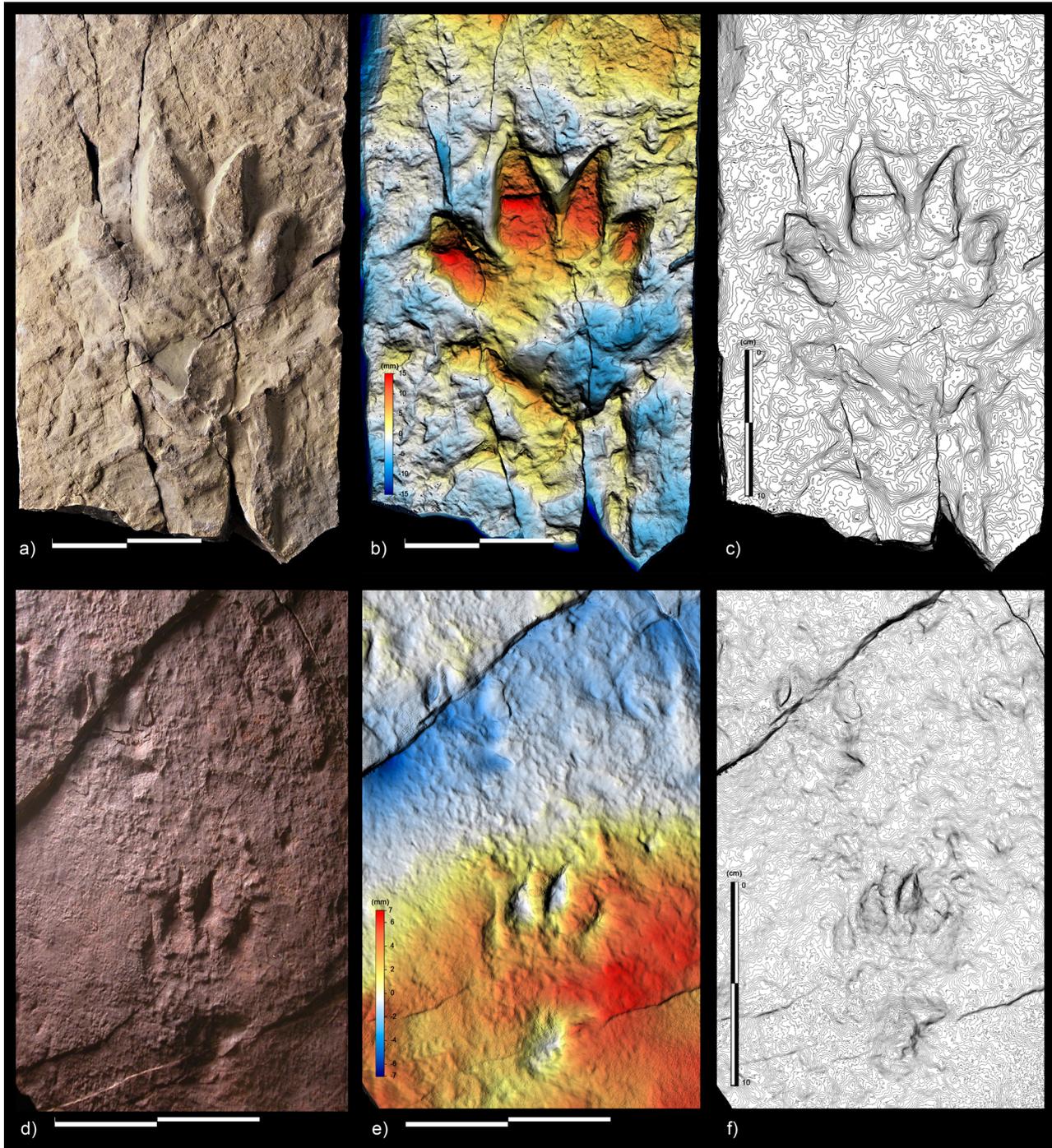


Fig. 5 - Middle Triassic (Anisian) Tetrapod footprints from the 3<sup>rd</sup> Depositional Sequence An 4 (Illyrian) of Adige Valley Basin (Trento and Bolzano/Bozen Autonomous Provinces). a-c) *Isochirotherium infernensis*, Inferno Brook (Termeno, Bolzano/Bozen); d-f) *Chirotherium* isp., Gerlano Valley (Vallarsa, Trento). All scale bars: 10 cm.

pelitic layers, referable to the Morbiac Limestone. The latter formation continued above the road at least another 10 m beyond the boundary with the overlying Contrin Formation. In addition to the many footprint specimens collected in the debris, now kept at MGP-Padova, two footprint-bearing layers were identified *in situ*. Layer FI5 is located below the road in the upper part of the Richthofen Conglomerate, about two m below the boundary with the Morbiac Limestone. The second layer, FI6, occurs about

120 cm above the road, inside the Morbiac Limestone.

The preliminary analysis (Avanzini and Mietto, 2008a) allowed to identify *Rhynchosauroides tirolicus*, possible *R. peabody* Faber, 1958 and *Rotodactylus* isp.

The Richthofen Conglomerate crops out along the road Caprile - Sella Pass at the bend on the right that after Andraz crosses the Ruaz Brook (Livinallongo del Col di Lana Municipality, Belluno Province). This unit, with an erosive base on the Gastropods Oolite Member

of the Werfen Formation, consists of at least 22 m of conglomerate, sandstone and siltstone, mainly reddish in color, set just below the boundary with the overlying Morbiac Limestone (De Zanche et al., 1993). About 250 cm below this boundary, the layer RZ11 preserves tetrapod footprints referred to *Rhynchosauroides tirolicus* (see Avanzini and Mietto, 2008a). A grey marly limestone layer of the Morbiac Limestone is very rich in *Rhynchosauroides* isp. footprints, but they are very poorly preserved. This layer occurs about 150 cm above the base of the formation. The collected samples are kept in the MGP-Padova.

#### 5.3.4. Western Dolomites (Trento Autonomous Province)

In Duron Valley locality of the Fassa Valley (Campitello di Fassa Municipality), a new ichnosite was discovered in 2006 within the Illyrian Morbiac Limestone (Avanzini et al., 2007b; Todesco et al., 2008a). The footprint-bearing section consists of decimetric-thick grey silty and silty limestone layers that towards the top grade to wackestones and packstones with foraminifers and ostracods (Fig. 6c). Several stromatolite bindstone and thin grey or green siltstone layers are present. Plant fossil debris is common. In the lower portion of the section, three layers of laminated silty limestone contain tetrapod footprints. The depositional palaeoenvironment is marine marginal like a terrigenous tidal flat. Twelve silty limestone slabs with one or more preserved footprints were recovered from this section. The tracks represent a typical Anisian Alpine ichnoassociation composed of *Rhynchosauroides tirolicus*, *Chirotherium barthii* (Fig. 6d), *Isochirotherium delicatum*, *Brachychirotherium* isp. (Fig. 6e). The slabs are currently stored at the MUSE-Trento and at the MGD-Predazzo.

Several unpublished footprints stored at MUSE-Trento come from the base of the Crepa di Socorda wall (Pozza di Fassa Municipality) in the Catinaccio d'Antermoia Massif (Fig. 6a), along the path between the Gardeccia Hutte and Scalette Pass (2100 m a.s.l.). The specimens have been found in basal levels of the Morbiac Limestone locally constituted by silty limestone related to a marine-marginal setting (M. Avanzini, pers. obs.). The ichnotaxa are represented by *Procolophonichnium* isp., *Rhynchosauroides* isp. and *Brachychirotherium* isp. (Fig. 6b).

#### 5.3.5. Northern Dolomites (Bolzano/Bozen Autonomous Province)

At the northern slope of the Braies and Valdaora/Prags und Olaner Dolomites (Bolzano/Bozen Autonomous Province) overlooking the Pusteria Valley/Pustertal, the Richthofen Conglomerate crops out extensively. In 1922, Julius Pia found the first Triassic footprints from the Dolomites in this formation, in the locality Lapadures (Flatschkofel/Col Valacia); they were later named *Rhynchosauroides tirolicus* by Abel (1926). Between the 70's and 80's of the 20<sup>th</sup> century similar outcrops, located at the northern slope of the Piz da Peres (Valdaora/

Olang Municipality), were investigated by the Innsbruck University (Bechstadt and Brandner, 1970) and Padua University (De Zanche et al., 1992). Several levels with tetrapod footprints were found in the fine-grained reddish facies (De Zanche et al., 1992). The specimens collected by the Padua researchers, stored at MGP-Padova, come from a level set at about three metres below the boundary with the Morbiac Limestone. They include *Rhynchosauroides tirolicus* and "archosaur"-like footprints. The footprints collected by the Innsbruck University researchers include *Rhynchosauroides tirolicus*, well-preserved *Brachychirotherium* aff. *parvum* and *Chirotherium* sp. cf. *C. rex* pedal prints (Brandner, 1973).

In the same site, several subsequent field excavations (2004-2008) carried out by the MSN-Bolzano/Bozen and the MUSE-Trento allowed to identify a relatively large ichnoassociation, in which several ichnogenera were recognized and confirmed (Todesco et al., 2008b) (Fig. 7). Most of the footprints and trackways belong to *Rhynchosauroides tirolicus* (Fig. 8 d,e). Less common but relatively diversified are the chirotheriid tracks which were referred to the ichnogenera *Isochirotherium* (with *Isochirotherium delicatum*), *Chirotherium* and *Brachychirotherium*; also, *Procolophonichnium* isp. has been identified (Fig. 8f).

The new ichnotaxon *Sphingopus ladinicus* (Avanzini and Wachtler, 2012) was related to the enigmatic Parachirotheriidae Haubold, 1969 (Fig. 8 a-c). *S. ladinicus* shows pentadactyl and narrow *pes* tracks, which are occasionally associated with small *manus* prints. *Pes* digits II-IV show little divarication (max 15°); the digit proportions are III>IV>II, with the metatarsal-phalangeal articulation forming a compact group. Tracks show a clear trend towards digitigrady with a functionally *pes*. Avanzini and Wachtler (2012) interpreted these characters as suggestive of the belonging to basal dinosaurs.

The site also yielded numerous plant fossil-bearing horizons and some scattered invertebrate traces and body remains (polychaete worms). Plants belong to the Sphenophyta, Pteridophyta, Pteridospermae, and Cycadophyta, while the conifer *Voltzia recubariensis* Schenk, 1868 is largely dominant (Todesco et al., 2008b). The specimens are stored into the MSN-Bolzano/Bozen.

#### 5.3.6. Sappada area (Friuli Venezia Giulia Region)

Venturini et al. (2009) reported the finding of some tetrapod footprints referred to *Rhynchosauroides* isp. on the southern slope of Mirtilli Hill, near the village of Cima Sappada (Sappada Municipality, Udine Province). The specimens, kept at the MUST-Roma, come from the upper part of the Richthofen Conglomerate.

### 6. LOWER (OLENEKIAN)-MIDDLE TRIASSIC (ANISIAN) TETRAPOD FOOTPRINTS FROM MARITIME ALPS (BRIANÇONNAIS DOMAIN)

The Triassic deposits of the Maritime Alps (Ligurian Briançonnais) are characterized at the base by coarse

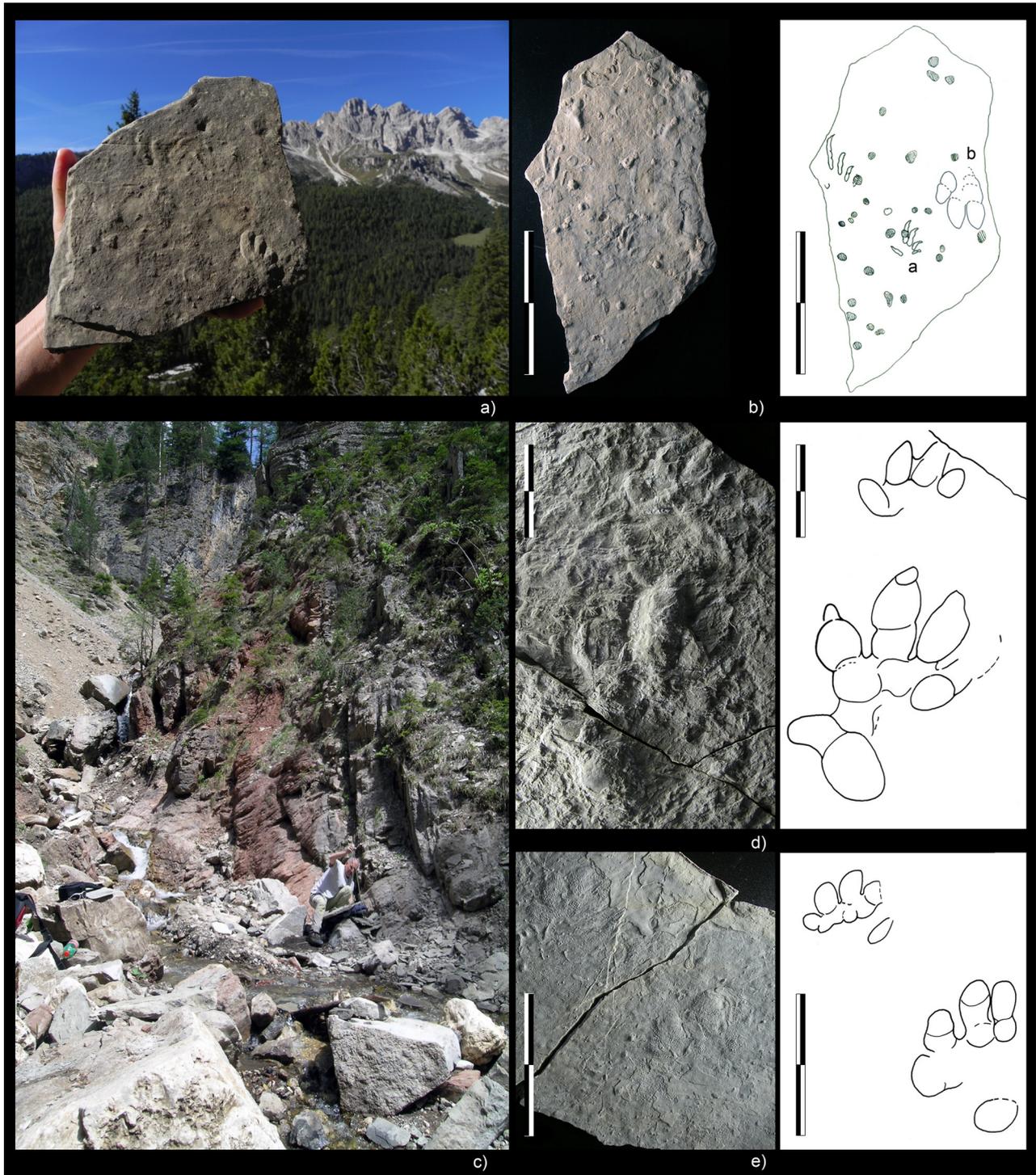


Fig. 6 - Middle Triassic (Anisian) Tetrapod footprints from Western Dolomites (Trento Autonomous Province). a) Crepa di Socorda ichnosite with the outline of the Catinaccio d'Antermoia massif nearby Gardeccia Hutte; b) Crepa di Socorda ichnosite (Catinaccio d'Antermoia): slab with *Rhyncosauroides tirolicus* and small *Brachychirotherium* isp. footprints, scale bar: 10 cm; c) Val Duron ichnosite (Campitello di Fassa) with the outcropping Richthofen Conglomerate layers; d) *Chirotherium barthii*, Val Duron ichnosite (Campitello di Fassa); e) *Brachychirotherium* isp., Val Duron ichnosite (Campitello di Fassa) with skin traces, scale bar: 10 cm.

siliciclastic deposits of the so called Verrucano Brianzonese resting unconformably on Permian volcanoclastics (Dallagiovanna and Gaggero, 2006), then by a thick sandstone unit (Ponte di Nava Quartzite Formation), followed by a thin greenish pelitic interval

(Case di Valmarenca Pelites Formation) transitional to the Middle Triassic marine carbonate deposits of the Costa Losera Formation (Lualdi and Bianchi, 1990; Costamagna, 2018). The age of this siliciclastic interval is not well-constrained due to the lack of significant



Fig. 7 - The Piz da Peres (Bolzano/Bozen Autonomous Province) ichnosite a-b) a trampled layer from the base of Morbiac Limestone (Illyrian); c) scheme of the same layer: 1) *Rhynchosauroides tirolicus* trackways, 2) *Rhynchosauroides* isp. footprints; 3) *Arenicolites longistriatus* tracks, 4) ripple marks, scale bar: 10 cm.

fossil levels. An Early-Middle Triassic age is inferred from the stratigraphic position between the Permian volcanoclastics and the well-dated Middle Triassic carbonates (Costamagna, 2018).

### 6.1. WESTERN LIGURIA REGION

In 2014, some tetrapod footprints were found, for the first time, in the Case Valmarenga Pelites Formation (Vanossi, 1974, 1991; Costamagna, 2018) cropping out in

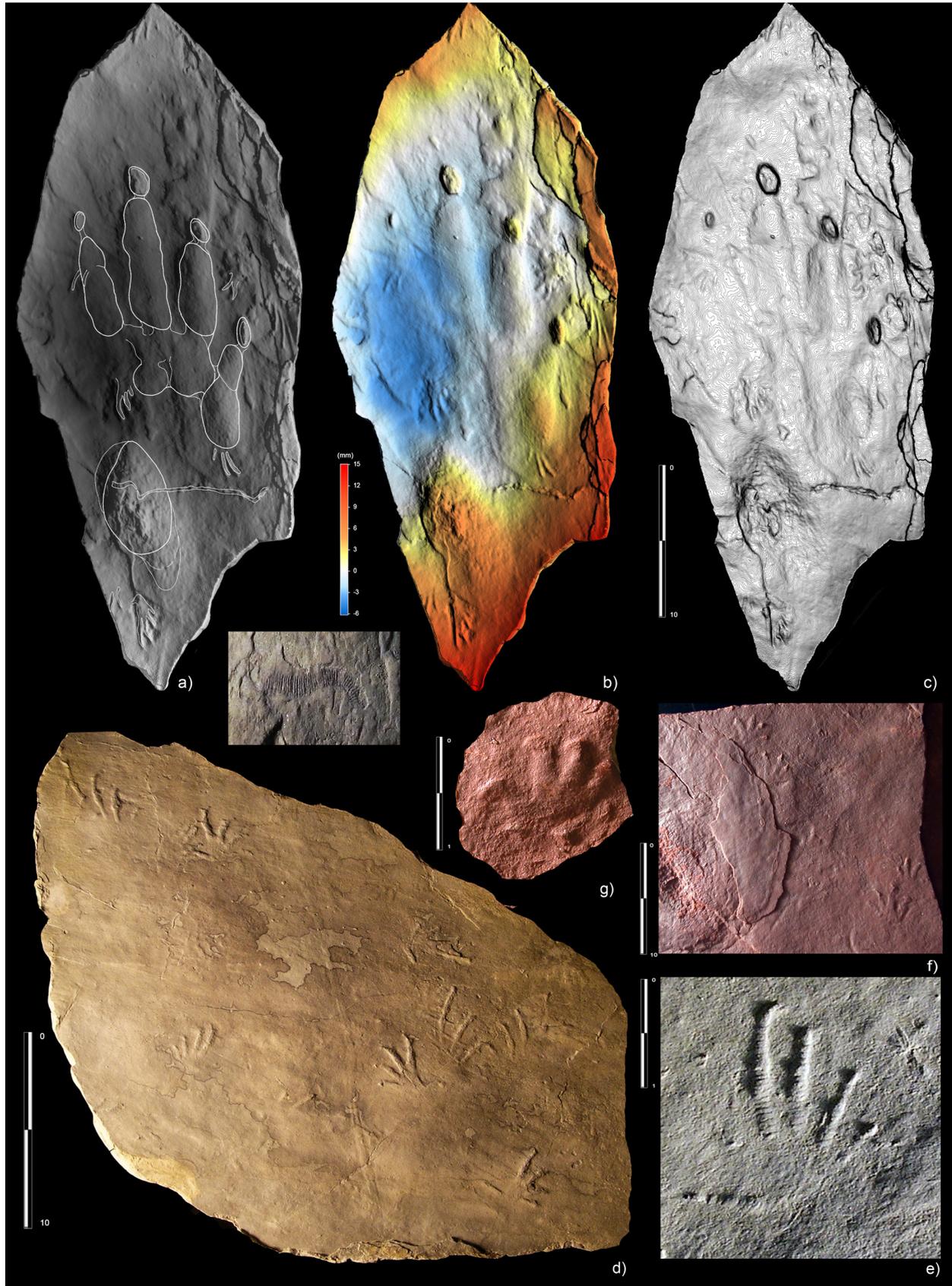


Fig. 8 - Middle Triassic (Anisian) Tetrapod footprints from the 3rd Depositional Sequence An 4 (Illyrian) of Adige Valley Basin (Trento and Bolzano/Bozen Autonomous Provinces). a-c) *Sphingopus ladanicus*, Piz da Peres, (Bolzano/Bozen) with a trampled polychaete worms on digit V (see close up image), scale bar: 10 cm; d) *Rhyncosauroides tirolicus* trackway, Piz da Peres, scale bar: 10 cm; e) *Rhyncosauroides tirolicus* manual print with skin impressions, Piz da Peres, scale bar: 1 cm; f) *Procolophonichnium* isp. trackway, Gerlano Valley (Vallarsa, Trento), scale bar: 10 cm; g) *Procolophonichnium* isp. manual print, Gerlano Valley, scale bar: 1 cm.

the Upega area near Ponte di Nava (Ormea Municipality, Savona Province). Two slabs (VM1 and VM2) contain footprints that have been referred by Santi et al. (2015) to archosauriforms, supposedly to the ichnogenus *Chirotherium*. Unfortunately, their incompleteness prevents a more precise determination. Also, the age of the succession bearing the footprints is not clear. However, these footprints appear to be forms pertinent to the “Biochron II” or the “*Chirotherium* assemblage zone” of Klein and Haubold (2007) and Lucas (2007); therefore, they are dated to the late Olenekian-early Anisian.

## 7. MIDDLE TRIASSIC (ANISIAN) TETRAPOD FOOTPRINTS FROM SARDINIA

### 7.1. NURRA REGION (NORTHWESTERN SARDINIA)

Recently, Citton et al. (2020) reported two loose Middle Triassic sandstone blocks with footprints from the coastal area north of Capo Caccia promontory (Alghero Municipality, Sassari Province, Sardinia Autonomous Region). The Triassic deposits of the Nurra region, where the blocks were found, belongs to the typical Germanic facies, characteristic of the southern edge of Paleo-Europe (Dercourt et al., 2000; Costamagna and Barca, 2002; Costamagna, 2012). The track-bearing blocks were assigned to the middle-upper portion of the Anisian Cala Viola Sandstones (“Buntsandstein”), a unit recording the evolution of a floodplain environment furrowed by relatively sinuous channels in terminal fan settings and under semi-arid conditions (see Citton et al., 2019). Footprints were assigned to the ichnotaxa *Rhynchosauroides* and *Rotodactylus*, two very common component of late Early Triassic and Middle Triassic ichnofaunas of Europe and United States.

## 8. UPPER TRIASSIC TETRAPOD FOOTPRINTS OF THE SOUTHERN ALPS

### 8.1. CAR 1 DEPOSITIONAL SEQUENCE (LOWER CARNIAN: JULIAN)

In the western Southern Alps, the SB of the sequence Car1 is an exposure surface on top of the Cassian Dolomite 1 (Gianolla et al., 1998), the correlative conformity is placed at the sharp increase in siliciclastics or at the base of the shale interval inside the San Cassiano Formation (Gianolla et al., 1998), and is dated to the *T. aon* Subzone (Trachyceras Zone, Julian). In Lombardy, the lowstand system tract (LST) and the highstand system tract (HST) are characterised by a strong siliciclastic-volcaniclastic input (Val Sabbia Sandstones) related to a Carnian phase of volcanic activity in an area located to the south (Garzanti, 1985). In the Dolomites the HST is represented by the shallow water carbonate platform of the Cassian Dolomite and from the upper San Cassiano Formation. The presence of tetrapod footprints in the interior platform facies of the Cassian Dolomite was reported by Avanzini et al. (2000), Petti et al. (2013) and Bernardi et al. (2018).

### 8.1.1. Western Dolomites (Veneto Region)

Along the path from Malga Pioda climbs to Rifugio Coldai, along the southern side of Mount Coldai (Selva di Cadore Municipality, Belluno Province), at 1970 m a.s.l., a dolostone boulder from the Cassian Dolomite contains a well-impressed footprint, which is still under study (P. Mietto, pers. obs.). It is a right *pes* print preserved as concave epirelief, which is moderately ectaxonic, semiplantigrade with a triangular sole pad, squat, and short and subparallel digit traces characterized by rounded apices (Fig. 9). At the preliminary inspection, the footprint morphology suggests a belonging to a therapsid synapsid.

In the Mondeval area, in front of the southern walls of the Lastoi di Formin, in Busa dei Cavai locality (Selva di Cadore Municipality, Belluno Province), there is a large boulder from the Cassian Dolomite 2 with a surface of 20 m<sup>2</sup>. Dozens of footprints preserved as concave epireliefs are visible on this surface (Fig. 10). They are mainly subcircular depressions (sometimes even with filling remnants); in some cases, they are aligned in trackways. Most of the footprints do not retain elements allowing an ichnotaxonomic determination. At the western side of the surface there are some ‘bell-shaped’ depressions, 25 cm long and 14 cm wide. Inside, each depression is subdivided into two small depressions. The largest of these ‘bell-shaped’ depressions is elongated; the smaller is subcircular (diameter is 6 cm) and in line with the first. On the side of the main depressions, there are two smaller depressions that are 5 cm long and subcircular. They are possibly associated with the first ones forming a quadrupedal trackway. The ‘bell-shaped’ footprints might be the *pes* prints with a deeper and expanded posterior part, given by the second rounder bearing. Considering the 60-cm-long step and the high step angle value, these footprints show a strong affinity with the ichnogenus *Chirotherium* (see Mietto et al., 2012a), whose trackmaker has been referred to quadrupedal non-crocodylian and non-ornithodiran archosauriforms.

Almost at the peak of the Mount Averau (Cortina d’Ampezzo Municipality, Belluno Province), not far from the Nuvolau Fork refuge, several tetrapod footprints are preserved on a bedding-surface of an outcrop of the Cassian Dolomite 2. They are possibly organized into a trackway, but their poor state of preservation prevents any further statement (Mietto et al., 2012b).

### 8.1.2. Brescian Prealps (Lombardy Region)

Two distinct track-bearing surfaces with six quadrupedal trackways and a several isolated footprints were described from Zone, at the northern side of the Lake Iseo (Zone Municipality, Brescia Province). The trampled horizons are dominated by chirotheriid tracks (Petti et al., 2009) and belong to the terrigenous-volcanoclastic succession of the Val Sabbia Sandstone, interpreted as an alluvial complex characterised by semiarid climate (Gnaccolini and Jadoul, 1990). The largest surface yielded 51 footprints organised in three distinct quadrupedal trackways (Fig. 11b). The smallest surface shows other 20 footprints arranged in



Fig. 9 - The dolostone block of Mount Coldai (Selva di Cadore, Belluno, Veneto Region) from the Cassian Dolomite 2 (Julian); a) the impressed block in situ, with the footprint possibly belonging to a therapsid synapsid; b) magnification of the same footprint.

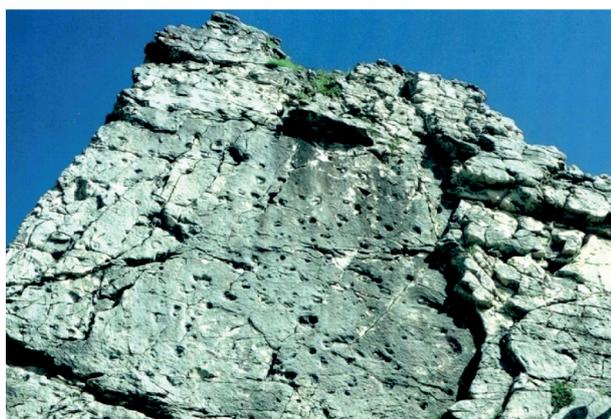


Fig. 10 - Among the many undetermined footprints preserved as concave epirelief, possible footprints referable to *Chirotherium* isp. have been identified in the dolostone boulder of Busa dei Cavai (Selva di Cadore, Belluno, Veneto Region) from the Cassian Dolomite (lower Carnian, Julian).

three short trackways but better preserved than those observed in the largest surface (Fig. 11a). Petti et al. (2009) assigned three of these quadrupedal trackways to the ichnogenus *Brachychirotherium*, representing the first documented evidence of this ichnogenus in the Upper Triassic of Southern Alps. The best-preserved trackways, made of three consecutive *manus-pes* couples, were assigned to *Brachychirotherium thuringiacum* (Rühle v. Lilienstern, 1938). All the discovered tracks at Zone were probably produced by quadrupedal archosauriforms. According to this ichnoassemblage, Petti et al. (2009) proposed an early-?middle Carnian age.

## 8.2. CAR 2 DEPOSITIONAL SEQUENCE (LOWER-UPPER CARNIAN: JULIAN-TUVALIAN)

The Car 2 depositional sequence is represented in the western Dolomites by the Heiligkreuz Formation (Neri et al., 2007; Breda et al., 2009; Stefani et al., 2010; Gianolla et al., 1998), a mixed terrigenous-carbonate lithostratigraphic unit recording the infilling of remaining upper Julian basins and the flattening of palaeotopography during a phase of an increase in run-off associated to the Carnian Pluvial Episode (Dal Corso et al., 2015, 2018). The presence of dinosaur-like footprints in the Heiligkreuz Formation was preliminarily reported by Avanzini et al. (2000), Conti et al. (2000), Petti et al. (2013) and Bernardi et al. (2018).

### 8.2.1. Eastern Dolomites (Veneto Region)

A small dolostone boulder from the Heiligkreuz Formation, found near Giau Fork (Selva di Cadore Municipality, Belluno Province) and fallen from the walls of the Lastoi di Formin, is now exhibited in the Museum of Selva di Cadore. On the surface some purported footprints are visible as convex hyporeliefs. One of them appears to have a tridactyl and mesaxonic shape and might be referable to a small theropod (P. Mietto, pers. obs.). In the same locality and in the adjacent area of Mondeval, other boulders have been identified with potential footprints, but those structures are too poorly preserved to prevent any observation.

On the surfaces of the dolomite layers of the Heiligkreuz Formation forming the eastern side of the Lastoi di Formin (Cortina d'Ampezzo Municipality, Belluno Province), at 2660 m a.s.l., some footprints with various

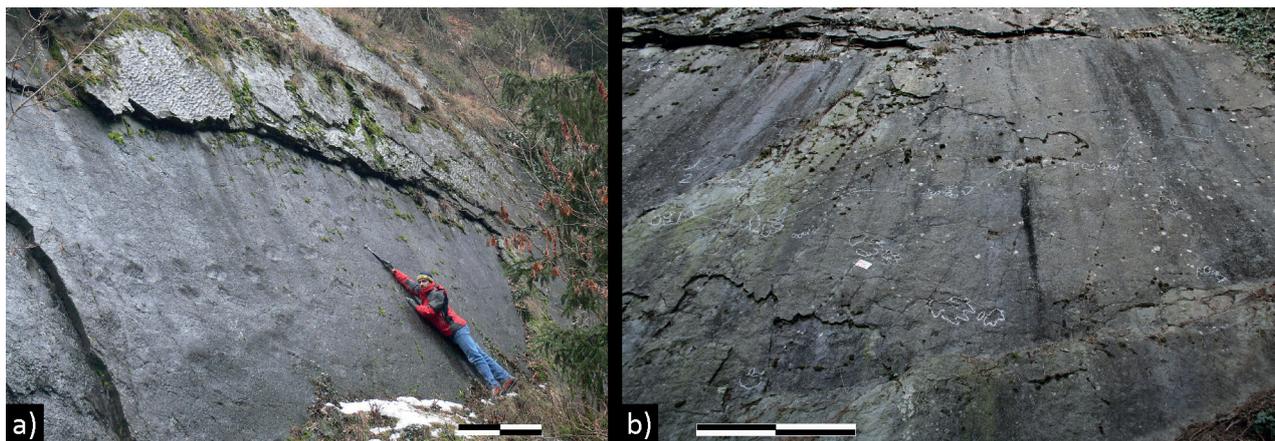


Fig. 11 - The site of Zone (Brescian Prealps, Lombardy Region), where the Val Sabbia Arenites (Julian) crop out; a) the first impressed surface with chirotheriid trackways (*Brachychirotherium* isp.); b) the second one. Scale bars: 1 m.

shapes and sizes have been observed *in situ*. Most of them have been worn out by glaciokarstic weathering processes. Among the many poorly preserved prints, a trackway consisting of four track couples stands out, belonging to a quadrupedal trackmaker. The *pes* is subtriangular and 'bell-shaped', with a FL ranging from 15 to 20 cm and a FW of 13 cm; it presents four short and arched traces in the anterior part that can be the impressions of the digits. Five digits are thus recognized, digit I impression is very shallow and placed on the medial side of the footprint; impressions of digits II and III are deeper and oriented lateral to the impressions of digits IV and V. The *manus* footprint is oval, wider (about 8 cm) than long (about 5 cm), positioned in axis in front of the *pes* footprints and without evident anatomical features. The trackway is narrow and 28 cm wide at maximum. The *pes* step is of 34 cm, the stride is of 63 cm, whereas the *manus* step is of 30 cm and its stride is of 64 cm. The angle of the *pes* step is about of 130°, while that of the *manus*, more variable, never exceeds 150°. According to Mietto et al. (2012a), these footprints, given their preservation state, are hardly attributable to any ichnogenus. However, considering age, size and characteristics of the tracks, a small quadrupedal basal sauropodomorph can be assumed as trackmaker (Fig. 12).

Some large landslide blocks have been identified in the wide basin that descends northwards from the Giau Pass towards Cortina d'Ampezzo, on the slopes of the western side of the Lastoi di Formin, in the locality Vare di Giau locality (Cortina d'Ampezzo Municipality, Belluno Province), with trampled surfaces. The conservation of the footprints, mostly as convex hyporeliefs, is generally poor. However, on a surface of about 20 m<sup>2</sup>, the footprints of a quadrupedal trackmaker have been identified (Fig. 13). The *pes* track has an elongated shape and slightly wider in the front (FL=30 cm, FW=25 cm) and it is rotated outwards respect to the trackway midline. The *manus* track is smaller, kidney-shaped, 19 cm long and 10 cm wide, and is placed in front and in axis with the *pes* print. The footprints are organized in a trackway, but the pace is



Fig. 12 - One of the basal sauropodomorph footprint *in situ* in the dolostone belonging to the Heiligkreuz Formation (Julian-Tuvalian) in the Lastoi di Formin locality (Cortina d'Ampezzo, Belluno, Veneto Region).

uneven and good quality information cannot be obtained. The shapes of hand and foot imprints are very similar, even if larger, to those footprints found *in situ* on the Lastoi di Formin (see above). They are comparable with the ichnogenus *Tetrasauropus* Ellenberger, 1970, whose trackmaker was probably a basal sauropodomorph who



Fig. 13 - Possible *Tetrasauropus* isp. footprints as convex hyporeliefs on the surface of the dolostone boulder from the Heiligkreutz Formation (Julian- Tuvalian), Vare di Giau Locality (Cortina d'Ampezzo, Belluno, Veneto Region).

walked with a quadrupedal stance (Mietto et al., 2012b).

In the locality Forada Fork (Borca di Cadore Municipality, Belluno Province), 20 large sub-elliptical footprints, apparently from an irregular trackway, are preserved on a very inclined layer surface of a bioclastic limestone of the Heiligkreutz Formation. Because of the poor preservation, at the current state of research it is not possible to classify these footprints nor to hypothesize precisely the characteristics of the original environment. In fact, it cannot be excluded that these are footprints left by a terrestrial animal in swimming conditions (Mietto et al., 2012b). A partial cast of the trampled surface of Forada Fork is exposed in the Museum of Selva di Cadore.

### 8.2.2. Western Dolomites (Bolzano/Bozen Autonomous Province)

Along the northern path that runs from the Valparola Pass along the Mount Settsass (San Cassiano/Sant Kassian Municipality), on a small bedding surface of a layer of the Heiligkreutz Formation (40 m below the Travenanzes Formation), a trackway segment about one-meter long was found. It is characterized by small and subcircular footprints produced by a small quadrupedal tetrapod with a broad body (Mietto et al., 2012b; Dalla Vecchia, 2013).

In the landslide scree located at the foot of the western slope of the Mount Sasso della Croce/Heiligkreutz (Badia/Abtei Municipality), a small boulder of dolostone was found, probably from the Heiligkreutz Formation. It bears an evident tridactyl, mesaxonic footprint possibly impressed by a small theropod dinosaur (Mietto et al., 2012b). The footprint is kept at the MUSE-Trento.

### 8.3. CAR 3 DEPOSITIONAL SEQUENCE (TRAVENANZES FORMATION AND EQUIVALENT: UPPER CARNIAN, TUVALIAN)

The SB of the sequence Car3 is a major regional unconformity that, in the Dolomites, corresponds to the

base of the Travenanzes Formation (Raibl Formation in Gianolla et al., 1998) and equivalent. It is characterised by sandstone, siltstone, varicoloured shale, aphanitic dolostone and muddy limestone from continental to lagoonal palaeoenvironments (Neri et al., 2007; Breda and Preto, 2011). In the Julian Alps, the Travenanzes Formation partly corresponds with the Monticello Member of the Dolomia Principale (Gianolla et al., 2003; Caggiati et al., 2018).

#### 8.3.1. Adige Valley Basin (Trento and Bolzano/Bozen Autonomous Provinces)

A diversified archosaur ichnofauna comes from distinct outcrops referred to the Travenanzes Formation along the eastern side of the Adige Valley (Mount Roen, Mostizzolo, San Gottardo Castle and Vela Brook).

The Mount Roen outcrop is located west of the village of Termeno/Tramin (Bolzano/Bozen Province) alongside the Inferno Brook valley at an altitude of 2000 m a.s.l. In this sector, the Travenanzes Formation is constituted by terrigenous, carbonate and evaporitic units deposited in fluvial, lagoonal and peritidal palaeoenvironments (Avanzini et al., 2010). Footprints were found about 6 m above the base of the Travenanzes Formation (Fig. 14). The track-bearing layer lies within an interval of 50 cm characterised by whitish aphanitic dolostones separated by thin levels of red and green shale (Gennaro, 2007). The tracks are preserved as natural casts at the top of the described interval. MTSN-TRA1, attributed to *Eubrontes Hitchcock*, 1858 *sensu* Lucas et al. (2006), was left *in situ*. It is a badly preserved pedal print, mesaxonic and slightly asymmetric, longer than wide (FL=27 cm; FW=22 cm). Digit impressions are broad and distally taper to possible claw traces. Digit III is longer than digits II and IV. Total divarication (II-IV) is about 75° (Bernardi et al., 2013).

The Mostizzolo outcrop, near the village of Cles (Trento Autonomous Province), is about 48 km north of Trento. In 2006, several tracks were discovered in the layers on various reddish to greenish carbonate layers of the Travenanzes Formation. The tracks are preserved both as impressions and natural casts. Among them there are several pedal and manual imprints made by quadrupedal "archosaurs". The material is now stored in the MUSE-Trento.

The best-preserved tracks (slab MTSN5650) are referable to the Late Triassic ichnospecies *Brachychirotherium eyermani* (Baird, 1957). Because Baird's (1957) diagnosis was based only on a single *pes* track and Olsen and Rainforth's (2001) description of this ichnotaxon referred only to incomplete material, the Mostizzolo specimen seems to represent the first evidence of a complete *manus-pes* couple of *B. eyermani* (Fig. 15).

An isolated and large tridactyl left *pes* (MTSN-TRA2 stored in the MUSE-Trento) (FL=26 cm; FW=21 cm) was found in the same site. Its digit marks are broad and distally taper to claw traces. Digit III is longer than digit II and IV. Total divarication (II-IV) is about 40°.

Given these characters, MTSN-TRA2 was referred



Fig. 14 - The Travenanzes Formation cropping out at the base of Mount Roen (Termeno/Tramin, Bolzano/Bozen Autonomous Province) (a) and a middle sized tridactyl footprint (b) from the same locality (scale bar: 10 cm).

by Bernardi et al. (2013) to the ichnogenus *Eubrontes sensu* Lucas et al. (2006) and seems to represent, together with MTSN-TRA1, one of the earliest evidences of large dinosaurs in the northern Pangea (Bernardi et al., 2013).

Several middle size tetrapod footprints were discovered in 2004 near the ruins of the 12<sup>th</sup> century San Gottardo Castle, above the Mezzocorona village (Trento Autonomous Province), about 18 km North of Trento (D'Orazi Porchetti et al., 2008). At San Gottardo Castle the eroded surface of the Anisian-Ladinian carbonate platform is overlain by white-grey, aphanitic to silty dolostone with beds of reddish or greenish shale, ascribed to the Travenanzes Formation. These lithofacies might be interpreted as a marginal marine palaeoenvironment intersected sometimes by distal terrigenous supplies, accompanied also by frankly marine, albeit shallow, sedimentation. This shallow lagoonal deposition has been interested by periodical subaerial exposure as marked by increasing in birdseyes levels, mudcrack surfaces and “archosaur” footprints. The trampled surfaces are exposed as hinges of a hanging layer where footprints are preserved as convex hyporeliefs (Fig. 16).

The analysis evidenced at least 50 footprints referred to quadrupedal non-dinosaur archosauriforms, dinosauriforms and dinosaurs preserved on three carbonate layers. A first morphotype is represented by tridactyl footprints attributed to *Grallator* Hitchcock,

1858 (Fig. 17 a-c).

Other tridactyl footprints are associated to small round impressions lying close to the apex of foot digit III. These small round impressions are here interpreted as *manus* prints. Comparisons of this record with known ichnotaxa highlighted its resemblance with *Atreipus* Olsen and Baird, 1986 (Fig. 17 d-f).

Two tridactyl footprints preserved on the basal layer show digit impressions that are slightly bent inwards and digit III is just a little longer than digits II and IV (FL=13.5 cm, FW=12.7 cm). The specimen was attributed to *Evazoum* Nicosia and Loi, 2003 (Fig. 17g). All specimens were left *in situ*.

Another tridactyl footprint has been identified in the basal levels of the Travenanzes Formation cropping out along the Vela Brook, 4 km west of Trento (M. Avanzini, pers. obs.). The footprint (FL=20 cm; FW=14 cm) is preserved as convex hyporelief at the base of a level of silty dolostones and was left *in situ*.

### 8.3.2. Julian Alps (Friuli Venezia Giulia Autonomous Region)

Carnian ichnofossils (footprints and nests) have been found in the Monticello Member of the Dolomia Principale near Chiout di Gus locality along the Dogna Valley (Dogna Municipality, Udine Province). The Monticello Member is a mixed terrigenous-carbonate

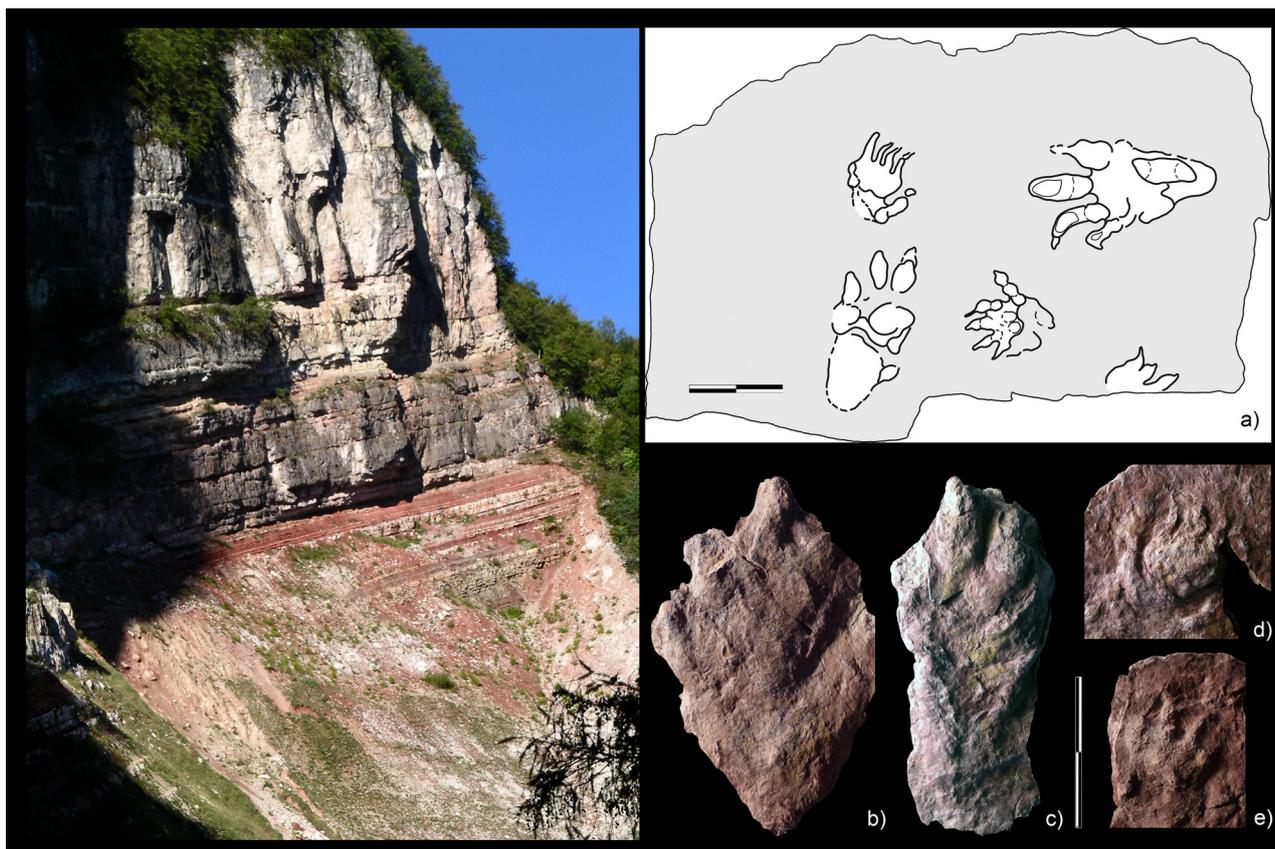


Fig. 15 - The Mostizzolo outcrop, near the village of Cles (Trento Autonomous Province); a) slab MTSN5650 with two *Brachychirotherium eyermani* manus-pes couple; b-c) *Brachychirotherium eyermani* pedal counterprints; d-e) *Brachychirotherium eyermani* manual counterprints (scale bar: 10 cm).

sequence representing a shallow marine or tidal flat environment with evidences of emersion. A rich palynoflora preserved in the marly layer covering the footprint-bearing bed supports a late Tuvalian age for the ichnofossils (Roghi and Dalla Vecchia, 1997).

The footprint-bearing layer was discovered in 1994 and its description was published two years later (Dalla Vecchia, 1996a, 1996b). The layer surface originally exposed at least five trackways composed of *pes* and *manus* prints and at least six isolated footprints. Only two trackways (the longest ones) and some isolated footprints survived the floodings of the Torrent Dogna. They were removed at the fall of 1995 and are now exhibited (after restoration) in a small museum in the town of Dogna. All of the tracks can be referred to the same kind of quadrupedal trackmaker. The surface of the footprint-bearing layer is covered by mud cracks indicating exposure and drying of the sediment before the passage of the trackmakers (Dalla Vecchia, 1996b).

The two main trackways (A and B) are straight and parallel to each other, but the trackmakers were moving in opposite directions (Fig. 18). Trackway A is made of six *manus-pes* pairs, whereas trackway B preserves five consecutive impressions of the right *pes* and three *manus* prints. The lower portion of the printed surface (Fig. 18, lower right corner) preserved three *manus-pes* pairs and

four *pes* prints apparently lacking an associated *manus* print. One left *manus-pes* pair is directed to the west, whereas the other tracks head to east and may belong to two different trackways (Dalla Vecchia, 2013).

The *pes* prints are about 17-20 cm long, twice the length of the *manus* print. Most of the *pes* prints shows the impression of four digits (see Dalla Vecchia, 1996b, Figs. 2,4,5), but the best-preserved tracks present the trace of a further digit (digit V), thus the *pes* of the trackmaker was pentadactyl (Fig. 19). The free portion of the five digits is short, narrow and pointed. Digit III is the longest and digit I is the shortest. The impression of digit V is narrow, recurved and cranially (forward) oriented, and set quite posteriorly in the footprint.

The *manus* prints are sub-circular and their morphology is less well-defined than that of the *pes* prints (Fig. 19). Some *manus* tracks have at least four digit impressions, but only three are well-impressed and visible only in the best-preserved tracks (see Dalla Vecchia, 1996b, Figs. 2 and 4,5; Dalla Vecchia, 2013, Fig. 58C).

Stride ranges from 67 to 72 cm in trackway A and from 60 to 70 cm in trackway B. Trackway A has an external width of about 30 cm and a pace angulation of the *pes* of about 100°. *Pes* and *manus* impressions are parallel or nearly parallel to the walking-direction. There are no drag traces of the belly or the tail.

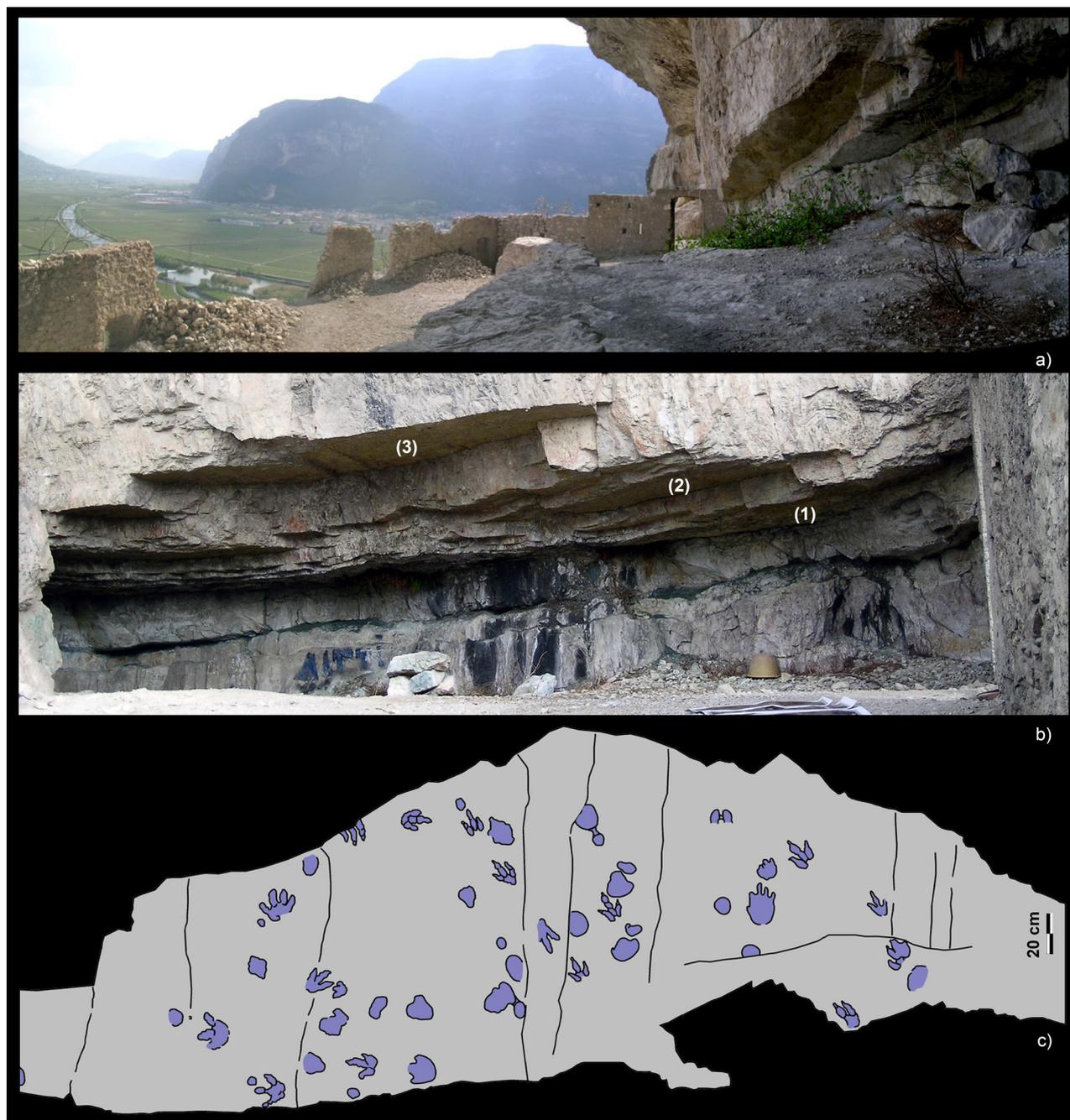


Fig. 16 - Upper Triassic (Upper Carnian: Tuvalian) outcrop of San Gottardo Castle (Mezzocorona, Trento Autonomous Province); a-b) the tree main trampled layers (1-3); c) scheme of the trampled layer n. 3, scale bar: 20 cm.

All this information suggests that the trackmaker was a plantigrade and quadrupedal tetrapod with a broad body and a slow walking gait, but with a relatively erect and not sprawling posture (Dalla Vecchia, 1996a).

Initially, these footprints were provisionally referred to phytosaurs by Dalla Vecchia (1996a) because of the resemblance of the *pes* prints with those of the extant crocodylians, but with five digits instead of the four apomorphic for extant crocodylians and supposedly also for the early crocodylomorphs (Padian and Pchelnikova, 2010). The oldest members of Crocodylomorpha appear in the fossil record at the end of the Carnian in South and

North America (e.g. *Trialestes romeri* Reig, 1963; *Carnufex carolinensis* Zanno, Drymala, Nesbitt and Schneider, 2015; see Irmis et al., 2013; Drymala and Zanno, 2016). Crocodylomorphs were excluded as trackmakers because at that time (1996) basal crocodylomorphs were considered to be relatively small-sized and cursorial animals, with erect stance, a gracile build and long limbs (Irmis et al., 2013). In taxa closer to crocodyliforms both the *manus* and *pes* were supposed to be digitigrade (Irmis et al., 2013). Furthermore, footprints referred to early crocodylomorphs are tetradactyl (*Batrachopus* Hitchcock, 1845; Haubold, 1986). Subsequently, the correspondence

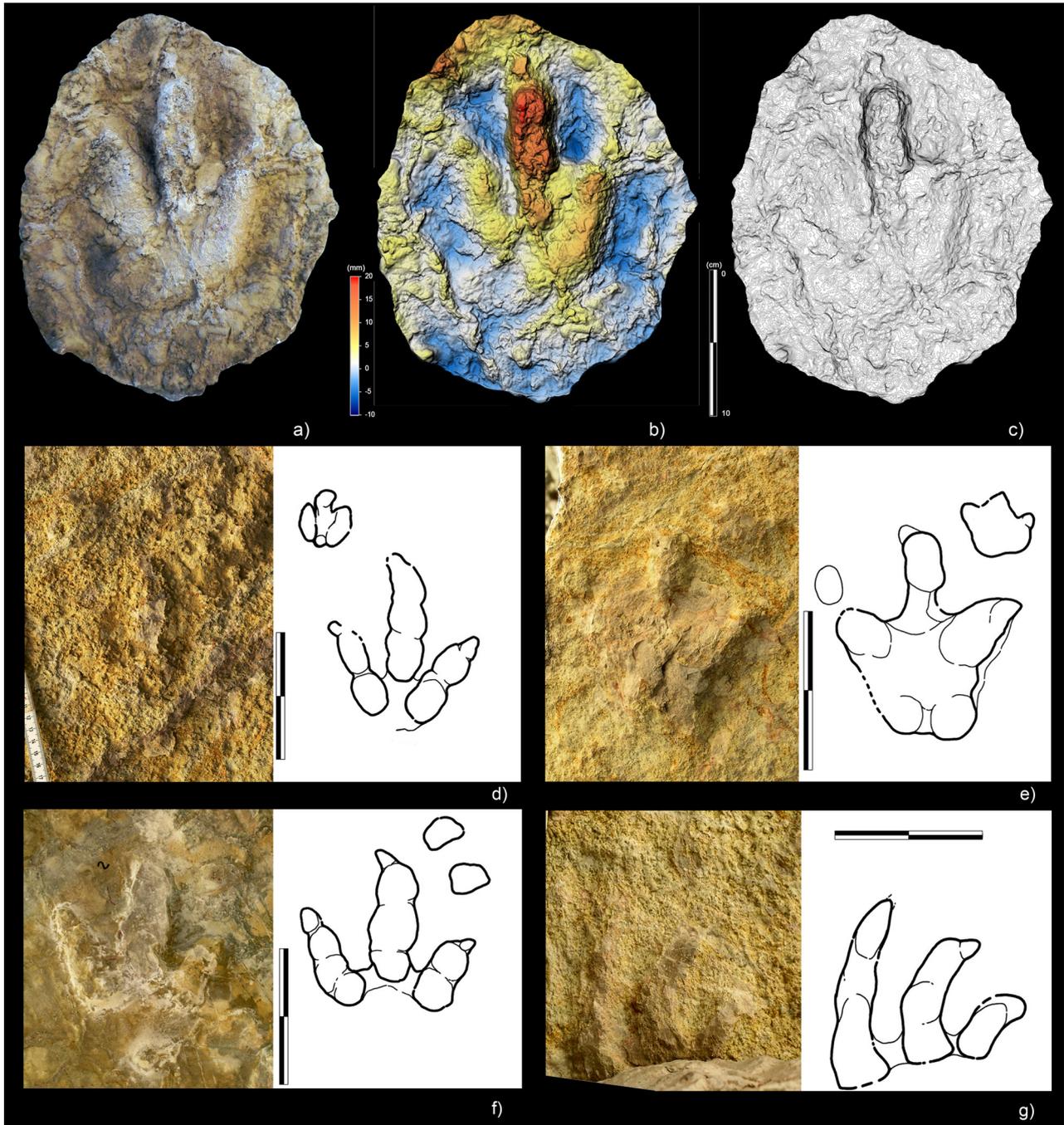


Fig. 17 - Upper Triassic tetrapod footprints from 3rd Depositional Sequence Car 3 (Upper Carnian: Tuvalian) of Adige Valley Basin (Trento and Bolzano/Bozen Autonomous Provinces). Archosaur footprints from San Gottardo Castle (Mezzocorona, Trento); a-c) *Grallator* sp., scale bar: 10 cm; d-f) *Atreipus* isp., scale bar: 10 cm; g) *Evazoum* isp., scale bar: 10 cm.

with the chirotheriid *pes* prints as for the position of the digit V impression, the trackway parameters and the comparison with the skeletal structure of the feet of the non-ornithodiran archosaurs suggested Dalla Vecchia (1996b, 2008), Roghi and Dalla Vecchia (1997) and Avanzini et al. (2007c) to refer them to the aetosaurus or to a still-unknown crocodylian-line archosaur. Based on the reconstruction of the aetosaur *Stagonolepis* Agassiz, 1844 the trackmaker would be about 2.5 meters long (Roghi and Dalla Vecchia, 1997). Later, Bernardi et al.

(2010) referred those trackways to a crocodylomorph with webbed feet. This referral may be supported today by the recent discovery of large Triassic crocodylomorphs (e.g. *Carnufex carolinensis* and *Redondavenator quayensis* Nesbitt, Irmis, Lucas and Hunt, 2005; see Drymala and Zanno, 2016). Unfortunately, their feet are not preserved and also those of other Triassic crocodylomorphs are poorly known (e.g. Colbert, 1952). Padian and Pchelnikova (2010) considered the footprints from Dogna to be like those of *Apatopus* Baird, 1957, which were ascribed to

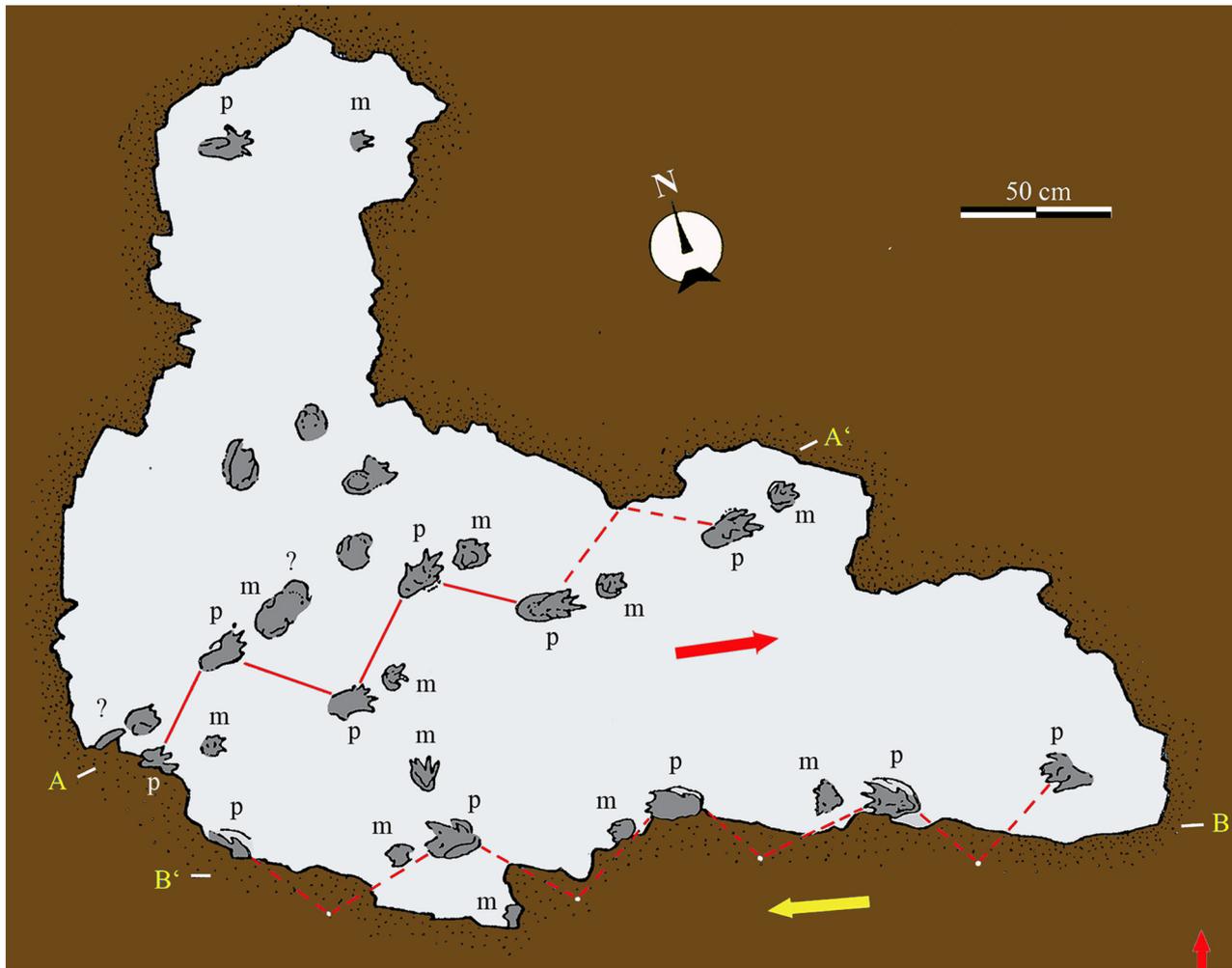
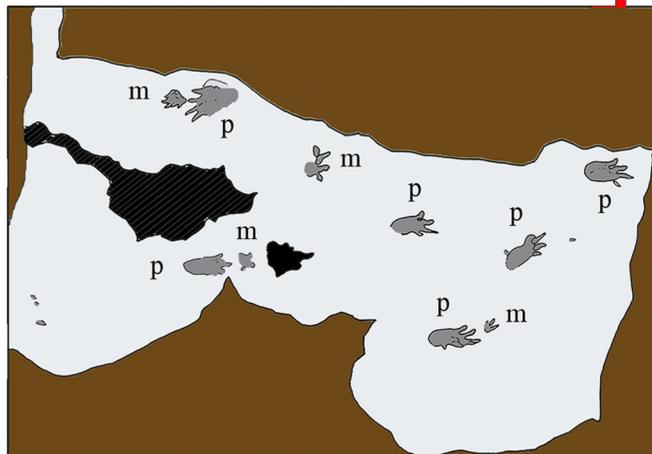


Fig. 18 - Map of the footprints from the Dogna Valley (Udine Province, Friuli Venezia Giulia Autonomous Region) in the Monticello Member of the Dolomia Principale (Upper Carnian, Tuvalian). Above: the main part of the footprint-bearing surface (which has been taken away and is now exhibited) containing the two main trackways A and B. Below: smaller portion of the footprint-bearing surface, which was located closer to the stream bed and was later covered by the debris. Long arrows point to the direction of movement of the trackmaker. Abbreviation: m=manus track; p=pes track. After Dalla Vecchia (1996b, 2013), modified.



the phytosaurs based on a new reconstruction of the foot skeleton of *Parasuchus hislopi* Lydekker, 1885, with digit IV as the longest (as in *Apatopus* Baird, 1957) instead of digit III. However, also the new reconstruction of the pes of that phytosaur by Padian and Pchelnikova (2010) does not match with those under discussion. Klein and Lucas (2013) referred the Friulian footprints to *Apatopus*, ascribing this ichnotaxon to phytosaurs. However, the longest pedal digit is the fourth in *Apatopus* and digit V is not as posterior as in the Dogna pes prints.

The nesting site was discovered in 2003 is the same outcrop as the footprints and only 130 cm below (stratigraphically) the footprint-bearing bed (Dalla Vecchia, 2013, Fig. 55). At the time of discovery, it was composed of 13 subcircular to hemicircular and rimmed depressions, some of which coalescent (Avanzini et al., 2007c). Depressions are close to each other, are located about half a meter from each other, the length of their main axis ranges from 100 to 160 cm and their depth ranges from 5 to 20 cm. The rim surrounding the

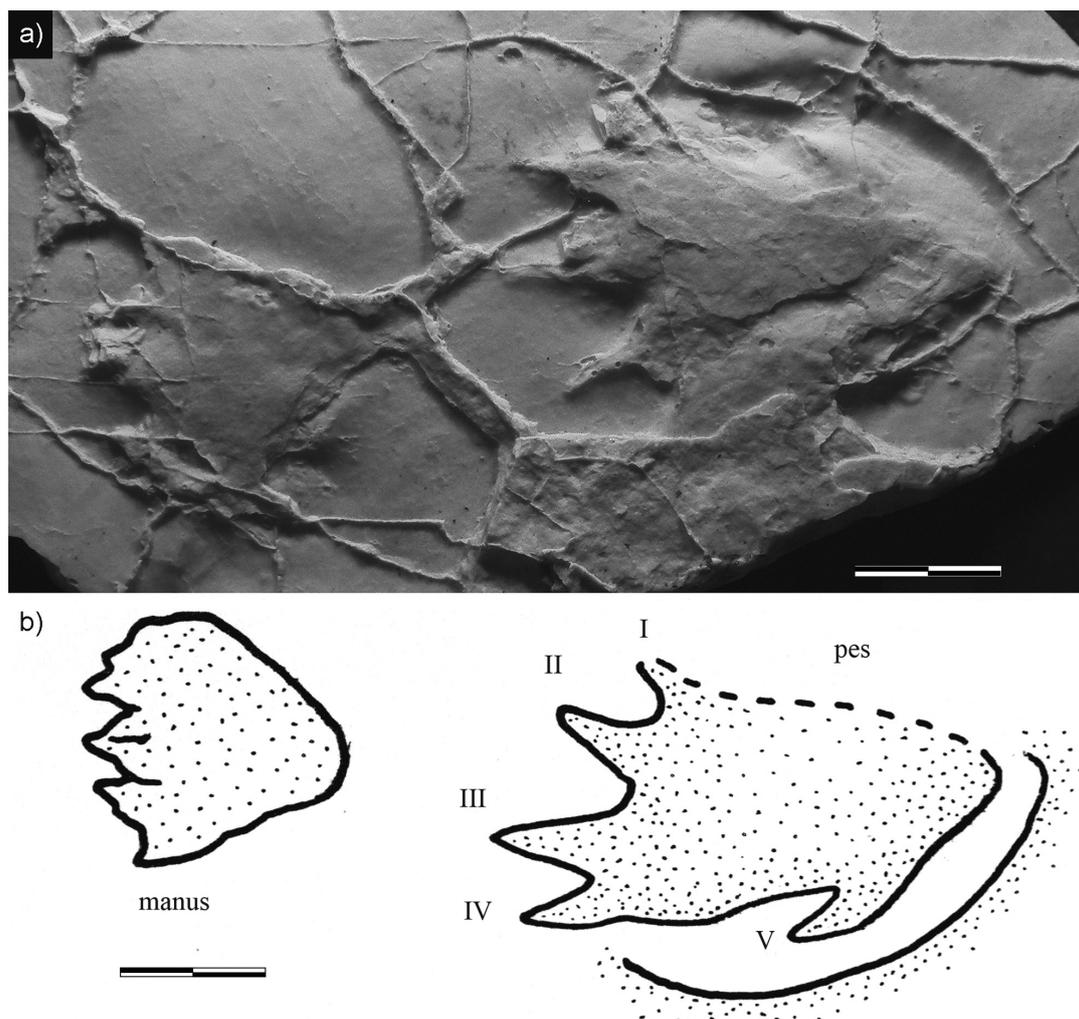


Fig. 19 - Footprints from the Dogna Valley (Udine Province, Friuli Venezia Giulia Autonomous Region): the first right *manus*- pair of the trackway B; a) Silicone rubber mould of the set. b) Interpretative drawing. I-V=digits I-V. Scale bars: 5 cm. Drawing after Dalla Vecchia (1996b), modified.

depressions is 16 to 45 cm wide and was produced by two or more carbonate mud displacements. These depressions cut a decimeter-thick layer of mudstone-packstone with pedogenetic features and are filled with blackish mudstone that covers both the floor and the rim (Fig. 20).

Despite of the absence of fossil eggs or eggshell fragments inside them, the depressions have been interpreted as rimmed nests dug in the carbonate mud (see Avanzini et al., 2007c for comparison with abiogenic structures and other vertebrate traces) and thus they represent a nesting site. Lacking evidences of the contrary and according to the Occam's razor principle, it is reasonable to refer the nests to the same author as the trackways. This is supported also by the diameter of the nests and their spacing which are in agreement with the body length of the trackmaker.

These relatively complex nests and their association show that the Triassic crocodylian-line archosaurs that had produced them had a reproductive behaviour that was more sophisticated than that of extant crocodylians. Unfortunately, some of the nests have been destroyed in

the summer 2008 (Dalla Vecchia, 2013) and the others are in danger of destruction because of the dip slope of the bedding and the sliding above rocks.

#### 8.4. CAR 3 DEPOSITIONAL SEQUENCE (DOLOMIA PRINCIPALE/MAIN DOLOMITE: UPPER CARNIAN-NORIAN)

The HST of the Sequence Car3 is characterised by the Dolomia Principale. Indeed, during the latest Carnian-Norian, throughout the Southern Alps, carbonate tidal flat and lagoon environments were established (Bosellini and Hardie, 1988; Caggiati et al., 2018).

After the first discovery of dinosaur footprints at Mount Pelmetto in the Cadore Dolomites, many other blocks with footprints have been identified in the Dolomites and in Carnic Prealps, but only in a few cases the exact original stratigraphic position of the fossils is known.

##### 8.4.1. Eastern Dolomites (Veneto Region)

The Mount Pelmetto (Val di Zoldo Municipality, Belluno Province) site was the first one discovered



Fig. 20 - The nesting site of Dogna Valley (Dogna, Udine Province, Friuli Venezia Giulia Autonomous Region) in the Monticello Member of the Dolomia Principale (upper Carnian, Tuvalian). The nests have been referred to aetosaurs or other crocodylian-line archosaurs; a) general view of the site before its partial destruction; scale: 2 m; b) view of a single nest; scale: 1 m; c) the cluster of nests; scale: 2 m.

bearing dinosaur footprints, in 1985, in the Dolomites and the first in Italy to show trackways of dinosaurs, thus documenting the frequent presence of dinosaurs in the tidal flat of the Dolomia Principale. Until then, in fact, only one isolate and very questionable dinosaur footprint was known in Italy, referred with doubt to a small theropod, coming from Mts. Pisani in Tuscany and named by Huene (1941) *Coelurosaurichnus toscanus*. The Mount Pelmetto site yielded numerous boulders collapsed from the basal part of the southern edge of the Mount Pelmetto, formed by the basal portion of the Dolomia Principale, close to the boundary with the underlying Travenanzes Formation (Neri et al., 2007; Breda and Preto, 2011). Thanks also the help of the “Amici del Museo della Val Fiorentina” association, at least ten blocks with footprints of various type and sizes have been identified. The most spectacular, for its size (about 8x6 m), the location above the landslide accumulation and the subvertical position of the footprint-bearing surface, is the so-called “Masso A” (Boulder A), described for the first time by Mietto (1988) and then by Bettiol and Mietto (1988), Mietto (1990, 1992, 1999b), Leonardi (2000), Mietto and Dalla Vecchia (2000), Mietto et al. (2012a) and Dalla Vecchia (2013). The ‘Masso A’ is located at 2050 m a.s.l., at the top of the landslide; about 10 m below towards the north-

eastern direction, the boulder C is located, whereas to the south, about 20 m below there are blocks B and D. About 10 m further down there is the large boulder E and another 20 m lower down there is the boulder I. The small numbered blocks F, G and H have been recovered and are now placed at the MCC-Selva di Cadore.

Boulder A: despite the trampled surface is poorly preserved and the footprints appear to be badly morphologically characterised as concave epireliefs, the analysis allowed to recognise about 100 footprints organised on at least five trackways. Three trackways of bipedal trackmakers formed by *Grallator*-like footprints, 6-7 cm long and with a stride of 60-70 cm, are attributable to small theropod dinosaurs. There is also a single bipedal trackway with about 15 footprints that shows evident displacement rims. This trackway, which presents an internal rotation of the footprints, was attributed by Mietto (1988) to small and primitive ornithischian dinosaur, but now such attribution is questionable. The trackway of the largest trackmaker (sub-circular footprints diameter is about 15 cm, stride length 1 m) shows discontinuous manus impressions. This trackway has been attributed to a basal sauropodomorph (Fig. 21 a,b).

On the back of Boulder A, a left medium-sized *pes* print is preserved as convex hyporelief (Fig. 21i); for its

characteristics, it has been referred to *Brachychirotherium* isp. (Mietto and Dalla Vecchia, 2000; Mietto et al., 2012b). Therefore, the trackmaker was probably a non-crocodylian pseudosuchian.

Boulder B: it bears two footprints (B1, B2) as convex hyporeliefs. They are *Grallator*-like footprints, tridactyl and mesaxonitic, which can be assigned to small theropods. The smaller one is 8 cm long and 6 cm wide, whereas the other is 12 cm long and 9 cm wide. Replicas of these footprints are exhibited in the MCC-Selva di Cadore (Fig. 21 c-e).

Boulder C: the boulder bears a single large footprint, which is a not well-preserved convex hyporelief. The *Eubrontes*-like footprint is tridactyl, mesaxonitic, 25 cm long and 22 cm wide, and can be assigned to a medium-size theropod (Fig. 21g). A replica of this footprint was made and it is now exposed in the MCC-Selva di Cadore. This footprint is similar to those, almost coeval, found in Switzerland (Belvedere et al., 2014).

Boulder D: it is a large boulder (about 3 m long) that preserves numerous small tridactyl, mesaxonitic, and *Grallator*-like footprints, but they are poorly-preserved.

Boulder E: a large boulder with an almost horizontal surface shows a 13-track-long quadrupedal trackway, preserved as convex hyporeliefs (Fig. 21f). The poor quality of the footprints makes their interpretation difficult: either they belong to a basal sauropodomorph or a quadrupedal non-crocodylian pseudosuchian.

Boulder F: it is a small block with a vaguely tridactyl footprint perhaps possibly impressed by basal ornithischian or an indeterminate bipedal dinosaur; it is now stored in the MCC-Selva di Cadore.

Boulder G: it is a small block that preserves a small, tridactyl, *Grallator*-like footprint. This specimen is the counterpart of one of the footprints preserved in the Boulder B. It is now stored in the MCC-Selva di Cadore.

Boulder H: this specimen is also kept in the MCC-Selva di Cadore; it is the convex hyporelief of a small, tridactyl, *Grallator*-like footprint.

Boulder I: it is a large boulder with a sub-vertical surface that preserves a large chirotheriid pedal footprints as convex hyporelief (Fig. 21h).

These footprints give information on the local population of dinosaurs and other reptiles during the latest Carnian-Norian interval: small and medium-sized theropods, perhaps small primitive ornithischians, basal sauropodomorphs, as well as quadrupedal non-crocodylian pseudosuchians.

The age of the footprints is difficult to determine but, given the probable provenance of the specimens from the basal part of the Dolomia Principale, a latest Carnian (latest Tuvalian) age can be inferred (De Zanche and Mietto, 1977; Neri et al., 2007; Breda et al., 2009; Gianolla et al., 2018).

A boulder with tetrapod traces has been found in the Pegolera Valley (Agordo Municipality, Belluno Province), at the foot of the Sun Mountains, at about 1000 m a.s.l., fallen from the overhanging cliffs. It is worth noticing that

the original boulder, referable to the Dolomia Principale, separated into two mirroring blocks, where the original surface with concave epireliefs and the corresponding one with convex hyporeliefs are visible (Fig. 22a). The footprint-bearing surface lies on a stromatolithic 50-cm-thick laminated level and it is 11 m long and 6 m wide. The preservation is notably poor; the convex hyporeliefs have suffered major erosion and are hardly identifiable. The preservation of the concave epireliefs is slightly better, and it was possible to recognize at least 20 tracks, arranged in three trackways that cross the surface with different directions (Belvedere et al., 2008a). Although the ichnotaxonomical attribution of these footprints is difficult, it is possible to discriminate at least two different morphotypes. The first morphotype (Track 1 in Belvedere et al., 2008a) and particularly the third print of the trackway (Fig. 22b) resembles the footprints described by Dalla Vecchia (1996a, 1996b) from the Tuvalian of Dogna (Friuli). The trackways of the second morphotype (Track 2 in Belvedere et al., 2008a) display a quite narrow gauge and both *manus* and *pes* impression are often present. This suggests a dinosaurian origin. They are similar to those of the Pista C of Mount Pelmetto site, attributed to a basal sauropodomorph (prosauropod in Mietto, 1988). The footprints association and the lithological observation suggests that the block come from the basal portion of the Dolomia Principale (Tuvalian/basal Norian in age, Bernardi et al., 2018).

#### 8.4.2. Western Dolomites (Trento Autonomous Province)

On the large ledge that develops at an altitude of about 2800 m, around the southern slope of Piz Ciavazes (Canazei Municipality) in the Sella Massif, there are some trampled boulders (G. Roghi, pers. obs.). They come from the overhanging walls constituted by the basal portion of the Dolomia Principale. Among these boulders, which can only be reached by climbing or by helicopter, one shows a series of footprints made up of almost three *manus-pes* couples preserved as concave epireliefs and arranged in a trackway impressed by a quadrupedal trackmaker (Fig. 23).

Although these observations are preliminary, the footprints appear to be comparable with those of Boulder "A" from the Monte Pelmetto site, which are attributed to a basal sauropodomorph.

#### 8.5. NO 1 DEPOSITIONAL SEQUENCE (NORIAN)

As noted by Gianolla et al. (1998b), the identification of the 3<sup>rd</sup> Depositional Sequences within the Dolomia Principale, which spans the whole Norian is a real problem throughout the Southern Alps. The Norian lasted over 20 Myr and several SBs are expected to have formed during such a long interval. In the western part of the Southern Alps, a possible No 1 SB within the Dolomia Principale in the western part of the Southern Alps could correspond to the erosional base of the Passo Buse Scure Breccia, a channelised fluvial deposit that bears abundant

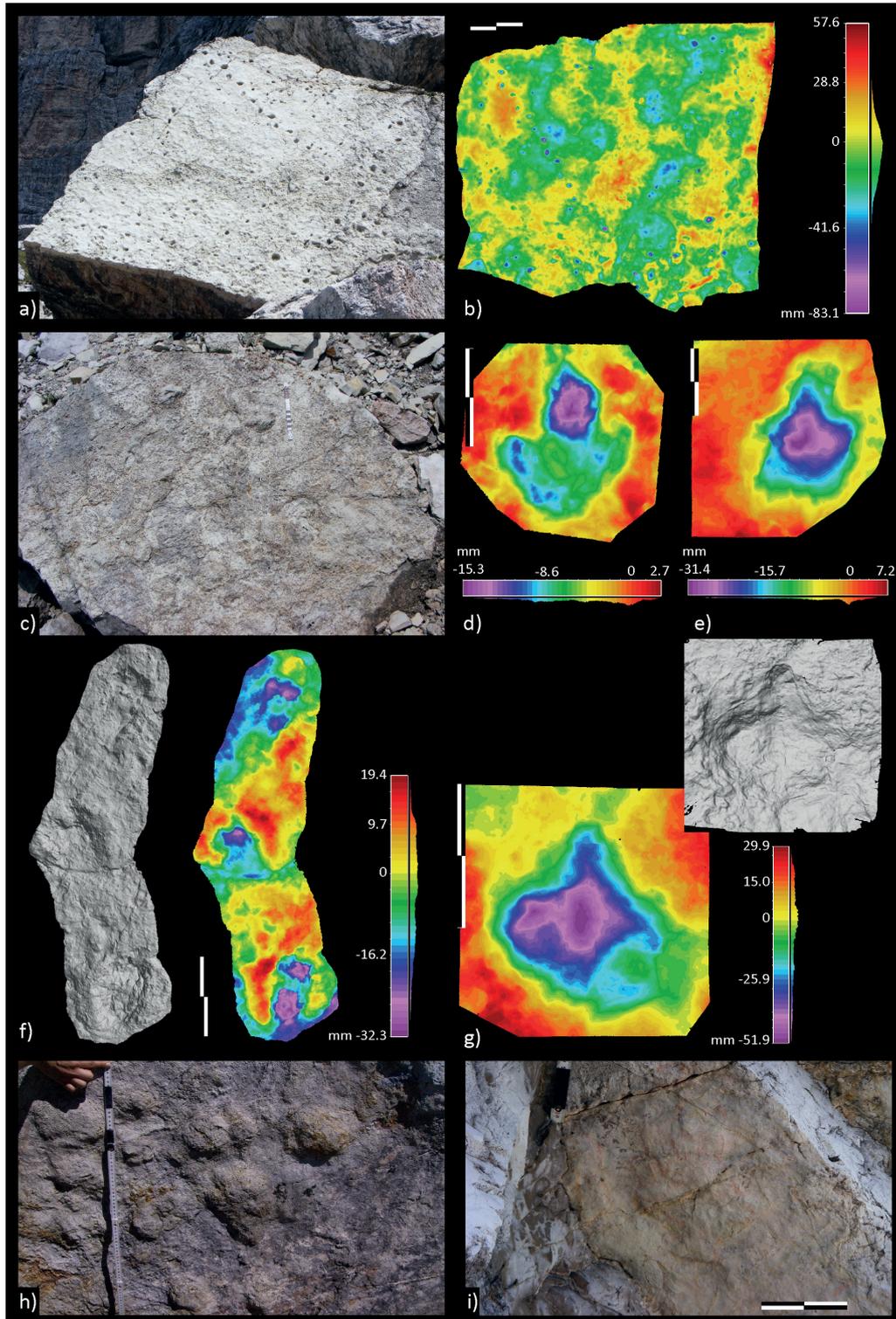


Fig. 21 - Mount Pelmetto (Pelmo Massif, Belluno, Veneto Region) ichnosites (Dolomia Principale, Upper Triassic); a) photograph of the main imprinted surface of the Boulder A; b) false colour depth map of the Boulder A generated from the 3D model of the cast hosted at the MCC-Selva di Cadore; scale bar: 1 m; c) photo of the Boulder B, which lays in the scree 20 metres below the main boulder; the two tridactyl tracks are visible on the top part of the surface; d) false colour depth map of tridactyl track B1 (*Grallator*-like) generated from the 3D model of the cast hosted at the MCC-Selva di Cadore; scale bar: 5 cm; e) false colour depth map of the tridactyl track B2 (*Grallator*-like) generated from the 3D model of the cast hosted at MCC-Selva di Cadore; scale bar: 5 cm; f) 3D model and false colour depth map of part of the quadrupedal trackway on the boulder E, generated from the 3D model of the cast hosted at the MCC-Selva di Cadore; scale bar: 20 cm; g) 3D model and false colour depth map of part of the medium-large tridactyl track (*Eubrontes*-like) of the Boulder C, generated from the 3D model of the cast hosted at the MCC-Selva di Cadore; scale bar: 20 cm; h) photo of the quadrupedal tracks on Boulder I; i) photo of the chirotheriid track (*Brachychirotherium* isp.), preserved as convex hyporelief on the back side of Boulder A; scale bar: 10 cm.

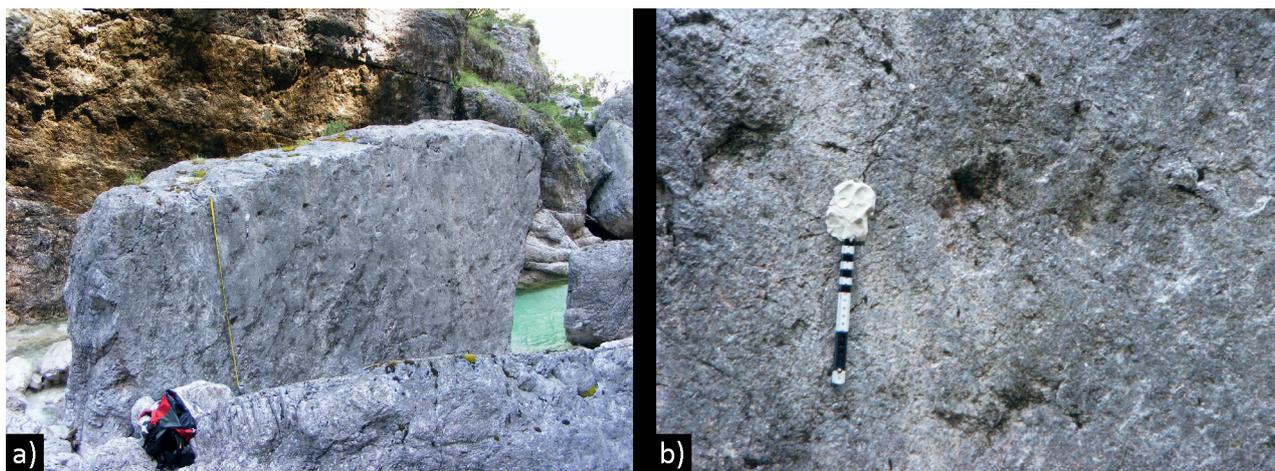


Fig. 22 - The dolostone boulder from the Dolomia Principale (Tuvalian-basal Laciian) in the Pegolera Valley locality (Belluno, Veneto Region); a) the main imprinted surface of the boulder; b) detail of a possible crurotarsal archosaur track.

clasts from the crystalline basement clasts and crop out in the Recoaro area (De Zanche and Mietto, 1983).

Only in one locality, tetrapod footprints (belonging to dinosaurs) were found *in situ* within the Dolomia Principale. This is the “Strada delle Gallerie” (Road of the Tunnels) site of Mount Pasubio in the Vicentinian Prealps, where it was also possible to date the imprinted surface to the middle Norian (Alaunian) (Belvedere et al., 2008b).

#### 8.5.1. Recoaro area (Vicentinian Prealps, Veneto Region)

In the Vicentinian Prealps, First World War frontline between the Italian and the Austro-Hungarian troops ran across the Pasubio Massif. To supply Italian troops, sheltered inside the mountain, a very daring road was dug directly on the southern walls of the massif. To build this road, known as “Strada delle Gallerie” (Valli del Pasubio Municipality, Vicenza Province), 52 tunnels were excavated inside the Dolomia Principale, following the bedding of the rocks where possible. Eleven footprints, preserved as convex hyporeliefs, were recognised on the ceiling of Tunnel n. 12 (Fig. 24a).

As noted by Belvedere et al. (2008b), the poor preservation of most of the footprints does not allow to make a detailed ichnotaxonomical evaluation. However, three morphotypes and two other distinct footprint types have been defined.

Morphotype A is tetradactyl and apparently biped and can be tentatively assigned to the ichnogenus *Pseudotetrasauropus* Ellenberger, 1972. *Pseudotetrasauropus* was possibly impressed by a sauropodomorph trackmaker. ‘SG-VI’ does not show the typical features of a tridactyl print. If the depression observed near digit III impression really corresponds to a broken digit (as suggested by Belvedere et al., 2008b), the footprint could be tetradactyl, digitigrade and very similar to *Evazoum* Nicosia and Loi, 2003.



Fig. 23 - The dolostone boulder from the Dolomia Principale (Upper Triassic) in the Piz Ciavazes locality (Sella Massif, Trento Autonomous Province) with a trackway belonging to a probable basal sauropodomorph.

Among tridactyl footprints, Morphotype B (represented by three footprints), with an elongated digit III and narrow interdigital angles, can be generically attributed to *Grallator*-like (Fig. 24b). However, some of the footprints of this assemblage (i.e., 'SG-V' which shows a higher II-IV interdigital angle) may be more similar to *Atreipus*. Morphotype C (represented by three footprints) shows close similarities with the ichnogenus *Eubrontes*.

A rock sample (ca. 4.5 kg) collected immediately below the track-bearing surface, has been worked for conodont investigations. Unexpectedly, an advanced *Epigondolella praeslovakensis* Kozur, Masset and Moix, 2007 (in Moix et al., 2007), transitional to *Mockina slovakensis* Kozur, 1972 and characterised by a slightly bifurcated keel, together with *Mockina slovakensis* are recovered. The co-occurrence of advanced *Epigondolella praeslovakensis* and *Mockina slovakensis* allowed dating the sample to the latest Alaunian (Belvedere et al., 2008b).

### 8.5.2. Eastern Dolomites (Veneto Region)

Because almost all the findings of tetrapod footprints in the Dolomia Principale occur on isolated blocks or boulders, only in few cases it was possible to trace their stratigraphic position of provenance within the formation and, consequently, within the sequential framework. Therefore, all of footprints preserved in these boulders are here prudently and provisionally referred to the Norian 3<sup>rd</sup> Depositional Sequence No 1 (*sensu* Gianolla et al., 2018).

Proceeding from south to north, the southernmost ichnosite is located towards the top of the Livinal del Bus (Val di Zoldo Municipality, Belluno Province), a gully that descends along the northern slopes of the Mount Sass di Duràm, on the north-eastern side of the Civetta-Moiazza Group. Along the gully, starting from an altitude of about

1600 m, there are several boulders of Dolomia Principale, probably Norian in age, which were fallen from the overlying walls (Mietto et al., 2012b). The 'boulder I' meets at about 1800 m of altitude; its dimensions are about 6 x 5 m and the surface facing downstream has small depressions in a row, often surrounded by displacement rims. The tracks are poorly preserved and do not allow any other observation (Fig. 25a).

'Boulder II' is partly covered by the debris and much smaller than the 'boulder I' (dimensions are 1.5x0.80 m). These boulder preserves twenty sub-elliptic depressions, which are poorly preserved, although sometimes are arranged in trackways (Fig. 25b). Two isolated tracks preserve digit impressions. The largest footprint is tridactyl, slightly longer (12.5 cm) than wide (11.5 cm) with almost equal interdigital angles (Fig. 25c). The morphological characteristics of this footprint allow the attribution to the ichnogenus *Atreipus* isp., whose trackmaker is debated: it could be either a bipedal dinosaur (perhaps an ornithischian) or one of those non-dinosaurian archosaurs that displayed a bipedal posture, such as *Poposaurus* Mehl, 1915. The other footprint is smaller, tridactyl and mesaxonic, but very poorly preserved, and perhaps it may be referred to a small theropod (Fig. 25d).

Dalla Vecchia (1995) reported the discovery, dating back to the 90's of the last century, of an isolated boulder of Dolomia Principale with two tridactyl footprints at Mount Civetta (Alleghe Municipality, Belluno Province). Despite subsequent research, the boulder has never been found again (Dalla Vecchia, 2013).

In the locality Ruina del Giau (Val di Zoldo Municipality, Belluno Province), a large boulder of Dolomia Principale literally covered with depressions was reported from the large accumulation of the ancient landslide that extends

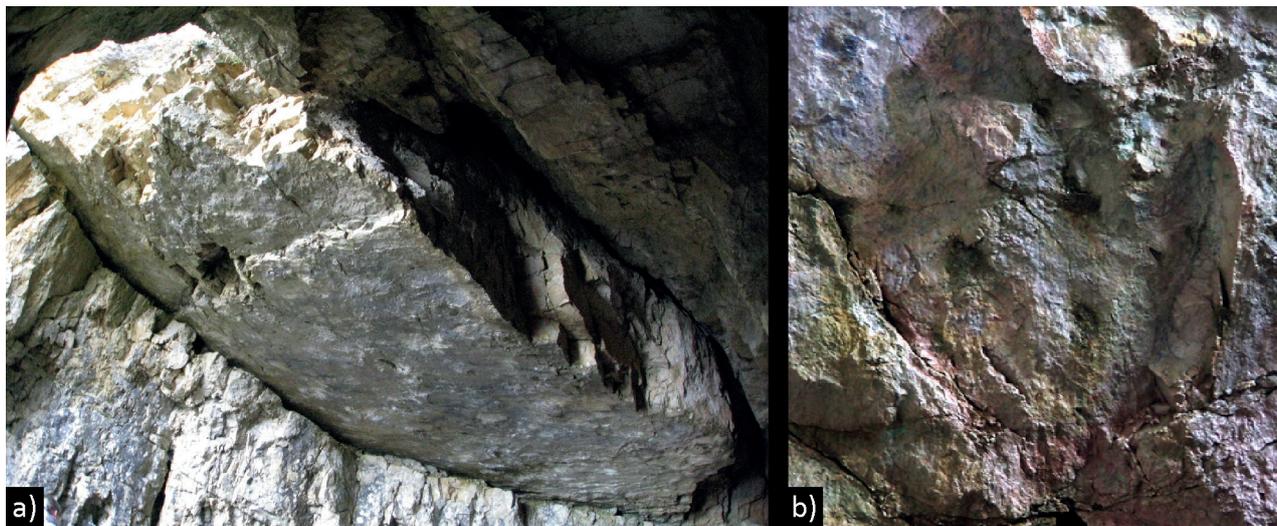


Fig. 24 - Strada delle Gallerie (Tunnels Road) of the Pasubio massif (Vicenza Province, Veneto Region) excavated in the Dolomia Principale (uppermost Alaunian); a) the ceiling of the Galleria 12 dedicated to Captain L. Miotti, with the tetrapod footprints preserves as convex hyporeliefs; b) the tridactyl footprint 'SG-III' referred to *Grallator* isp.

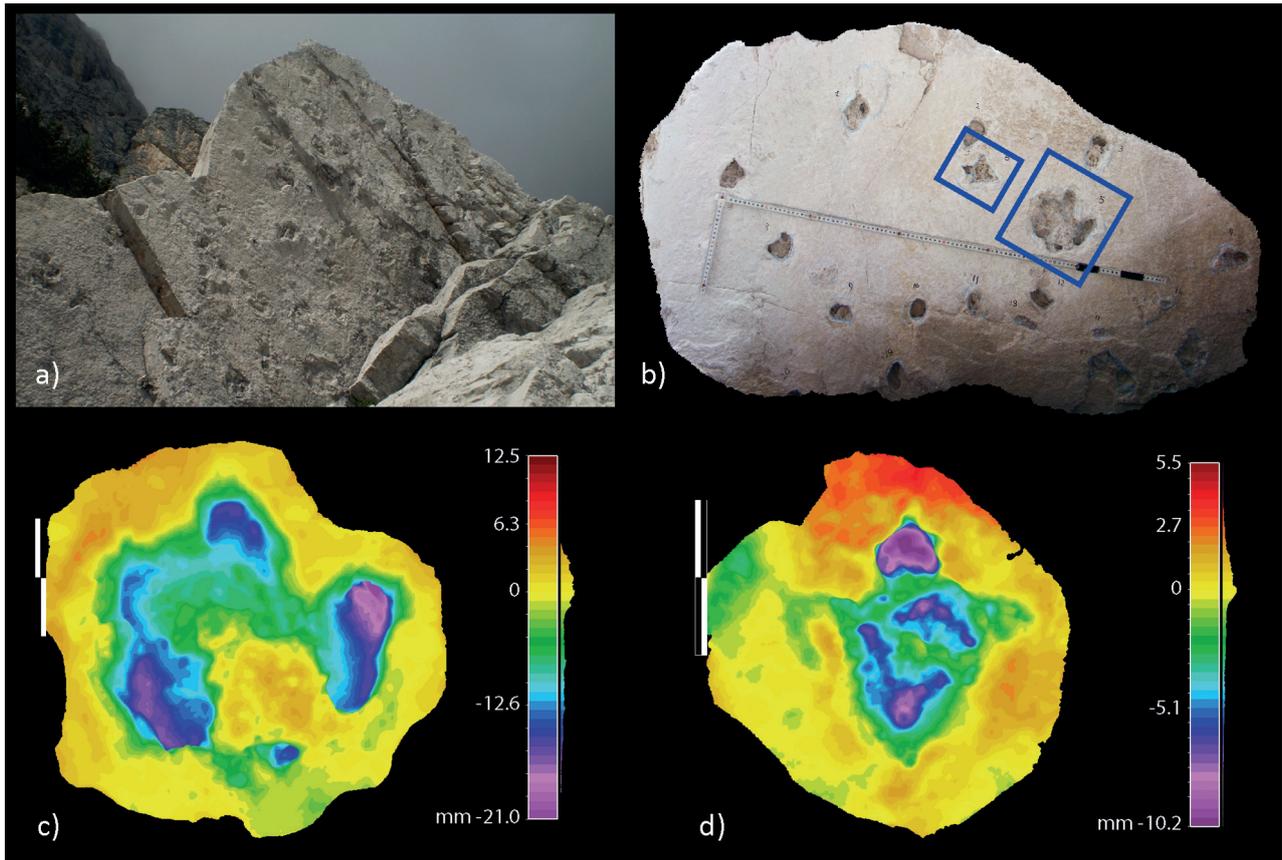


Fig. 25 - Dolostone boulder from the Dolomia Principale (Upper Triassic) of the Livinal del Bus locality (Moiazza Massif, Belluno Province, Veneto Region); a) the impressed surface of the 'boulder I'; b) orthophoto generated from photogrammetric 3D model of the impressed surface of the 'boulder II'; c) false colour depth map generated from laserscans of a rubber cast of the original larger footprint of the 'boulder II' (*Atreipus* isp.); scale bar: 5 cm; d) false colour depth map generated from laserscans of a rubber cast of the original smaller footprint of the 'boulder II' (*Atreipus* isp.); scale bar: 5 cm.

on the southern slope of the Pelmo Massif. Unfortunately, these tracks are poorly preserved for any further consideration (Mietto et al., 2012b).

At least one large tridactyl footprint has been found in the Dolomia Principale boulders that build the landing area of the chairlift on the north slope of Nuvolau Fork (Cortina d'Ampezzo Municipality, Belluno Province), not far from the trek to the Alpine refuge Scoiattoli (M. Belvedere, pers. obs.). The footprint is very shallow and still partly infilled with rock, but its morphology allows the identification of a theropod footprint (Fig. 26). Further ichnotaxonomical identification is, however, prevented. Possibly, another track (or undertrack) of comparable size occurs on the boulder, but it is even more filled, and any identification is prevented.

### 8.5.3. Northern Dolomites (Veneto Region)

At the base of the southern walls of the Tre Cime di Lavaredo (Auronzo di Cadore Municipality, Belluno Province) on the landslide debris along the path that goes from the Auronzo refuge to the Locatelli refuge and near the little church dedicated to Maria Help of Christians, there is a sub-squared boulder of Dolomia Principale of about 2 m side (Mietto, 1992). On the surface facing the

path, two footprints have been identified in succession (Fig. 27a). As often happens with the footprints found in the Dolomia Principale, the preservation is not optimal. In the second track (the lower in Fig. 27a) it is however possible to identify three robust digit impressions with tapering ends. The footprints are about 25 cm long and show affinities with the ichnogenus *Eubrontes*. The trackmaker was most likely a medium-sized theropod dinosaur with a hip height of 1.5 m and a length of 6 m (Mietto, 1992, 1999b).

The surface was moulded and its cast is now exhibited at the PCM-Auronzo di Cadore. It was photographed in grazing light and digitally acquired by laser scanner (Fig. 27b). The grazing light photographs, and the analysis of the three-dimensional model allowed detecting at least two more footprints. They are tridactyl and probably aligned into a trackway. Despite the poor state of preservation, it is possible to identify morphological features unlike those of the larger ones; they are small (about 15 cm long and 8 cm wide) and with much tapered and elongated digit impressions. The characteristics of the footprints, although for an accurate determination, show similarities with the ichnogenus *Grallator* (Mietto et al., 2012b).

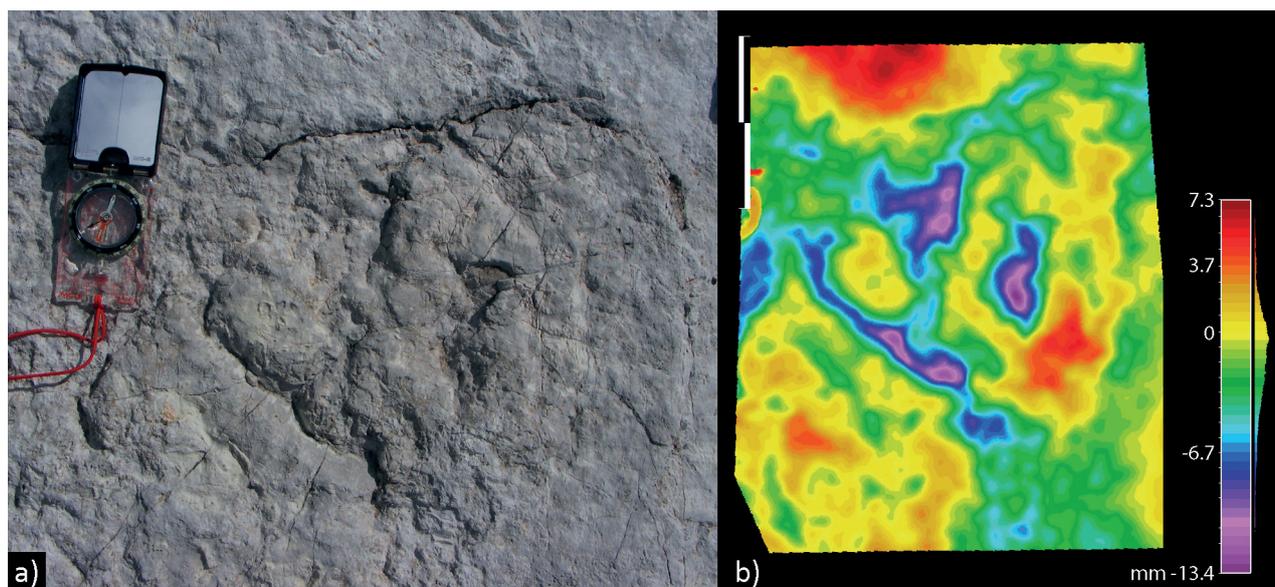


Fig. 26 - The tridactyl footprint in the boulder from the Dolomia Principale (Upper Triassic) of the Nuvolau Fork (Belluno Province, Veneto Region); a) photograph of the footprint; b) false colour depth map generated through photogrammetry; scale bar: 10 cm.

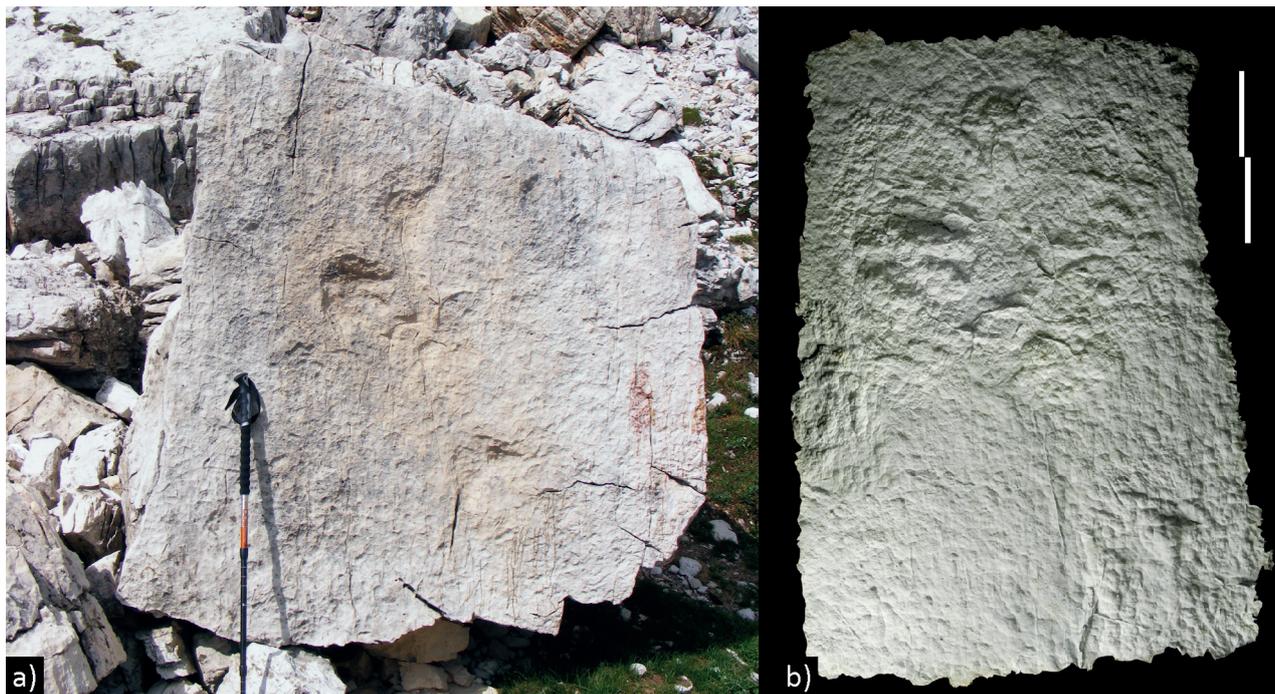


Fig. 27 - The boulder of Dolomia Principale located at the base of the southern walls of the Tre Cime di Lavaredo (Belluno Province, Veneto Region); a) the imprinted surface; b) photograph under controlled light of the cast of the surface, hosted at the PCM-Auronzo di Cadore; scale bar: 30 cm.

#### 8.5.4. Western Dolomites (Bolzano/Bozen Autonomous Province)

Leonardi and Avanzini (1994) and Leonardi (2000) reported an isolated tridactyl footprint from the Puez Plateau (Corvara in Badia/Kurfar Municipality, Bolzano/Bozen Autonomous Province). It was attributed to a bipedal dinosaur.

#### 8.5.5. Carnic Prealps (Friuli Venezia Giulia Autonomous Region)

All the footprints from the Dolomia Principale of Carnic Prealps (the part of them known also as Friulian Dolomites) been found on isolated boulders in the territory of the Claut, Cimolais and Andreis municipalities (Pordenone Province). To date, 18 footprint-bearing

boulders have been recorded (Dalla Vecchia and Mietto, 1998; Dalla Vecchia, 2013; Marzola and Dalla Vecchia, 2014; Fig. 28).

As the boulders are fallen from the mountain walls and have been possibly transported by floodings and glaciers, their reference to a precise 3<sup>rd</sup> Depositional Sequence is in most cases not possible. Formations underlying the 1500-2000 m-thick Dolomia Principale are not exposed in the part of the Carnic Prealps where the footprints have been found, whereas the Dolomia Principale is there overlain by the Soverzene Formation (Carulli et al., 2000). Thus, all footprints preserved in these boulders are here prudently and provisionally referred to the Norian 3<sup>rd</sup> Depositional Sequence No1.

Most of the footprints are tridactyl and mesaxonic with a length ranging 9-35 cm, although nearly all of them are 15-25 cm long (Fig. 29 a-j). They were produced by functionally tridactyl, digitigrade and bipedal trackmakers that have been identified as theropod dinosaurs by Dalla Vecchia and Mietto (1998) and Marzola and Dalla Vecchia (2014). Many footprints are organised into short trackway segments; two trackways were produced also by quadrupedal trackmakers (Fig. 29n). A few footprints are tetradactyl or pentadactyl (Fig. 29k-m; see below). For details about the footprint and trackway parameters see Dalla Vecchia and Mietto (1998) and Marzola and Dalla

Vecchia (2014).

According to Marzola and Dalla Vecchia (2014), the footprint assemblage from the Carnic Prealps is characterized by the rarity of chirotheriid footprints, by the dominance of middle-sized (*Anchisauripus* Lull, 1904 size-class *sensu* Olsen et al., 1998) tridactyl footprints and the presence of large (*Eubrontes* size-class *sensu* Olsen et al., 1998) tridactyl footprints.

The first footprints in the Carnic Prealps were found in a large boulder fallen at the base of a waterfall in a brook located northeast of Casera Cjasevent (Claut Municipality, Pordenone Province) (1 in Fig. 28). The boulder contains two footprints (concave epireliefs) of a trackway made by a bipedal trackmaker, but only one of them is complete (Dalla Vecchia, 2013, Fig. 68). This is a 35-cm-long tridactyl footprint (Fig. 29a), which is the largest tridactyl footprint found to date in the Dolomia Principale of the Carnic Prealps, falling in the *Eubrontes* size-class. The height at the hip of the trackmaker was estimated in 140-176 cm (Dalla Vecchia and Mietto, 1998). The footprints are preserved in a laminated stromatolite interval.

In the gorge known as Ciol de la Fratta (Claut Municipality, Pordenone Province) (2-3 in Fig. 28), two footprint-bearing boulders (A and B; Dalla Vecchia and Mietto, 1998) have been identified.

The boulder A (2 in Fig. 28) preserves two trackways, at least five isolated footprints and 15 depressions, which are probably poorly preserved footprints; they are all preserved as concave epireliefs. All footprints, except one, are tridactyl and 15.5-20 cm long. Trackway CFA1 is composed of four consecutive prints and shows a relatively high pace angulation (165°-170°). The best-preserved footprint (CFA1-3; Fig. 29.G) is 17-18 cm long, falling in the *Anchisauripus* size-class. Trackway CFA2 is made of three consecutive footprints with lengths ranging from 15.5 to 19 cm and has a high pace angulation.

The 18-cm-long footprint CFA4 is apparently tetradactyl (Fig. 29k). Dalla Vecchia and Mietto (1998) underlined the morphological correspondence with the ichnogenus *Sphingopus*. However, this ichnogenus is reported only from the Middle Triassic (Klein and Haubold, 2007). The footprint matches with the *pes* skeleton of small and gracile basal sauropodomorphs (see Galton and Upchurch, 2004). However, other primitive saurischians (for example, herrerasaurids; see Langer, 2004) may have produced footprints with the impression of digit I. Marzola and Dalla Vecchia (2014) suggested alternative interpretations as a tridactyl footprint like the others occurring in the same boulder, which is casually associated with a close but distinct depression, or as an incomplete chirotheriid *pes* impression.

The boulder B (3 in Fig. 28) originally contained a trackway with seven pairs of *manus-pes* tracks (Fig. 29n) preserved as convex hyporeliefs. The track-bearing surface was nearly vertical and impossible to observe directly without climbing; the study by Dalla Vecchia and Mietto (1998) was based on a map drawn by climbers. Successively, the boulder moved downstream, was broken

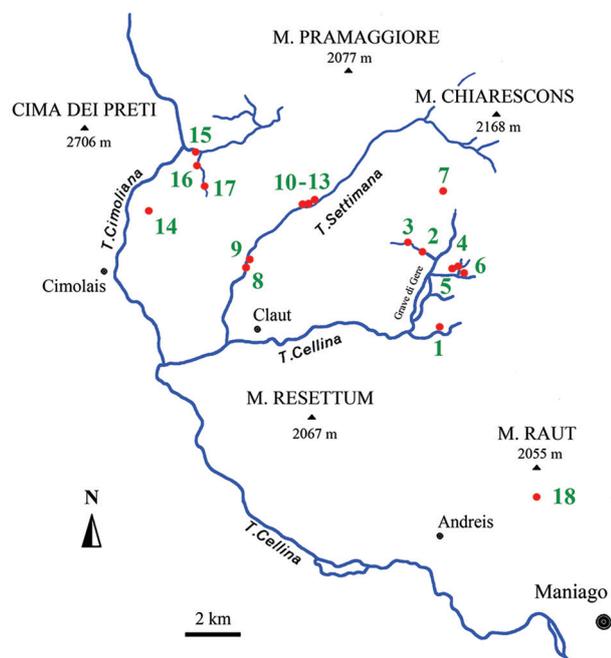


Fig. 28 - Location of the boulders with tetrapod footprints in the Dolomia Principale of the Carnic Prealps (Pordenone Province, Friuli Venezia Giulia Autonomous Region). 1) Cjasevent, Claut; 2) Ciol della Fratta A, Claut; 3) Ciol della Fratta B, Claut; 4-6) Ciolòn Brook and surroundings, Claut; 7) Pregoane Fork, Claut; 8-13) Settimana Valley, Claut; 14) Scandoler Valley, Cimolais; 15) Torrent Pezzeda, Cimolais; 16) Ciol del Tramontin 1, Cimolais; 17) Ciol del Tramontin 2, Cimolais; 18) upper Susaibes Brook, Andreis.

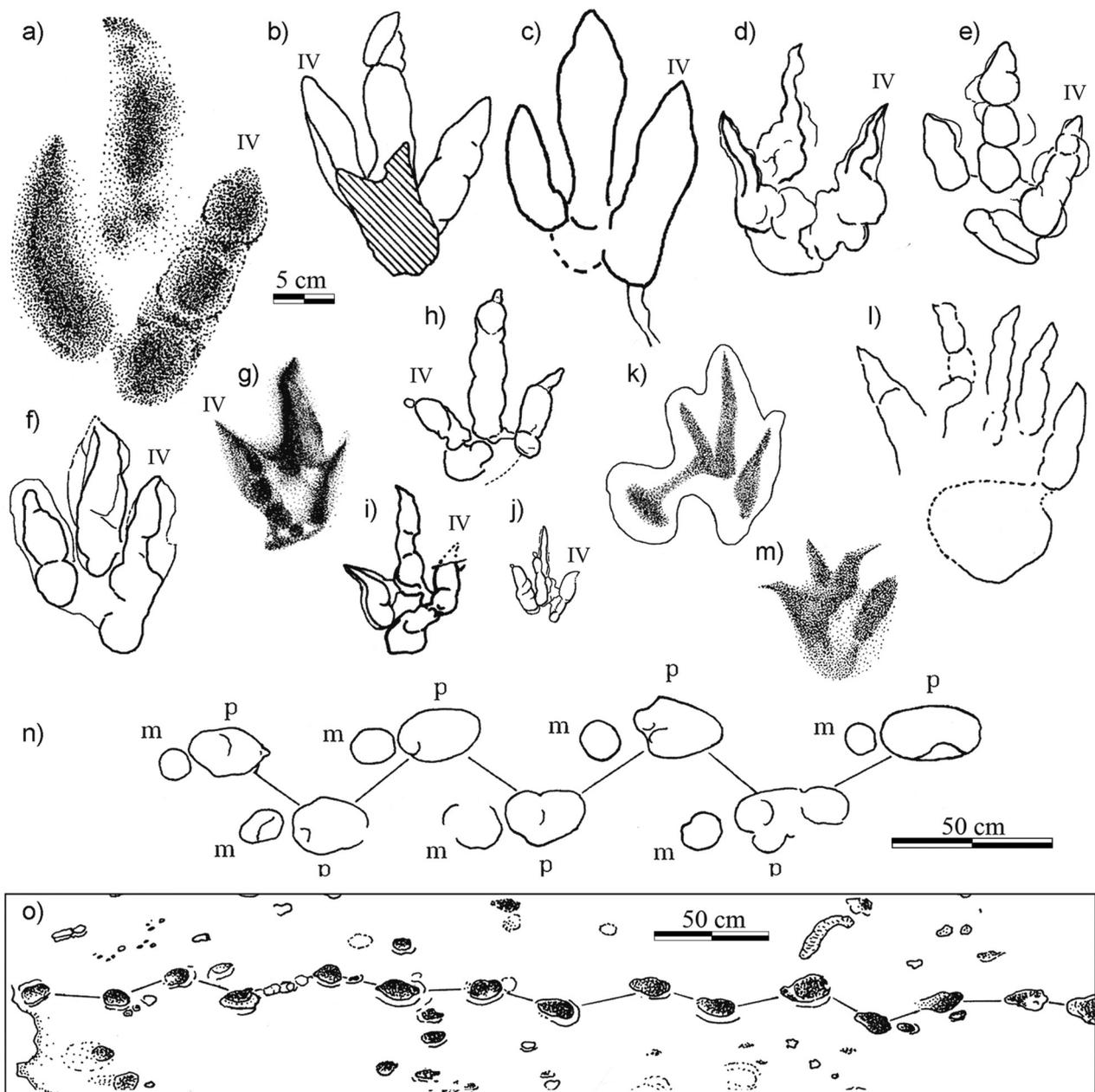


Fig. 29 - A sample of the reptile footprints from the Dolomia Principale of the Carnic Prealps (Pordenone Province, Friuli Venezia Giulia Autonomous Region). a) Casera Cjasevent, Claut; b) upper Susaibes Brook, Andreis; c) AVG3, Ciolòn Brook, Claut; d) Ciol del Tramontin 1, Cimolais; e) VPE1-1B, Pezzeda Valley, Cimolais; f) VSE2-1A, Settimana Valley, Claut; g) CFA1-3, Ciol della Fratta A, Claut; h) VSE3, Settimana Valley, Claut; i) Ciol del Tramontin 2, Cimolais; j) VSE 5, Settimana Valley, Claut; k) CFA4, Ciol della Fratta A, Claut; l) upper Susaibes Creek, Andreis; m) SU-B1.1m, upper Susaibes Creek, Andreis; n) trackway of the boulder B, Ciol della Fratta B, Claut; o) trackway SCA1, Scandoler Valley, Cimolais. Abbreviations: IV=impression of digit IV; m=manus print; p=pes print. a, b, d, g, i and k-o are from Dalla Vecchia and Mietto (1998); c, e, f, h and j are from Marzola and Dalla Vecchia (2014). The scale bar in a-m: 5 cm; scale bars in n-o: 50 cm.

and part of the track-bearing surface was destroyed (Dalla Vecchia, 2013). The *pes* tracks are elliptical or oval and 27-28 cm long. Only the third *pes* print appears to be roughly tridactyl and mesaxonic with very short and rounded digit impressions in the map (Fig. 29n). There is no pedal rotation. The 10-16-cm-long tracks of the *manus* are sub-circular and placed in front of the *pes* tracks or slightly medial to them. There are no drag traces

of the belly or tail. The external width of the trackway is 43-45 cm and the pace angulation is low ( $102^{\circ}$ - $111^{\circ}$ ). The trackway was produced by a quadrupedal trackmaker with a comparatively broad body and slow gait. Dalla Vecchia and Mietto (1998) referred the trackway to a quadrupedally-moving basal sauropodomorph or to a large 'crurotarsal' archosaur (possibly an aetosaur considering the low pace angulation).

Three footprint-bearing boulders (AVG1 to 3, described by Marzola and Dalla Vecchia, 2014) were found in the Ciolòn Brook (Claut Municipality, Pordenone Province) and surroundings (southern slope of Mt. Caserine Basse; 4-6 in Fig. 28).

Boulder AVG1 preserves several poorly preserved tracks (they are concave epireliefs; Marzola and Dalla Vecchia, 2014, Fig. 8), a dozen of which can be referred to small tridactyl footprints about 13-13.5 cm long, in the size-range of *Grallator sensu* Olsen et al. (1998). Some of these footprints are organised into two short trackway segments. Footprints were probably preserved in a laminated stromatolite level with mud-cracking.

Boulder AVG2 presents 18 tridactyl tracks as convex hyporeliefs (Marzola and Dalla Vecchia, 2014, Fig. 9). Three consecutive footprints, about 21 cm long (*Anchisauripus* size-range), form the trackway AVG2-2, with pace angulation 174°. Two consecutive tracks, about 18 cm long (AVG2-1A-B), are probably poorly-preserved tridactyl footprints of the same trackway. The poorly preserved isolated tracks AVG2-3 to 11 are 18-20.5 cm long, within the size-range of *Anchisauripus*. AVG2-4 has an unusually short digit III impression and Marzola and Dalla Vecchia (2014) hypothesized that it might be an incomplete chirotheriid track or an incomplete track of another pentadactyl or tetradactyl ichnogenus, if this shortness reflects the anatomical length of the trackmaker's digit. Footprints are probably preserved in stromatolithic dolostone.

Boulder AVG3 preserves a 25.1-cm-long tridactyl footprint (Fig. 29c) as convex hyporelief. It is at the boundary between the size-range of *Eubrontes* and *Anchisauripus*. The boulder is probably made of stromatolithic dolostone and the track-bearing surface shows evidence of mud-cracking.

At the Pregoane Mountain Pass (Claut Municipality, Pordenone Province) (7 in Fig. 28; misspelled Pregoiane in Dalla Vecchia and Mietto, 1998), a boulder preserves eight aligned depressions. Four of them (32-40 cm long) are similar to large and approximately tridactyl *pes* prints and four, much smaller (17-20 cm long) and rounded, would correspond to the *manus* prints (Dalla Vecchia and Mietto, 1998, Fig. 8). These depressions vaguely resemble a quadrupedal trackway of an iguanodontid dinosaur. However, the purported *manus* prints are located medially respect to the *pes* prints and the pace is unusually short respect to the *pes* print size. These depressions could be just erosional structures and Dalla Vecchia and Mietto (1998) only provisionally referred them to potential footprints, waiting for a future personal visit to the locality (they only saw a photo of them), which never happened.

Six footprint-bearing boulders (VSE1 to 6, described in Marzola and Dalla Vecchia, 2014) were found along the Settimana Valley (Claut Municipality, Pordenone Province) (8-12 in Fig. 28). Three of them (VSE2 to 4) were used to build the levee of the right bank of the Settimana Brook. All boulders, except VSE6, preserve the footprints in laminated stromatolite intervals.

The boulder VSE1 (8 in Fig. 28) presents two poorly preserved and close to each other tridactyl footprints as shallow negative epireliefs (Marzola and Dalla Vecchia, 2014, Fig. 2). The best preserved footprint is about 22 cm long and the other has a similar size (*Anchisauripus* size-class).

The boulder VSE2 (10 in Fig. 28) contains two tridactyl footprints, which are consecutive prints of the right foot in a short trackway segment (the left footprint in between is missing; Marzola and Dalla Vecchia, 2014, Fig. 3A). They are concave epireliefs and the better preserved is VSE2-1A (Fig. 29f), which is 21.5 cm long and falls in the *Anchisauripus* size-class. The printed surface shows small mud cracks.

The boulder VSE3 (11 in Fig. 28) shows a single tridactyl footprint, which is 17.3 cm long and falls in the lower size-range of *Anchisauripus* (Fig. 29h). It is a concave epirelief with a proportionally long digit III impression. The boulder VSE4 (12 in Fig. 28) has a single, poorly preserved tridactyl footprint (Marzola and Dalla Vecchia, 2014, Fig. 5). It is a 22 cm long concave epirelief in the size-range of *Anchisauripus*.

The boulder VSE5 (13 in Fig. 28) preserves a single small tridactyl footprint. It is a shallow concave epirelief which is only 9 cm long, representing the smallest footprint of the sample and one of the few in the Carnic Prealps sample to fall within the *Grallator* size-class.

The boulder VSE6 (9 in Fig. 28) contains a single and very poorly preserved tridactyl footprint (Marzola and Dalla Vecchia, 2014, Fig. 7). It is a 25.7-cm-long convex hyporelief. Size, broadness, total digital divarication and relative shortness of digit III are within the limits of the ichnogenus *Eubrontes*. The boulder is made of massive dolostone.

An enormous boulder preserved inside a landslide or moraine accumulation along the Scandoler Valley (Cimolais Municipality, Pordenone Province) (14 in Fig. 28) exposed a 10 x 20 m wide trampled surface. The vertical surface was mapped by hanging climbers (see Dalla Vecchia and Mietto, 1998 for further details). Subsequently, the boulder collapsed and got destroyed (Dalla Vecchia, 2013). Within many scattered and misshapen concave epireliefs, a trackway (SCA1) composed of 15 consecutive *pes* prints could be identified (Fig. 29o). The footprints were apparently circular to drop-like depressions, about 18 cm long and without clear digit impressions. The pace angulation ranged 140°-160° and footprints showed outer rotation ranging 8°-28°. The trackway has been tentatively referred to a relatively small and bipedal dinosaur, possibly a gracile basal sauropodomorph like *Thecodontosaurus* Morris, 1843 and *Anchisaurus* Hitchcock, 1865, although a bipedal non-dinosaurian archosaur was not discarded as a trackmaker.

The boulder VSE6, found along the Torrent Pezzeda (Cimolais Municipality, Pordenone Province) (15 in Fig. 28) contains a trackway composed of four shallow, tridactyl footprints preserved as concave epirelief (Marzola and Dalla Vecchia, 2014, Fig. 11A-B). The best-

preserved footprint, VPE1-1B (Fig. 29e), is 20.3 cm long and falls within the size-range of *Anchisauripus*. The mean pace angulation is high (~175°), but the stride is short (mean is 57 cm). Footprints are preserved at the top of a laminated stromatolite set.

Two footprint-bearing boulders have been reported from the gorge known as Ciol del Tramontin (Cimolais Municipality, Pordenone Province) by Dalla Vecchia and Mietto (1998). In both boulders, footprints were impressed on a laminated stromatolite set. The first boulder (Ciol del Tramontin 1; 16 in Fig. 28) preserves four tridactyl footprints and several depressions which could be partially worn away footprints. Length ranges from 16 to 21 cm; the largest footprint is the best preserved (Fig. 29d).

The second boulder (Ciol del Tramontin 2; 17 in Fig. 28) contains two footprints possibly belonging to a single trackway, but only one is well preserved. It is a 15-16-cm-long (lower limit of the *Anchisauripus* size-range) tridactyl footprint with a relatively long digit III impression (Fig. 29i).

Along the upper Susaibes Brook (Andreis Municipality, Pordenone Province), NW flank of the del Mt. Zuccul de Zan Modest (18 in Fig. 28), two boulders close to each other present tetrapod footprints on their surfaces. They are probably two fragments of the same broken boulder and shows the same footprint-bearing surface (Dalla Vecchia and Mietto, 1998). In both boulders, footprints are preserved in a laminated stromatolite interval.

The larger boulder (size 6x3 m) split in a way to expose the two sides of a single bedding plane. True prints remained in a part whereas their moulds (convex hyporeliefs) remained on the other. The hyporeliefs had been studied instead of the true prints because they were better visible under the natural illumination. The boulder preserves a trackway made of four consecutive tridactyl footprints, but the third one is barely identifiable (Dalla Vecchia, 2013, Fig. 89). The best-preserved track is the fourth one (Fig. 29b), which is 24 cm long (upper limit of the *Anchisauripus* size-range), has a long digit III mark and was impressed by the right foot. The long stride (~180 cm) suggests a relatively fast gait.

Close to the trackway, there is a single, shallow and apparently pentadactyl footprint (Fig. 29l). The digit impressions are sub-equal in length, slender and forward directed, except the first from the left in figure 29l, which is tapering, with a relatively broad proximal part and slightly splayed outwardly. Dalla Vecchia and Mietto (1998) noticed that these footprints resemble some Late Triassic pentadactyl tracks referred to *Tetrasauropus*, *Pseudotetrasauropus*, *Pentasauropus* and *Otozoum* in the literature. If the footprint is actually pentadactyl and not the product of the overlapping of two tracks, the trackmaker may be a massive quadrupedal archosaur or even a large dicynodont synapsid. According to Dalla Vecchia (2013), it would be similar to *Pseudotetrasauropus*, *Otozoum* and *Evazoum*, if the footprint were tetradactyl (the aberrant outer digit not belonging to it). In that case,

the trackmaker might be also a basal sauropodomorph.

Several other structures on the surface are probably poorly preserved tetrapod tracks.

The other boulder (Dalla Vecchia, 2013, Fig. 92) preserves a partial tridactyl footprint as concave epirelief (Dalla Vecchia and Mietto, 1998, Fig. 11 left) which is very similar to the fourth track of the trackway contained on the larger boulder and may be part of the same trackway.

Close to the tridactyl footprint, a poorly preserved trackway (SU-B1) made by a quadrupedal trackmaker was identified. The best-preserved footprints (SU-B1.1m and 3m in Dalla Vecchia and Mietto, 1998, Fig. 11 left) are two subcircular, relatively small (their length is 13 cm) and preserved as concave epireliefs; Fig. 29 m). They are tetradactyl with a short free digital portion and were identified as *manus* impressions, apparently the consecutive prints of the same *manus*. The associated *pes* prints are larger and shallower, and their outlines are poorly defined and do not allow any interpretation about the foot morphology. The pace angulation of the trackway is low (~110°). Dalla Vecchia and Mietto (1998) tentatively interpreted it as an atypical chirotheriid trackway, although chirotheriid *manus* prints are pentadactyl when well preserved. These authors also noticed that tetradactyl *manus* prints occur in trackways referred to *Tetrasauropus*.

## 9. UPPER TRIASSIC TETRAPOD FOOTPRINTS FROM NORTHERN APENNINES

One of the most interesting Triassic succession of the Northern Apennines is that in the area around La Spezia, where the Metamorphic Succession of Punta Bianca and the Tuscan Nappe crop out. These series document the Hercynian basement of the Adria Plate and its sedimentary cover (Passeri, 1988; Abbate et al., 2005). In the metamorphic succession of Punta Bianca ("Alpine" greenschist facies metamorphism) almost two sedimentary cycles, Middle and Late Triassic in age, and characterized by continental siliciclastic passing to marine carbonates, can be recognized. The first cycle (Punta Bianca sequence: late Olenekian/early Anisian to Ladinian p.p.) starts with meta conglomerates and meta arenites unconformably overlying the Palaeozoic basement, then shallow marine carbonates, submarine volcanic and cherty beds. The second cycle (Mts. Pisani sequence: late Ladinian-Carnian) starts with siltstones and metaconglomerates of the so called "Verrucano Auct" or Montemarcello Formation (cf. Martini et al., 1986; Passeri, 1988; Abbate et al., 2005; Cassinis et al., 2018), referred to alluvial plain or fluvial flood plain grading upward into coastal-deltaic sediments and to marginal marine clastics (S. Terenzo schist) followed upward by Upper Triassic carbonates.

### 9.1. LERICI (LIGURIA REGION)

Surfaces with several trackways and isolated footprints were described from Lericci (La Spezia Province) at the

end of the '90 of the last century (Sirigu and Nicosia, 1996). All surfaces are exposed on the coastline in spotted outcrops between Punta Santa Teresa and Punta Galera. Footprint-bearing rocks belong to the Montemarcello Formation, and possibly to its youngest portion (S. Terenzo schist). Nicosia and Loi (2003) proposed a late Carnian age for this assemblage. Three different levels at two separate sites have yielded a composite ichnofauna, with bipedal and quadrupedal forms. The largest surface has about 40 footprints, partly organised in trackways. At least five trackways were recognised by Nicosia and Loi (2003). Isolated footprints are scattered on smaller surfaces. A plaster cast of the largest surface, along with isolated natural casts and molds are stored at MLC-Lerici. Nicosia and Loi (2003) organised all chirotheriid and dinosaurian footprints in five morphotypes: two dimensionally separated chirotheriid forms, a grallatorid trackway of five consecutive steps, a sequence of two footprints with features similar to *Anomoepus* Hitchcock, 1848, and two trackways plus several isolated footprints of tetradactyl biped trackmaker.

On this latter material, Nicosia and Loi (2003) erected the ichnotaxon *Evazoum sirigui*. This ichnotaxon is characterized by being medium-sized bipedal tetradactyl footprints (often tridactyl), ectaxonic to mesaxonic, functionally tridactyl, nearly as wide as long; digit I is forwardly oriented while the other digits are often splayed giving an overall fan-shaped impression; digits are relatively fleshy and show well-developed pads. Triangular, slightly smoothed, long, claw marks occur on all digits. As stated in Nicosia and Loi (2003), *Evazoum* differs from *Otozoum* by the splayed posture of digits and the broader trackway width, while it differs from the Lesotho *Pseudotetrasauropus* (*sensu* Ellenberger, 1972) for the occurrence of clear claw marks, lacking in the African material.

## 10. TRIASSIC TETRAPOD FOOTPRINTS FROM NORTHERN APENNINES OF INDETERMINATE EXACT AGE

### 10.1. MOUNTS PISANI (TUSCANY REGION)

Among the Upper Triassic Italian fossil tracks, those from the Mounts Pisani (Pisa and Lucca Provinces, Tuscany Region) are undoubtedly the most famous and historically important. They were described at the end of the 19<sup>th</sup> century by Tommasi (1886) and later by Fucini (1915, 1936) and von Huene (1940, 1941), and then discussed by Rau and Tongiorgi (1974a) and Tongiorgi (1980). They include dozens of traces referred to various ichnogenera and ichnospecies. Geological data collected mainly by Rau and Tongiorgi (1974b) show that all the tracks found in this geographical area can be referred to two main stratigraphic layers in the upper part of the "Verrucano" in the Quarziti di Monte Serra Formation: the lower one is in the Scisti Verdi Member and the upper one in the Zoned Purple Quartzites Member. The Scisti Verdi Member consists of lagoon and tidal plain

deposits, dated by a rich bivalve association earliest (Rau and Tongiorgi, 1966). These layers, cropping out at Passatoio, and also at Piavola and S. Allago, have yielded many undetermined traces and a few tracks that von Huene (1941) called *Cryptobranchichnus infericolor* and attributed to an amphibian.

The Zoned Purple Quartzites, referred to the upper Carnian, preserve the highest number of traces. This formation corresponds to sediments deposited in a low delta plain, largely covered by a thin layer of brackish water and periodically emergent. Near the border with the underlying White-Pink Quartzites and especially from the outcrops near Agnano, these deposits yielded the tracks found by A. Tommasi in the second half of the 19<sup>th</sup> century, to which was then added the abundant material collected by A. Fucini (starting from 1910) and later studied also by von Huene (1941).

Previous authors described the Mounts Pisani ichnoassociation as being composed of many endemic ichnospecies: *Cryptobranchichnus infericolor* Huene, 1941, *Rhynchocephalichnus pisanus* Fucini, 1915, *R. etruscus* Huene, 1941, *Thecodontichnus verrucae* Tommasi, 1886, *T. fucinii* Huene, 1941, *Coelurosaurichnus toscanus* Huene, 1941, *Chirotherium angustum* Huene, 1941, *Procolophonipus italicus* Huene, 1941 and *Procolophonipus* Rühle von Lilienstern, 1839 isp. (Fig. 30).

However, this nomenclature is nowadays probably misleading. Some of these names refer to tracks whose differences are exclusively related to preservational factors; if revised according to modern ichnological systematics, they would mostly be put in synonymy with common Triassic morphotypes. A complete revision more than 60 years after the first study, is therefore much needed. A preliminary examination of the material carried out during the reorganisation of the Florentine collections housed in the MSN-Firenze (Avanzini, 2010), revealed that most of the traces in Tommasi's and Fucini's collections can be attributed to reptilian forms typical of associations that are older than the Carnian age given to the Mounts Pisani material.

In particular, both the overall composition of the association, dominated by tracks of small archosauromorphs and lepidosauromorphs, and the presence of forms comparable with ichnogenera *Rhynchosauroides*, *Chirotherium*, *Synaptichnium* and *Rotodactylus* usually found in Middle Triassic rocks makes this set of fossils particularly interesting, on one side, and highlights a possible incongruity between the composition of the faunas and the age proposed by studies of the stratigraphic succession on the other side. A further peculiar and enigmatic issue within the Mounts Pisani ichnofauna is the presence of the track *Coelurosaurichnus toscanus*. The name assigned to the ichnogenus by F. von Huene reflects the author's conviction that the track was left by a small dinosaur. This record, whose implications have long been underestimated, was for almost 50 years the only evidence of the possible presence of dinosaurs



Fig. 30 - Triassic tetrapod footprints from the Mounts Pisani (Pisa and Lucca Provinces). a) *Synaptichnium* isp. (MC-Calci); b) *Rotodactylus* isp. (MC-Calci); c) *Chirotherium angustum* (IGF5147 MSN-FI); d) *Thecodontichnus verrucae* (IGF5161 MSN-FI); e) *Rhynchocephalichnus pisanus* (rectae *Rhynchosauroides* isp. IGF5209 MSN-FI) with tail trace; f) *Coelurosaurichnus toscanus* (IGF5200 MSN-FI); g) *Thecodontichnus verrucae* (IGF5159 MSN-FI); h) *Thecodontichnus verrucae* with skin impression (rectae *Synaptichnium* isp. IGF5175 MSN-FI); all scale bars: 10 cm.

in Italy (Tongiorgi, 1980), i.e. until the discovery of the tracks of Mt. Pelmetto in the Dolomites (Mietto, 1988). G. Leonardi and M. Lockley re-examined the track and concluded that it was made by a dinosaur-like trackmaker (*Grallator* isp.) but that there was no hope for a more precise systematic attribution (Leonardi and Lockley, 1995; Leonardi and Mietto, 2000). Further investigations on the reliability of these specimens should be undertaken to remove the remaining doubts.

Sirigu and Tongiorgi (1996) reported the discovery of new footprints in the Mount Serra Formation from the Mounts Pisani, found near the towns of Calci and Agnano. The material, now stored in MSN-Firenze, comes from the transitional facies between the White-Pink Quartzites and the Zoned Purple Quartzites members. According to the authors, these are two dinosaur footprints: the first, preserved as a hyporelief, is a tridactyl, mesaxononic footprint with low interdigital angular values; they interpreted a depression in the distal position of the footprint as a *manus* impression. Therefore, the track was referred to an ornithischian dinosaur. Because of the low value of the interdigital angles, we reinterpret it as an archosauriform footprint possibly *Parasynaptichnium*-like. The second footprint, preserved as an epirelief, is tridactyl, strongly digitigrade, mesaxononic, with squat, expanded and pointed digit impressions. Sirigu and Tongiorgi (1996) referred footprint to a theropod dinosaur, or alternatively to a "thecodont". Because of the type of impression and, in particular the shape of the digits, we reinterpret it as a more likely chirotheriid footprint.

The brief remarks highlight that the ichnological association of the Mounts Pisani, with extremely diversified small and large reptilian footprints, is an extremely interesting record of Triassic life that needs to be re-examined by using modern comparative methods.

## 11. CONCLUSION

After the comprehensive works of Conti et al. (1997, 2000), Avanzini et al. (2001), Avanzini and Mietto (2005) and Petti et al. (2013), this paper presents for the first time a complete and updated account of Triassic tetrapod ichnoassemblages from Italy.

When compared to the ichnofossil-rich associations discovered in other regions of the world, the Italian Triassic footprint record can be summarised as follows:

i) the Lower Triassic record is heavily biased by environmental and taphonomic issues. The nearly monotypic record of lizard-like tracks should be interpreted as a sub-sample of the plausible actual taxonomic diversity that is recorded in close regions, e.g. the Central German Basin, by high diversity and high abundance associations of chirotheriid footprints.

ii) The Middle Triassic record is much more similar to that of other close regions. It shows high ichnotaxonomic diversity and a remarkable abundance in the Anisian, whereas the uppermost Anisian-Ladinian sequences are almost completely barren due to environmental bias. The

record from the Bithynian-Pelsonian-Illyrian is so rich to be used as reference for high resolution biocorrelations.

iii) The Upper Triassic record, although not remarkably diverse nor rich, is notable for showing three clearly distinct associations that document a rapid shift in composition from a quadrupedal non-dinosaurian archosauriform-dominated assemblage in the Julian (lower Carnian), to a mixed assemblage in the Tuvalian (upper Carnian) and to a dinosaur-dominated assemblage in the upper Tuvalian-Norian.

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