Lower and Middle Triassic footprint-based Biochronology in the Italian Southern Alps

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ABSTRACT - The Early and Middle Triassic ichnoassociations of the Italian Southern Alps appear particularly important due to their excellent state of preservation and the ample vertical distribution of the dated trampled levels. On the basis of the ranges of single ichnotaxa, it is possible to define a series of different associations, characterized by different evolutionary stages. They correspond to informal evolutionary units that can be estabilished as faunal units (FUs).
The Scythian is characterized by the presence of *Rhynchosauroides schochardti* that disappears in the Anisian. In the Anisian, characterized by the appearance of *Rhynchosauroides tirolicus*) a progressive increase in the complexity of the ichnoassociations from the Bithynian to the Illyrian is documented. In the Bithynian - Early Pelsonian interval the faunal assemblage is dominated by *Parasynaptichnium gracilis* and *Synaptichnium pseudosuchoides.* The Early Pelsonian - Early Illyrian interval is characterized by the dominance of *Isochirotherium delicatum* and *Brachychirotherium circaparvum*.

Key words: *Southern Alps, Middle Triassic, ichnoassociations,faunal age*

INTRODUCTION

From the Southern Italian Alps, Triassic footprints are known since the first decade of 1900 (Abel, 1926; Leonardi, 1967; Brandner, 1973) but extensive research took place only in the last 30 years with the discovery of vertebrate tracks at many sites of the Dolomite region and surrounding areas (Conti et al., 2000; Avanzini et al., 2001). The ichnoassociations documented so far, appear particularly important due to their excellent state of preservation and the ample vertical distribution of the trampled levels (Avanzini and Neri, 1998, Avanzini, 1999; Avanzini et al., 2001). The most abundant footprints are those of small lizard -like reptiles referable to the ichnogenus *Rhynchosauroides* Maidwell 1911, but also present are trackways and footprints that can be attributed to archosaur trackmakers. Amongst these the ichnogenera *Chirotherium* Kaup 1835, *Brachychirotherium* Beurlen 1950, *Isochirotherium* Haubold 1971b, *Synaptichnium* Nopcsa 1923 and *Parasynaptichnium* Mietto 1987 have been recognized. The ichnological material also includes footprints referable to *Procolophonichnium*, others probably to therapsids, and invertebrate trails.

In the Southern Alps, a first attempt to use footprints-based biochronology was made by Conti et al. (1997) for the Permian, and a second attempt, for the Permo-Triassic interval, by Avanzini et al. (2001). This third attempt is based on an updated and much richer ichnological database for the Early and Middle Triassic interval. In recent years the ichnological literature regarding Northern Italy (Southern Alps) has increased enormously due to the discovery of many new tetrapod footprint-bearing outcrops that have been studied. Up to the summer of 2005, in the Italian Southern Alps, a total of 36 Lower and Middle Triassic tetrapod footprint-rich outcrops had been identified. After a stratigraphical calibration we selected all the data coming from Lower and Middle Triassic outcrops to check the stratigraphical value of footprints. For calibration we used data from ammonoids, conodonts, sporomorphs and sequence stratigraphy (De Zanche et al., 1993; Mietto and Manfrin, 1995; Gianolla et al., 1998). In fact, in the Triassic units of the Southern Alps it was possible to use ammonoid standard biozonation followed by calibration with marine standard chronostratigraphic and geochronologic units. In most outcrops footprints were present in isolated levels but we use outcrops with thick sequences of track-bearing sediments as a main reference (i.e. Braies Dolomites and Adige Valley). Despite the fact that in many cases the systematics is still in progress and frequently the names given to the footprints still preserve uncertain systematic positions, the results are summarized below.

TETRAPOD FOOTPRINT DATABASE

The Permo-Triassic palaeogeography of the Alpine region originated a peculiar geological situation in which marine sediments, footprint rich continental deposits and volcanites are interfingered (Avanzini et al., 2001).

Figure 1 – Sketch map showing the location of the areas where Triassic tetrapod footprints were collected. 1, Braies Dolomites; 2, eastern Dolomites; 3; western Dolomites; 4 northern Adige Valley and Non Valley; 5, central Adige Valley; 6 Recoaro Area.

Lower Triassic

Werfen Formation (Induan - Olenekian)

The Werfen Formation is composed of shallow sea marine facies, representing the beginning of the Triassic marine transgression in the Eastern Tethys.

The fossil content is relatively abundant and is important for the stratigraphy of the formation that can be subdivided into 6 large sedimentary cycles with a regressive character (depositional sequences) (Pisa, Farabegoli and Ott, 1978; Broglio Loriga et al, 1983; Neri and Posenato, 1988; Broglio Loriga et al., 1990).

The sedimentary environment was that of shallow shelfs with mud -dominated low-energy, offshore deposits and shallow tidal plains in which there were sub-environments above sea level that isolated areas of restricted circulation and strong evaporation.

Tracks are present only in the middle- upper part of the Formation (Smithian to Spathian in age):

Rhynchosauroides aff. *palmatus* (Lull 1942)

Rhynchosauroides schochardti (Rühle von Lilienstern 1939)

Capitosauroides cf. *bernburgensis* Haubold 1971a

Middle Triassic

Lower Serla Dolomite (Aegean)

This is a fully carbonatic formation conformably overlying the Werfen Fm. and regarded as ?Uppermost Scythian–Early Anisian in age. It usually consists of well-bedded, light grey dolomites forming classic peritidal shallowing cycles, few meters thick, locally deposited in hyperhaline conditions. In its upper portion, an increase in supratidal facies (marked by mud cracks and tepees) is related to a significant decrease in accommodation space.

The Lower Serla Dolomite is referred to a broad shallow carbonate platform environment.

Tetrapod footprints are rare and very localized, among them only one form has been recognized:

Rhynchosauroides sp.

***Gracilis* Formation (Bithynian)**

This unit mostly consists of more or less dolomitized, decimetre-thick, even to slightly undulated, locally nodular, wackestone and calcsiltite beds interlayered locally by gypsum (e.g. Recoaro area). Fossil remains are generally rare and only indirect chronostratigraphic data permit us to determine the age of this unit (De Zanche and Mietto, 1981; De Zanche et al., 1993). The depositional environment could be referred to a carbonate ramp, with low terrigenous input.

Tetrapod footprints are very rare and represented only by:

Rhynchosauroides sp.

"Dinosauromorpha"?

Voltago Conglomerate (?Bithynian – Earliest Pelsonian)

This unit is made up of conglomerates, sandstones, siltstones and claystones mostly red in colour. Plant debris is abundant throughout the unit (this unit corresponds with the "*Voltzia* beds" in the Recoaro area). Owing to the presence of the binodosus Subzone ammonoids in the overlying Recoaro Limestone and a comparison with marine etheropic sediments in Dolomites and Carnia, this unit has an early Pelsonian age (cuccense Subzone).

It probably reflects a transitional continental to marine environment characterized by coastal delta mouth bars deposited under relatively arid conditions.

The ichnotaxa found in the unit are:

Procolophonichnium sp.

Parasynaptichnium gracilis Mietto 1987

Synaptichnium pseudosuchoides Nopcsa 1923

Synaptichnium cameronense (Peabody 1948)

Synaptichnium diabloense (Peabody 1948)

Rhynchosauroides tirolicus Abel 1926

Isochirotherium delicatum Courel and Demathieu 1976

Chirotherium barthii Kaup 1835

Chirotherium cf. *rex* Peabody 1948

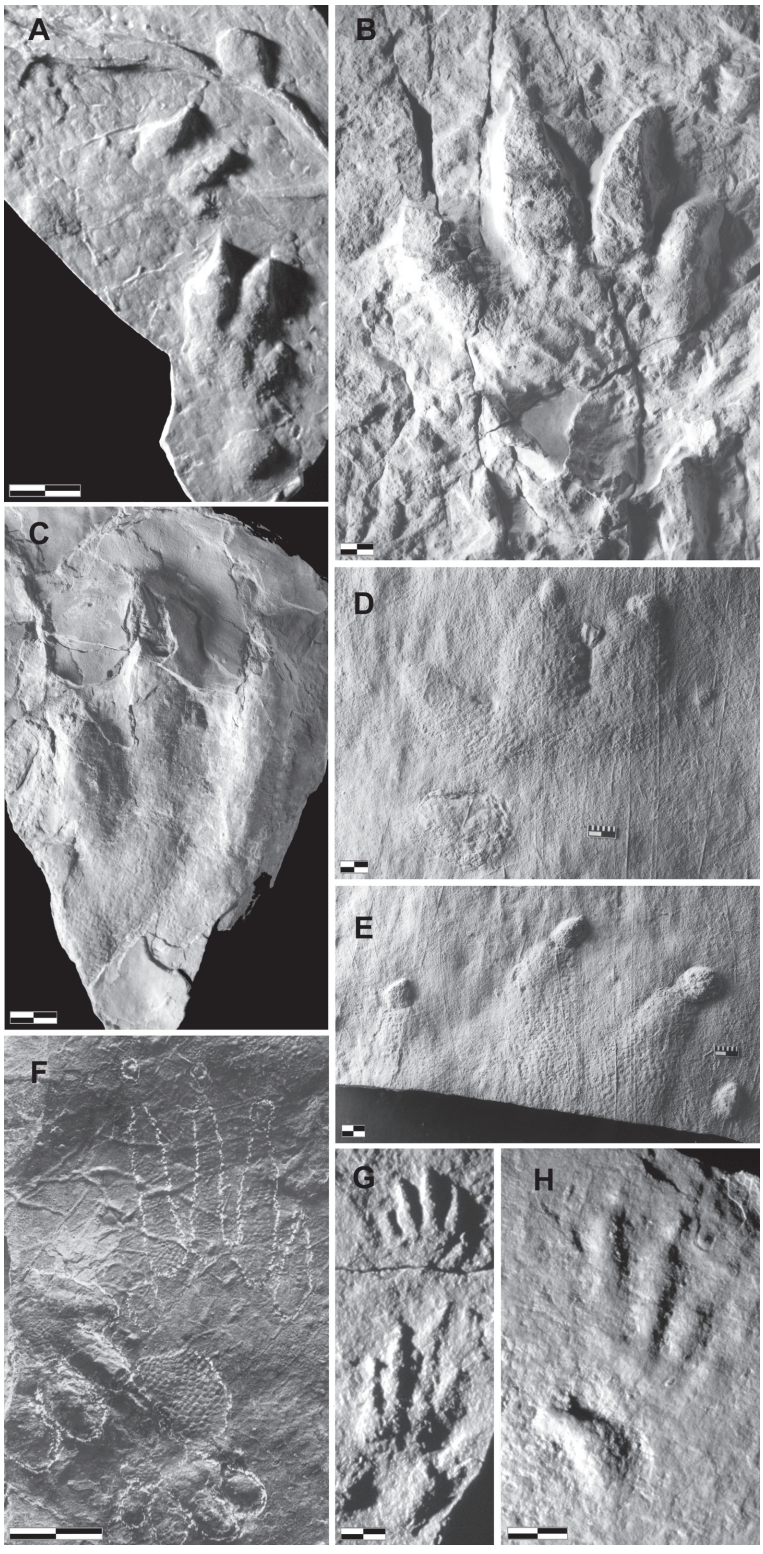

Figure 2 – Middle Triassic tetrapod footprints from several sites of Southern Italian Alps: A, *Isochirotherium delicatum*; B, *Isochirotherium infernense*; C, *Parasynaptichnium gracilis*; D, *Chirotherium* cf. *rex* manus; E, *Chirotherium* cf. *rex* pes; F, *Synaptichnium* sp. with skin impressions and a small *Brachychirotherium* sp.; G, *Synaptichnium pseudosuchoides*; H, *Synaptichnium cameronense* (Scale bar: 2 cm).

Brachychirotherium sp.
Brachychirotherium circaparvum Demathieu 1967
Rotodactylus sp.
"Dinosauromorpha"

Recoaro Limestone (Pelsonian)

The unit is typical of the western Dolomites and is replaced in the eastern sector by the Agordo Formation (Framont dark Limestone). It predominantly consists of nodular, bioturbated, fossil-rich packstones and packstones/grain-

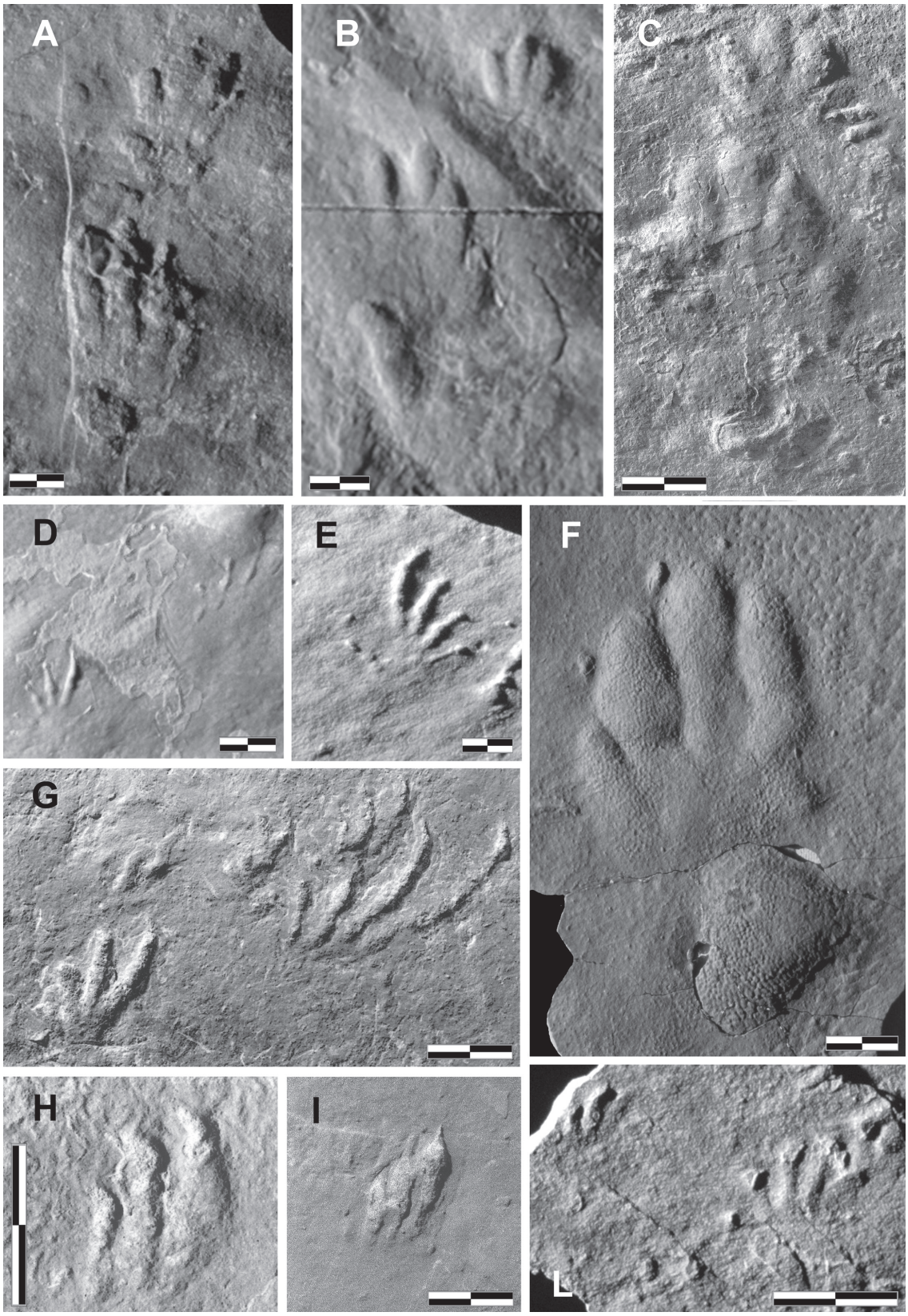

Figure 3 – Middle Triassic tetrapod footprints from several sites of Southern Italian Alps. A, *Brachychirotherium* sp.; B, *Brachychirotherium* sp.; C, *Brachychirotherium circaparvum*; D, *Rhynchosauroides tirolicus*; E, *Rhynchosaurodes peabodyi* manus; F, *Brachychirotherium* aff. *parvum* (sensu Brandner, 1973); G, *Rhynchosauroides peabodyi*; H, *Rotodactylus lucasi*; I, *Rotodactylus* cf. *cursorius*; L, *Procolophonichnium* sp. (Scale bar: 2 cm).

stones arranged in decimetre-thick layers alternating with thin calcsiltite beds that contain angular fine grained quartz.

The invertebrate fauna is locally abundant (e.g. Recoaro area), and mainly made up of brachiopods (*Coenothyris vulgaris* [Schlotheim], *Tetractinella trigonella* [Schlotheim], *Decurtella decurtata* [Girard], bivalves, gastropods (*Undularia scalata* [Schlotheim], crinoids (*Encrinus liliiformis* Lamark), echinoids, coelenterate and ammonoids of the Binodosus Subzone (*Bulogites zoldianus* Mojsisovics). Scattered marine vertebrate remains are reported (Dalla Vecchia and Avanzini, 2002; De Zanche and Mietto, 1981).

The depositional environment is referable to a carbonate ramp slightly contaminated by terrigenous input.

The vertebrate ichnofauna which comes from several sites located along the Adige Valley consists of:

Chirotherium cf. *rex* Peabody 1948
Isochirotherium infernense Avanzini and Leonardi 2002
Synaptichnium cameronense (Peabody 1948)
Rhynchosauroides peabodyi (Faber 1958)
Rhynchosauroides tirolicus Abel 1926
Procolophonichnium sp.

Richthofen Conglomerate (Illyrian)

This unit is dominated by red sandstones and siltstones which alternate with subordinate conglomerate beds.

The Richthofen Conglomerate has been interpreted as being deposited in a fluvial, or locally in a transitional continental to marine environment.

The vertebrate ichotaxa recorded in this stratigraphic unit are:

Procolophonichnium sp.
Rhynchosauroides peabodyi (Faber 1958)
Chirotherium barthii Kaup 1835
Brachychirotherium circaparvum Demathieu 1967
Brachychirotherium aff. *parvum* (Hitchcock 1859) (*sensu* Brandner,1973)
Chirotherium cf. *rex* Peabody 1948
Rhynchosauroides tirolicus Abel 1926
Rotodactylus cf. *cursorius* Peabody 1948
Rotodactylus lucasi Demathieu and Gand 1973
Isochirotherium delicatum Courel and Demathieu, 1976

Morbiac dark Limestones (Illyrian)

It prevalently consists of silty, decimetre-thick grey or light brown lime wackestones and packstones with foraminifers and ostracods. Stromatolite bindstones and thin grey or green siltstone layers are interbedded (Pisa, Farabegoli and Ott, 1978). Plant debris is common.

The depositional environment is referable to a marine marginal setting with lagoons and swamps contaminated by terrigenous inputs.

In the lower portion of the unit the following taxa are represented:

Rhynchosauroides sp.
Rhynchosauroides tirolicus Abel 1926
Rhynchosauroides peabodyi (Faber 1958)
Isochirotherium delicatum Courel and Demathieu, 1976
Chirotherium barthii Kaup 1835
Brachychirotherium aff. *parvum* (sensu Brandner, 1973)

ANALYSIS OF THE ICHNOASSOCIATIONS

The Earliest Triassic ichnoassociations of the Southern Alps are preserved in the Upper Scythian (Smithian) members of the Werfen Formation. They contain isolated and often badly preserved tracks which can be attributed to some species of the ichnogenus *Rynchosauroides*. Amongst these, *Rhynchosauroides palmatus* (sensu Conti et al., 1997) and *Rhynchosauroides schochardti* (Rühle von Lilienstern 1939) can be recognised (Mietto, 1986). The type specimens of *Rhynchosauroides palmatus* (Lull 1942) comes from the Middle Triassic Chugwater Formation (Wyoming) but its chronostratigraphic distribution certainly extends into the late Permian (Conti et al., 2000). *Rhynchosauroides schochardti* (Rühle von Lilienstern 1939) is a typical form of the Thüringischer Chirotheriensandstein (Spathian) with a possible extension to the middle Anisian (Haubold,1971a). The global frequency in the Scythian (Haubold 1971a; 1984) coincides with the chronostratigraphic position of our sample.

From the upper part of the Werfen Formation (Spathian) of the Southern Alps *Capitosauroides* cf. *bernburgensis* is reported, a typical taxon of the Scythian of Europe (Mittlerer -Oberer Buntsandstein) and North America (Lower Moenkopi Fm.) (Haubold, 1971a; 1971b).

At the end of the Scythian the palaeogeography of the Southern Alps did not favour the preservation of vertebrate tracks which only reappear in the fossil record at the base of the Pelsonian. In this interval more complex ichnoassociations develop, and the vertical distribution of several taxa appears particularly significant.

Among the taxa present in the early Pelsonian, the ichnogenera *Synaptichnium* and *Parasynaptichnium* seem to represent the most frequent forms. The type specimen of *Parasynaptichnium gracilis*, comes from the lower part of the Pelsonian (Voltzia Beds) (Mietto, 1987) of the Recoaro area (Vicenza). All the specimens belonging to this species come from the same stratigraphic interval. For this reason *Parasynaptichnium* would seems to represent a taxon confined to the base of the Pelsonian.

Often associated with *Parasynaptichnium gracilis,* is *Synaptichnium pseudosuchoides*. *S. pseudosuchoides* corresponds to type D3 of Beasley (1905) of the Helsby Sandstone dated to the Lower Anisian (Treasise and Sarjeant, 1997; Benton et al., 1994, King and Thompson, 2000). The species seems to be confined globally to the early Anisian and, perhaps in part to the late Scythian (Spathian) as Demathieu and Haubold (1982) and Haubold (1984) reported

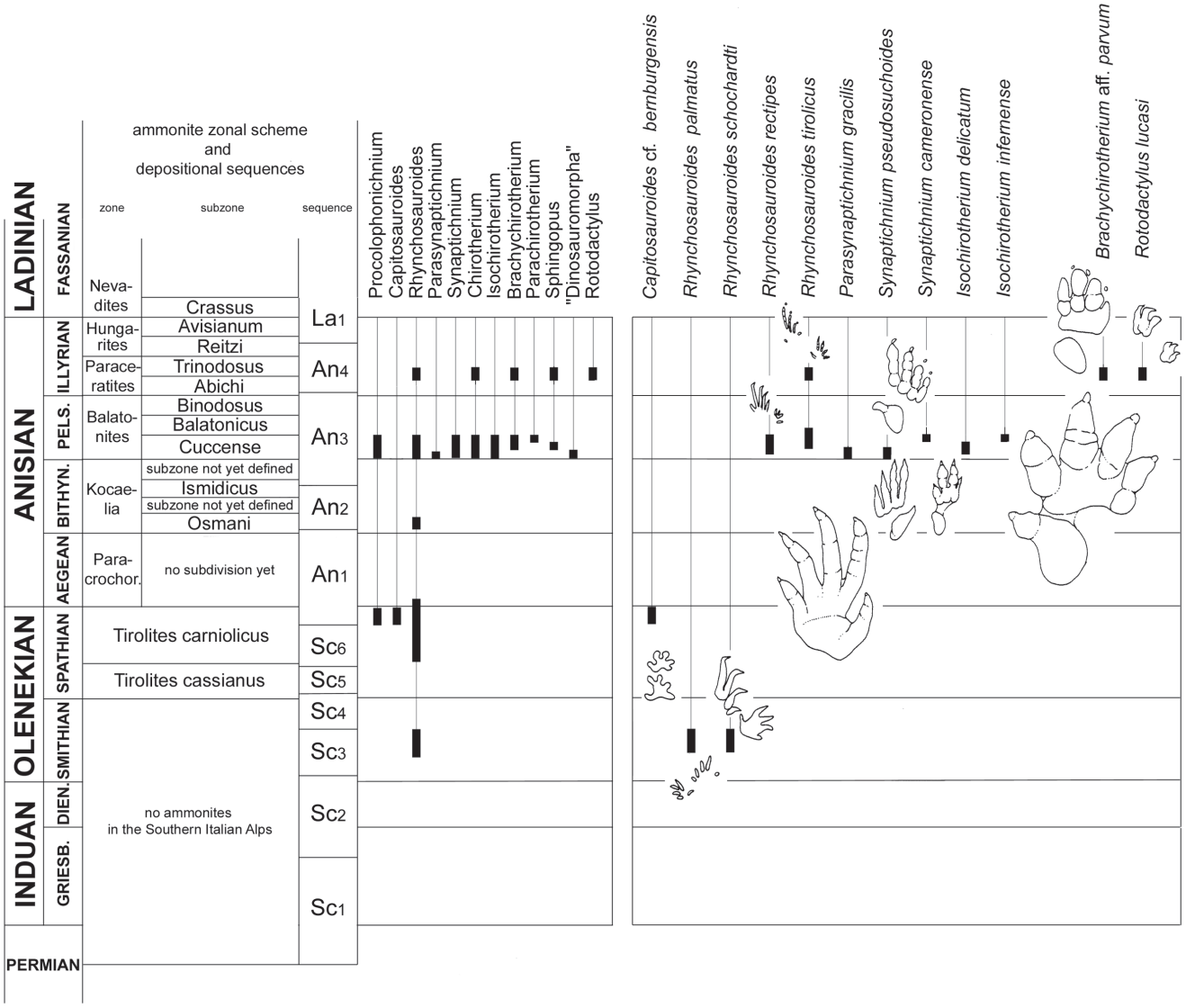

Figure 4 – Stratigraphic distribution of the main tetrapod ichnogenera (left) and ichnospecies (right) in the Lower to Middle Triassic of Southern Italian Alps. The chronostratigraphy, ammonite zonal scheme and sequence stratigraphy for the Early- Middle Triassic of Southern Alps are reported.

a form similar to *S. pseudosuchoides* in the Thüringischer Chirotheriensandstein. This form is also associated with *Rhynchosauroides rectipes*. The type specimen of *Rhynchosauroides rectipes* comes from the Keuper Sandstone of the quarry at Runcorn Hill (GB). The source stratigraphic unit has been identified as the same as that of *Synaptichnium pseudosuchoides* and therefore dated to the Early Anisian (Treasise and Sarjeant, 1997; Benton et al., 1994, King and Thompson, 2000). *Rhynchosauroides rectipes* (syn. *R. membranipes* Maidwell, 1911) has recently been reported also in the Lower Anisian Ormskirk Sandstone from Hilbre (equivalent of the Helsby Sandstone Formation and Tarpoley Siltstone Fm.) (King and Thompson, 2000).

This stratigraphic position is also confirmed in the Southern Alps, where *R. rectipes* and *S. pseudosuchoides*, associated to *Parasynaptichnium gracilis,* represent characteristic forms of the lower Pelsonian.

In the middle Pelsonian the ichnofaunas increase in complexity and to *Parasynaptichnium gracilis* and *Synaptichnium pseudosuchoides* various other ichnotaxa related to archosaurs and to lizard –like reptiles are associated. Amongst these, are several small forms referable to the ichnogenus *Brachychirotherium*. The presence of small forms very close to *Brachychirotherium circaparvum* would seem sufficiently consistent with the global distribution of these forms, even if it is not extremely significant from a stratigraphical point of view. *B. circaparvum* is typical of the French Middle Triassic (Illyrian), as reported by Demathieu and Haubold (1974). In our succession small *Brachychirotherium* forms range from the upper part of the Pelsonian to the Illyrian. The distribu-

tion range would therefore be equivalent, but with a downwards widening. This widening seems to be confirmed by the presence of *Brachychirotherium paraparvum* in the Lower Muschelkalk (Oolit Member) of Holland attributable to the Upper Bithynian (Demathieu and Oosterink,1988; Diedrich, 2001). *Brachychirotherium paraparvum* is a species that is very close to *Brachychirotherium circaparvum* with which it could fall into synonymy (Demathieu and Oosterink,1988; Karl and Haubold, 1998).

A characteristic taxon, present in these Middle Pelsonian ichnoassociations is *Isochirotherium delicatum*. The tracks referable to this taxon show a morphology that is distinctive. This form was identified for the first time at the Anisian−Ladinian boundary in the area of Largentière (Ardèche, France) (Courel and Demathieu, 1973; 1976). It also also seems to be characteristic of the French Massif Central. In our successions, *I. delicatum* occurs with numerically significant associations (Avanzini and Lockley, 2002) in levels attributed to the Middle Pelsonian, which would retrodate the appearance of this form. However, it is possible that the French successions are not calibrated correctly from a chronostratigraphical point of view. In the Southern Alps, this taxon shows a distribution between Middle Pelsonian to Illyrian.

Parasynaptichnium gracilis and *Synaptichnium pseudosuchoides* disappear in the middle part of the Pelsonian and are replaced by *Synaptichnium cameronense* which becomes exclusive. *Synaptichnium cameronense* is a form typical of the Upper Moenkopi Fm. dated to the Anisian and this coincides with our distribution.

Also of stratigraphical interest in the Middle Pelsonian units seem to be *Rhynchosauroides tirolicus* and *Rhynchosauroides peabodyi*, that are very similar in their general shape and stratigraphic distribution. *Rhynchosauroides peabodyi* of Central Europe has been recently attributed to the Middle and Upper Anisian (Bithynian to Illyrian) (Diedrich, 2000) while *Rhynchosauroides tirolicus* shows a distribution between Late Pelsonian to Illyrian. In both ichnospecies the digits of the manus and pes are relatively long and thin, with a manus inward oriented and a pes outward oriented in respect to the trackway midline. The similarity is so marked that *Rhynchosauroides tirolicus* could perhaps be the older synonym of *Rhynchosauroides peabodyi* as affirmed by Diedrich (2002). However, *R. peabodyi* seems slightly more robust than *R. tirolicus* and shows manual digits that are outward rotated. The skin cover on several specimens of *R. tirolicus* and *R. peabodyi*, evidences a possible diversity of the two ichnospecies (Demathieu and Oosterink 1983: fig.23 and 29; Diedrich 2000: fig.3; Avanzini and Renesto, 2002). Notwithstanding that the question of possible synonymy between the two forms has not been resolved, their chronostratigraphical distribution does not show great difference and both forms, if valid, are confined to the Anisian. In our associations their frequency grows towards the Late Anisian (Pelsonian – Illyrian boundary), where they represent the dominant and exclusive species. The same characterization was found for German associations by Diedrich (2002) according to whom *Rhynchosauroides peabodyi* (syn. *R. tirolicus sensu* Diedrich, 2002) practically represents the only species attributable to the ichnogenus *Rynchosauroides* which colonized the Anisian tidal flats of central Europe.

The Middle Pelsonian is characterised by the association of these two taxa with *Synaptichnium cameronense* and *Isochirotherium infernense.*

Isochirotherium infernense represents a rather short robust and wide form of chirotherian that is morphologically similar to *I. marshalli* (Peabody, 1948). The hypothesis that they may represent larger specimens than those documented up to now (Peabody, 1948; Haubold, 1971a; 1971b; 1984; Avanzini and Leonardi, 2002) relative to the ichnospecies *I. marshalli* does not seem to be confirmed due to the difference in the metatarsal-phalangeal pad V which, because of its robustness, appears to be peculiar to *I. marshalli* and due to the less robust and different shape of the claws. (Avanzini and Leonardi, 2002). The similarity with *I. marshalli* could be due to morphological variability that is typical of Anisian isochirotherian forms.

Scattered small tridactyl footprints come from the same stratigraphic levels (but also at the levels on the Bithynian - Pelsonian boundary) which can be referred to archosaurs with a functionally tridactyl pes (Avanzini, 2002). These footprints are generally longer than wide, with digit III long and straight, digital pad impressions and claws marks on the digits. Tridactyl tracks from the Pelsonian (and possibly from Bithynian) of Southern Alps are wider and sturdier than those illustrated by Demathieu (1989) as *Anchisauripus bibractensis* Demathieu 1971b. Closer comparison can be made with *Coelurosaurichnus perriauxi* Demathieu and Gand 1972 and *Coelurosaurichnus largentierensis* Courel and Demathieu 1976. It seem, therefore, that these tracks provide further evidence of the presence of small bipedal archosaurs with a primitive functionally tridactyl pes (Demathieu, 1989) in the Early and Middle Pelsonian. These footprints make our ichnofaunas similar to the other Middle Triassic ichnoassociations of western and central Europe, especially to those of the Triassic of the eastern border of the French Massif Central.

The passage to the Illyrian marked the disappearance of most of the Pelsonian taxa with the survival, in the ichnological documentation of the Southern Alps, of *Rhynchosauroides tirolicus, Rhynchosauroides peabodyi, Chirotherium* cf. *rex, Chirotherium barthii, Isochirotherium delicatum* and small *Brachychirotherium* forms which are associated with forms that were not present earlier, such as *Brachychirotherium* aff. *parvum* and *Rotodactylus lucasi.*

Some of the Illyrian taxa, do not show any precise chronostratigraphical confinement and are distributed in a continuous manner throughout the Anisian. Amongst the other forms that correspond at a global level and which show a wide temporal distribution (Scythian - Anisian) we report *Chirotherium barthii* and *C.* cf. *rex* (Peabody, 1948; Haubold, 1971a; 1971b; 1984; Demathieu and Haubold, 1974).

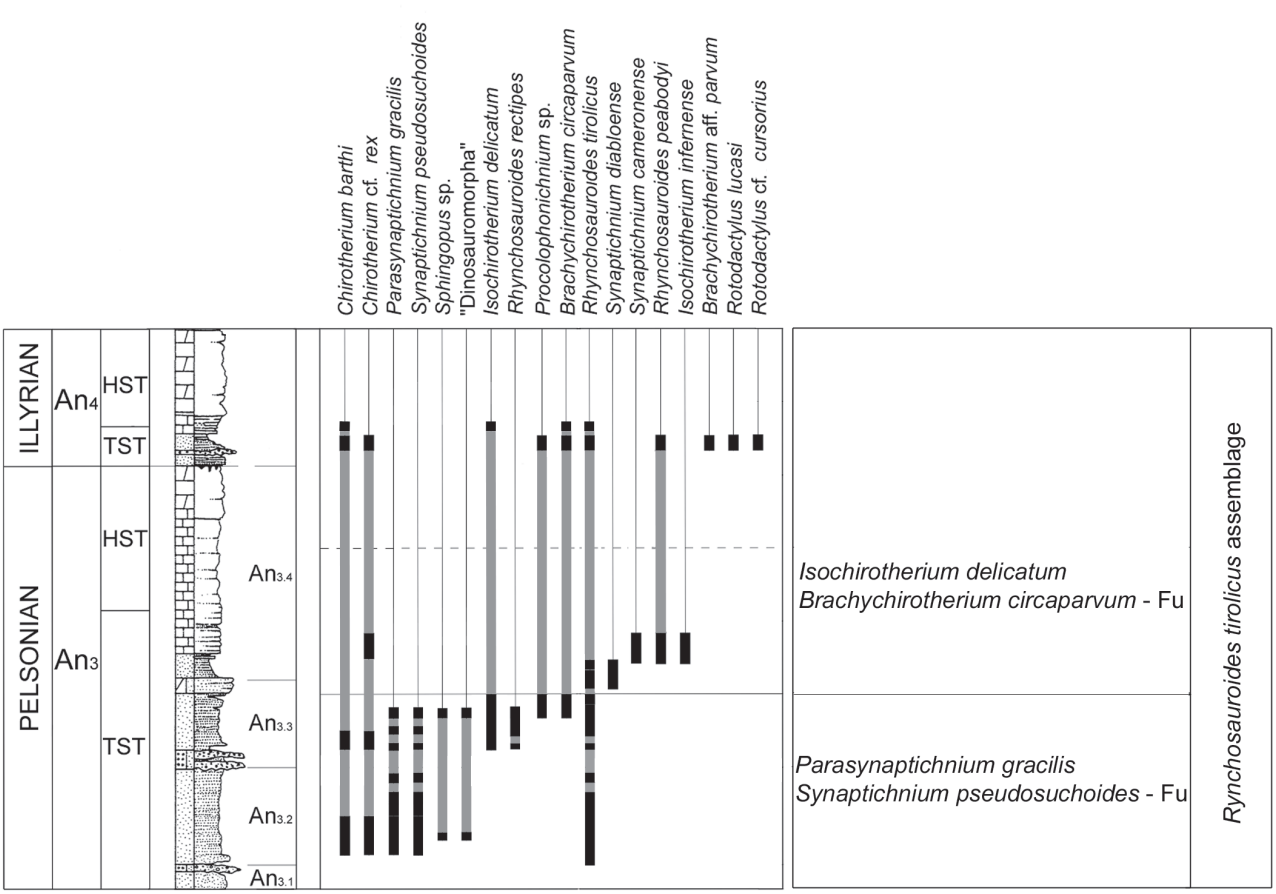

Figure 5 – Within the Pelsonian - Illyrian interval of the Italian Southern Alps some ichnotaxa characterized by a narrow vertical distribution has been recognized. On the basis of these ichnotaxa ranges, it seems possible to propose a series of informal Faunal Units.

Brachychirotherium parvum is considered characteristic of the Upper Triassic (Brunswick Fm.) (Hitchcock, 1859; Haubold, 1971a). In our successions a form similar to *B. parvum* (*B.* aff. *parvum*) was described for the first time by Brandner (1973) in levels dated to the Illyrian. This form, of medium dimensions, seems to be exclusive to this chronological interval but shows substantial similarities with *B. circaparvum*, typical of the French Middle Triassic (Illyrian). This latter taxon was recognised, as seen earlier, with sporadic small sized specimens in the upper part of the Pelsonian. In the Illyrian it continues to be present with larger sizes which, however, never reach the size of *B*. aff. *parvum*. These taxa are probably synonymous but we prefer to continue to consider *B*. aff. *parvum* and *B. circaparvum* as two valid taxa (even if they are close each other) while awaiting further investigation. Their distribution would seem to be confined to the Late Pelsonian - Illyrian.

Rotodactylus lucasi is a form typical of the French Illyrian (Haubold, 1984; 1999). The chronological position coincides perfectly with the position in our succession. The species appears in the Richthofen Conglomerate. It is associated to another form of *Rotodactylus* similar to *R. cursorius* Peabody, 1948 but the lack of material does not allow its vertical distribution to be specified at present.

CONCLUSIONS: A FAUNAL UNITS PROPOSAL OF ZONATION

At the end of this study on Scythian-Anisian ichnoassociations in the Southern Alps it is believed that, on the basis of the ranges of single ichnotaxa, it is possible to define a series of different assemblages, characterized by different evolutionary stages. They correspond to evolutionary units that can be estabilished as informal faunal units (FUs)

Scythian – ***Rhynchosauroides schochardti*** Assemblage

The Scythian is characterised by the scarce presence of vertebrates, a factor linked to palaeogeography which did not favour the permanence of complex and consistent faunal associations in the Southern Alps. The Scythian ichnoassociations are dominated by *Rhynchosauroides* probably due to a trackmaker that was adaptable to a broad ecological spectrum, amongst which *R. palmatus* (Permian survivor) and *R. schochardti*. In the Anisian the presence of *R. schochardti* has not been noted, contrary to what is suggested by Haubold

(1971a; 1984). Associated to them, in the upper part of the succession appears *Capitosauroides* cf. *C. bernburgensis* which is globally documented between the late Spathian and the base of Anisian (Aegean) (Haubold, 1971a; 1984, Demathieu and Haubold, 1974). These forms disappear in the Anisian.

Anisian – ***Rhynchosauroides tirolicus*** Assemblage

In the Anisian, a progressive increase in the complexity of the ichnoassociations from the Bithynian to the Illyrian is documented. Unlike what happened at the base of the Pelsonian, the Middle Pelsonian and the Illyrian are dominated by medium-large chirotherians.

The detailed analysis of the stratigraphical distribution of ichnofaunas crossed with the sequence stratigraphy and the ammonoid biostratigraphy as led to the identification, within the Pelsonian - Illyrian interval of several taxa characterized by a narrow vertical distribution associated to taxa which have a more generalized presence in the Anisian. From the bottom towards the top of the stratigraphic succession the following two clusters can be distinguished:

a) Bithynian - Early Pelsonian

Parasynaptichnium gracilis – Synaptichnium pseudosuchoides **Faunal Unit**

To *Parasynaptichnium gracilis* and *Synaptichnium pseudosuchoides* are associated: *Chirotherium barthii, C.* cf. *rex* and "Dinosauromorpha".

b) Early Pelsonian - Early Illyrian

Isochirotherium delicatum - Brachychirotherium circaparvum **Faunal Unit**

To *Isochirotherium delicatum* and *Brachychirotherium circaparvum* are associated: *Brachychirotherium paeneparvum, Chirotherium barthii*, *C.* cf. *rex*, *Parasynaptichnium gracilis, Synaptichnium pseudosuchoides,* "Dinosauromorpha", *Rhynchosauroides tirolicus, R. rectipes, Procolophonichnium* sp.

Disappearance of: *Parasynaptichnium gracilis, Synaptichnium pseudosuchoides, Rhynchosauroides rectipes*.

These FUs represent the time interval of existence of the selected members of the ichnoassociation and thus the interval of persistence of such biological equilibria. Consequently the FUs can easily be transformed into Faunal ages (FAs), or biochronological units with a well-fixed age calibration as those here reported.

The discovery of these new Anisian ichnoassociations confirms the ichnological potential of the Southern Alps continental formations. It seems likely therefore, that the use of these ichnoassociations could represent a regionally useful instrument for the definition of continental units which do not have elements traditionally used for dating.

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REFERENCES

Abel, O. 1926. Der erste Fund einer Tetrapodenfährte in den unteren alpinen Trias. Paläontologische Zeitschrift, 7: 22-24.

Avanzini, M. 1999. New Anisian vertebrate tracks from the Southern Alps; pp. 17-21. *In* Renesto S. (ed.), Third International Symposium on lithographic limestones. Bergamo, Italy. Suppl. Rivista Museo Civico Scienze Naturali "E.Caffi" Bergamo, 20.

Avanzini, M. 2002. Dinosauromorph tracks from the middle Anisian (middle Triassic) of the Southern Alps (Valle di Non - Italy). Bollettino Società Paleontologica Italiana, 41 (1): 7-40.

Avanzini, M., Ceoloni, P., Conti, M.A., Leonardi, G., Manni, R., Mariotti, N., Mietto, P., Muraro, C., Nicosia, U., Sacchi, E., Santi, G., & Spezzamonte, M. 2001. Permian and Triassic tetrapod ichnofaunal units of Northern Italy: Their potential contribution to continental biochronology. Int. Congr. The Continental Permian of the Southern Alps and Sardinia (Italy). Natura Bresciana, monografie 25: 89-107.

Avanzini, M. & Leonardi, G. 2002. *Isochirotherium inferni* ichnosp. n. in the Upper Anisian (Illyrian) of Adige Valley (Bozen, Italy). Bollettino Società Paleontologica Italiana, 41 (1): 41-50.

Avanzini, M. & Lockley, M. 2002. Middle Triassic archosaur ontogeny and population structure: interpretation based on *Isochirotherium delicatum* fossil footprints (Southern Alps – Italy). Palaeogeography, Palaeoclimatology, Palaeoecology, 185 (3-4): 391-402.

Avanzini, M. & Neri, C. 1998. Impronte di tetrapodi da sedimenti anisici della Valle di Non (Trentino occidentale - Italia): nota preliminare. Annali Museo Civico Storia Naturale Ferrara, 1: 5-19.

Avanzini, M. & Renesto, S. 2002. A review of *Rhynchosauroides tirolicus* Abel, 1926 ichnospecies (Middle Triassic: Anisian-Ladininian) and some inferences on Rhynchosauroides trackmaker. Rivista Italiana Paleontologia e Stratigrafia, 108 (1): 51-66.

Beasley, H.C. 1905. Report on footprints from the Trias, part II. Report of the British Association for the

Advancement of the Science, 74: 275-282.
Benton, M.J., Warrington, G., Neweel, A.J., & Spencer, P.S. 1994. A review of the British Triassic tetrapod assemblages; pp.131-160. *In* Fraser N.C. & Sues H.D. (eds.), In the shadow of the dinosaurs, Cambridge University press, Cambridge.
Beurlen, K. 1950. Neue Fährtenfunde aus der fränkischen Trias. Neues Jahrbuch für Geologie und Paläontologie, 1950 B: 308-320.
Brandner, R. 1973. Tetrapodenfährten aus der unteren Mitteltrias der Südalpen. Festschrift Heissel Veröffentlichungen der Universität Innsbruck, 86: 57-71.
Broglio Loriga, C., Goczan, F., Haas, J., Lenner, K., Neri, C., Oravecz Scheffer, A., Posenato, R., Szabo, I., & Toth Makk, A. 1990. The Lower Triassic sequences of the Dolomites (Italy) and Transdanubian mid-mountains (Hungary) and their correlation. Memorie Scienze Geologiche, 42: 41-103.
Broglio Loriga, C., Masetti, D., & Neri, C. 1983. La Formazione di Werfen (Scitico) delle Dolomiti occidentali: sedimentologia e biostratigrafia. Rivista Italiana Paleontologia Stratigrafia, 88 (1982), 4: 501-598.
Conti, M.A., Mariotti N., Nicosia, U. & Pittau, P. 1997. Selected bioevents succession in the continental Permian of the Southern Alps (Italy): improvements of intrabasinal and interregional correlations; pp.51-65. *In* Dickins, J. M., Zunyi, Y., Yhongfu, Y., Lucas, S. G. & Acharyya, S. J. (eds.), Late Palaeozoic and Early Mesozoic Circum-Pacific Events and Their Global Correlation, Cambridge University Press, Cambridge.
Conti, M.A., Leonardi, G., Mietto, P., & Nicosia, U. 2000. Orme di tetrapodi non dinosauriani del Paleozoico e Mesozoico in Italia; pp. 297-320. *In* Leonardi, G. & Mietto, P. (eds.), Dinosauri in Italia. Le orme giurassiche dei Lavini di Marco (Trentino) e gli altri resti fossili italiani, Accademia Editoriale, Pisa, Roma.
Courel, L., & Demathieu, G. 1973. Données récentes sur le Trias du Mont d'Or Lyonnais dans les domaines de la stratigraphie et de l'ichnologie. Geobios, 6: 5-26.
Courel, L. 1976. Une ichnofaune reptilienne remarquable dans les grès Triassiques de Largentière (Ardèche, France). Palaeontographica Abteilung A, 151: 194-216.
Dalla Vecchia, F. & Avanzini, M. 2002. New remains of Triassic reptiles from northeastern Italy. Bollettino Società Paleontologica Italiana, 41 (2-3): 215-235.
Demathieu, G. 1971a. Les empreintes de pas de vertébrés du Trias de la bordure N.E. du Massif Central. Cahiers de Paléontologie C.N.R.S., 211 pp.
Demathieu, G. 1971b. Cinq nouvelles espèces d'empreintes de reptiles du Trias de la bordure N.E. du Massif Central. Comptes Rendus de l'Académie des Sciences Paris, D 272 : 812-814.
Demathieu, G. 1984. Une ichnofaune du Trias moyen du bassin de Lodève (Hérault, France). Annales de Paléontologie (Vert-Invert.), 70: 247-273.
Demathieu, G. 1989. Appearance of the First Dinosaur Tracks in the French Middle Triassic and their probable significance; pp. 201-208. *In* Gillette, D.D. & Lockley, M.G. (eds). Dinosaur Tracks and Traces, Cambridge University Press, Cambridge.
Demathieu, G. & Gand, G. 1972. Les pistes dinosauroides du Trias moyen du Plateau d'Antully et leur signification paléozoologique. Bulletin Société Histoire Naturelle d'Autun, 62 : 2-18.
Demathieu, G. & Gand, G. 1973. Deux espèces ichnologiques nouvelles des grès à empreintes du trias du Plateau d'Antully. Bulletin de la Société d'Histoire Naturelle d'Autun, 67 : 11-27.
Demathieu, G. & Haubold, H. 1974. Stratigraphische Aussagen der tetrapodenfährten aus der terrestrischen Trias Europas. Geologie, 21: 802-836.
Demathieu, G. & Haubold, H. 1982. Reptilfärthen aus dem Mittleren Buntsandstein von Hessen. Hallesches Jahrbuch für Geowissenschaften, 7: 97-110.
Demathieu, G. & Leitz, F. 1984. Wirbeltier-fahrten aus dem Rot von Kronach (Trias, Nordost-Bayern). Mitteilungen Bayer. Staatsslg. Paläont. historische Geologie, 22: 63-89.
Demathieu, G. & Oosterink, H.W. 1983. Die Wirbeltier-Ichnofauna aus dem Unteren Muschelkalk von Winterswijk (Die Reptilfährten aus der Mitteltrias der Niederlande). Staringia, 7: 1-51.
Demathieu, G. & Oosterink, H.W. 1988. New discoveries of ichnofossils from the Middle Triassic of Winterswijk (the Netherlands). Geologie en Mijnbouw, 67 (1): 3-17.
De Zanche, V., Gianolla, P., Mietto, P., Siorpaes, C., & Vail, P.R. 1993. Triassic Sequence Stratigraphy in the Dolomites (Italy). Memorie Scienze Geologiche, 45: 1-27.
De Zanche, V. & Mietto, P. 1981. A review of the Triassic sequence of Recoaro (Italy) and related problems. Rendiconti Società Geologica Italiana, 4: 25-28.
Diedrich, C. 2000. Neue wirbeltierfährten aus dem Unteren Muschelkalk (Mitteltrias) des Osnabrücker Berglandes und Teutoburger Waldes (NW Deutschland) und ihre stratigraphische und paläogeographische Bedeutung im Germanischen Becken. Neues Jahrbuch für Geologie und Paläontologie Abhandlungen 217: 369-395.
Diedrich, C. 2001. Vertebrate track bed stratigraphy of the Röt and basal Lower Muschelkalk (Anisian) of Winterswijk (East Netherlands). Netherlands Journal of Geosciences 80: 31-39.
Diedrich, C. 2002. Vertebrate track bed stratigraphy at new megatrack sites in the Upper Wellenkalk member and orbicularis member (Muschelkalk, Middle Triassic) in carbonate tidal flat environments of the western Germanic basin. Palaeogeography, Palaeoclimatology, Palaeoecology, 183: 185-208.
Faber, F.J. 1958. Fossiele voetstappen in de Muschelkalk van

Winterswijk. Geol. Mijnb. Nieuwe Ser., 20: 317-321.
Gianolla, P., De Zanche, V. & Mietto, P. 1998. Triassic Sequence Stratigraphy in the Southern Alps (Northern Italy): definition of sequences and basin evolution; pp. 721-747. In de Gracianski, P.C., Jacquin, T. & Vail, P.R. (eds.) Mesozoic and Cenozoic Sequence Stratigraphy of European Basins. SEPM sp. publ. v.60, Tulsa.
Haubold, H. 1971a. Die Tetrapodenfährten des Buntsandsteins in der Deutschen Demokratische Republik und in Westdeutschland und ihre Äquivalente in der gesamten Trias. Paläontologische Abhandlungen 4 (3): 395-660.
Haubold, H. 1971b. Ichnia Amphibiorum et Reptiliorum fossilium; pp.1-124. *In* Kuhn, O. (ed.) Handbuch der Palaeoherpetologie v.18. G. Fischer, Stuttgart.
Haubold, H. 1984. Saurierfährten. Die Neue Brehm-Bucherei, A. Ziemsen, Wittenberg. Lutherstadt. 231 pp.
Haubold, H. 1999. Tracks of the Dinosauromorpha from the Lower Triassic. Zeitblatt Geologie Paläontologie. Teil I, 7-8: 783-795.
Hitchcock, H. 1859. Ichnology of New England: A Report on the Sandstone of the Connecticut Valley, especially its fossil footmarks. Natural Sciences of America, Reprint. Boston: W. White. 220 pp.
Karl, C, & Haubold, H. 1998. *Brachychirotherium* aus dem Coburger Sandstein (Mittlerer Keuper, Karn/ Nor) in Nordbayern. Hallesches Jahrbuch *für Geowissenschaften*, B20: 33-58.
Kaup, J.J. 1835. Mitteilung über Tierfährten bei Hildburghausen. *Neues Jahrbuch für Mineralogie, Geologie und Paläontologie*, 1835: 327-328.
King, M., & Thompson, D.B. 2000. Triassic vertebrate footprints from the Sherwood Sandstone Group, Hilbre, Wirral, northwest England. *Proceedings of the Geologists' Association*, 111: 111-132.
Kummel B., 1969. Ammonoids from the late Scythian (Lower Triassic). *Bulletin of the Museum of Comparative Zoology*, 137 (3): 311-702.
Leonardi, P. 1967. Werfeniano (Trias inferiore); pp.107-128. *In* Leonardi, P. (ed.) Le Dolomiti, 1. Manfrini, Rovereto, Trento.
Lull, R.S. 1942. Chugwater footprints from Wyoming, *American Journal of Science*, 240: 500-504.
Maidwell, F.T. 1911. Notes on footprints from the Keuper of Runcorn Hill. *Proceedings of the Liverpool Geological Society*, 11: 140-152.
Mietto, P. 1986. Orme di tetrapodi nella Formazione di Werfen del Recoarese. *Rivista Italiana di Paleontologia e Stratigrafia*, 92 (3): 321-326.
Mietto, P. 1987. *Parasynaptichnium gracilis* nov. ichnogen., nov. isp. (Reptilia: Archosauria Pseudosuchia) nell'Anisico inferiore di Recoaro (Prealpi vicentine - Italia). *Memorie Scienze Geologiche*, 39: 37-47.
Mietto, P. & Manfrin, S. 1995. A high resolution Middle Triassic ammonoid standard scale in the Tethys Realm. A preliminary report. *Bulletin de la Societé Géologique de France*, 166 (5): 539-563.
Neri, C. & Posenato, R. 1988. New biostratigraphical data on uppermost Werfen Formation (Scythian), Southeastern Dolomites, Italy. *Bollettino Società Paleontologica Italiana*,14 (3)(1985): 83-107.
Nopcsa, F. 1923. *Die Familien der Reptilien*. Fortschritte der Geologie und Paläontologie. 210 p.
Peabody, F.E. 1948. Reptile and Amphibian Trackways from the Lower Triassic Moenkopi Formation of Arizona and Utah. *University of California Publications, Bulletin of the Department of Geological Sciences*, 27 (8): 295-468.
Pisa, G., Farabegoli, E, & Ott, E. 1978. Stratigrafia e paleogeografia dei terreni anisici della conca di Agordo e dell'alta Val di Zoldo (Dolomiti sudorientali). *Memorie della Società Geologica Italiana*, 18: 63-92.
Rehnelt, K. 1950. Ein Beitrag über Fährtenspüren im unteren Gipskeuper von Bayreuth, *Berichte der Natürwissenschaftlichen Gesellschaft Bayreuth 1950*: 27-36.
Rühle von Lilienstern, H. 1939. Fährten und Spuren im Chirotheriumsandstein von Südthüringen. *Fortschritte der Geologie und Palaeontologie*, 12 (40): 293-387.
Ryan, J.D. & Willard, D. 1947.Triassic footprints from Bucks County, Pa., *Proceedings of the Pennsylvanian Academy of Science*, 21: 91-93.
Treasise, G., & Sarjeant, W.A.S. 1997. *The tracks of Triassic vertebrates. Fossil evidence from North-West England*. The Stationery Office, 204 p.