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The saga of tetrapod tracks, trackmakers and trackers in Italy

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ABSTRACT - The 150th anniversary of the publication by Giulio Curioni, the first Italian scientific contribution on fossil tetrapod tracks from Italy, is an opportunity to take stock of the current state of tetrapod ichnology in Italy. This paper introduces this branch of palaeontology, its methodology and applications, and summarises the first hundred years of the history of this discipline in Italy, also including ichnologic research developed by Italian ichnologists in other countries. Between 1870 and the early 1900's, tracks were reported mainly from the now classic localities of Trentino-Alto Adige, Lombardy and Tuscany. Until the mid-1900's publications in this field were sporadic and often linked to research activities undertaken for other purposes. For almost thirty years, between 1940 and 1967, Piero Leonardi initiated the first systematic tetrapod ichnological activity, focusing on tetrapod tracks from the late Permian of the Trentino-Alto Adige, thus entrenching the way the discipline is undertaken in Italy. After 1972 four undergraduate students from the University of Rome "La Sapienza" followed in the footsteps of Leonardi and relaunched, on a larger scale, the ichnology of Italian vertebrates, through targeted fieldwork activities and systematic studies on Permian tetrapod tracks. Around the same period, also in Padua, research was begun specifically devoted to vertebrate ichnology of Palaeozoic and Triassic. From these forages, and subsequent activities and projects, arose the vertebrate ichnology schools of Rome, Padua, Pavia etc. Since then the field has expanded consistently and currently about thirty Italian vertebrate scientists are dedicated to researching tetrapod footprints and trackways from Italy and many other countries. Until the 1980s it was considered almost impossible to find tetrapod tracks in Mesozoic and earlier Cenozoic deposits in Italy because of the predominantly marine depositional conditions. Since then, dozens of footprint sites, including dinosaurs, have been discovered in more than half of the 20 Italian regions, with a stratigraphic range from the Upper Palaeozoic to the Holocene.

Keywords: vertebrate fossil tracks; Italian Vertebrate Ichnology; Italian tracks; Italian vertebrate ichnologists.

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1. INTRODUCTION - WHY VERTEBRATE ICHNOLOGY?

Let us to report an example, without resorting to the classic one with which the novel "The Name of the Rose" by Umberto Eco begins, about the horse of the abbot. On a rainy afternoon one day at the end of summer 1973, one of us came up from the Bletterbach (Radein, Bolzano/Bozen) with a backpack filled with slabs with footprints. As usual, his clinical eyes had been scanning the mud underfoot for fresh footprints of wild and domestic animals observed in the field, when he was met by two young herdsmen from the Zirmerhof farm, asking if he had seen any steers which they were trying to find. He answered: "I did not see them, but they crossed the path half a kilometer away, shortly after the rain, and went to the west, there were eight, in a row". They, amazed, asked him: "How do you know this if you did not see them?".

To be an ichnologist means "to see" animals - and also plants - by observation of the traces of their activity: tracks, trails, galleries, dens, nests, eggs, nibbles, excrements, even the semi-circular traces that tufts of grasses leave on the sandy soil of the dunes and beaches when shaken by the wind, as well as the holes formed by roots which no-longer exist, and so on.

Hunters, especially those who depend on this activity for a living, are able to make incredibly accurate deductions from traces, including identifying the species, sex, age, health conditions and behaviour. As reported by Paul Ellenberger, with wonder and admiration, the native people of Lesotho (known as Bushmen) killed only one animal during each lunar cycle, choosing it carefully by studying the traces in every detail.

In Italy, for example, there can be no doubt that ancient

humans were remarkably skilled ichnologists, not for research and study, but to procure meat for survival they needed to know and understand the footprints, excrement, hair torn by thorny plants, habits, and the activities of the fauna, similar to indigenous people of various continents.

Palaeoichnology is the study of ancient invertebrate and vertebrate traces and other effects of their activity. Because vertebrates have a faster evolutionary rate, the study of their traces is more complicated. Generally, the palaeoichnologist has never seen the trackmaker and at most has seen only skeletons or bones. Usually in lithological units bearing good fossil footprints, skeletons are not preserved or are rare. It needs to be remembered that the body fossil record for any moment in time, whether it is represented by almost complete skeletons or isolated bones, testifies to only a small percentage of the actual diversity existing in that place and time. Skeletons provide limited information about the behaviour of fossil animals, and very little or nothing of their palaeoenvironment.

Despite these difficulties, an accurate study of the fossil tracks and other traces of animals (and even plants) can provide much information about the fauna (and possibly the flora) when body fossil evidence is lacking. Several inferences can be made about the environment in which they lived, individual and social behaviour, posture, adopted gaits, speed and direction of movement. All these inferences can have a dramatic impact in regional reconstructions, especially those focused on the physiography and palaeoenvironment. Tracks can reveal shorelines, the depth of lakes, lagoons and of other ancient bodies of water. These local aspects of the landscape depend on the presence of water bodies surrounded by bands of plastic and consistent mud that enabled imprinting of good tracks. The presence and arrangement of these water bodies are, in turn, frequently due to spacing along regional tectonic alignments (Godoy and Leonardi, 1985; Leonardi, 1989). Other times, as happens with body fossils, trackways represent crucial constraints in palaeogeographic reconstructions (e.g. Zarcone et al., 2010).

Analysis of both trackways and isolated footprints enables compilation of a fossil registry to understand the structure and possible composition of the fauna (e.g. herds and flocks of herbivores, packs or prides of carnivores, gangs of omnivores and insectivores, piscivorous dinosaur herds), the simultaneous occurrence of different species, their possible interaction in a particular geographic area, as well as reconstructing biomass pyramids and feeding networks (Leonardi and Mietto, 2000a).

It should be noted that in many areas and rocky formations, especially in continental deposits, body fossils are not preserved. In all these cases biogenic-sedimentary structures, i.e. organism tracks and other traces, can provide the only documentation of life forms and can be used for stratigraphic and palaeoenvironmental studies, taking into account their intrinsic autochthony, i.e. they can neither be modified nor transported.

Also in the association of skeletons and/or other body remains it is possible, only in a general sense, to unequivocally state that skeletons came from the same area, but only rarely it is possible to demonstrate that these animals actually co-existed and interacted. Conversely, from a good track-bearing trampled surface it is possible to state that: right here, in these few square meters, in a short span of time until the hardening of the ground, a herd of eight sauropods, with the appearance of brachiosaurids, passed, including two juveniles, followed by thirty-two large theropods, probably abelisaurids (Leonardi, 1984). Thus, ichnocoenosis reflects a biocoenosis.

Vertebrate palaeoichnology is an ancient field of science, that can be traced back to the early 19th century and is now almost 190 years old. However, there have been periods, in Italy and elsewhere, in which this branch of science was not greatly revered: it was considered a kind of science fiction. One of us, when wanting to undertake a dissertation on the Permian tetrapod tracks of Bletterbach, was given the retort: "Why don't you do a thesis on good bones? We have some nice skeletons of Pleistocene mammals for you, which are very good". So he did, and it was a worthwhile experience, but as soon as possible he returned to ichnology, especially reptilian tracks, and he continues to study and publish on bones as well.

A now historic informal research group, consisting of Maria Alessandra Conti, Giuseppe Leonardi, Nino Mariotti and Umberto Nicosia, who were still students in the early 1970s, had difficulty in publishing a large monograph (their first) on late Permian tracks, because the topic was considered too metaphysical. This scenario not only existed in Italy. For example the ichnologist Bill Sarjeant told us (1985) that, having submitted an article to a palaeontological journal, it was turned down on the basis of the revision of a referee who had written: *"I have not read this article, but I object to its publication because I consider the study of fossil footprints to be a waste of time"*. Even today, despite the advances in vertebrate ichnology, vertebrate palaeontologists studying skeletons often forget to mention in their papers the results determined by ichnologists. Possibly because they do not take care to read their publications!

In addition, museums and curators of geological and palaeontological collections in research centres and universities frequently remove track-bearing slabs and flagstones from collections because they are large, heavy, and difficult to store. This phenomenon has resulted in the field of vertebrate ichnology suffering periods of glory and eclipse, both in Italy and internationally.

2. THE BEGINNING OF VERTEBRATE ICHNOLOGY

Throughout the world, fossil footprints and trackways have been noted many times in the ancient past. Their discovery, as well as that of gigantic fossil bones, possibly evoked legends of dragons, such as Fafner of ancient

Germans, or Tianlong, Zhulong, Feilong and many others in China. In these cases, one is dealing with etiological explanations by prescientific peoples who did not know about the fossil animals.

The first reliable mention of fossil tracks was in 1800 or 1802, when the young farmer-student Pliny Moodie found a short Jurassic dinosaur trackway on his farm in Connecticut. Dr. Dwight, who had bought the slab, liked to show the trackway slab to visitors suggesting, with remarkable imagination, that it was the tracks of the crow of Noah which were imprinted towards the end of the so-called worldwide Deluge on the first dry patches. The title of an excellent book on Vertebrate Ichnology recently published by James (Jim) O. Farlow "Noah's Ravens" (Farlow, 2018) refers jokingly to this famous biblical episode; see also the parallel and oldest story about the hero of the flood Utnapištim, secondary protagonist of the Sumerian, Akkadian and Assyrian cosmogonic poem called "The Epic of Gilgameš" or Ša nagba inuru.

Excluding the publication in 1822 of potential but dubious human footprints (Mississippi Valley) by Schoolcraft and Benton (1822), the first scientific work on tetrapod ichnology was that of Duncan (1831), about Permian tracks in Scotland. There is also the historic published letter of Sickler (1834) to Blumenbach and the publication of Kaup (1835) on the first findings of *Chirotherium* in Thuringia. These Triassic footprints, discovered by Sickler (1834) were given two names by Kaup (1835), *Chirotherium* or *Chirosaurus*. The first name, by priority, has been used up to now, but it refers to mammals, while the tracks are actually attributed to Triassic reptiles.

Ichnology became widespread during the following 50 years, especially in Great Britain, Germany and the United States, even although the early interpretations were debateable. This initial enthusiasm later waned and there were few ichnological papers from these pioneering countries in the first few decades of the 19th century. In contrast, the newborn discipline continued to spread in Italy, Canada, Slovenia, Australia, China, countries of the Maghreb, Portugal, and Georgia. Here too, trace fossil studies later waned until the 1960s and 1970s when vertebrate ichnology progressively reaffirmed itself.

Discoveries and publications flourished all over the world. Geology and palaeontology conferences held symposia devoted to ichnology, and ichnology journals were founded in the 1980s. Today ichnology is undoubtedly in an expansion phase and offers a valuable complement to osteological research, to other fossils, and to other fields of Earth Sciences such as stratigraphy and palaeogeography.

2.1. THE BEGINNING OF VERTEBRATE ICHNOLOGY IN ITALY

In Italy (Fig. 1), unlike the ichnology of invertebrates that started much earlier, that of vertebrates began about 40 years after the birth of ichnology as a science. The first reference to Italian fossil vertebrate tracks was in a letter of Eduard Suess to Hanns Bruno Geinitz, later published by Geinitz (1869). The letter reported the discovery made on an uncertain date (before 1868) by Fr. Giovanni Bruni (1816-1880; Fig. 2), the parish priest of Collio (Upper Val Trompia, Brescia), of a small Permian slab with fossilized tracks, found in the mountains surrounding his native village. Giovanni Bruni, besides being a priest, was also a

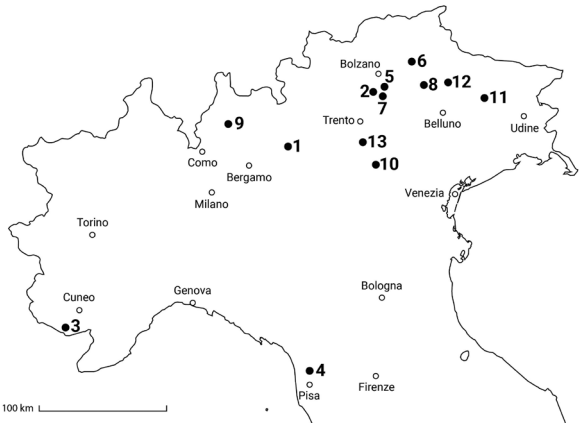

Fig. 1 - Map of northern Italy with the localization of the main ichnosites mentioned in the chapter (1-14). 1-Collio and surroundings: Val Trompia, Val Camonica, Val Seriana, Val Sabbia; 2-Egna and Cislon Mount; 3-Argentera Mount; 4-Mount Pisano; 5-Bletterbach and surroundings: Redagno di Sopra/Oberradein, Nova Ponente/Deutschnofen, Weissenstein; 6-Ortisei and surroundings: Bulla, Seceda Mount; 7-Doladizza/ Kalditsch-Pausa; 8-S. Pellegrino Pass; 9-Alpi Orobie; 10-Recoaro Terme; 11-Carnia; 12-Pelmetto and Pelmo Mounts, Dolomites; 13-Lavini di Marco.

Fig. 2 - Fr. Giovanni Bruni, parish priest of Collio (Upper Val Trompia, Brescia), the passionate naturalist and cultured discoverer of the first vertebrate tracks in Italy.

passionate and cultured naturalist, particularly interested in botany, geology and palaeontology and was in contact with several scientists (Marchetti et al., 2018).

The first Italian publication devoted to vertebrate ichnology was by Curioni (1870), stratigrapher and palaeontologist from Milan (Fig. 3), and focused on the description and illustration of a short Permian trackway of *Amphisauropus* Haubold, 1970, and some small incomplete footprints attributable to *Dromopus* Marsh, 1894 (Marchetti et al., 2018) from Val Trompia (Brescia; Fig. 4).

It should be noted that the publication of this collective special issue in 2020 highlights the 150th anniversary of the first scientific contribution on Italian tetrapod tracks by Giulio Curioni in 1870. The same slab had been noted also by Gümbel (1880). The original specimen (Fig. 4) is curated and has been catalogued in the palaeontological collections of the Italian National Institute for Environmental Protection and Research (ISPRA, Rome) with the inventory number 4426, in the famous Curioni collection. The slab was recently rediscovered, studied, and described by Marchetti et al. (2016, 2018).

Eocene tracks (of a bird and of an urodele or Caudata tracks), from Piemonte (more exactly in the Maritime Alps at the foot of the Mt. Argentera, Cuneo) were described in detail by Alessandro Portis from Turin (Portis, 1879), one of the founding members of the Italian Geological Society in 1881. A few years later, Permian tracks were discovered by Friedrich Glassner not far from Egna/Neumarkt at the south-western slopes of Mount Cislon in the province of Bolzano/Bozen, then a province of the Austro-Hungarian Empire, and the tracks were recognized by Kittl (1891) as reptilian tracks. Along with tracks from the Bletterbach gorge (Redagno/Radein), these footprints were studied by Abel (1929).

In 1904 Paolo Vinassa de Regny, from Florence, published a paper on the tracks from Montenegro, later an Italian protectorate (Vinassa de Regny, 1904). The following year, Alberto Fucini of the University of Pisa and then of Catania described the tetrapod tracks of Monte Pisano (Pisa) (Fucini, 1915), later revised by

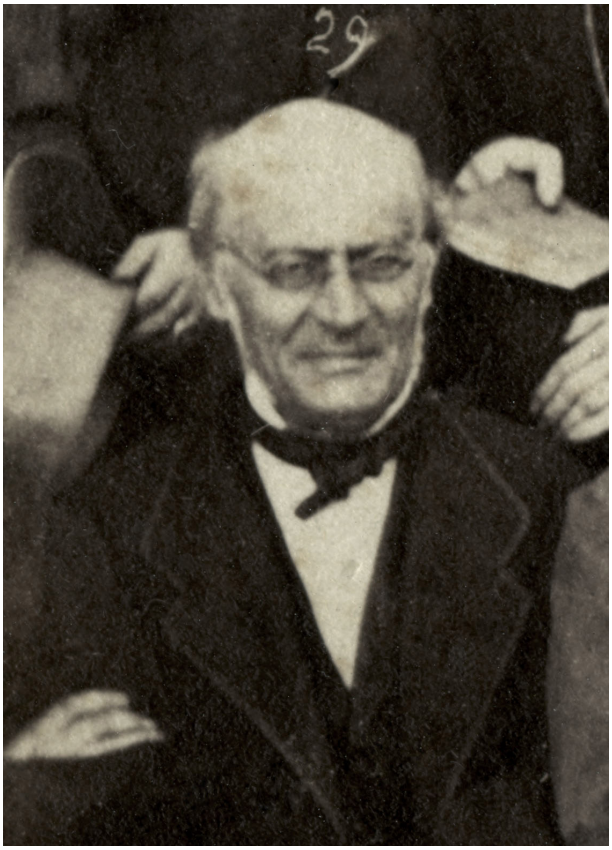

Fig. 3 - A rare portrait of Giulio Curioni, the first tetrapod ichnologist in Italy. Detail taken from the group photo of the Assembly of Natural Sciences, held in Biella in 1864. Photo by Vittorio Besso. Courtesy Fondazione Sella o.n.l.u.s., Biella.

Fig. 4 - A slab with an incomplete trackway *Amphisauropus* Haubold, 1970 and some incomplete footprints attributable to *Dromopus* Marsh, 1894, from the Permian Collio Formation (late Kungurian, late Cisuralian), from the *Pulpito* locality near Collio, Upper Val Trompia, Brescia. These are the first fossil tracks of vertebrates published by Giulio Curioni (150 years ago) in Italy. They are kept in the Italian National Institute for Environmental Protection and Research (ISPRA, Rome). Courtesy of Lorenzo Marchetti. Scale bar 2 cm.

Huene (1940a, 1940b, 1941) and many years later by Tongiorgi (1980), who demonstrated that these tracks were not Cretaceous but Late Triassic. They included, together with numerous lacertoid tracks, chirotherian tracks and an isolated footprint of a small theropod, the very first one in Italy (Fig. 5). This footprint was named *Coelurosaurichnus toscanus* by Huene (1941), but its interpretation was changed by Leonardi and Lockley (1995), who synonymised it with *Grallator* Hitchcock, 1858.

In 1926, Othenio Abel noticed, for the first time, tetrapod tracks from the Middle Triassic of the Alps (Abel, 1926), and in 1935 Jean Jacques Dozy published an article about Permian tracks of the Orobic Prealps (Dozy, 1935). Migliorini (1947) reported possible Eocene fossil tracks. In total, only a dozen new Italian vertebrate ichnology publications had appeared over a period of about 70 years.

3. THE ICHNOLOGICAL WORK OF PIERO LEONARDI AND COLLABORATORS

In the early 1950s the Venetian Piero Leonardi (Fig. 6), after gaining experience through the study of a slab with a fossil trackway from the Buntsandstein of Thuringia (Leonardi, 1940), began to dedicate himself to the study of fossil tracks from the Alto Adige/Südtirol area, mostly in the Bletterbach Gorge (Fig. 7), and afterward in Trentino (Leonardi and Sarjeant, 2000). At the time he was a professor associated with Padua University and had been the founder, in 1949, of the school of Geology of Ferrara University, Piero's research in this field, began in the Arenaria di Val Gardena Formation (Richthofen, 1860) at Mazzon in the area of Egna/Neumarkt in Adige valley (Leonardi, 1948). His work continued in the Butterloch/Bletterbach canyon, at that time in the county of Redagno/Radein, now located in the wider municipality of Aldino/Aldein, which also includes Redagno. In 1950, he wrote to the News Bulletin of the Society of Vertebrate Paleontology, of which he had been appointed Regional Editor for Italy: "Last year I had the good luck to discover a beautiful series of reptilian footprints in middle Permian sandstone near Redagno in Alto Adige (Province of Bolzano), and I have written a comparative paper on them, soon to be published in the Memorie dell'Istituto Geologico dell'Università di Padova." (Leonardi, 1950). Below is a short list with descriptions of the tracks found and the names of some outdated taxa.

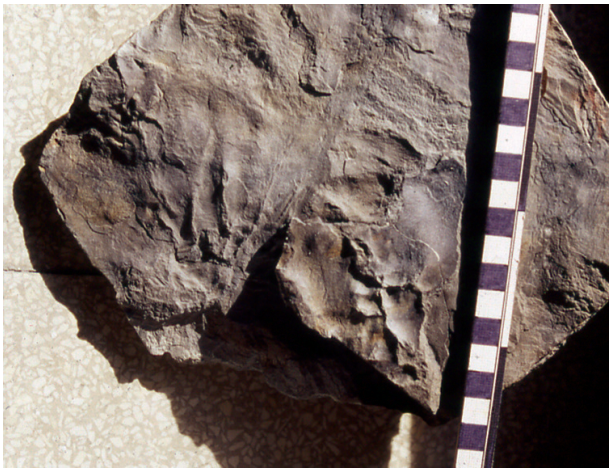

Fig. 5 - The holotype of *Coelurosaurichnus toscanus* Huene, 1941, later synonymized with *Grallator isp*. Hitchcock, 1858. The slab comes from the base of the Upper Triassic from the tracksite of Agnano, Monte Pisano, Pisa and is housed in the Museum of Geology and Paleontology of the University of Florence, with the inventory number IGF 5200. Photo by Giuseppe Leonardi. Graphic scale in cm.

Fig. 6 - Piero Leonardi (right) together with Bruno Accordi (left), in the field (1950, Col di Rosc, above Canazei, Val di Fassa, Dolomites).

The attention of Piero Leonardi to the Bletterbach gorge had been alerted because of a short article by the engineer Leo Perwanger (1946) on fossil plants found in that valley in the journal "Der Schlern" (Avanzini and Kustatscher, 2011), the monthly magazine for South Tyrolean regional studies, science and culture. During two visits to the Bletterbach, Leonardi found some fossil plant specimens and, in September 1948, the first fossil footprints (Leonardi, 1948, 1950, 1951a, 1951b). In addition to tracks of reptiles and parareptiles, an assortment of invertebrate traces and remains of leaves, fronds, trunks, other plant organs, and also corresponding palynological material discovered at the Bletterbach (including those from the Arenaria di Val Gardena) were collected and later studied.

Fig. 7 - The Bletterbach gorge near Redagno/Radein (Bolzano/Bozen), in which the Arenaria di Val Gardena appear extensively. This continental sandy unit has returned, especially from this classic locality, an imposing quantity of traces of tetrapod (and invertebrates) of late Permian age, many of which are new for science. Photo by Giuseppe Leonardi.

Piero Leonardi again included an item on unpublished data in the Society of Vertebrate Paleontology News Bulletin "A new series of tracks was discovered during 1950 by prof. Leonardi in the lower-middle Permian near Ortisei in Val Gardena (Dolomites), in the Lower Triassic of the Val Camonica (Prov. Brescia), and in Val Travignolo (Dolomites). These new tracks, apparently made for the most part by reptiles, are being studied at present." (Leonardi, 1951b, pp. 29-30).

Then reptile tracks were discovered near Weissenstein (Municipality of Nova Ponente/Deutschnofen), between the hamlets of Doladizza/Kalditsch and Pausa (Municipality of Montagna/Montan) in Alto Adige/Südtirol and at the San Pellegrino pass on the border between Trentino and the Cordevole valley in Veneto. This was part of a plan of systematic research on fossil footprints on outcrops of the Arenaria di Val Gardena in Trentino and in large part of the Alto Adige/Südtirol developed by Piero Leonardi and collaborators, including his sons (Leonardi, 1953a, 1953b, 1953c, 1955, 1957, 1960, 1967). Piero Leonardi also found two tetrapod footprints in the Lower Triassic (Induan, Werfen) of Travignolo valley (Trento; Leonardi, 1952, 1967) and a slab with indistinct tetrapod footprints which were not identifiable, from Werfen Formation layers at the foot of Mount Piz, to the left of Val Gardena near Bulla hamlet (Leonardi, 1952).

An interesting anecdote on Permian tracks concerns the post-congress excursion to the Dolomites of the Italian Geological Society (Annual Congress of the S.G.I. 1955). During that year, Piero Leonardi was president of the Society and he organized both the congress and the excursion in the Bletterbach, a gorge that was much admired by all the members of the coach party, among whom were many renowned foreign and Italian geologists and palaeontologists. None of the approximately fifty participants could find fossil footprints, apart from Piero Leonardi and his children who understood the type of material and how to orientate the sandstone slabs so that the sun would highlight the footprints. This episode is related to illustrate that, at that time, the majority of Italian and Western European geologists and palaeontologists had no field experience in vertebrate ichnology.

Piero Leonardi also studied and published Triassic

chirotherian trackways from Rillo, 5 km NW of Molina de Aragón (Zaragoza) and from Moncayo (Tarazona, Zaragoza), Spain (Leonardi, 1959).

Despite the important contribution of Piero Leonardi to ichnology, his publications in the field were peripheral to his many other fields of geological, palaeontological and prehistoric research. In fact, his publications relating to fossil tracks amount to only 2.98% of his research outputs. Of a research output of 503 publications, 15 papers relate to fossil tracks (Dietz et al., 2000). Of importance is the fact that his papers not only related to track description and taxonomic classification, but reference was also made to the environment, climate, flora, age, and hypotheses proposed on the trackmakers, even if not always with correct results.

Piero Leonardi, as a pioneer, had a passion for these fossil structures. However, it is strange that, especially in Bletterbach, he discovered so few complete trackways and that (together with his collaborators) he had not noticed the presence of the large footprints, such as those of pareiasaurs and gorgonopsids which were found later. In palaeontological field research, we often find what we seek and expectations sometimes determine the result. This is one of the psychological biases from which a researcher must defend himself. However, the opposite can also happen: a case in point is that of the ichnologists working on Upper Triassic, Jurassic or Cretaceous deposits, who are dazzled by discovering and studying large and fascinating dinosaur footprints, but do not stoop to find the smaller accompanying tracks of turtles, crocodiles, birds and mammals.

As Marchetti et al. (2016) correctly observed with the relation to the trackway slab described by Giulio Curioni in 1870, all fossil tracks discovered and studied in the first century of Italian tetrapod ichnology should be carefully curated by the institutions in which they were deposited, not only for their palaeontological value but also for their intrinsic historical importance relating to geological heritage.

4. A NEW TEAM OF TRACKERS

After a short interlude, following the path set by Piero Leonardi and with the encouragement of Bruno Accordi (Fig. 6) from the SAPIENZA University of Roma, and with the logistical support and hospitality of the family of Mr. Josep (Sepp) Perwanger from Zirmerhof (Radein, Bolzano), the team of four that included Maria Alessandra Conti, Giuseppe Leonardi, Nino Mariotti and Umberto Nicosia (Fig. 8), then undergraduate students in geological and natural sciences at the same University, began to study the Bletterbach gorge and its surrounding area.

During the spring of 1972 Odoardo Girotti took students of the Regional Geology course on a field trip to the Dolomites, which also included a day at the Bletterbach Gorge. In the summer of the same year, Umberto Nicosia, Maria Alessandra Conti, Nino Mariotti, Guido Parisi and Giovanni (Jack) Pallini returned to the same area while on vacation, and at the Bletterbach Umberto

Fig. 8 - The ichnological team that includes from left to right G. Leonardi, M.A. Conti, U. Nicosia and N. Mariotti in the Bletterbach, on the threshold of the waterfall that separates the two parts of the gorge, in 1986. Photo by Paola Ceoloni.

Nicosia discovered a surprisingly large and new form of footprint. Up to that time, only tracks and trackways produced by small trackmakers had been discovered and published from Bletterbach, almost all which are ascribed to *Rhynchosauroides* Maidwell, 1911. The discovery of this isolated large footprint stimulated a first publication (Leonardi and Nicosia, 1973) and gave rise to a new phase of vertebrate ichnology in Italy.

In preparing this publication and in pursuit of advice and additional knowledge, the authors and the rest of the team came into contact with foreign ichnologists of the previous generation. These included Rodolfo Casamiquela (Viedma, Río Negro, Argentina), George R. Demathieu (Dijon, France) and William (Bill) A.S. Sarjeant (Saskatchewan, Saskatoon, Canada). Piero Leonardi and Bruno Accordi, also a specialist of the Bletterbach and of the Arenaria di Val Gardena, actively encouraged the work of the new team. Accordi had previously produced a stratigraphic study of the section of the Arenaria di Val Gardena in the Bletterbach (Accordi, 1958). Because of the very steep and slippery rocky inclines in the area, this had been a dangerous undertaking and he had put his life at risk on several occasions.

Following the encouragement of numerous scientists, systematic expeditions were undertaken, beginning in the summer of 1973, which led to the discovery of a large number of footprints and trackways. Many of these were new forms which led to a systematic, stratigraphic and palaeoenvironmental study, and the revision of their chronological attribution (from middle to the late Permian), and thereafter to their ichnofaunal and ichnotaxonomic revision (Conti et al., 1975, 1977, 1980a, 1980b; Leonardi, 1974, 1979; Leonardi et al., 1975).

The first of this series of ichnological excursions (July-August 1973) by this team produced substantial results and offered the participants excellent training in hard field-work in this area. It resulted in the discovery of numerous new forms, also large tracks of new taxa and especially the pareiasaurian *Pachypes dolomiticus* Leonardi P., Conti, Leonardi G., Mariotti and Nicosia, 1975 (Fig. 9). Amongst the discoveries associated with the fossil footprints were fish and bivalves (Conti et al., 1975).

Fig. 9 - A giant hind-footprint of *Pachypes dolomiticus*, pareiasaurian track that has become like a symbol of the Arenaria di Val Gardena. Photo by Umberto Nicosia. Graphic scale in cm.

The discovery of *Pachypes dolomiticus* deserves special mention. Sandra Conti, Umberto Nicosia and Giuseppe Leonardi were examining sandstone slabs on the steep detrital cone on the left side of the Bletterbach gorge. Nino Mariotti in turn was looking for footprints in the stream bed. At a certain point he lifted his head and triumphantly showed the others something that looked like a huge baseball glove, shouting: "I've found a giant footprint!". Giuseppe, with twenty-five years experience in periodic field-work at the Bletterbach, where they had previously found only small tracks (Leonardi and Sarjeant, 2000), answered aloud "There were no such large animals in Permian times!". Following this exciting discovery, the team, while still in the field, decided that this was a pareiasaurian track.

On their return at the end of the day, they passed by Cavalese, in Val di Fiemme, to show the new discovery to Prof. Piero Leonardi, who was then on vacation in that village of the Dolomites. At the time he was strolling in front of his country house, in a small square named after Demetrius Leonardi, his great-grandfather who was a 19th century geologist. When the team alighted from their field vehicle, from afar they showed the large footprint to the elderly ichnologist, who retorted "Come on, kids, don't joke! It's a pareiasaur footprint!". This accorded with the earlier identification of the team but twenty years earlier, in one of his papers, Leonardi (1953b, Fig. 2 D-E) had illustrated two pareiasaur feet as possible trackmakers.

Another memorable day of the 1973 campaign was the discovery of a sandstone bed with thirty-four *in situ* palaeoniscoid fishes together with numerous small fossil tracks (Conti et al., 1975, 1980b). This slab has now been reconstructed and is on display in the gallery of the Geological Museum of the Dolomites in Predazzo (Trento). The huge slabs were carried, with great difficulty and effort, up the narrow and steep and only occasionally exposed pathway leading to the Zirmerhof and to the parking. This was a huge undertaking and at a certain point one of us had run ahead to the Zirmerhof, and Sepp Perwanger came to the rescue with an off-road vehicle and a bottle of homemade raspberry schnapps (brandy). Since that day, Sepp Perwanger has ensured that a bottle of that nature is left in the rhododendron bushes under the fir trees, to fortify the field-team after an exhausting day.

A major difficulty for a team of university undergraduate students, who had not yet established a research reputation, was to find the necessary funding to undertake research and excavation expeditions. This was enabled through the hospitality at the Casa della Cultura of Predazzo, which operated as the base for teaching and research activities of the Institute of Geology of the University of Ferrara. Here the members of the team were able to meet and interact with many geologists, including Elio Sommavilla, Alfonso Bosellini, Riccardo Assereto

and Giulio Pisa. The ichnological team became known as "the Romans" who returned the hospitality helping in the kitchen. Some time later the team began a detailed study of the ichnological material collected on the first expedition, which had been stored in a laboratory in the basement of the Institute of Geology of the University of Ferrara.

5. EXPANSION OF ITALIAN VERTEBRATE ICHNOLOGY

In the following years, Maria Alessandra Conti, Umberto Nicosia and Nino Mariotti conducted annual excursions to the Bletterbach gorge and its surroundings. In 1980, Paolo Mietto (Padova) joined the team and in later years scientific collaboration was established with Claudio Neri (Ferrara), Francesco Massari (Padova) and Paola Pittau (Cagliari). The positive research results encouraged other students and young researchers to join the initial group. These included Paola Ceoloni (Ceoloni et al., 1986, 1988), and later Fabio Massimo Petti, Eva Sacchi, Simone D'Orazi Porchetti, Mara Valentini, Paolo Citton and Marco Romano.

Meanwhile Giuseppe Leonardi left to work in Brazil (1974-1989) as a missionary, but did not limit himself to pastoral ministry. He continued to collaborate with his colleagues from Rome and started an intense series of field expeditions (more than 90) in Brazil and other Latin American countries on vertebrate (especially dinosaur) ichnology, as well as on stratigraphy. In the process he discovered dozens of new tetrapod ichnosites. This gave rise to a Brazilian ichnology school, as well as to a glossary and manual which contributed to international unification of the terminology and methods in the field of tetrapod ichnology (Leonardi, 1987). It also led to the first comprehensive treatise of fossil tetrapod tracks on a continental level (Leonardi, 1994). Further expeditions in later years (up to 2020) led him to the discovery of fossil tracks (mostly dinosaur) in Argentina, Australia, Bolivia, Brazil, Democratic Republic of Congo, West Bank, Paraguay, and other countries. Leonardi returned to Italy in 1989 and, at the request of the Museum of Natural Sciences of Trento, he worked (mainly with Paolo Mietto and Marco Avanzini) for twelve years, on the research plan at the Lavini di Marco and other Lower Jurassic ichnosites in Trentino (Leonardi, 2000; Leonardi and Mietto, 2000a, 2000b, 2000c).

In the 1990s a thematic museum for the tracks of Bletterbach at Redagno/Radein was initiated by Josep (Sepp) Perwanger and other inhabitants of that village based on the active work of Umberto Nicosia and others. In 2005 the site of Bletterbach was recognized as a Geopark and managed by the "Associazione pro Museo di Aldino/Museumsverein Aldein", with tours for visitors to local documentation centres (Loppi et al., 1998, 2000; Avanzini and Kustatscher, 2011).

Since 2005 the main gate of this park has been at the Visitor's Center which has a small museum and book-shop, and is located not far from Aldino/Aldein on the right of the canyon of Bletterbach. On the left side of the canyon is the museum of Redagno/Radein, which is part of the same organization. However, the true open-air Bletterbach museum is the Bletterbach gorge itself, also called Butterloch near the waterfall.

The Geopark has trained guides that lead groups of visitors, in the tourist season (May to November), to visit the valley and to see *in situ* fossil trackways and geological phenomena such as the eruptive neck, the contact between the ignimbritic effusions of the Athesian "porphyric" plateau and the upper Permian sandstones, medieval copper ore mines, and interfingering of white and pink gypsum. Visitors can also experience the tranquillity of beautiful landscape and sight roe deer, squirrels, fox or grouse.

As far as the team of the Padua University is concerned, this all began with the chance discovery of a small sandstone slab with tetrapod footprints (Fig. 10) which was found by Ottaviano Violati Tescari near Merendaore (Recoaro Terme, Vicenza) and donated to Paolo Mietto, then a researcher in Padua. Intrigued by the discovery, in 1974 he began exploring Permian outcrops of the Arenaria di Val Gardena in the Recoaro area and discovered more ichnological material, including a large pareiasaur footprint (Mietto, 1975, 1981). This research was conducted with the assistance of local enthusiasts (Olivo Gonzo e Antonio Rossi), collaborators from the Civic Museum "Domenico Dal Lago" of Valdagno (Vicenza), where most of this material is now stored (Marchetti et al., 2017). The research was then fruitfully extended to the deposits of the Lower and Middle Triassic, also from the Recoaro area (De Zanche and Mietto, 1977; Mietto, 1986, 1987). In collaboration with the Friulan Museum of Natural History of Udine, two amphibian footprints have been discovered from upper Carboniferous deposits of Carnia (Mietto et al., 1985). These are the oldest tetrapod footprints reported in Italy, together with those found by Fondi (1980a, 1980b) and referred to microsaurs.

In the fall of 1984, led by Piero Gianolla, then a young

Fig. 10 - The first slab with tetrapod footprints found in 1972 in the Recoaro area, Upper Permian, Arenaria di Val Gardena. Photo by Paolo Mietto. Scale bar 1 cm.

student in Padua, Paolo Mietto decided to verify the reliability of a report of vertebrate footprints on the subvertical surface of a large boulder collapsed from the south wall of Mount Pelmetto in the Cadore Dolomites (Figs. 11, 12). This had been reported by Vittorino Cazzetta, a research enthusiast from Selva di Cadore (Belluno), to whom the local Museum would later be dedicated (Mietto, 1990, 2000). In the Museum a cast of the entire surface of the boulder is exhibited, and was realized with financial support from the Friends of the Association of the Museum of Selva di Cadore. The first survey of the scree at the foot of Monte Pelmetto, using a heavy wooden ladder which had been carried to the wall, made it possible not only to verify the Cazzetta report but also attribute the footprints to dinosaurs. The dolomite boulder in question is from the Dolomia Principale Formation which is Late Triassic in age and outcrops extensively in the Southern Alps. Later study of the surface of the boulder, carried out with the help of the rock climbers of the Club Speleologico Proteo of Vicenza (Fig. 12), made it possible to identify about one hundred footprints of mostly small theropods, but also of a prosauropod and a possible ornithischian (Mietto, 1988, 1990, 1995; Mietto and Dalla Vecchia, 2000). Along with the dinosaur trackways, but at a stratigraphically lower level, there was also a brachychirotherian footprint (Leonardi, 2000; Mietto and Dalla Vecchia, 2000).

On the basis of the stratigraphic data on the age of the Dolomia Principale, the Pelmetto footprints have been referred to the upper Carnian and constitute the first reliable documentation of dinosaurs in Italy. At that time, indeed, it was thought that it was not possible to find dinosaur tracks (or bones) in Italy, since the area was predominantly marine: an archipelago in the Tethys, between Late Triassic and Cretaceous.

This discovery aroused considerable media interest and was followed by other findings in the Dolomites (Mietto, 1992) and later in Carnia (Dalla Vecchia and Mietto, 1997, 1998), so confirming not only the presence of dinosaurs in the Upper Triassic of the Southern Alps but also paving the way for subsequent discoveries of extraordinary ichnosites with dinosaur footprints in Lower Jurassic and of the Cretaceous carbonate platform deposits throughout the Peninsula (this issue).

Intrigued by the reports of tetrapod footprints in the Collio Formation of Lombardy (Curioni, 1870; Casati and Gnaccolini, 1967; Casati, 1969) and especially those of the Brescia Prealps (Berruti, 1969), the collaboration between "Romans" and "Paduans", with the inexhaustible stimulus of Giuseppe (Bepi) Cassinis of Pavia University, beginning in 1986 lead to a new phase of ichnological field research into the lower Permian deposits of the Collio Formation (Fig. 13). This new research was extended not only to the classic localities of Val Trompia, previously reported by Curioni (1870) and Berruti (1969), but also to Val Camonica and Val Sabbia, and in particular, to the

Fig. 11 - The Carnian boulder fell from Mt. Pelmetto (2.990 m a.s.l.; Zoldo Valley, Belluno). A trackway attributed to an early ?ornithischian cuts across the surface. On the right, there is a semi-bipedal prosauropod trackway and everywhere isolated theropod footprints and trackways. Photo by Giuseppe Leonardi.

Fig. 12 - Autumn 1985: execution of the reliefs on PVC sheet of the trampled surface of the Monte Pelmetto boulder, with the help of the friends of the Club Speleologico Proteo of Vicenza. Photo by Paolo Mietto.

Fig. 13 - The collaboration between "Romans" and "Paduans", since 1986 led to a new phase of ichnological field research into the lower Permian Collio Formation, in Val Trompia, Val Camonica and Val Sabbia (Brescia). The photo shows a team working at the classic Pulpito ichnosite, on the slopes of Mt. Colombine, Upper Val Trompia. Photo by Umberto Nicosia.

surroundings of Bagolino, not far from Collio (Ceoloni et al., 1987, 1988; Conti et al., 1991). This enabled the first attempts at correlation of Permian tetrapod footprint faunas from Southern and Central Europe (Ceoloni et al., 1988; Conti et al., 1989).

The relatively recent discoveries of dinosaur tracks in Italy questioned the palaeogeographic reconstructions of the western Tethys and opened a new line of research. Thus, the importance and the role of palaeoichnology in palaeogeographic reconstruction has been underscored by a number of studies that created models which are supported by both geological and ichnological data (Bosellini, 2002; Dalla Vecchia, 2002; Conti et al., 2005; Piubelli et al., 2005; Petti, 2006; Nicosia et al., 2007).

Pleistocene tracks in Italy have also attracted media interest with the discovery of the Pleistocene hominin footprints of Roccamonfina (Caserta), the so-called *"Ciampate del diavolo"* ("the footprints of the devil"; Mietto et al., 2003; Fig. 14), which at the time of discovery were credited as the oldest footprints attributable to the genus *Homo*.

6. CONCLUSIONS

The history of further vertebrate ichnological research (especially tetrapods) in Italy is told in the following chapters, which record, in chronological succession, the history of the discoveries, research and progress in understanding of the value of tracks, and their application to palaeogeography, palaeoclimatology, sedimentology and stratigraphy, and use in dating of stratigraphic units.

The study of ichnology has impacted on a number of fields of Earth Sciences. Even although Italy, from

Fig. 14 - 2005, October: *"Ciampate del Diavolo"* of Central Italy, on the side of the Roccamonfina volcano (Caserta), an ichnosite with hominin footprints impressed in the Middle Pleistocene Brown Leucitic Tuff. In the picture Paolo Mietto while watching the characteristics of the prehistoric trail. Photo by Adolfo Panarello.

Fig. 15 - Gradually, Italian Vertebrate Ichnology has grown in the number of personnel, in discovered ichnosites, in published research, in means and working methods. Here, in autumn 2014, it was useful to use a helicopter to transport materials and the team of Paolo Mietto to 3,047 m of altitude. This ichnosite with Early Jurassic dinosaur tracks *in situ*, partly visible in the photo, is located on the ridge of the northeast buttress of Mt. Pelmo (Dolomites, Belluno). Photo by Francesco Sauro, one of the discoverers.

the latest Permian to Cretaceous, was a predominantly marine archipelago area, ichnological studies have pointed out that, starting from the latest Permian (Calcari a Bellerophon Formation), Italy had practically never been free of abundant tetrapod faunas during this extensive period.

On this point it is necessary to underline again the importance of the discoveries of a large amount of dinosaur tracks and, in lesser proportion, of other typically continental animals, in the Mesozoic Italian deposits during the last four decades. This happened first in the Upper Triassic of Mount Pelmetto and gradually throughout the area of the Dolomites and Carnia; then in the Lower Jurassic deposits of Lavini di Marco and in the whole area of outcrops of the Calcari Grigi Group. Later on, several important discoveries followed in many localities of central and southern Italy in Cretaceous deposits. Dinosaurs and other continental animals found indeed different ways to pass from one island to another and to colonize a good part of the area that today is Italy.

Currently interest in vertebrate ichnology in Italy (as in the rest of the world) is on the increase (Fig. 15) and there are no less than thirty specialist ichnologists, or geologists and palaeontologists with a strong interest in vertebrate ichnology. As much ichnological work remains to be done we trust that this positive trend which has characterized vertebrate ichnology in Italy continues into the future. This celebration of a 150 years milestone in Italian ichnological studies provides an opportunity remember the companions of adventure who are no longer with us today: in particular, Piero Leonardi, Bruno Accordi, Giovanni (Jack) Pallini, Claudio Neri, Vittorino Cazzetta, Josep (Sepp) Perwanger, Ottaviano Violati Tescari, Ottavio Gonzo and Antonio Rossi.

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