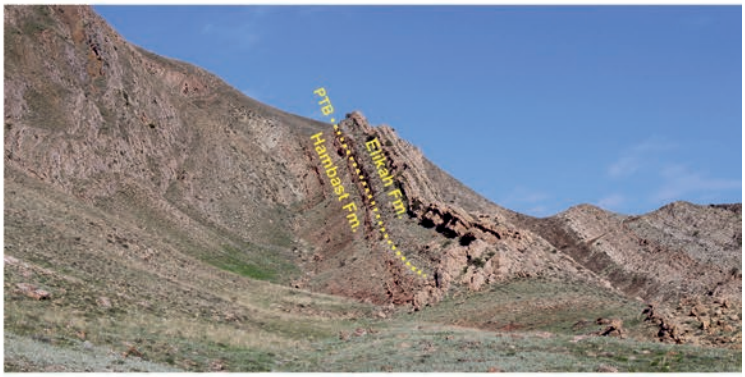
Permophiles

International Commission on Stratigraphy



Newsletter of the Subcommission on Permian Stratigraphy

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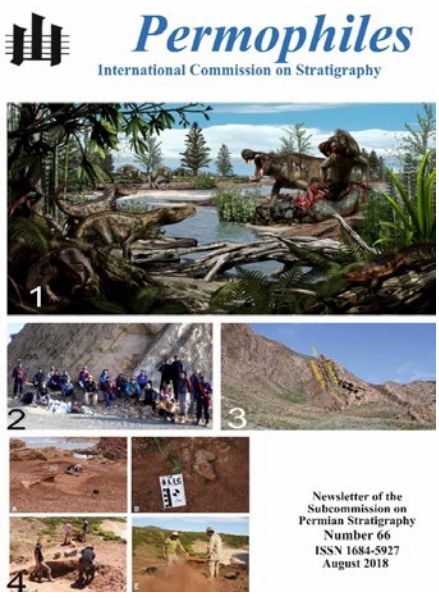

Fig. 1. The reconstructed Lopingian lush equatorial ecosystem at the Bletterbach site. Artwork by Davide Bonadonna. Bernardi et al., this issue.
Fig. 2. Participants to a joint field excursion was organized by the Department of Earth Sciences, COMSATS Institute of Information Technology, Abbottabad, Pakistan, the Nanjing Institute of Geology and Palaeontology, and the Institute of Tibetan Plateau Research of the Chinese Academy of Sciences during March, 2018. Courtesy S. Shen.
Fig. 3. Hambast and Elikah formations at the Zal section and the putative Permian-Triassic boundary. Gennari et al., this issue.
Fig. 4. Recovery and preliminary analysis of the sphenacodontid material from Nurra area, NW Sardinia. Romano et al., this issue.

Pebble Beds (Ambrose et al., 2014). Warrington et al. (2012, fig. 3) concluded that this hiatus extends from the late Lopingian into the Early Triassic and that the Permian-Triassic boundary is not represented in the rock succession. Hounslow et al. (2017, fig. 11) and Hounslow and Balabanov (2018, fig. 7) have illustrated a comparable situation, with a Capitanian to Wuchiapingian age assigned to the Aylesbeare Mudstone and the system boundary, between the Changhsingian and the Induan stages, not represented in the rock succession seen at outcrop.

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Permian tetrapod localities in the Nurra region (NW Sardinia, Italy): The State of the Art

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Introduction

The Nurra area in NW Sardinia is quite well known for the outcropping of a thick succession of more than 600 m of post-Variscan continental deposits (Fig. 1), with several dedicated studies and contribution already starting from the first half of the twentieth century (e.g. Lotti, 1931; Oosterbaan, 1936; Pecorini, 1962; Vardabasso, 1966; Gasperi and Gelmini, 1980). An intensive

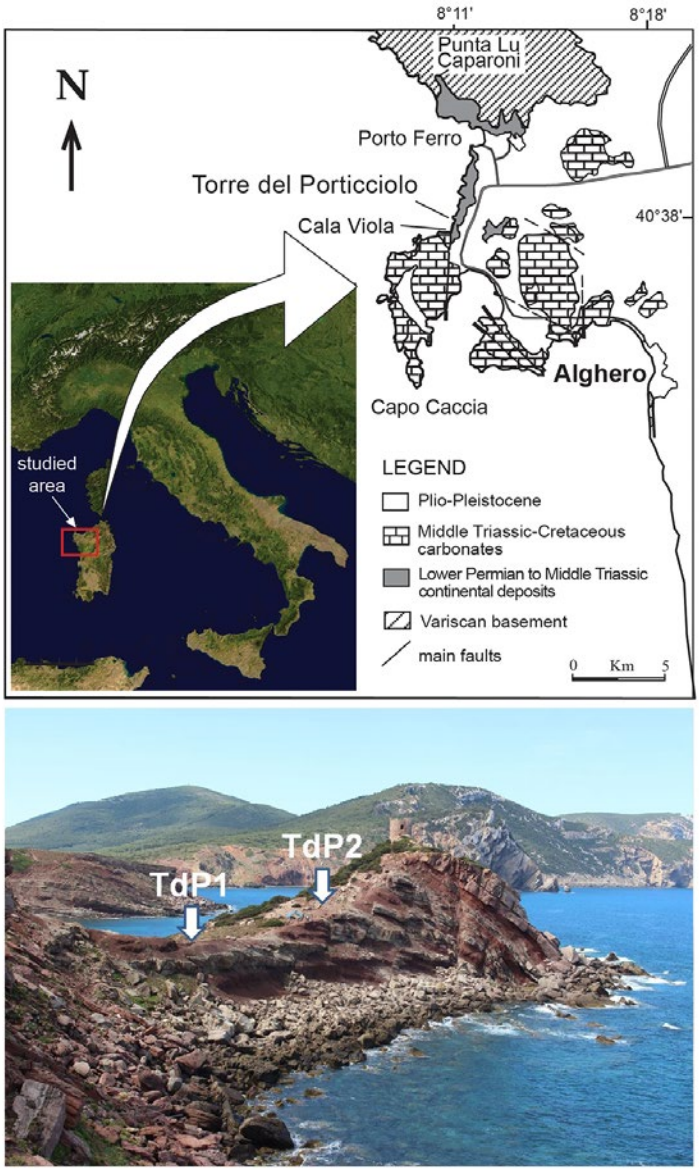

Fig.1. Simplified geological setting of the Nurra area, modified from Romano et al. (2018, fig. 1) (top); location of the two productive sites for osteological material TdP1 and TdP2 (bottom).

research program in the last 20 years has led to a better understanding and definition of the sedimentology and stratigraphy of the area, with the 600-m-thick Permian and Triassic continental succession subdivided in the following six formations (from base to top): Punta Lu Caparon., Pedru Siligu, Porto Ferro, and Cala del Vino formations for the Permian, and the Conglomerato del Porticciolo and Arenarie di Cala Viola for the Triassic (Gasperi and Gelmini, 1980; Cassinis et al., 2002a, 2003). The careful sedimentological analysis of the Permian-Triassic succession of the Nurra area allowed lithostratigraphic correlation with the deposits outcropping around Toulon in Provence (Cassinis et al., 2002a, 2003; Durand, 2006, 2008), with the Cala del Vino Fm. showing quite superimposable lithofacies and fluvial architecture to the one characterizing the Saint-Mandrier Fm. (Durand, 2008).

Despite intensive study of the area especially in the last twenty years, the fossiliferous content of the outcropping deposits in the Nurra is historically rare, and for a long time was essentially represented by macrofloral and microfloral remains from the basal portion of the Punta Lu Caparoni Fm (Gasperi and Gelmini, 1980; Pecorini, 1962; Ronchi et al., 1998) providing a middle Autunian age, and in the upper portion of Arenarie di Cala Viola, indicating an Early Triassic age (Pecorini, 1962). This situation changed dramatically and unexpectedly when, in 2008, a student from the University of Pavia found accidentally eight articulated vertebrae, still partially embedded in the red Permian sediments of the Cala del Vino Formation, outcropping in the Torre del Porticciolo promontory (Fig. 2). Since that day, more than fifteen field works have been conducted in the area, headed by a team of the Department of Earth Sciences of Sapienza of Rome in collaboration with the University of Pavia, to collect a truly unique material for both Italian and European Permian panorama. Overall, about eighty bones were recovered, both complete and fragmentary, all referable to the post-cranial skeleton of a very huge animal (Fig. 2). The preparation and study of the material allowed the description and formalization of a new taxon of the Family Caseidae, *Alierasaurus ronchii* (Romano and Nicosia, 2014) from 'Aliera' or 'Alighera', the old traditional name of the city of Alghero in Sardinia, and Ronchi in honor of Prof. Ausonio Ronchi from Pavia who reported us the new discovery.

In 2015, during a field work to collect additional material referable to the huge caseids, a second productive site (Torre del Porticciolo 2, TdP2) was discovered about hundred metres from the original *Alierasaurus* site (TdP1) (Fig. 1, bottom). Field works conducted in the new site in 2016 and 2017 led to the recovery of several bones and bone fragments both still embedded in the original deposits, and isolated elements in the deposit deriving from the erosion of the productive sedimentary body (see Romano et al., 2018) (Fig. 3). Despite a system of normal alpine fault displacing the meandering river deposits, the productive sedimentary bodies of TdP1 and TdP2 can be referred essentially to the same stratigraphic level (see Romano, 2018, fig. 4). A detailed taphonomic analysis allowed to refer all the recovered material to the same and single individual; in addition, a preliminary study of the most diagnostic elements among the already prepared bones allowed to refer the new specimen to a member of the Sphenacodontidae (Romano et al., 2018). Sphenacodontids are a crucial clade of highly predaceous non-therapsids synapsids (traditionally known as "pelycosaurs"), essentially known from the Permian beds outcropping extensively in the south-western United States. The new finding represents the first record of the group in Italy, throwing new light on the occurrence and dispersal of the clade in the European continent.

In the summer of 2017, during the excavation of skeletal remains at TdP2 locality, palaeontological survey was conducted along the sedimentary succession outcropping towards SSW and a reddish sandstone slab bearing an isolated tetrapod track was found as loose material. The prospecting was then focused in the area of the discovery and yielded two joined slabs preserving two couples of footprints (Fig. 4), coming from a very close horizon to the bone-bearing ones (TdP3), about one kilometre from TdP1 and TdP2 localities.

The new material constitutes the first ichnological evidence from the Permian of Sardinia and provides a more comprehensive

Fig. 2. Recovery of post cranial material referred to the giant caseid *Alierasaurus ronchii* from the siteTdP1. In top left, the first eight articulated caudal vertebrae found in 2008.

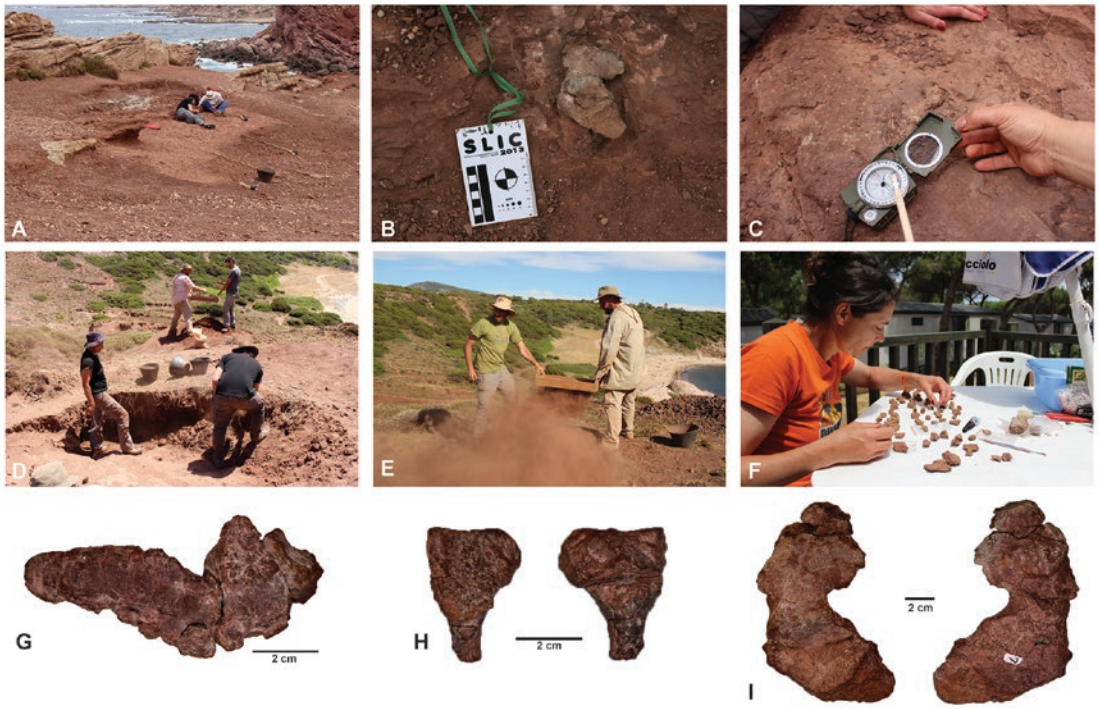

Fig. 3. Recovery and preliminary analysis of the sphenacodontid material from the site TdP2. A) Initial cleaning of an outcrop surface of about 40 square meters; B) a partial left portion of the pelvis in its original disposition within the productive sedimentary body; C) Before being extracted from the sediment, all the original orientations of each individual bone in the sediment were measured and recorded; D) digging and analysis of the debris deposited at the base of the productive sedimentary body; E) about seven cubic meters of debris were excavated and sifted in detail, using a sieve with 0.5 cm meshes which led to the recovery of several small bones and fragments; F) many of the recovered fragments were compatible and, after a long process of puzzling, it was possible to reconstruct even larger and diagnostic elements; G) Partial right maxilla MUST NS 166/8 in lateral view; H) isolated anterior tooth MUST NS 166/9 in lateral (left) and medial (right) view; I) portion of the left pelvis MUST NS 166/7 in lateral (left) and medial (right) view. MUST NS = Museum of Paleontology, University of Rome, Rome, Italy, New Series.

understanding of the faunal composition of the Cala del Vino Fm. As a matter of facts, the Torre del Porticciolo site turned out to be one of the few, rare, sites in Europe where both body fossils and ichnofossils are jointly preserved, enhancing our knowledge about the Permian faunal diversity and ecosystem structure in this area of Pangea.

***Alierasaurus ronchii*: the giant of "pelycosaurs"**

The first accounts on the new large caseid from Sardinia was provided by Ronchi et al. (2008) and Ronchi et al (2011). Ronchi et al. (2011) describe in detail the geology and taphonomy of the first site at Torre del Porticciolo area (TdP1), showing how all the material collected can be referred to the same individual. The taphonomic analysis highlighted a series of complex biostratinomic processes (see Ronchi et al, 2011) including: i) a first energetic transport phase, from the place of death to a second place, which caused the breaking of some long bones when the collagen was still present; ii) a phase of decay with ablation of the fragile haemal arches (broken during the energetic first transport); iii) a flooding episode (a flash-flood) who took in charge the bone material and buried them along with fine grained sediment, leading to the final deposit in a in a third place; this last event would explain why the bones are found scattered at various depths in the productive body.

Ronchi et al. (2011) in addition figure and briefly describe some vertebral, ribs and pedal material of the new caeseid, stressing the great affinities with the large North American caseids. The authors preliminary refer the new specimen to as ?*Cotylorhynchus* sp. Stovall, 1937. Ronchi et al. (2011) also discuss the stratigraphic occurrence of both North American and European caseids; using the North American Land Vertebrate faunochrons proposed by Lucas (2006), the authors suggest a late Kungurian–Roadian age for the upper part of the Cala del Vino Formation, and discuss the implication for the litostratigraphic correlation with the Permian-Triassic succession outcropping in Provence.

Romano and Nicosia (2014) provide the first detailed description of the new material with the formalization of the new caseid *Alierasaurus ronchii*. The author stress how great part of the preserved post-cranial material, especially conformation in ribs and foot elements are fully compatible with the known anatomy of large north American caseids, in particular with that characterizing the genus *Cotylorhynchus*. However, *Alierasaurus* shows apomorphic character, especially in the autopodial elements, supporting the erection of a new genus and species of Caseidae. Romano and Nicosia (2014) discuss the huge size of the new taxon comparable only to the giant North American species *Cotylorhynchus hancocki*, more than six meters in total length. The author in addition stress how the conformation of preserved large ribs allow to infer a very large "barrel-shaped" rib cage, indicating an high-fibers herbivorous diet (see Hotton et al., 1997; Sues and Reisz, 1998).

Romano et al. (2017) describe further postcranial material referable to *Alierasaurus*, collected during several field works in PdP1 site, and from the same sedimentary body in which the holotype was found. The new material confirms the attribution of all the collected bones to the same individual, based on the same kind of preservation and on the lack of double ore repeated elements. New diagnostic material includes caudal neural spine showing a broad bifid distal termination, a synapomorphy characterizing the more derived caseids. Even if the collected material is quite limited, and no diagnostic skull material was available, a phylogenetic analysis including the fragmentary Sardinian taxon was conducted using a recent cladistics analysis of Caseidae performed by Romano and Nicosia (2015). *Alierasaurus* posits in sister group relationship with the North American genus *Cotylorhynchus*, and result autapomorphic with the monophyletic Caseidae in the gen-

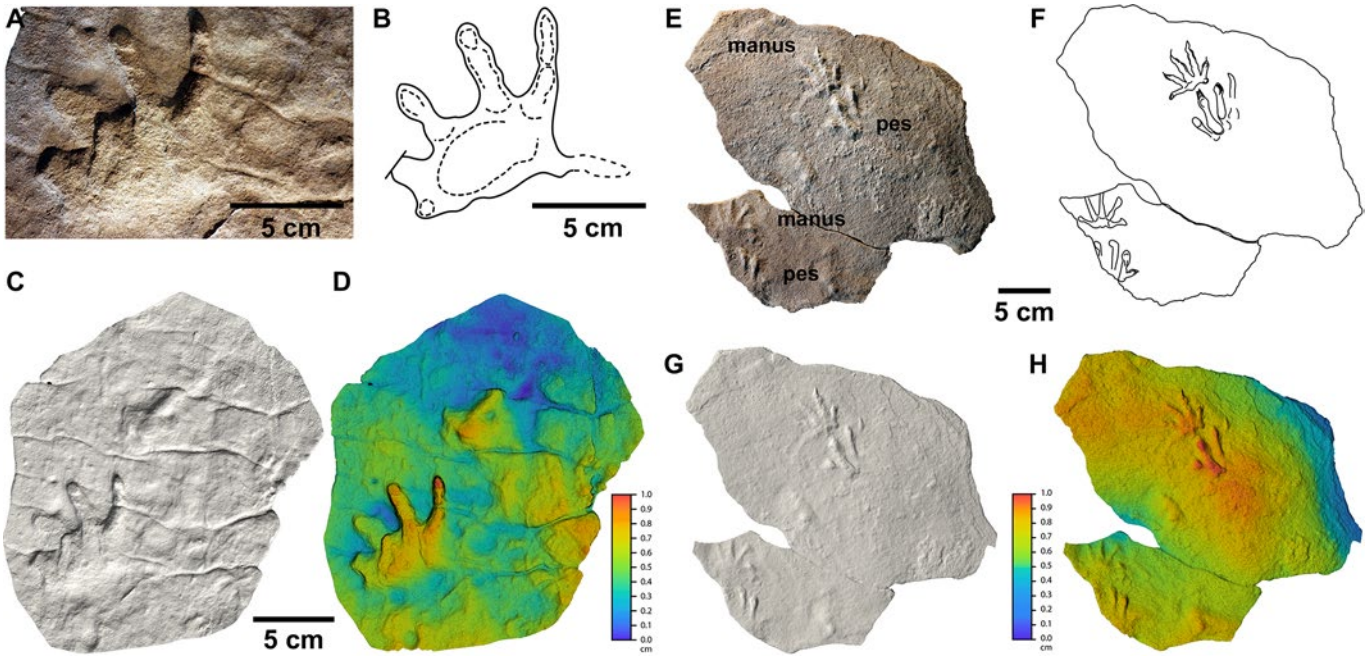

Fig. 4. Ichnological material from TdP3 site. A, isolated pes track found as loose material; B, interpretative drawing of the footprint; C, solid three-dimensional model; D, colour topographic profile with contour lines. E, manus-pes sets of smaller dimension; F, interpretative drawing of the footprints; G, solid three-dimensional model; H, colour topographic profile with contour lines.

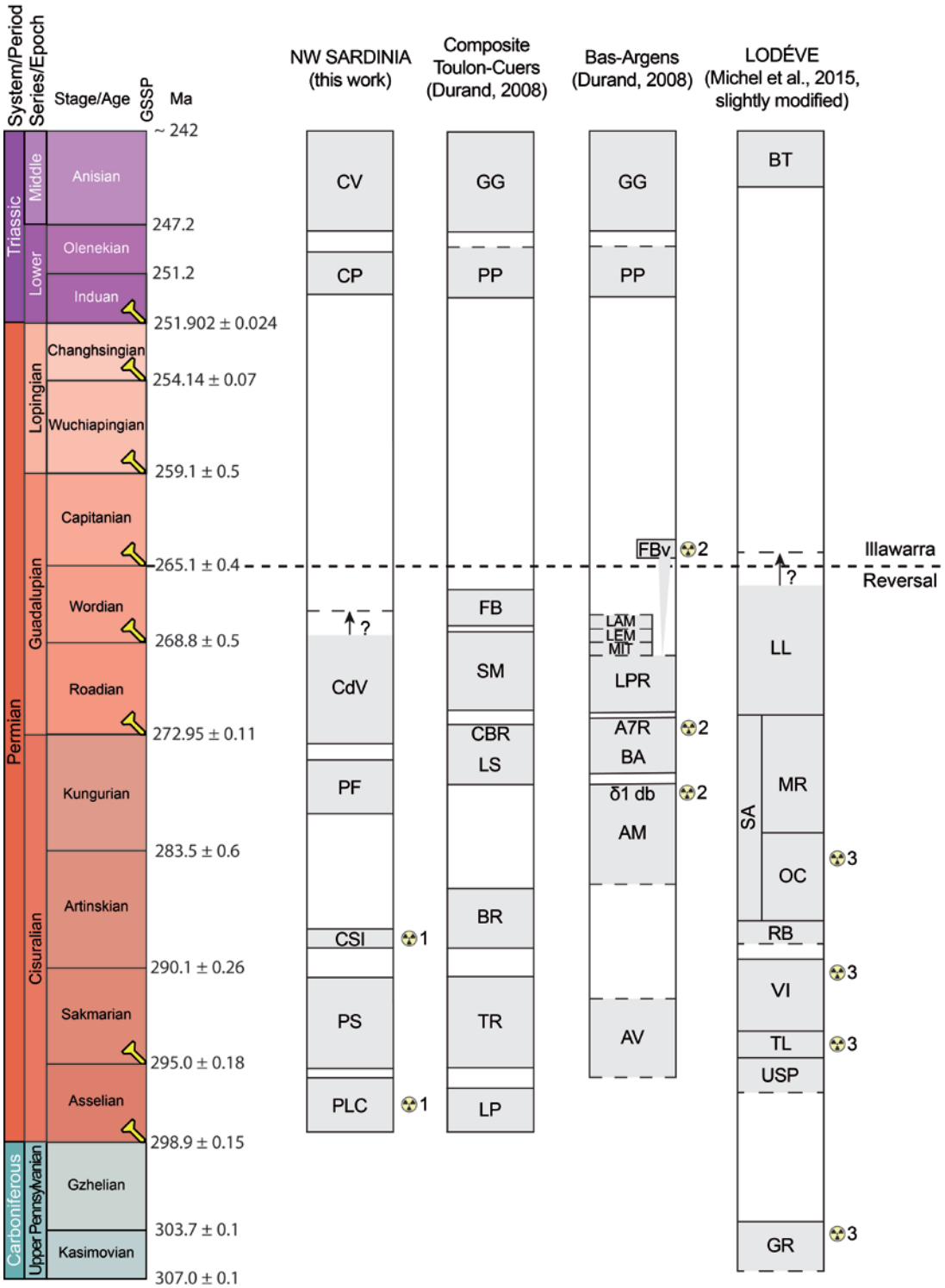

Fig. 5. Continental successions from Nurra (NW Sardinia) and French basins. Radiometric data available from: 1 - Gaggero et al. (2017); 2 – Zheng et al. (1992); 3 – Michel et al. (2015). Dashed blue lines superimposed to the ICC v2017/02 indicate the base of the Roadian and the Roadian-Wordian boundary according to Davydov et al. (2018). Lithostratigraphic units: A7R - A7 Rhyolite; AM - Ambon Fm.; AV - L'Avellan Fm.; BA - Bayonne Fm.; BR - Bron Fm.; BT - 'Buntsandstein'; CBR - Calcaires du Bau Rouge Mb.; CdV - Cala del Vino Fm.; CP - Conglomerato del Porticciolo; CSI - Casa Satta Ignimbrite; CV - Cala Viola Sandstone; δ1 db - δ1 doleritic basalt; FB - Fabregas Fm.; FBv - Fluorite-Barite vain with adularia; GG - Gres de Gonfaron; GR - Graissessac Fm.; LAM - La Motte Fm; LEM - Le Muy Fm.; LL - La Lieude Fm.; LP - Les Pellegrins Fm.; LPR - Les Pradineaux Fm.; LS - Les Salettes Fm.; MIT - Le Mitan Fm.; MR - Merifons Mb.; OC - Octon Mb.; PF - Porto Ferro Fm.; PLC - Punta Lu Caparoni Fm.; PP - Poudingue du Portissol; PS - Pedru Siligu Fm; RB - Rabejac Fm.; SA - Salagou Fm; SM - Saint-Mandrier Fm.; TL - Tuilieres-Loiras Fm.; TR - Transy Fm.; USP - Usclas-St. Privat Fm.; VI - Viala Fm.

eral construction of MT-IV and proximal phalanx IV-I.

The new collected material, especially a very big dorsal rib, confirms the extremely huge size of the Sardinian caseids, and a first *in vivo* restoration was provided in collaboration with the Italian artist Emiliano Troco (Romano et al., 2017, fig. 11). On the base of the possible reconstruction and comparison with published material or stored at museum collection, *Alierasaurus* resulted as one of the larger "pelycosaurs" ever found, with an estimated length that could reach seven meters, thus also bigger than the giant Nord American species *Cotylorhynchus hancocki* (Romano et al. 2017). The authors also discuss the huge body size reached by some members of caseids, and the ecological and general physiological advantage of large body size, not simply in relation to a specialized herbivorous lifestyle.

The first sphenacodontids of Italy

Field works activities in the new site (TdP2) were carried out in two principal phases (see Romano et al., 2018). A first phase consisted in the cleaning of an outcrop surface of about 40 square meters (Fig. 3A), followed by a careful excavation of the sediment in place; the process led to the recovery of about 30 bones, with both complete and fragmentary elements. Before being extracted from the sediment, all the original orientations of each individual bone were measured and recorded (Fig. 3C). A second phase consisted in the digging and analysis of the debris deposited at the base of the productive sedimentary body. In total, about seven cubic meters of debris were excavated and sifted in detail, using a sieve with 0.5 cm meshes (Fig. 3D-E). Many of the recovered fragments were compatible and, after a long process of puzzling (Fig. 3F), it was possible to reconstruct even larger and diagnostic elements such as a right maxillary, a portion of a left pelvis and a femur (Romano et al., 2018). The careful study of the various taphonomic evidence initially represented a very big puzzle, since some of these evidences seemed in open contradiction for the reconstruction of a single and unitary process. In particular, the evidence suggests the following elements: i) a very short ablation time, considering that long bones, ribs and autopodial elements, which are usually the first to be disarticulated, are preserved in the same place and some still in articulation (such as metapodials and phalanges); this indicates that some sort of ligaments, or soft tissues, had to be present at the time of burial. This element is also indicated by vertebral centra slightly deformed when the collagen was still to be present in the bones; ii) a relatively short time of sub-aerial exposure, and an early burial, indicated by the absence of superficial flaking or cracking (due to the bones weathering; rank "0" in the classic weathering scale of Behrensmeyer, 1978), lack of spiral fractures, and lack of biological reworking of bones, with no traces of scavenging or other type of bio-erosion. The essentially fragmentary state of the bones indicates a condition of fracture and general breakage of the material affecting more than 80% of the recovered bones. Both the bones recovered still embedded within sediment, and those coming from the debris, show straight and clean fractures, orthogonal to the long axis; these elements indicate fractures occurred in total absence of collagen, when the material was already diagenized.

The set of evidences were interpreted by Romano et al. (2018) according to the following multiphasic taphonomic process: i) the animal died very close to the flooding zone, without any transport of the body (no bones broken when the collagen was still present, as differently found for the large caseid in the first site); ii) the body, partly disarticulated partly still in articulation, was taken in charge and buried by a flooding after a short period of subaerial exposure, which prevented the bones to be scattered, to undergo weathering or to be reworked by scavengers; iii) in the buried skeleton some bones were deformed by the weight of the sediments when the collagen was still present, and the entire skeleton underwent processes of early diagenesis; iv) subsequently, the body was exhumed and transported by a very energetic current during another flooding event, which led to the formation of a crevasse-splay. The bone remains, and the embedding sediments, were transported by a high-density flow for a very short distance, and then re-deposited a second time in proximity of the main channel. To this stage are referred all the observable fractures in the already diagenized bones, found broken within the sedimentary deposits (see Romano et al., 2018, fig. 7).

Romano et al. (2018) also provide a brief description of some informative bones among the already prepared material. One of the most diagnostic element is a portion of the right maxilla, with 10 preserved teeth still in place, showing only the proximal portion of the crown preserved (Fig. 3G). In more basal "pelycosaurs", such as Eothyrididae, Caseidae and Edaphosauridae, the ventral margin of the maxilla is essentially straight; differently in the more derived clades the margin is slightly to consistently convex (Romer and Price, 1940; Reisz, 1986). In particular, the rather convex lower margin, that characterizes the maxilla in the new specimen, results a typical feature of the carnivorous group Sphenacodontidae. Furthermore, the most anterior portion of the ventral margin of the maxilla curves sharply upward, forming a peculiar notch in the bone profile. This structure is fully reminiscent of the so-called "maxillary step", a typical and exclusive feature of sphenacodontids within non-therapsid synapsids, to accommodate the anterior larger marginal teeth. The preserved basal portion of the teeth is strongly labio-lingually compressed, another typical feature of sphenacodontids, and the number of preserved marginal teeth in the maxilla are compatible with the classical count in the well-known genera *Dimetrodon* and *Sphenacodon*. On the base of such diagnostic characters of the maxilla, Romano et al. (2018) preliminary referred the new specimen to an indeterminate sphenacodontid.

The first Permian tetrapod footprints from Sardinia

The ichnological material from TdP3 locality, consisting of a single isolated pes track (Fig. 4A-D) and two complete manus-pes sets (Fig. 4E-H) all preserved as convex hyporeliefs, was described and discussed by Citton et al. (2018). The isolated track is impressed on a medium-grained, reddish sandstone slab, while the two sets are preserved on a grey-reddish, fine- to medium-grained and poorly cemented sandstone. On the whole, the footprints are wider than long. Pes tracks are tetradactyl to pentadactyl, with digit length increasing from digit I to digit IV; digit III and IV are comparable in size, while digit V is longer than digit I and comparable to digit II. Digit traces have slightly pointed digit tips and are straight, even if the central ones (i.e. digit II, III and IV) can be slightly medially bended at their tips.

In some cases, digit tips appear rounded, most likely as a result of a powerful kick-off phase and of a deeper entrance of digits into the sediments during trampling. Digital bases I-IV are associated with sub-circular traces, on the whole arranged in an arched way, which were most likely left by the metatarsal-phalangeal joints of the trackmaker autopod. Manus tracks are pentadactyl showing digit traces increasing in length from digit I to IV, with digit V longer than digit I. Digit are straight and, as observed in the hind prints, are characterized by pointed distal tips. A distinctive character of both fore and hind prints is the subparallel orientation of digit I with respect to the footprint proximal margin. Glenoacetabular distance, obtained from the manus-pes sets, indicated a trunk length of about 19 centimetres and suggested a trackmaker of about 50 centimetres in total body length. The isolated pes track, larger than the other footprints, most likely indicated a trackmaker one metre in total body length.

Citton et al. (2018) identified several characters shared with footprints collected from the uppermost portion of the Permian succession in the Lodève Basin (i.e., La Lieude Fm.) and referred by Gand et al. (2000) to as *Merifontichnus thalerius.* The variability observed in some track features(e.g. digit I orientation, morphology of digit tips and orientation with respect to the midline) was deemed consistent with the internal variability of the ichnotaxon, as illustrated by Gand et al. (2000) based on the type material, and finally enabled the authors to refer the ichnological material from TdP3 locality to as *Merifontichnus*, excluding at the same time other Late Palaeozoic ichnotaxa (see Citton et al., 2018). Moreover, previous ichnotaxonomic attributions to *Merifontichnus* of footprints from Northern Italy were rejected (see Citton et al., 2018) and the material from TdP3 locality turned out to be the first reliable report of the ichnogenus from Italy.

Concluding remarks and future directions

Known for over a century for the spectacular outcropping of Permian-Triassic deposits and for the almost total absence of fossil remains, the area of Nurra in the last decade of field work turned out to be otherwise of primary importance for the study of late Palaeozoic tetrapods in the European context. In fact, whereas the large part of non-therapsid synapsids is known from the highly productive site in North American, European basal synapsids are historically rare, with very few sites in western, northern, and central Europe (see a complete list in Romano et al., 2018). Considering the very poor European record fossil for basal synapsids, the new findings from the island of Sardinian are crucial to shed new light on the group evolution and dispersal outside of North America.

The finding and description of the first caseid from Italy, *Alierasaurus ronchii*, provides the first biochronological constrains for the age of the Cala del Vino Formation. In particular, the finding indicated the presence of a large hiatus between the Cala del Vino Fm. and the Triassic Conglomerato del Porticciolo, with a gap of about 20 million years. In addition *Alierasaurus* prove to be the largest "pelycosaurs" described to date, throwing new light on increasing body size within herbivorous non-therapisd synapsids.

The new finding from the second site (TdP2) represent the second basal synapsid from Sardinia and the first sphenacodontid from Italy. As briefly reported above, the great part of the sphenacodontid material comes from North America, with just five sphenacodontid taxa described from Europe, represented by *Neosaurus* from Moissey, France (see Leidy, 1854; Fritsch, 1889; Nopcsa, 1923; Fröbisch et al., 2011; Sphenacodontidae indeterminate in Falconnet, 2015), *Dimetrodon teutonis* from Thuringia, Germany (Berman et al., 2001; Berman et al., 2004), *Macromerion* from Kounová, Czech Republic (very poor material), *Cryptovenator hirschbergeri* from the Rhineland Palatinate, Germany (Fröbisch et al., 2011), and *Sphenacodon* (previously "*Oxyodon*" *brittanicus*, see von Huene, 1908; Paton, 1974) from England. In addition Falconnet (2015) reported three further specimens from Lodève Basin (France), referred to Sphenacodontidae indeterminate. The new specimen from Sardinia thus represent the ninth occurrence of the clade in the European continent. In addition, considering the late Kungurian–Roadian inferred age for the Cala del Vino Formation, the Sardinian specimen would represents the youngest sphenacodontids in Europe, throwing new light on the occurrence of the clade.

In Sardinia, calibration of Upper Palaeozoic continental deposits was based on tetrapod footprints, skeletal and plant remains, and radiometric ages in the Nurra region obtained from rhyolitic ignimbrites (see Citton et al., 2018 and references therein). A lithostratigraphic correlation between Permian and Triassic succession of Nurra region and southern Provence was already proposed by Cassinis et al. (2002a, 2003) and Durand (2006, 2008), which correlated the Cala del Vino Fm. to the Saint Mandrier Fm. of the Toulon-Cuers Basin (Fig. 5). The lower portion of this last unit was also correlated to the Les Pradineaux Fm. of the Estérel Basin in Provence (Durand, 2006, 2008). This unit was tentatively referred to the Wordian based on the available ichnoassemblage (Gand et al., 1995), palynological and palaeobotanical evidences (Visscher, 1968; Toutin Morin et al., 1994), as well as for an ostracod association (Lethiers et al., 1993). However, the Les Pradineaux Fm. lies above the A7 Rhyolite, dated Roadian (272.5 Ma; Zheng et al., 1992) and is cutted by a fluorite-barite vein with adularia dated about 264 Ma (Zheng et al., 1992) (Fig. 5). In the Lodéve Basin (Hérault, SW France), tetrapod tracks were reported from different lithostratigraphic units, comprising the Salagou Fm. and the La Lieude Fm, from which *Merifontichnus* was erected. These units were referred by Roscher and Schneider (2006) respectively to an age between the Kungurian and the Wuchiapingian (i.e. Salagou Fm.) and to the Wuchiapingian p.p. - Changhsingian p.p. (i.e. La Lieude Fm); however, the chronostratigraphy of the succession was recently revised by Michel et al. (2015), who ascribed the topmost part of the Salagou Fm. in the Roadian and the uppermost portion of the La Lieude Fm. around the Capitanian base (Fig. 5). This age is in agreement with the ichnoassociation of the La Lieude Fm., which was referred to the 'tapinocephalid stage' corresponding to the North American Roadian and Wordian (Cassinis et al., 2002b). According to this chronostratigraphic framework and the proposed age for the Cala del Vino Fm., the new ichnological material allows anticipating the occurrence of *Merifontichnus* to the early Guadalupian (Roadian).

The palaeontological record from the Nurra region, besides providing highly significant and punctual information, converted

the Torre del Porticciolo site in a strikingly significant palaeontological site for the Permian of Europe, due the co-occurrence of skeletal and ichnological remains. The other remarkable example of a productive and diversified fossiliferous site is the Bromacker quarry locality in the Thuringian Forest (Germany), the most productive locality for terrestrial vertebrates in the Lower Permian of Europe. Here, a notable vertebrate assemblage preserved in different levels of the Tambach Fm. (Tambach Basin) was unearthed since the last century (Eberth et al., 2000). At Bromacker, 12 tetrapod taxa were identified and described, among which amniotes (bolosaurid parareptile, sphenacodontid, eureptiles, varanopid synapsid, and caseids) and anamniotes (amphibamid, ostodolepidid microsaur, seymouriamorphs, diadectomorphs, and trematopids) (Berman et al., 2014). In addition, the Bromacker locality is well-known for preserving a rich and very well detailed ichnofauna, referable at least to five ichnogenera, namely *Ichniotherium*, *Dimetropus*, *Amphisauropus*, *Varanopus* and *Tambachichnium* (Pohlig, 1885; Pabst, 1895, 1908; Haubold, 1971, 1973, 1998; Voigt and Haubold, 2000; Voigt, 2005; Voigt et al., 2007; Romano and Citton, 2015; Romano et al., 2016; Buchwitz and Voigt, 2018). In the case of Bromacker locality, the combined ichno and body fossil record offered the unique opportunity to find a strong match between bones and tracks, as highlighted by Voigt et al. (2007) for the two diadectids *Diadectes absitus* and *Orobates pabsti* and the two ichnospecies *Ichniotherium cottae* and *Ichniotherium sphaerodactylum*. Later, Romano et al. (2016) corroborated the attributions and showed that once established a track-trackmaker correspondence, footprints can be used to improve and correct assumptions made only on the basis of skeletal remains.

As Bromacker, the Torre del Porticciolo site represents a sumptuous reservoir of data, conveying information difficult to achieve together if the preservational requirements of the two type of record are considered, and improving our understanding of the ancient ecosystems and the palaeoecological relationships between different clades. Currently, the record of the Nurra region is providing a more complete understanding, and different integrated representations, of the faunal composition. While the skeletal remains indicated a medium to large sphenacodontid and a giant herbivorous caseid, footprints added also a small animal, probably to be sought among synapsid therapsids, as a further constituent of the terrestrial palaeofauna. On the whole, the new evidence indicates for the time being a fauna with tetrapods ranging from 50 cm up to more than seven meters in length.

Next steps in the research will include a detailed description and illustration of the new material from TdP2 site, which will probably lead to the formalization of a new taxon within sphenacodontids, on the basis of some autapomorphies characterizing especially the ilium in the pelvis, and the general structure of the femur. New field work and prospections will be conducted in the Cala del Vino and Cala Viola areas, searching for new osteological and ichnological material, to further enhance our understanding

Fig. 6. Excavation Team, Torre del Porticciolo, September 2015. From left to right: back, Marco Romano, Davide Bonadonna and Andrea Pirondini; center, Paolo Citton, Umberto Nicosia, Eva Sacchi and Simone Maganuco; front, Anna Giamborino and Teresa Coppola.

of the faunal diversity of this area of Pangea during the latest Early Permian to early Middle Permian time interval. The field works will be carried out also thanks to the great support of the Associazione Paleontologica e Paleoartistica Italiana (A.P.P.I.), that, in recent years, has financed part of the excavations as well as helping consistently in the field operations (Fig. 6).

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On the age of the deepest part of the glacigene Al Khlata Formation in the Mukhaizna Field, Oman, based on palynology

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The glacigene Al Khlata Formation has been the subject of palynological study for almost half a century, mainly because it bears hydrocarbons in the subsurface of interior Oman. The Al Khlata Formation comprises clastic lithologies that range from conglomerates through diamictite, gravels, pebbly sandstones, siltstones to silty shales (Levell et al., 1988).

A study of the Mukhaizna Field in south-central Oman distinguished five biozones in the Al Khlata Formation working downhole mainly with cuttings samples but also with small amounts of core and sidewall core (Stephenson et al., 2008). The top of the highest, Biozone A, is marked by the first downhole increase of *Microbaculispora tentula* and *Cycadopites cymbatus* and is associated with high gamma-ray readings indicating the Rahab Member of the Al Khlata Formation. The top of Biozone B is distinguished by the first downhole appearance (FDA) of, amongst others, common cavate-zonate spores. It is associated with shaley diamictites and more distal lacustrine mudstones with considerable lateral variability. The top of Biozone C is marked by the FDA of *Anapiculatisporites concinnus* but also