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A NEW RECORD OF TRIASSIC DINOSAUR FOOTPRINT FROM MONTE PISANO (NORTHERN APENNINES, ITALY): TRUE OR FALSE?

Abstract - *A new record of triassic dinosaur footprint from Monte Pisano (Northern Apennines, Italy): true or false?.* The Upper Triassic continental deposits of Monte Pisano (Northern Apennines) preserve a high number of tetrapod tracks: some of them are among the most ancient italian records of dinosaurs. In this work we describe a putative, isolated ichnite (the "Agnano track") from the top member of the Monte Serra Quartzites Formation consisting of a small-sized, tridactyl possible pes impression. Being concave and lying on the sole of a fine-grained arenaceous bed, this feature poses some serious difficulties in order to fully embrace its tetrapod-related origin, although concave hyporeliefs have been recently pointed out (but not investigated) by some authors. If the observed concave hyporelief is not an artefact, it could have been formed during the early phases of the diagenesis by differential compaction of the sandy layer immediately overlying a well-indurated undertrack. After having tentatively interpreted the "Agnano track" as a sort of "second generation" imprint, we emphasize its similarities with the *Anomoepus*-like group of vertebrate ichnites, thus proposing it could testify the passage of a basal ornitischian dinosaur.

Key words - Monte Pisano, Italy, Triassic, track, dinosaurs, concave hyporelief

Riassunto - *Nuova segnalazione di un'impronta dinosauriana triassica sul Monte Pisano (Appennino settentrionale, Italia): vera o falsa?.* I depositi continentali del Triassico Superiore del Monte Pisano conservano un buon numero di tracce di tetrapodi: alcune di esse sono fra le più antiche testimonianze della presenza dei dinosauri in Italia. In questo lavoro è descritta una possibile impronta isolata osservata nel membro più alto della Formazione delle Quarziti del Monte Serra, le Quarziti Viola Zonate. Essa presenta piccole dimensioni ed è compatibile con un piccolo piede tridattilo. Tuttavia, la possibile traccia è concava e giace sul fondo di uno strato arenitico a grana fine, e ciò pone alcuni problemi nell'accettarne un'origine per calpestamento, nonostante iporilievi concavi dinosauriani siano stati recentemente segnalati da alcuni autori. Se l'impronta osservata non è un artefatto, essa potrebbe derivare dalla compattazione differenziale subita durante le prime fasi della diagenesi da un livello sabbioso immediatamente soprastante una controimpronta precocemente bio-compattata ed indurita. Avendo interpretato l'impronta studiata come una sorta di orma "di seconda generazione", si sottolinea la sua affinità con l'icnogenere *Anomoepus* e se ne propone un'origine legata al passaggio di un piccolo dinosauro ornitischio.

Parole chiave - Monte Pisano, Italia, Triassico, impronta, dinosauri, iporilievo concavo

Introduction

The Monte Serra Quartzites Formation in the Southwestern side of Monte Pisano displays a high diversity of Upper Triassic (upper Carnian according to Rau & Tongiorgi (1974)) tetrapod tracks attributed to various groups of urodele amphibians, lacertilians, non-ornithodiran archosauromorphs (rhyncosaurs, procolophonids and generic "thecodonts" *Auctt*.) and basal dinosaurs (Sirigu & Tongiorgi, 1997; Bianucci & Landini, 2005). These ichnofossils have been known for more than 130 years and gained wide attention following the works of von Heune (1940a; 1940b; 1941) who convincingly proved the presence of at least one basal theropod footprint attributed to the new ichnotaxon *Coelurosaurichnus toscanus*, later assigned by Leonardi & Lockley (1995) to the ichnogenus *Grallator* Hitchcock, 1858. For almost half a century this track remained the only dinosaurian fossil of Italy and one of the oldest evidences worldwide of early dinosaurian spread. In 1988 a new tetrapod track assemblage was discovered in a metapelitic outcrop near Lerici (La Spezia, Liguria) belonging to the Montemarcello Formation (Sirigu & Nicosia, 1995). This ichnosite presents strong similarities with the one from Monte Pisano both in age (Carnian) and in faunal composition (Leonardi, 2000; 2008). In 1997, Sirigu & Tongiorgi described two newly discovered ichnofossils from the Upper Triassic of Monte Pisano, attributing them to a basal carnivore saurischian and to a small-sized quadrupedal ornithischian respectively. The latter track is particularly interesting in the way it contributes to the extremely poor Triassic fossil record of the ornithischians and suggests the adoption of a quadrupedal posture well before the earliest (Jurassic) osteological evidences for quadrupedal ornithischians (Owen, 1861; Wilson et al., 2009). Here we provide the first description of a possible dinosaur pes imprint (the "Agnano track") from the Upper Triassic of Monte Pisano, we investigate its origin (tetrapod-related or artefact?) and propose a tentative zoological attribution.

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Geological Setting

The Monte Pisano is an isolated mountain that separates the Pisa's plain from Lucca's plain between Arno and Serchio valleys (Fig. 1) (Rau & Tongiorgi, 1974) and, together with Alpi Apuane, Montagnola Senese, and Monti di Monticiano-Roccastrada, constitutes the Middle Tuscan Ridge in which relics of the continental crust of Adria are exposed. The stratigraphic sequence of Monte Pisano is characterized by a Palaeozoic basement surmounted by Triassic to Oligocene carbonatic-siliciclastic metasedimentary formations. These metamorphic formations are surmounted by the substantially unmetamorphosed Tuscan Nappe.

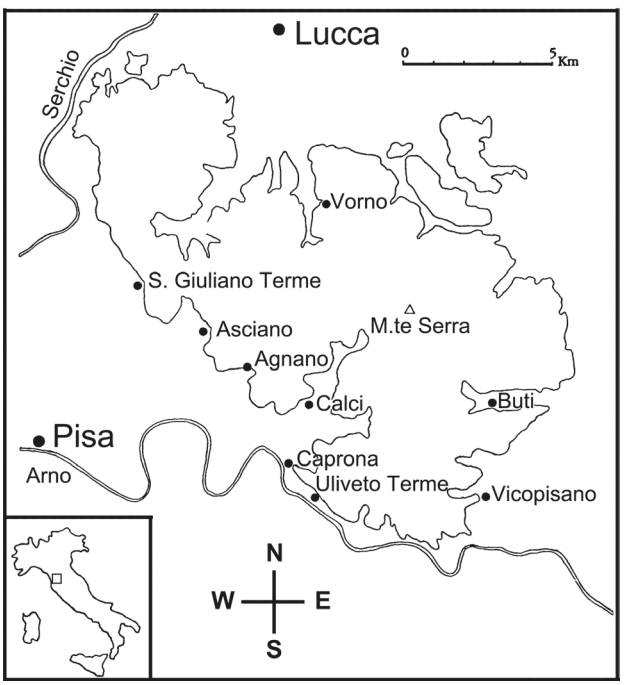

Fig. 1 - Map of the Monte Pisano area. The study area is located about 400 m north to Agnano. Modified after Ragaini (1992).

The basis of the metamorphic Mesozoic - Cenozoic succession is characterized by a thick Triassic siliciclastic sequence, divided in two formations: the Verruca Formation and the Monte Serra Quartzites Formation (Rau & Tongiorgi, 1974).
The Monte Serra Quartzites are divided into four members from the bottom to the top: the Green schists, the Green Quartzites, the White - Pink Quartzites and the Violet Banded Quartzites (Rau & Tongiorgi, 1974).
The abundant fossil footprints described by von Huene (1940a; 1940b; 1941) were found in the Violet Banded Quarzites, which represent a pond system covered only by shallow water and periodically dried up (Rau & Tongiorgi, 1974).
The possible track here studied lays about 2.5 m above the ground on a subvertical arenitic slab outcropping in an inactive quarry 400 meters north to Agnano (San Giuliano Terme, PI) (Latitude 43°44'34" N; Longitude 10°29'26" E); it has been known among professional paleontologists and amateur collectors for about 10 years and was possibly pointed out by Bianucci & Landini (2005). In the Agnano quarry a ~20 m tall, ~50 m long section of NW-dipping strata is exposed. This monoclinal succession is part of the Upper Triassic Monte Serra Quartzites Formation. In particular, the rocks outcropping in the quarry belong to the Violet Banded Quartzites, which are composed of very fine-grained, well stratified reddish arenites that alternate with purplish, finely laminated phyllites. The Agnano quarry outcrop is rich in well-preserved structures (rain drops, mud cracks, ripple marks, flute casts, tool marks, groove casts, scour and fill structures) which illustrate a transitional terrestrial-to-marine deltaic depositional environment (Figs. 2a - 2d).

Descriptive Ichnology

The "Agnano track" (Figs. 3a-3b) relies on the bottom of an arenitic bed which features also well-preserved structures as ripple marks and way-up indicators (bounce-marks, skip-marks and invertebrate burrows). It consists of a concave hyporelief, tridactyl, dinosaurian-like possible pes impression. The putative footprint is small-sized and inscribable in an ellipse about 8×11 cm. It looks superimposed on at least one tool mark, and as such, it was likely impressed while the fine-grained sandy layer was still soft. The three putative digits are short and similar in size; they are moderately sharp and form small angles between each other. A raised edge can be locally observed along the imprint perimeter, reminding the so-called displacement rim often observed in well-preserved tetrapod tracks. Between the left and the middle digit impressions, the lithified sand surrounding the putative track is faintly lifted up, thus resembling the feature (*"cuneo di pressione"*) shown by some vertebrate tracks in correspondence of the hypexes (G. Leonardi, personal communication).

Discussion And Conclusions

The putative footprint here studied has surprisingly negative relief, and this character poses some serious difficulties in order to fully embrace its tetrapod-related origin. A concave hyporelief (*sensu* Seilacher, 1964) should be complementary to a convex epirelief

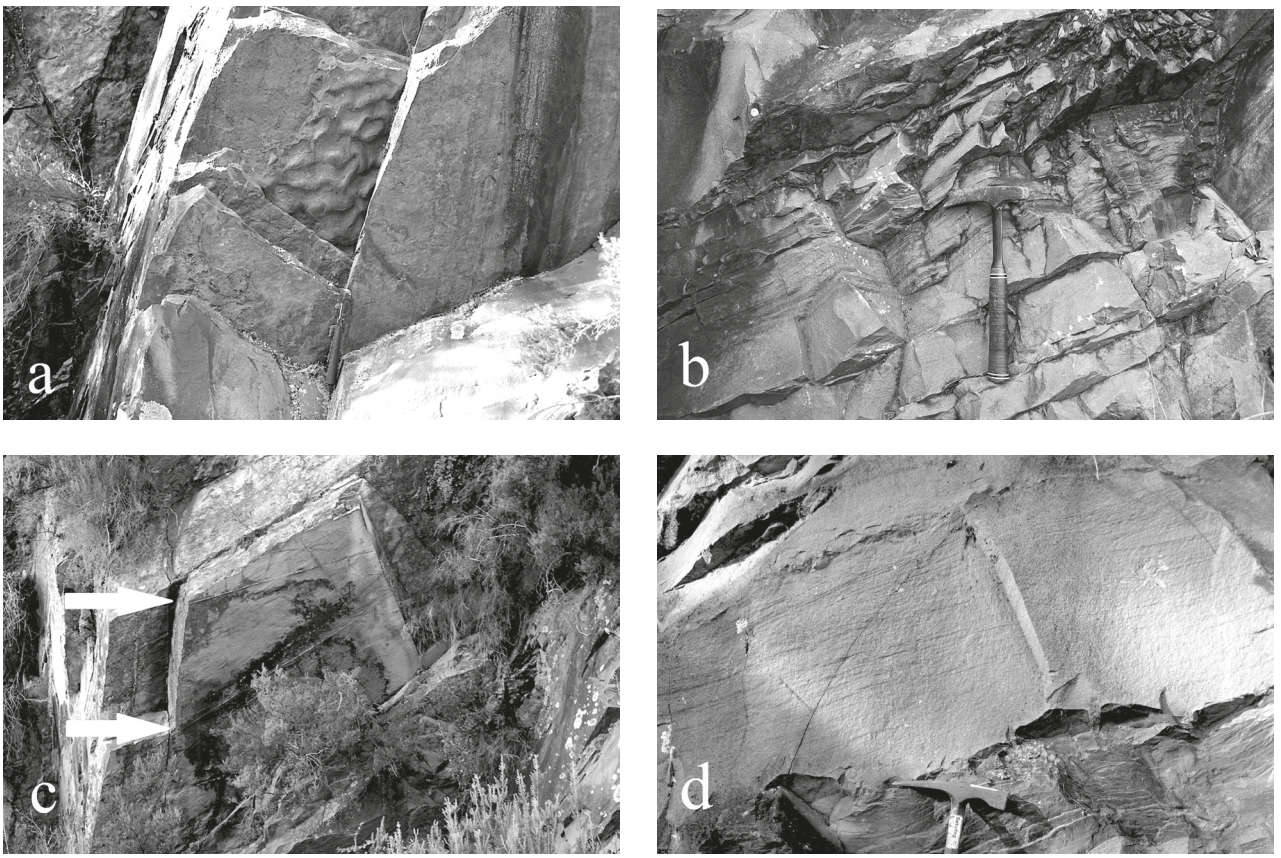

Fig. 2 - Some sedimentary features observable at the Agnano quarry, with geological hammer for scale. a) Ripple marks. b) Alternation of fine-grained arenites and finely laminated phyllites. c) Groove marks. d) Scour and fill structures.

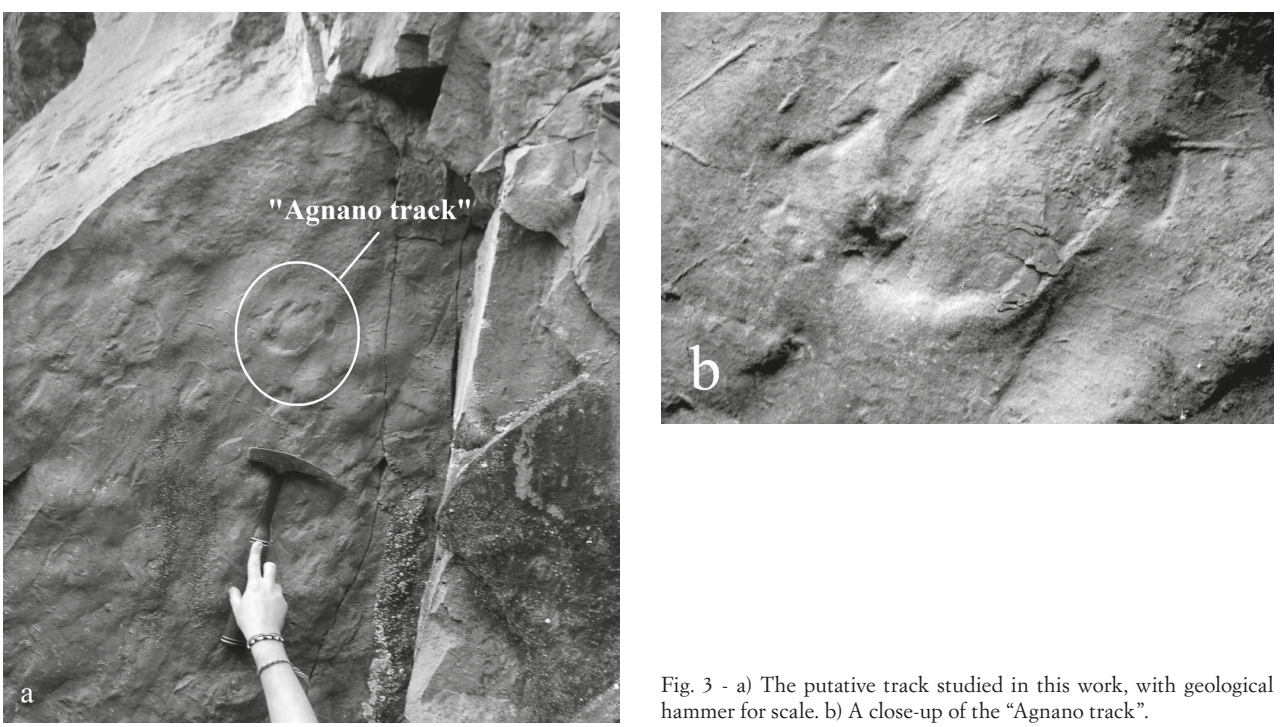

Fig. 3 - a) The putative track studied in this work, with geological hammer for scale. b) A close-up of the "Agnano track".

track. Dinosaurian convex epirelief tracks are in fact known from various tracksites, and they are generally interpreted as subsurface "undertracks" (or "compression shapes") due to the footfall compression of the sand below the ground, which locally bio-compacted the sediment favoring its strong lithification (Kappus & Cornell, 2003). The exceptionally preserved, early Cretaceous convex epireliefs of Costalomo (Spain) have been otherwise interpreted as 3D casts (sandy infills) of the dinosaur feet which stepped in a muddy ground (Huerta *et al*., 2012). Dinosaurian concave hyporeliefs are surely far less common than their convex epirelief analogues, and their mechanism of genesis and preservation has not been explored at all; anyway, they have been (although not always unambiguously) pointed out by few authors (e.g., Le Lœuff *et al*., 2006; 2009), even in association with concave epireliefs and convex hyporeliefs. Furthermore, the possible formation of a concave hyporelief starting from a concave epirelief "true track" was illustrated by Allen (1997) with regard to a two-toed mammal.

The mechanism here proposed in order to explain the "Agnano track" is illustrated in Fig. 4. Following Kappus & Cornell (2003), we assume a tridactyl foot which compresses the sand below the ground, thus generating a precociously dehydrated, well-indurated undertrack, potentially able to produce a convex epirelief. This rigid, early compacted undertrack could have acted like a nodule during the early stages of diagenesis, thus compacting less than the part of the sediment pile adjacent to it ("differential compaction" *sensu* Nichols, 2009). In this model, layers may have become draped via water expulsion around the undertrack, which is now recorded as a concave hyporelief in the immediately overlying bed (that is, the sandstone slab now hosting the "Agnano track").

This mechanism could be able to explain other tetrapod concave hyporelief tracks around the world.

On the other hand, if a footprint-related origin for the "Agnano track" is rejected, the concave hyporelief could have been generated in two ways:

1 – It could be the result of the occurrence on the ground of indeterminate objects able to generate a concave hyporelief on the superimposed layer.

2 – It could be the result of differential compaction around a foot-shaped abiogenic nodule.

Among the reported possible genetic mechanisms of the "Agnano track", on the basis of the existing literature, we preliminarily accept a tetrapod-related origin. Since it has been interpreted as a sort of "second generation" imprint, any effort to classify the "Agnano track" following ichnotaxonomic rules and, even more, any tentative zoological interpretation should be made and regarded with high caution. The observed concave hyporelief is compatible with a tridactyl foot,

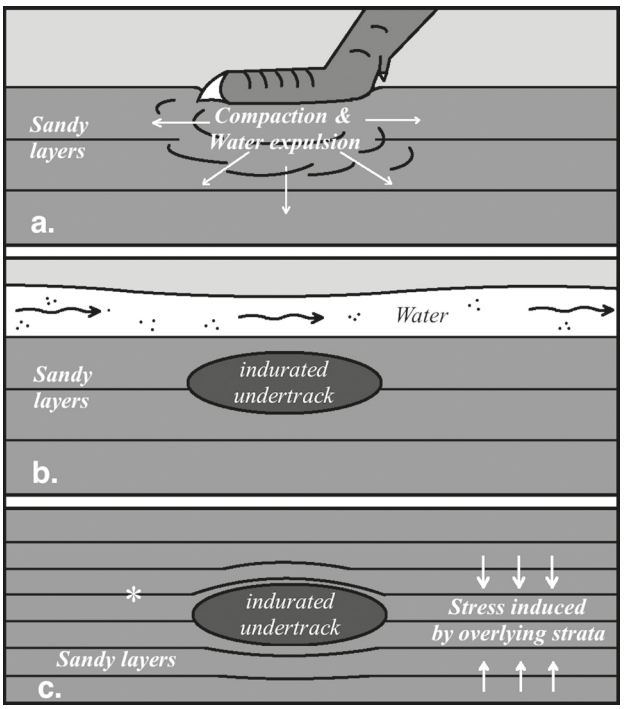

Fig. 4 - Proposed genetic mechanism for the "Agnano track". a) A tridactyl foot compresses the sand below the ground, thus generating an indurated undertrack. b) Deposition continues above the layers containing the undertrack. c) Differential compaction of the sandy layers around the undertrack occurs during diagenesis. The horizon marked with an asterisk presents a concave hyporelief induced by the underlying undertrack. Figure not to scale.

and as such, it is possibly dinosaur-related. Furthermore, the "Agnano track" is clearly non-grallatorid since the middle digit is not much more elongated than the two surrounding ones, and resembles instead some footprints belonging the Late Triassic – Early Jurassic ichnogenus *Anomoepus* Hitchcock, 1848 (e.g., the ichnospecies *Anomoepus intermedius* Hitchcock, 1865). As the *Anomoepus*-like group of tracks are nowadays attributed to early ornitischian dinosaurs (Olsen & Rainforth, 2003), and the non-predominance of the middle digit has been recognized as a typically ornitischian character for a long time (Olsen & Baird, 1986; Farlow & Lockley, 1993), the "Agnano track", if not an artefact, could testify the passage of a basal ornitischian dinosaur. It should be noted that footprints compatible with the ichnogenus *Anomoepus* are known from both the Montemarcello Formation (Leonardi, 2000) and the Violet Banded Quartzites (Sirigu & Tongiorgi, 1997).

Further investigations are required in order to resolve the genesis and possibly the ichnotaxonomic and zoological status of the "Agnano track".

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