

Tracks and trackways of “*Praemegaceros*” cazioti (Depéret, 1897) (Artiodactyla, Cervidae) in Pleistocene coastal deposits from Sardinia (Western Mediterranean, Italy)

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ABSTRACT - Tracks and trackways, belonging to the ichnogenus *Bifidipes* Demathieu, Ginsburg, Guérin & Truc, 1984, produced by the endemic cervid “*Praemegaceros*” cazioti (Depéret, 1897) have been recently discovered in Pleistocene deposits cropping out along the northern and western coast of Sardinia (Italy). Several morphotypes of *Bifidipes* traces have been observed in foreshore, backshore, washover fan, aeolianites and lagoon deposits. A preliminary analysis of the ichnofossils has been performed in order to illustrate their morphology and spatial distribution in relation to nature of substrate, and animal gait, as well as to compare the tracks left by the Sardinian cervid with those left by *Myotragus balearicus* Bate 1909, recently assigned to the new ichnospecies *Bifidipes aeolis* by Fornós, Bromley, Clemmensen & Rodríguez-Perea (2002). Shape and size of the tracks and trackways are consistent with footprints left by a middle-sized artiodactyl, travelling over more or less damp sands or sandy muddy carbonate. Moreover, footprints features (for instance: distance between two successive manus/pes tracks, stride, pace, pace angle, manus and pes rotation with respect to the midline of trackway travel direction, and pressure pad) suggest a tracemaker having the capability to move with agility on sand beaches or damp aeolian deposits. Sardinian tracks and trackways can be assigned to the ichnogenus *Bifidipes*, but due to the dissimilarities with respect to *B. velox* and the Balearic *B. aeolis*, their specific attribution remains uncertain.

RIASSUNTO - [Impronte di “*Praemegaceros*” cazioti (Depéret, 1897) (Artiodactyla, Cervidae) nei depositi costieri pleistocenici della Sardegna] - Impronte e piste del cervide endemico “*Praemegaceros*” cazioti (Depéret, 1897) sono state recentemente scoperte in depositi pleistocenici affioranti lungo la costa settentrionale ed occidentale della Sardegna (Gallura, Anglona, Nurra, Bosano, Sinis e Sulcis-Iglesiente). Le ricerche fino ad oggi condotte, hanno consentito di riconoscere in più di cinquanta sezioni migliaia di impronte riferibili all'ichnogenere *Bifidipes*, sia sulle superfici di strato che in sezione verticale, in sedimenti attribuibili ad ambienti di battigia, alta spiaggia, washover fan, lagunari e dunari. Sono state riconosciute due tipologie principali: piste (trackways), tre o più tracce consecutive prodotte dallo stesso individuo che possono essere seguite per metri; superfici di calpestio (trampling areas), gruppi di diverse tracce solitamente sovrapposte in maniera caotica che non consentono la determinazione della direzione di spostamento degli individui. Alcune impronte, si presentano come tracce semplici (simple tracks), dove le tracce della mano e del piede sono separate e non si sovrappongono, altre come tracce composte (compound tracks), dove le tracce della mano e del piede si sovrappongono completamente o parzialmente.

L'analisi degli icnofossili è stata effettuata al fine di illustrare la morfologia e la struttura delle impronte, le relazioni spaziali lungo le piste ed i rapporti tra la morfologia delle impronte e la natura del substrato. In relazione al tipo di substrato sono distinte tre tipologie principali di impronte: tracce in fanghi carbonatici sabbiosi, tracce in sabbie da medie a grossolane e ghiaie umide. Il confronto tra i parametri delle trackways (grado di sovrapposizione, passo doppio, passo, angolo del passo e scarto laterale), prodotti su differenti substrati da cervidi attuali quali *Cervus elaphus* e *Dama dama* sono simili a quelle prodotte da “P.” cazioti. Le caratteristiche delle piste oggetto di questo studio sono coerenti con la tipologia delle impronte impresse da un cervide di taglia medio-grande, che si muoveva agilmente su substrati sabbiosi o sabbiosi-siltosi umidi con un'andatura prevalente al passo o al piccolo trotto. Il materiale sardo è attribuibile all'ichnogenere *Bifidipes* Demathieu, Ginsburg, Guérin & Truc, 1984 (ichnospecie tipo *Bifidipes velox*); tuttavia, in base alle caratteristiche morfometriche si differenzia sia da *B. velox*, sia da *B. aeolis* Fornós, Bromley, Clemmensen & Rodríguez-Perea, 2002, ichnospecie istituita per le impronte del bovide endemico *Myotragus balearicus* Bate 1909. La nomenclatura del materiale sardo, attualmente ancora in corso di studio, rimane pertanto aperta.

INTRODUCTION

Tetrapod tracks, trackways and related deformation structures can constitute an important source of palaeontological and sedimentological information. Moreover, in recent times our knowledge of mammalian tracks in Holocene and Pleistocene beach, dunes, washover fans and related environments, has been significantly increased by new discoveries (for example Lewis & Titheridge, 1978; Fornós & Pons-Moyà, 1982; Loope, 1986; Lea, 1996; Fornós et al., 2002; Frey &

Pemberton, 1986; Jeong et al., 2004). In particular, Fornós et al. (2002) described tracks and trackways, produced by the extinct endemic bovid *Myotragus balearicus* Bate 1909, in the Pleistocene aeolianites from Mallorca (Balearic Islands). These tracks are preserved on steeply dipping strata of aeolian origin. Accordingly, a new ichnospecies (*Bifidipes aeolis* Fornós, Bromley, Clemmensen and Rodríguez-Perea, 2002) has been erected within the ichnogenus *Bifidipes*, created by Demathieu et al. (1984) for didactylous traces left by artiodactyls.



Fig. 1 - Location map showing fossiliferous localities: 1) Santa Teresa di Gallura; 2) Punta Tramontana; 3) Alghero (several sites); 4) Bosa; 5) Funtanamare and Porto Paglia; 6) Porto Pino.

The aim of this work is to give preliminary notice on the occurrence of abundant footprints belonging to *Bifidipes* ichnosp. indet. recently found in foreshore, backshore, washover fan, aeolianites, and lagoonal Pleistocene deposits, locally cropping out along the northern and western Sardinian coast (Gallura, Anglona, Nurra, Bosano, Sinis, and Sulcis-Iglesientes; Fig. 1).

MATERIAL AND METHODS

The material consists of almost one thousand tracks recognised on both bedding surface and vertical sections. The degree of weathering is, in this preliminary phase of analysis, not very important, because only the best-preserved footprints have been described.

Tracks and trackways assigned to *Bifidipes* have been observed in more than fifty stratigraphical sections and outcrops located at Santa Teresa di Gallura, Punta Tramontana (Castelsardo), Cala Bona, Il Cantaro, and at neighbourhoods of Alghero (Nurra), Torre Argentina and Torre Columbargia (Bosa), Funtanamare and Porto Paglia (Gonnesa), and Porto Pino (Sant'Anna Arresi) localities (Fig. 1).

Tracks and trackways have been here described adopting nomenclatures and methods proposed by

Sarjeant (1975), Lockley (1991), Allen (1997), and Fornós et al. (2002); the most common measured parameters are: stride (distance between two successive impressions left by the same foot), pace (distance between the impression of the right *manus* or right *pes* and the left *manus* or left *pes* on opposite side), step angle or pace angulations (angle formed by lines joining the midpoint of three successive *manus* or *pes* - left-right-left or right-left-right - imprints in trackway), and side skid (straddle distance between the right and left side imprints in a trackway).

DESCRIPTION

Tracks and trackways have been found on naturally exposed surfaces mainly corresponding to originally stiff or firm sandy carbonate mud, and fine, coarse or pebbly sands having more or less high moisture content.

On the bedding surface, groups of numerous tracks are frequent. Two morphotypes prevail: first, trackways (two or more consecutive footprints belonging to a single individual) that can be followed for meters (the longest documented consist of about 3-4 m; Figs. 2, 7), second, groups of several tracks, sometimes overlapping in various degree, that can be observed within rather restricted trampling areas (about 50 square cm; Pl. 1, fig. 5), thus the original direction of movement cannot be detected.

Tracks are also seen in vertical section, mainly corresponding to natural sections exposed by erosion or collapsed and fallen blocks, showing horizons with a sequence of single or compound traces, corresponding to a trackway. In some case, many horizons are trampled in such a degree that individual tracks cannot be distinguished (Fig. 3).

Some footprints appear as "simple tracks", where the tracks of *pes* and *manus* are separated and do not overlap. "Compound tracks", where the tracks of *manus* and *pes* overlap or coincide in various degrees, produced a double track; the last type seems to be more frequent.

Traces on sandy mud

On firm sandy carbonate mud footprints are on average smaller, more or less deep, with well defined shapes, anatomical features and evident marginal ridges, whereas in zones of plastic deformation "pressure pads" are very reduced or absent, especially on the posterior side (Pl. 1, fig. 5). The radial fractures, typical of muddy humid substrata (Allen, 1997), are reduced or apparently absent. Drag marks are occasionally present even if poorly developed, whilst external posterior pits (imprints produced by second and fifth digits) are uncommon. Plastic deformation caused folding of sediment in the interdigital clefts, toes are clearly separate and slightly divergent and finally the *manus* had rather more divergent hoofs than in the *pes*. Undulating undertraces and related smoothed microfolds are present within sediments for a few millimetres. Dimensions of single tracks vary from about 60 to 70 mm (length) and from 57 to 69 mm (width). In the compound tracks, the average dimensions are 98 (length) x 80 (width).

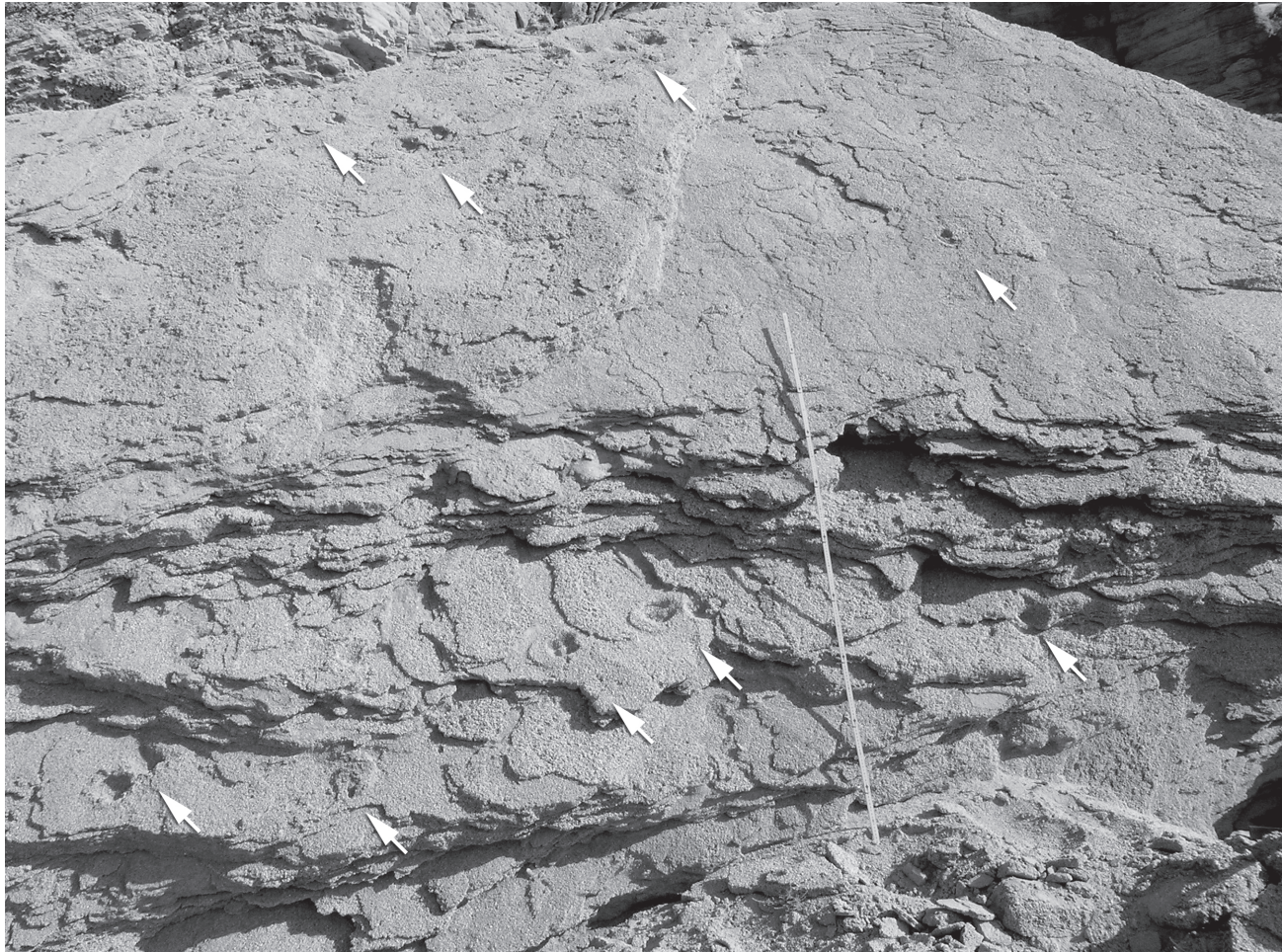


Fig. 2 - Trackways on pebbly coarse sandstones. Porto Paglia (Gonnesa), south-west Sardinia.

Traces on damp sand

Traces impressed on damp sandy sediments are usually deeper than those impressed in mud sediments. Tracks show less defined marginal ridges and anatomical features could sometimes be recognised on the bottom of the foot impression (distal transversal section, *sensu* Fornós et al., 2002), whereas the external zone of deformation and "pressure pads" are widely extended, especially on the lateral and posterior side of the trace (Fig. 4). Single radial large fractures can occasionally be observed. Drag marks and external posterior pits are absent. In longitudinal section, deformation produced during the penetration of fore and hind limbs are extensively developed, whilst deformation caused by hoof rotation are not always detectable. Backward thrust of the limb during forward movement caused displacement of sediment along a shear, slightly concave surface (pressure pad), visible on the sediment surface as concentric fractures, having millimetric vertical dislocation and microfaults. The presence of shear zones, the depth of the bioturbation, its morphology and the amount of sediment moved during the impression, is consistent with a rather high content of water into the sediment when the trackway was made.

The dimensions of compound tracks, prevailing on damp sandy bedding surfaces, vary from about 80 to 110 mm (length) and from 55 to 100 mm (width).

Traces on pebbly sand

Footprints found on pebbly and coarse sands are similar in shape, but less deep, than those impressed on damp sands (Figs. 2, 5). Nonetheless, the presence of an extended lateral-posterior deformation, as well as of

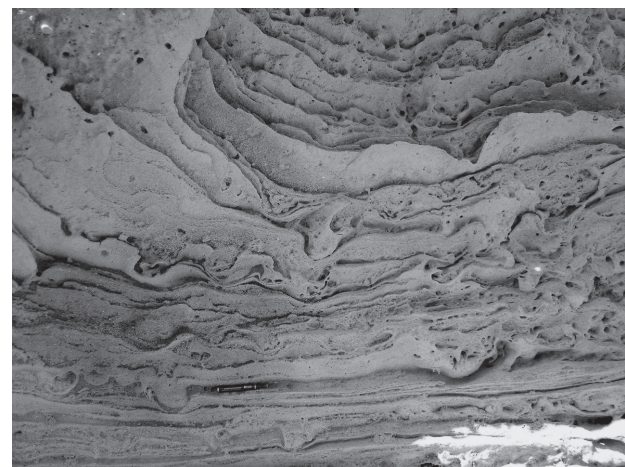


Fig. 3 - Trampled grounds, observed in vertical section, showing a high degree of trampling but with some preservation of lamination. Torre Columbargia (Bosa), north-west Sardinia.

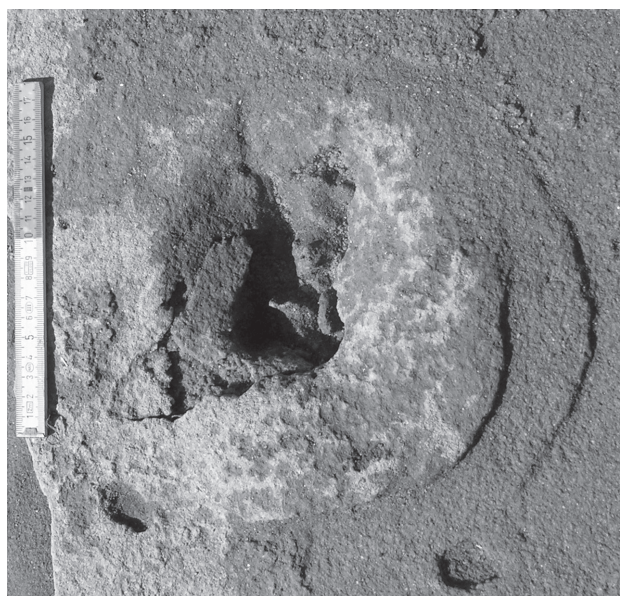


Fig. 4 - Compound tracks impressed on the damp sand; note the curved microfaults separating pressure pads. Porto Paglia (Gonnesa), south-west Sardinia.

curved shear surface and circular microfault boundary, suggest a low water content. The bioturbation of footprint impressions and relative deformations of the underlying laminae may reach 10 cm below the topmost surface. Dimensions of the single tracks vary from about 100 to 110 mm (length) and from 70 to 90 mm (width).

Compound tracks are clearly recognisable in trackways on bedding-parallel surfaces. *Pes* track is superimposed on the *manus* track, but the overlap is rarely complete. The *pes* trace, even if not rotated or laterally/medially shifted was not impressed exactly within the pre-existing *manus* track, but fell close behind the *manus* trace. As a result, details of structural deformation produced by fore and hind foot may be complicated. The pressure pad belonging to the *manus* track, where present, is normally cut across by the *pes* track and a new pressure

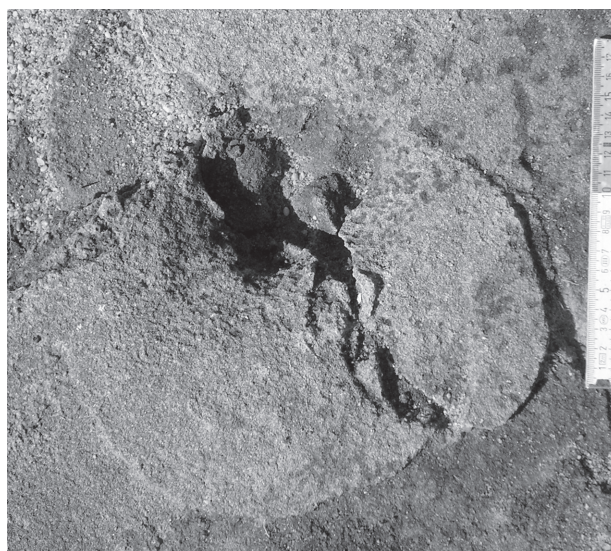


Fig. 6 - Compound tracks impressed on damp sand. Note the marked upward displacement of sediment due to the pressure of the *pes* on the pressure pad produced by the *manus*. Porto Paglia (Gonnesa), south-west Sardinia.

pad develops. Such a deformation may create significant upward displacement of sediment in damp sands, that can produce one or more large radial fracture (Fig. 6). Compound tracks on sandy carbonate mud do not usually have any evident pressure pads.

Measurements on the best-preserved trackways, impressed on damp sandy substrate (Fig. 7) (dimensional range: stride = 95-100 cm; pace = 45-50 cm; side skid = 9-12 cm; pace angulation = 155°-165°) are referable with a slow trotting or walking. During this movement, the fore foot (right or left) was lifted and placed on the ground at the same time as the opposite hind foot.

A “foot in foot” pattern of tracks (Bang & Dalström, 2001), typical of deer walking at slow speed, seems to be uncommon; in any case, it is difficult to recognise this pattern especially in very short trackways, and when tracks were impressed at more or less equal distance.

DISCUSSION

In Sardinia, cervid remains ascribed to the endemic species “*Praemegaceros cazioti*” (Depéret, 1897) are relatively common in the late Middle and late Pleistocene deposits. The majority of the specimens have been retrieved from karstic fissure fillings and cave deposits, whereas only isolated remains have been found in aeolianites or in alluvial deposits (cf. Palombo 2005, Palombo, 2006 and references therein). Cervid remains in anatomical articulation have also been recorded in “aeolian” deposits (Comaschi Caria, 1953; Fanelli, 2003).

Therefore, during the Pleistocene, endemic deers were present in coastal areas, such as beaches and dunes, where probably they were, as occurs nowadays, attracted by salt crusts. For this reason, “*P.*” *cazioti*’s herds and



Fig. 5 - Tracks showing slight upward displacement of “pressure pad” on the left side, made during the impression of the footprint into moist pebbly and coarse sandstone. Porto Paglia (Gonnesa), south-west Sardinia.

single males were usual frequenters of these places, which are particularly suitable for track preservation.

Indeed, the main characteristic of the sediments which play a significant role in track preservation are: grain size (in coarse sediments anatomical features are less preserved); moisture content (defined or undefined shapes, as well as clearly impressed or blurred tracks depend on water content); sediment macrofabric; cohesion of the substrate and slope of the substrate surface (Frey & Pemberton, 1986; Allen, 1997). In addition, there are also influences due to reworking by external agents (waves and tides, wind) and time of exposure and/or burial. Further intensive trampling and the extent of vegetation cover (occurrence of grass, reeds or scrub brush, carpet the ground surface) avoid foot impressions.

The behaviour gait and size of the tracemaker are also fundamental for preservation (for instance, tracks produced by heavy individuals deeply impress in the substrate, and are easily preservable, (see Sarjeant, 1975; Laporte & Behrensmeyer, 1980; Scrivner & Bottjer, 1986; Allen, 1997; Fornós et al., 2002).

The most suitable environment are represented by tidal and flood plains, lagoons periodically subject to water level oscillations and even complete desiccation, and distal portions of washover fans, where moist, coherent, fine-grained sediments are present. Mammals trampling on such muddy sandy sediment, still damp or wet, impress footprints that can easily be preserved if the sediment surface hardens, and then are covered by low-energy flooding, whose suspension load fills and buries the tracks (Sarjeant, 1975).

As far as the studied ichnofossils are concerned, they were impressed, as in sub-modern environments, on various substrates, ranging from moist coarse to fine sands and rather plastic sandy carbonate mud. The ideal conditions were approached in the case of firmer muddy horizons, locally showing mud cracks, where the tracks are more or less clearly impressed and commonly well-defined in shape (Pl. 1, fig. 5; Fig. 8). The depositional environment of these tracks could be represented by stagnation areas, covered by a fine water film, periodically subjected to desiccation.

Preliminary tests on imprints production carried out during this study in present-day sands and pebbly sands of the Porto Paglia beach, shows that the most favourable conditions for well-defined track production *versus* preservation occurs when the water content is within 15 to 17%. These data has been obtained producing imprints in very humid to dry deposits and making comparisons with the morphology and shape of the produced traces with those preserved on sandstones (Figs. 4-5). The sediment with the more significant imprints has been sampled and the water content calculated by evaporation. For equivalent granulometries, in wet to very humid fine sands and pebbly sands, the footprints show less defined anatomical features and do not show pressure pads, while in moist sands the footprints are deeper and the pressure pads are well defined. The footprints produced in dry deposit are less deep, do not show clear anatomical features, and the pressure pads are undefined.

So, tracks represent a useful tool, coupled with sedimentological data, that help to evaluate the moisture

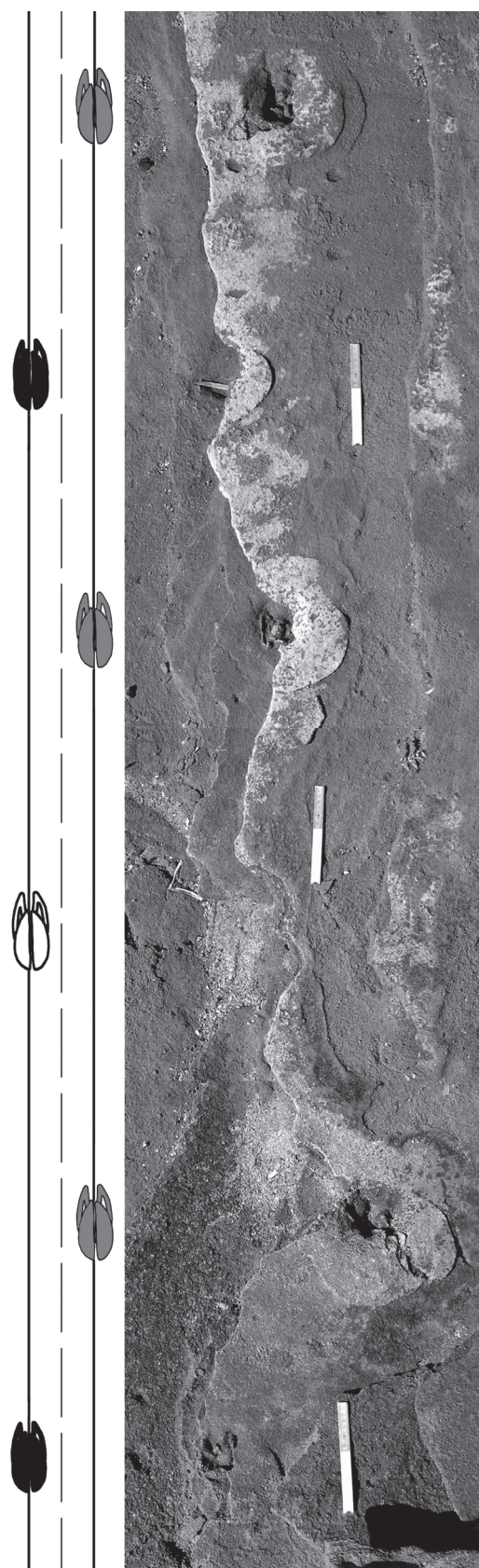


Fig. 7 - Right: trackway (about 4 metres) impressed on damp sand by a slow walking single animal, as indicated by incomplete overlapping of the *pes* tracks on *manus* tracks. Left: line drawing of same trackway showing *pes* and *manus* in black, the right *pes* and *manus* in grey and a track affected by erosion in white. Porto Paglia (Gonnesa), south-west Sardinia.



Fig. 8 - Single track impressed on muddy carbonate, showing well-defined anatomical features. Porto Paglia (Gonnesa), south-west Sardinia.

content of the substrate at the time when traces were made. “*P.*” *cazioti*’s tracks, for example, have been recognized on bed surfaces, from distal fan depositional environments or lagoonal edge (low-energy shallow waters) and backshore deposits. The presence of defined tracks and pressure pads on these bedding surfaces suggest a moist substrate, not wet, but periodically emergent.

The individual attributes of trackmakers should not be underestimated. Dimensional variability of single tracks is actually affected by an animal’s weight and size, so strictly connected with its age and sex.

The comparison between the trackway parameters (stride, pace, side skid, and pace angulation) on different substrates left by modern cervids (*Cervus elaphus*) and fallow-deer (*Dama dama*), are similar to those produced by “*P.*” *cazioti* studied here.

However, we note that the parameters observed on trackways left by “*P.*” *cazioti* are indicative of animals having a size slightly larger than the average fallow-

deer. These parameters are very close to those of *Cervus elaphus*, excluding the adult males belonging this species.

In equivalent substrate conditions, tracks produced by *Myotragus balearicus* (assigned to *Bifidipes aeolis*) and “*P.*” *cazioti*’s tracks are very similar and differ only in size and shape. Both track and trackway differences are referable to the size and the skeleton morphology, and consequently to the gait. *M. balearicus* is characterized by powerful gait and lack of pogostick locomotion (Sondaar, 1977; Bover, 2004), while “*P.*” *cazioti* had a mostly rapid gait and more autopodial and acropodial flexibility (Caloi & Palombo, 1995). Although *M. balearicus* had short limbs and a walking or slow trotting gait, the side skid is proportionally bigger than the Sardinian deer.

Accordingly, Sardinian tracks and trackways can be assigned to ichnogenus *Bifidipes*, but due the dissimilarities with respect to Balearic *B. aeolis*, their specific attribution remains still open.

CONCLUSIONS

The study of thousands of tracks and trackways from the Pleistocene deposits, located along the northern and western coast of Sardinia (Italy), allows us to assign the traces fossil to *Bifidipes* ichnosp. indet. The footprints were left by middle-sized artiodactyls, assigned here to the endemic cervid “*Praemegaceros*” *cazioti*, (that is the single cloven-hoofed artiodactyl present on the island at that time). The tracks occur on bedding surfaces, from lagoonal, distal fan and backshore deposits environments and aeolianites.

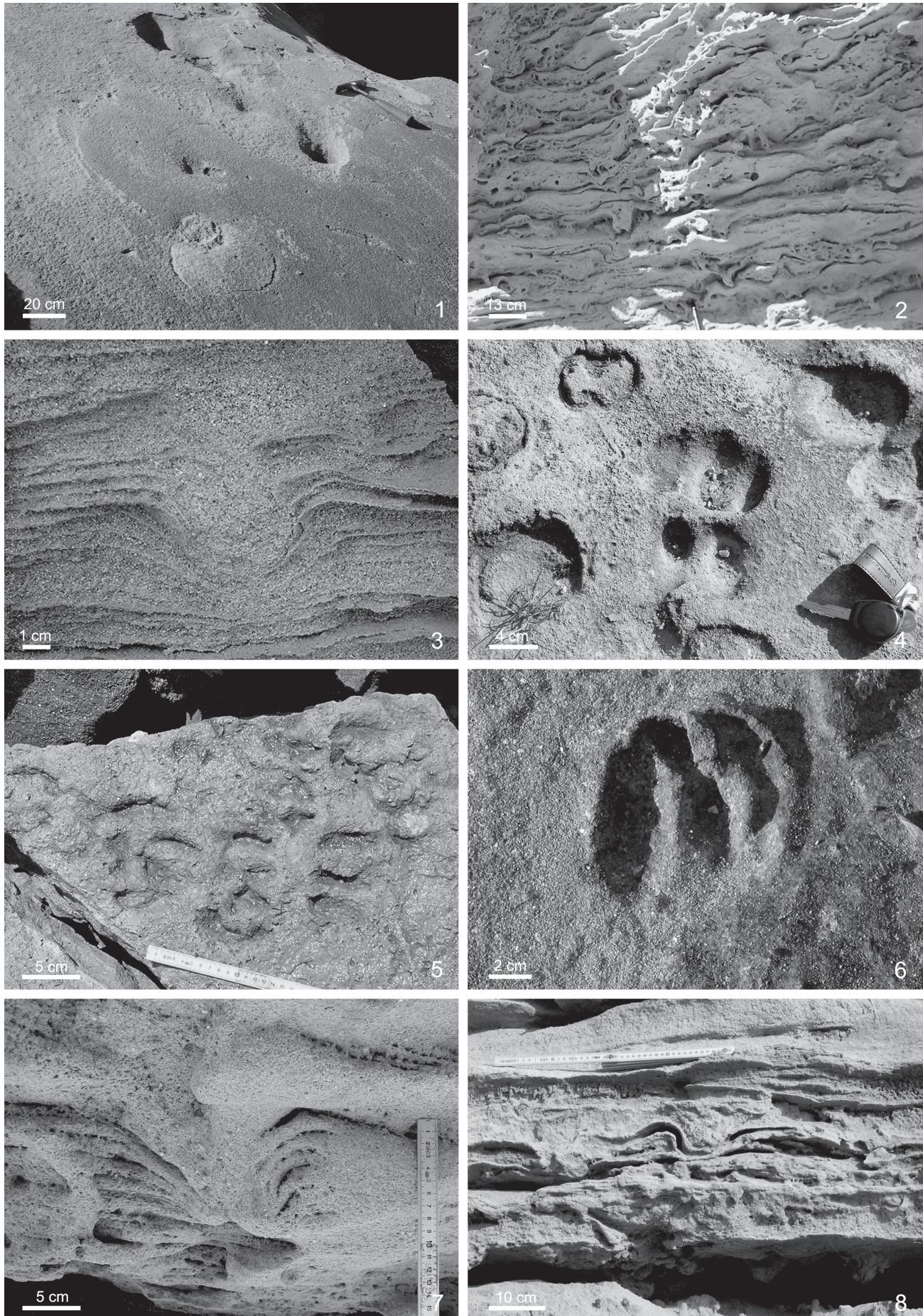
Two main imprints associations were produced: simple tracks and, more frequently, compound tracks.

As suggested by trace production tests, the morphology of the tracks is strongly related to the substrate conditions (mainly grain size and water content) and to the sedimentary context (potential of preservation); thus, the comparison with *Bifidipes* figured here, allow us to estimate the moisture content of the substrate at the time when the traces were made.

EXPLANATION OF PLATE I

figs. 1-8 - *Bifidipes* ichnospecies indet.

- 1 - Tracks on steeply dipping surfaces. Porto Pino (Sant’ Anna Arresi), south Sardinia.
- 2 - Trampled ground seen in cross section. Torre Columbargia (Bosa), north-west Sardinia.
- 3 - Oblique section showing rather deep undertraces and curved laminae. Santa Teresa di Gallura, north Sardinia.
- 4 - Trampled surface showing proximal to medial horizontal sections of tracks. Sediment deposited within the tracks is locally preserved. Alghero (Nurra), north-west Sardinia.
- 5 - Trampled bedding surface showing single and compound tracks impressed on sandy carbonate mud. Porto Paglia (Gonnesa), south-west Sardinia.
- 6 - Compound track on damp sand. Porto Paglia (Gonnesa), south-west Sardinia.
- 7 - Cross section of sandstone showing footprints impression and relative deformation of the underlying laminae. Porto Paglia (Gonnesa), south-west Sardinia.
- 8 - Tracks and trackway in cross or external oblique section on different horizons. Il Cantaro (Alghero), north-west Sardinia.



The relationships between granulometry/water content face to the same tracemaker can be summarized as follow:

- on firm sandy carbonate mud footprints are on average smaller, more or less deep, with well-defined shapes;

- on damp sandy sediments they are usually deeper than those impressed in mud sediments and tracks show less-defined anatomical features, whereas the external zone of deformation and "pressure pads" are widely extended, especially on the lateral and posterior side of the trace;

- on pebbly and coarse sands, the tracks are similar in shape, but less deep, than those impressed on damp sands; nonetheless, the presence of an extended lateral-posterior deformation, as well as of curved shear surface and circular microfault border, suggest a low water content.

The comparison between the tracks left by *Cervus elaphus* and *Dama dama* are very similar to those produced by "*P.*" *cazioti*, however, the parameters observed on trackways left by "*P.*" *cazioti* are indicative of animals having a size slightly larger than the average of fallow-deer and smaller than the adult males of *C. elaphus*.

The tracks impressed by "*P.*" *cazioti* show some common features with the ichnospecies *Bifidipes aeolis* (left by *Myotragus balearicus*) when produced in similar substrates. Both track and trackway dissimilarities are referable to the size and the skeleton morphology, and consequently to the gait.

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