

## New dinosaur tracksites from the Sousa Lower Cretaceous basin (Paraíba, Brasil)

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**SUMMARY** - *New dinosaur tracksites from the Sousa Lower Cretaceous basin (Paraíba, Brasil)* - During our 30<sup>th</sup> expedition to the Lower Cretaceous Rio do Peixe basins (Paraíba, Northeastern Brasil) the following new dinosaur tracksites were discovered: Floresta dos Borba (theropods, sauropods, ornithopods), Lagoa do Forno (theropods, sauropods), Lagoa do Forno II (one theropod), Várzea dos Ramos II (theropods), Várzea dos Ramos III (theropods). In the previously known sites the following new material was discovered: at Piau, a sauropod trackway; at Serrote do Letreiro a new theropod trackway; at Riacho do Cazé, some sauropod and theropod tracks; at Mãe d'Água, new sauropod, theropod and ornithopods footprints. At Fazenda Paraíso new theropod and sauropod tracks were discovered and a new map of the main rocky pavement including theropod tracks is provided here. The farms at Saguim de Cima, Várzea da Jurema, Tabuleiro, Catolé da Piedade (WNW of Sousa, in the Sousa Formation) and at Pau d'Arco (SE of Sousa, in the Piranhas Formation) were explored without results.

**RIASSUNTO** - *Nuove piste di dinosauri nel bacino di Sousa (Cretaceo inferiore, Paraíba, Brasile)* - Durante la nostra 30<sup>a</sup> spedizione ai bacini del Rio do Peixe (Cretaceo inferiore; Paraíba, Brasile nord orientale) sono stati scoperti i seguenti nuovi siti con piste di dinosauri: Floresta dos Borba (teropodi, sauropodi, ornitopodi), Lagoa do Forno (teropodi, sauropodi), Lagoa do Forno II (un teropodo), Várzea dos Ramos II (teropodi), Várzea dos Ramos III (teropodi). Nelle località già note, è stato scoperto nuovo materiale: al Piau, una pista di sauropodo; al Serrote do Letreiro una nuova pista di teropodo; al Riacho do Cazé, alcune orme di sauropodi e teropodi; a Mãe d'Água, nuove orme di sauropodi, teropodi e ornitopodi. Nella Fazenda Paraíso sono state trovate nuove orme di teropodi e sauropodi; viene qui pubblicata una nuova mappa del pavimento roccioso principale con piste di teropodi. Le esposizioni di sedimenti nelle fattorie di Saguim de Cima, Várzea da Jurema, Tabuleiro, Catolé da Piedade (WNW di Sousa, nella Formazione Sousa); Pau d'Arco (SE di Sousa, Formazione Piranhas) sono state esplorate per ora senza risultato.

**RESUMO** - *Novas localidades com pegadas de dinossauros da bacia de Sousa (Cretáceo Inferior, Paraíba, Brasil)* - Durante a 30<sup>a</sup> expedição à Bacia do Rio do Peixe, Cretáceo Inferior (Nordeste do Brasil) foram descobertas as seguintes novas localidades com pegadas de dinossauros: Floresta dos Borba (Theropoda, Sauropoda e Ornithopoda), Lagoa do Forno (Theropoda e Sauropoda), Lagoa do Forno II (um Theropoda), Várzea dos Ramos II (Theropoda), Várzea dos Ramos III (Theropoda). Novos achados nos sítios já conhecidos são aqui apresentados: no Piau, uma pista de Sauropoda; no Serrote do Letreiro uma pista de um novo Theropoda; no Riacho do Cazé, algumas pegadas de Sauropoda e Theropoda; em Mãe d'Água, novo Sauropoda e pegadas de Theropoda e Ornithopoda. Na Fazenda Paraíso, novas pegadas de Theropoda e Sauropoda foram descobertas; um novo mapa do principal pavimento rochoso desta localidade com pistas de Theropoda é apresentado. As localidades Saguim de Cima, Várzea da Jurema, Tabuleiro, Catolé da Piedade (WNW de Sousa, na Formação Sousa), Pau d'Arco (SE de Sousa, na Formação Piranhas) foram exploradas sem resultado.

**Key words:** dinosaurs, tracks, Lower Cretaceous, Sousa (Brasil)

**Parole chiave:** dinosauri, orme, Cretaceo inferiore, Sousa (Brasile)

**Palavras chaves:** dinossauros, pegadas, Cretáceo Inferior, Sousa (Brasil)

### 1. INTRODUCTION

The so-called Brazilian “Dinosaur Valley” (*Vale dos dinossauros*) is a Lower Cretaceous basin (~50 km E-W x ~17 km N-S) in the *Sertão do Rio do Peixe*, i.e. the semi-arid valley of the Peixe River, that

contains large numbers of dinosaur tracks (Leonardi 1994). This basin, called formally Sousa Basin, along with the Uiraúna-Brejo das Freiras and Pombal Basins, is located on the west of Paraíba State, Northeast Brasil.

The tetrapod ichnofauna comprises isolate foot-

prints and trackways of large and small theropods, sauropods, ornithopods and quadrupedal ornithischians. There are also invertebrate ichnofossils. The body fossils include palynomorphs, plant fragments, ostracods, giant conchostraceans, fish scales and crocodylomorph bone fragments preserved in alluvial fans, anastomosing and meandering rivers and shallow lakes deposits of Neocomian age-Berriasian to lower Barremian.

The Sousa basin is important for the abundance of its dinosaurian ichnofaunas. Twenty two ichnofossiliferous sites have been mapped and preliminary reports published: they include 296 large theropod tracks, 29 smaller theropods, 42 sauropods, two quadrupedal ornithischians, two small ornithopods, 28 graviportal ornithopods, a set of batrachopodid footprints, one lacertoid footprint, a large number of unclassifiable dinosaurian tracks and a very large number of small chelonian half-swimming tracks. Prior to this last expedition, the number of classified dinosaurian individual tracks was about 400 (Fig. 1).

The area including the dinosaur tracks at Passagem das Pedras (Ilha Farm), in Sousa County, is nowadays a natural park, the Dinosaur Valley Natural Monument (*Parque do Vale dos dinossauros*). The park, with an area of 40 ha, is presently one of the best preserved paleontological sites in Brasil (Schobbenhaus *et al.* 2002). The park has a rather large tourism infrastructure which includes a resort and a trained staff to guide tourists and to protect the paleontological sites (Fig. 2).

## 2. GEOLOGICAL CONTEXT

The origin of the Peixe River basins is related to fault movements along preexisting structural lines of the basement, during the South Atlantic Ocean opening. The age of their deposits is Berriasian to lower Barremian. These deposits reflect a direct control of sedimentation by tectonic activity. Along the faulted borders of the basins, the paleoenvironments consisted of alluvial fans, changing to an anastomosing fluvial system more distally. In the central region of the basins, a meandering fluvial system was established, with a wide floodplain that included perennial and temporary lakes (Carvalho 2000a).

Mabesoone (1972) and Mabesoone & Campanha (1973/1974) formally designated the Rio do Peixe Group with a total thickness of 2,870 meters and subdivided it into the Antenor Navarro, Sousa and Piranhas Formations.

The Antenor Navarro and the Piranhas Formations are composed of immature sediments, including breccias and conglomerates, with pebbles of metamorphic and magmatic rocks in a coarse arkose matrix. The first formation is located near the faulted northern

border of the basin and the second along the southern border of the same basin. Toward the basin depocentre, there are conglomeratic and fine sandstones, sometimes interbedded with siltstones and shales. Cross-channel and tabular stratification, climbing-ripples and ripple marks are the main sedimentary structures. The lithologies are conglomerates, coarse sandstones and sandstones interbedded with siltstones. The lithofacies, sedimentary structures and geometry of the beds suggest sedimentation in fan-delta, alluvial fan and anastomosing fluvial environments.

The Sousa Formation is composed of reddish sandstones, siltstones, mudstones and carbonate nodules; marls also may occur. Common sedimentary structures include mud cracks, convolute structures, ripple marks, climbing ripples, rain drop marks and bioturbations (Leonardi & Carvalho 2002).

## 3. THE NEW SITES

The authors were recently invited by the city of Sousa and its Mayor Salomão Gadelha as speakers at the local "1<sup>st</sup> International Festival of the Valley of Dinosaurs" (Sousa, 19-20 December, 2003). Before and after the event, one of us (G.L.) went to the field and so accomplished his 30<sup>th</sup> expedition in this area (15<sup>th</sup>-29<sup>th</sup> December 2003).

### 3.1. Floresta dos Borba (code: SOFL)

The occurrence of tracks in the hamlet of Floresta dos Borba and environs was reported to us by Mr Robson Araújo Marques and Mr Luiz Carlos da Silva Gomes. The site is located almost at the foot of the Serrote Jerimum, at the northern margin of the Sousa Basin, 14.7 km WNW of Sousa, as the crow flies (6°41'39"S; 38°20'54"W) (Fig. 3). The conglomerates and yellow sandstones of this outcrop belong to the Antenor Navarro Formation. A short on-the-spot investigation was done here, in the last day of this expedition. However, there is scope for considerably more research to be carried out at this site.

In the area, around the small hamlet of Floresta dos Borba, an extense rusty rocky surface (strike N40°W, dip 6°-10° to the S), the following dinosaurian tracks were discovered from West and Eastwards.

- Three large theropod isolated tracks. SOFL 1 is a large, very deep, tridactylous, right footprint, 45 cm long, 52 cm wide, with high digit divarication (II-IV), up to 84°: the trackmaker was heading ~S75°W (Figs 4a, 5). SOFL 3 is a large, very shallow, tridactylous, left footprint, recognizable only from the different color of the sediment, 39 cm long, 46 cm wide, with high digit divarication (II-

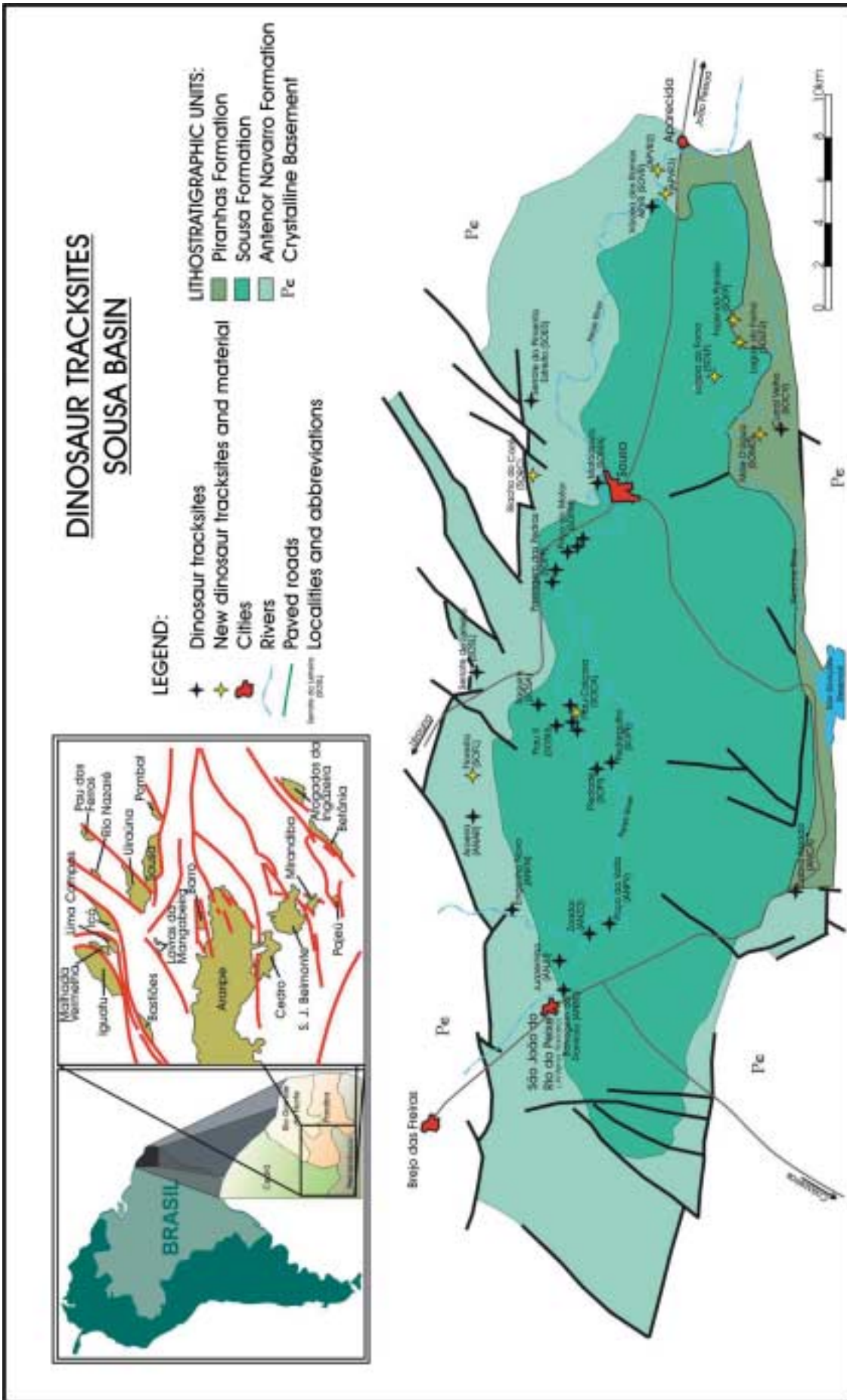


Fig. 1 - Location map of Sousa basin, Paraíba, Northeast Brasil, and of its local ichnofaunas. The symbols of the new sites and new material are printed in yellow. The small map is redrawn from Leonardi & Carvalho (2002).

Fig. 1 - Mappa di localizzazione del bacino di Sousa, Paraíba, Nordest del Brasile, e delle sue icnofaune locali. I simboli dei nuovi siti e dei siti con nuovo materiale sono indicati in giallo. La mappa a scala minore è ridisegnata da Leonardi & Carvalho (2002).

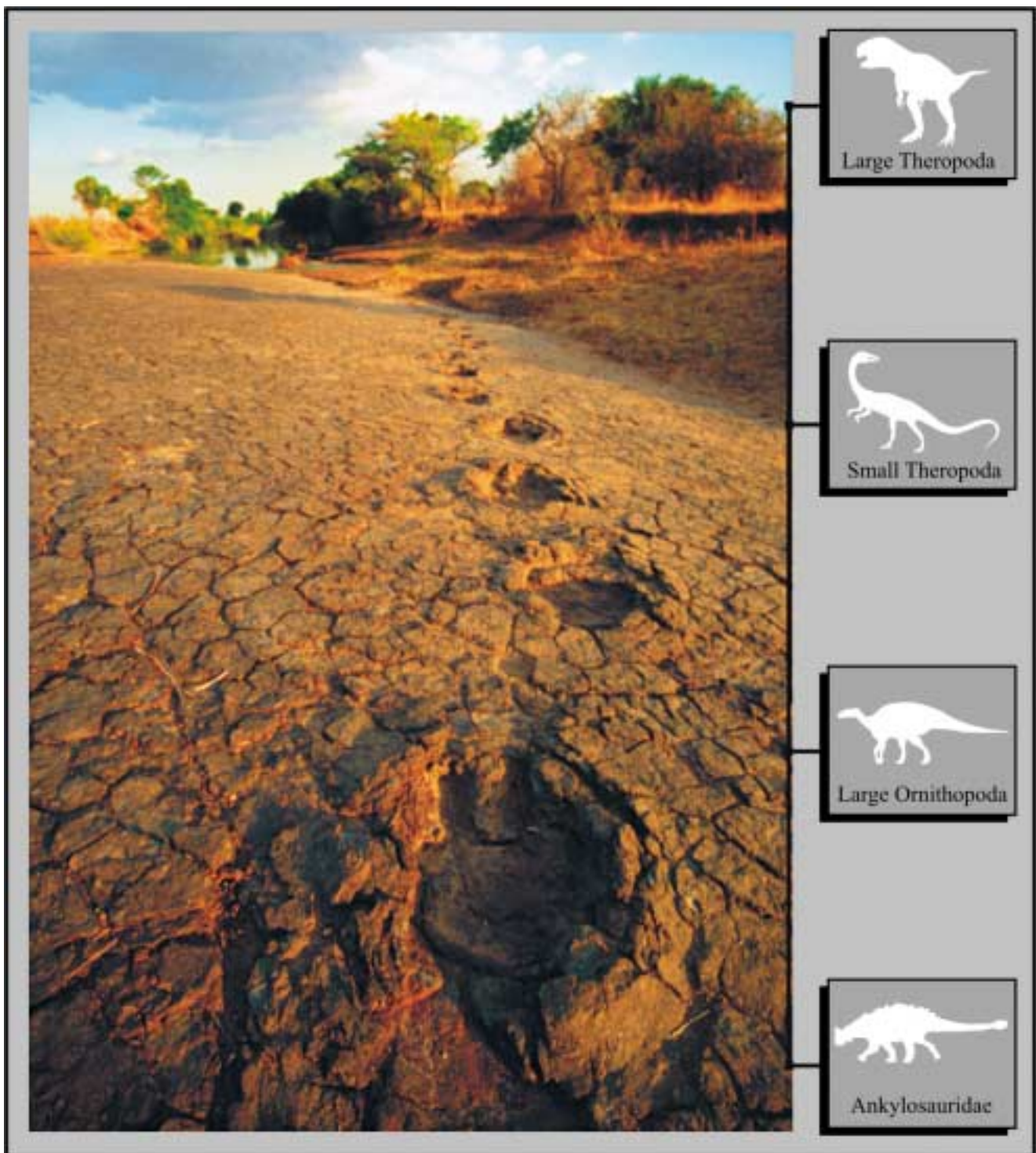


Fig. 2 - The Natural Park Vale dos dinossauros at Passagem das Pedras, Ilha Farm, with 40 ha of area, is presently one of the best preserved paleontological sites in Brasil. This area is now a tourism infrastructure and offers a tourism resort, besides a trained staff to guide tourists and to protect this and the other paleontological sites of the Sousa basin. The Ilha Farm ichnofauna includes large and small theropod, ornithopod and ankylosaur tracks. All photos by Giuseppe Leonardi.

*Fig. 2 - Il Parco Naturale Vale dos dinossauros, nel sito Passagem das Pedras, nella Fazenda Ilha, con 40 ha di area, è attualmente uno dei siti paleontologici meglio preservati del Brasile. Quest'area è un'infrastruttura turistica e offre un centro di informazioni e servizio, e un piccolo museo. Un gruppo guide accompagna i visitatori e vigila su questo sito paleontologico come pure sugli altri del bacino di Sousa. L'icnofauna della Fazenda Ilha comprende piste di teropodi di piccole e grandi dimensioni, ornitopodi e anchilosauri. Tutte le foto sono di Giuseppe Leonardi.*



Fig. 3 - The site Floresta dos Borba (Sousa) is located almost at the foot of the Serrote Jerimum, at the northern margin of the Sousa Basin, in the Antenor Navarro Formation. The ichnofauna preliminarily consists of large theropods, sauropods and two forms of large ornithopods.

Fig. 3 - Il sito di Floresta dos Borba (Sousa) si trova quasi ai piedi del Serrote do Jerimum, al margine settentrionale del bacino di Sousa, nella Formazione Antenor Navarro. L'icnofauna comprende, per ora, orme e piste di grandi teropodi, sauropodi e due forme di grandi ornitopodi.

IV), up to 76°, very wide displacement rim diameter (up to 62 cm), heading ~S85°W (Fig. 4b). SOFL 1 and SOFL 3 are among the larger theropod footprints of the Rio do Peixe basins. SOFL 2 is an incomplete theropod footprint, where only the free part of the digits is impressed. There are other theropod tracks in the area.

- A great number of sauropod tracks, many of them large, deep and with a high displacement rim; among them there are some hand-foot sets (Figs 6, 7). The foot-prints reach 90 cm x 60 cm in diameter; the horse-shoe-shaped hand-prints are barely discernable, being almost completely infilled by the anterior part of the displacement rim of the foot. However, a few sauropod footprints in this place are relatively shallow and at least one is in relief, due to the suction effect of the foot being removed from the sediment, similar to prints described from a herd at Serrote do Letreiro in the rocky bed of the Riacho do Pique (Leonardi 1994; Carvalho 2000b). The sauropods were probably gregarious and travelling in a herd, but no clear direction of travel is discernable. The main group of sauropod footprints are concentrated inside the hamlet.

- Some rare and well preserved ornithopod footprints. Among them, there is a well imprinted tridactylous footprint with a wide III toe hoof and small hooves in the II and IV toes. This print is most likely attributable to *Staurichnium diogenis* Leonardi, 1979: it is 29 cm long, 24 cm wide and is heading more or less to the West (SOFL 4) (Figs 4c, 8); a large, very shallow, tridactylous footprint, 56 cm long and 53 cm wide, is attributable to *Caririchnium magnificum* Leonardi 1984, with a wide but very shallow displacement rim (SOFL 5) (Fig. 4d) and heading in a Northerly direction.

### 3.2. Lagoa do Forno (SOLF)

In this farm two new localities were found. The first (SOLF I) is situated at 6°48'6"S, 38°11'W, 7.1 km SE of the centre of Sousa as the crow flies (1500 m along the road from the octagonal chapel of the hamlet Lagoa do Forno), in the municipality of Sousa, very probably at the border between the Sousa and Piranhas Formations.

On the dirt roadbed, almost completely erased by the road bulldozers, there are at least six poor quality sauropod and four theropod footprints (Figs 9, 10).

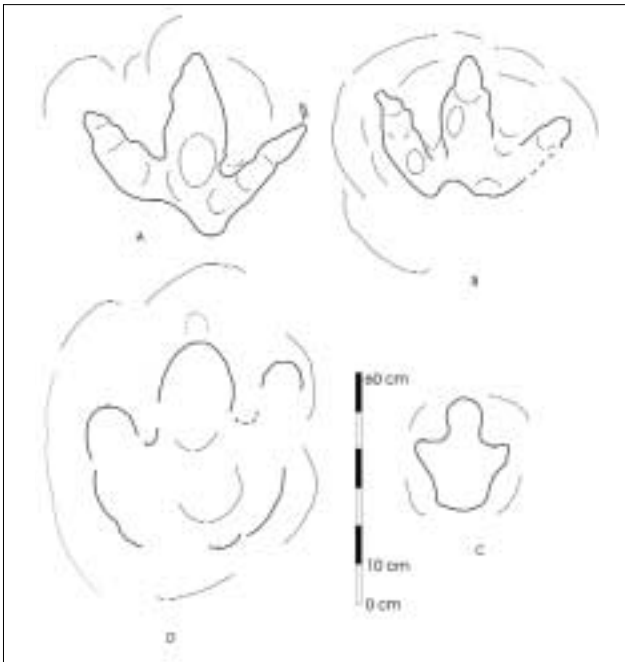


Fig. 4 - Theropod and ornithopod footprints from Floresta dos Borba (Sousa). a) SOFL 1, a large theropodian isolated footprint; b) SOFL 3, a large theropodian isolated footprint; c) an isolated ornithopodian footprint *Staurichnium diogenis* Leonardi, 1979; d) a large isolated ornithopodian footprint similar to *Caririchnium magnificum* Leonardi, 1984. Scales always in cm.

*Fig. 4 - Orme di teropodi e ornitopodi di Floresta dos Borba (Sousa). a) SOFL 1, orma isolata di teropodo di grandi dimensioni; b) SOFL 3, orma isolata di teropodo di grandi dimensioni; c) un'orma isolata di ornitopodo Staurichnium diogenis Leonardi, 1979; d) un'orma isolata di ornitopodo di grandi dimensioni, simile a Caririchnium magnificum Leonardi, 1984. Scale grafiche qui e altrove sempre in cm.*



Fig. 5 - Floresta dos Borba. SOFL 1: A large and deep theropodian isolated footprint, one of the largest of this group in Brasil.

*Fig. 5 - Floresta dos Borba. SOFL 1: una grande e profonda orma isolata di teropodo, una delle più grandi di questo gruppo nel Brasile.*



Fig. 6 - The tracks (overtrampling) of a herd of sauropods with roundish feet at Floresta dos Borba.

*Fig. 6 - Orme di una mandria di sauropodi a piedi posteriori tondeggianti, con fenomeno di overtrampling, a Floresta dos Borba.*



Fig. 7 - A sauropod hand-foot set at Floresta dos Borba.  
 Fig. 7 - Una delle orme (coppia mano-piede) di sauropodo a Floresta dos Borba.



Fig. 8 - Floresta dos Borba. SOFL 4, an isolated ornithopod footprint *Staurichnium diogenis* Leonardi, 1979.  
 Fig. 8 - Floresta dos Borba. SOFL 4, orma isolata di ornitopodo, classificata *Staurichnium diogenis* Leonardi, 1979.

They are almost always seen in a horizontal section. There is also a well preserved hand-print (FL 34, FW 50 cm) (Fig. 11), the only that shows its displacement rim. Also in this site, 35 m ESE from the main group, there is a partial theropodian footprint that appears to have been left by a swimming animal.

Another isolated very large theropod footprint is imprinted beside the above-mentioned octagonal chapel, on the roadbed, 8.4 km SE of the centre of Sousa, 6°48'32"S; 38°10'30"W (tracksite Lagoa do Forno II, SOLF II).

### 3.3. Várzea dos Ramos II and III (APVR II and III)

Two new tracksites were found in the bed of Peixe River on the Várzea dos Ramos Farm, in the municipality of Aparecida (Paraíba), formerly a district of the Sousa municipality, downstream from the already published Várzea dos Ramos locality (APVR, formerly SOVR; Santos & Santos 1989) (Figs 12-14).

The first locality has been named Várzea dos

Ramos II (Fig. 15) and is situated 15 km ESE as the crow flies from the centre of Sousa and 1,5 km WNW of Aparecida; 6°46'38"S; 38°05'42"W. At this site, on a dark-grey rocky pavement crossing the river, a theropodian trackway was discovered (Figs 16, 17), along with small theropod isolated tracks. The trackway contains eight footprints and has the following approximate parameters: pace 90 cm, stride 180 cm, pace angulation 175°, footprint length 30, footprint wide 27 cm, interdigital divarication (II-IV) 90°.

The second locality has been named Várzea dos Ramos III and is situated 14 km ESE as the crow flies from the centre of Sousa and 2,5 km WNW of Aparecida; 6°46'38"S; 38°06'15"W. In this place the river has high banks, exposing a large number of layers, a very rare case in this river (Fig. 18). At the foot of the left bank, on a rippled red surface, six small isolated theropodian footprints were found, all of them with very narrow digits because of the collapsing of the mud. In the same surface, four half-swimming theropodian tracks are seen.



Fig. 9 - At Lagoa do Forno (Sousa), on the roadbed, almost completely erased by the road bulldozer, there are at least six poor quality sauropod and four theropod footprints. Piranhas Formation.

*Fig. 9 - Nel sito Lagoa do Forno (Sousa), sul letto stradale, ci sono almeno sei orme di sauropodi e quattro di teropodi, di cattiva qualità per l'azione delle macchine di manutenzione stradale. Formazione Piranhas.*

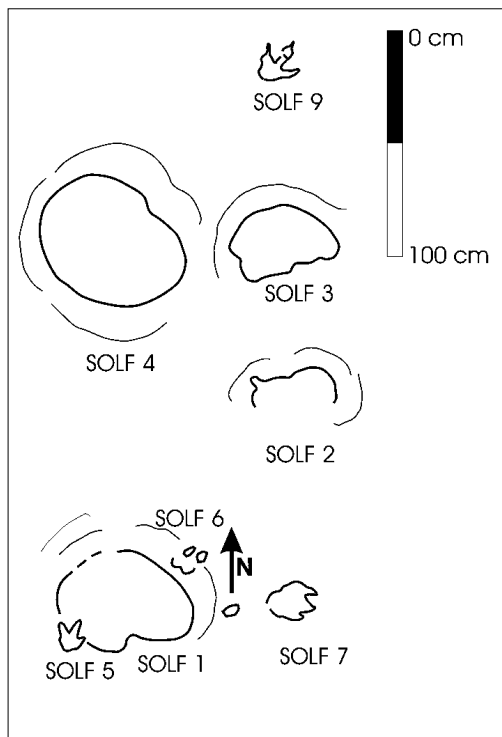


Fig. 10 - Sauropod and theropod tracks on the roadbed at Lagoa do Forno.

*Fig. 10 - Orme di sauropodi e teropodi sul letto stradale di Lagoa do Forno.*



Fig. 11 - An isolated sauropodian hand-print with its displacement rim on the roadbed near Lagoa do Forno. Dirt road Sousa-Acauã.

*Fig. 11 - L'orma isolata del piede anteriore di un sauropodo, con il suo bordo di espulsione, sul letto stradale vicino a Lagoa do Forno. Strada Sousa- Acauã, tagliata nei sedimenti della Formazione Piranhas.*



Fig. 12 - A siltite surface of the Sousa Formation in the bed of Peixe River. Várzea dos Ramos Farm, municipality of Aparecida (Paraíba), formerly a district of the Sousa municipality (code APVR, formerly SOVR); the ichnofauna contains a lot of theropod and one sauropod footprints.

*Fig. 12 - Superficie di uno strato di siltite della Formazione Sousa nel letto del Fiume Peixe. Fazenda Várzea dos Ramos, município di Aparecida (Paraíba), già frazione di Sousa (codice APVR, già SOVR); l'icnofauna comprende decine di orme di teropodi e una di ornitopode.*



Fig. 13 - Mr Robson Araújo Marques points to a pair of theropod tracks at Várzea dos Ramos (Aparecida, Paraíba).  
*Fig. 13 - Robson Araújo Marques indica un paio di orme di teropodi a Várzea dos Ramos (Aparecida, Paraíba).*



Fig. 14 - Várzea dos Ramos Farm, one of the more than 60 theropodian footprints.  
*Fig. 14 - Una delle più di sessanta orme di teropodo nel sito Várzea dos Ramos.*



Fig. 15 - At the new site, Várzea dos Ramos II (Aparecida, Paraíba), on a dark-gray rocky pavement crossing the river, a theropodian trackway was discovered. Sousa Formation.

*Fig. 15 - Nel nuovo sito Várzea dos Ramos II (Aparecida, Paraíba), si nota una pista di teropodo che incrocia il letto asciutto del fiume, sulla superficie nerastra di uno strato. Formazione di Sousa.*



Fig. 16 - The theropodian trackway of Varzea dos Ramos II (SOVR II 1), on a mud-cracked surface.

*Fig. 16 - La pista di teropodo di Varzea dos Ramos II (SOVR II 1), su una superficie di fanghi poligonali.*



Fig. 17 - One of the theropodian footprints of the trackway SOVR II-1.

*Fig. 17 - Una delle orme della pista di teropodo SOVR II-1.*



Fig. 18 - Várzea dos Ramos III (Aparecida, Paraíba). In this place the river has high banks, a very rare case in this river. The ichnofauna contains a number of theropod footprints.

Fig. 18 - Várzea dos Ramos III (Aparecida, Paraíba). In questo sito il fiume corre tra alte sponde, un caso molto raro in questo fiume. L'ichnofauna consiste di alcune orme di teropodi.

#### 4. NEW ICHNOLOGICAL MATERIAL FROM OLD SITES

##### 4.1. Piau Farm

Piau Farm is a very interesting locality, because in such a restricted area it includes at least 25 horizons with dinosaurian ichno-associations. To date, a total of almost 200 individual dinosaurian trackways and isolated footprints have been uncovered, along with hundreds of footprints of very small reptiles, probably turtles, that appear to have been half-swimming. A study of the ichnofauna reveals: a great predominance of theropodian tracks (170 individuals), among which 129 were made by large predators and 27 by small predators; nine trackways or isolated footprints of ornithopods, almost all Iguanodontidae; a set of very large roundish subtracks, attributed to sauropods, seven of them probably in a herd; one crocodyloid hand-foot set, attributable to the Batrachopodidae. The Piau Farm site was well documented by one of us (G.L.) during the 1980's.

Since a more recent visit in 2001, a new well preserved sauropod trackway had been exposed by erosion at the bottom of the bed at level 13/site 8 (Figs 19-21). Currently, the trackway includes four hand-

foot sets, with very wide and high displacement rims. The footprints are oval, ~78 cm long and ~46 wide; no morphological details are evident. The horseshoe-shaped hand-prints are almost completely infilled by the anterior part of the (high up to 20 cm) displacement rim of the foot. The trackway is narrow-gauge and of the *Parabrontopodus* type. The footprints do not overlap the midline but are very close to it. The animal was heading in a westerly direction.

##### 4.2. Fazenda Paraíso (SOF)

This site was discovered and described by Sérgio A.K. Azevedo of the National Museum of Rio de Janeiro (1993). A new map of the rocky pavement of the Piranhas Formation is herein recorded (Fig. 22). The site is in the municipality of Sousa, 9.8 km ESE of the city centre as the crow flies, 1100 m ESE from the octagonal chapel of Lagoa do Forno hamlet, and 300 m ESE of the iron cross on the margin of the Forno reservoir; 6°48'31"S; 38°09'30"W.

The main rocky pavement with tracks (Fig. 23) (strike S64°W; dip 14° to the S) is situated alongside the tracks of the narrow-gauge railway Fortaleza-João Pessoa. The site contains a fine trackway of a large theropod individual (SOF 1, Fig. 24), imprinted in a

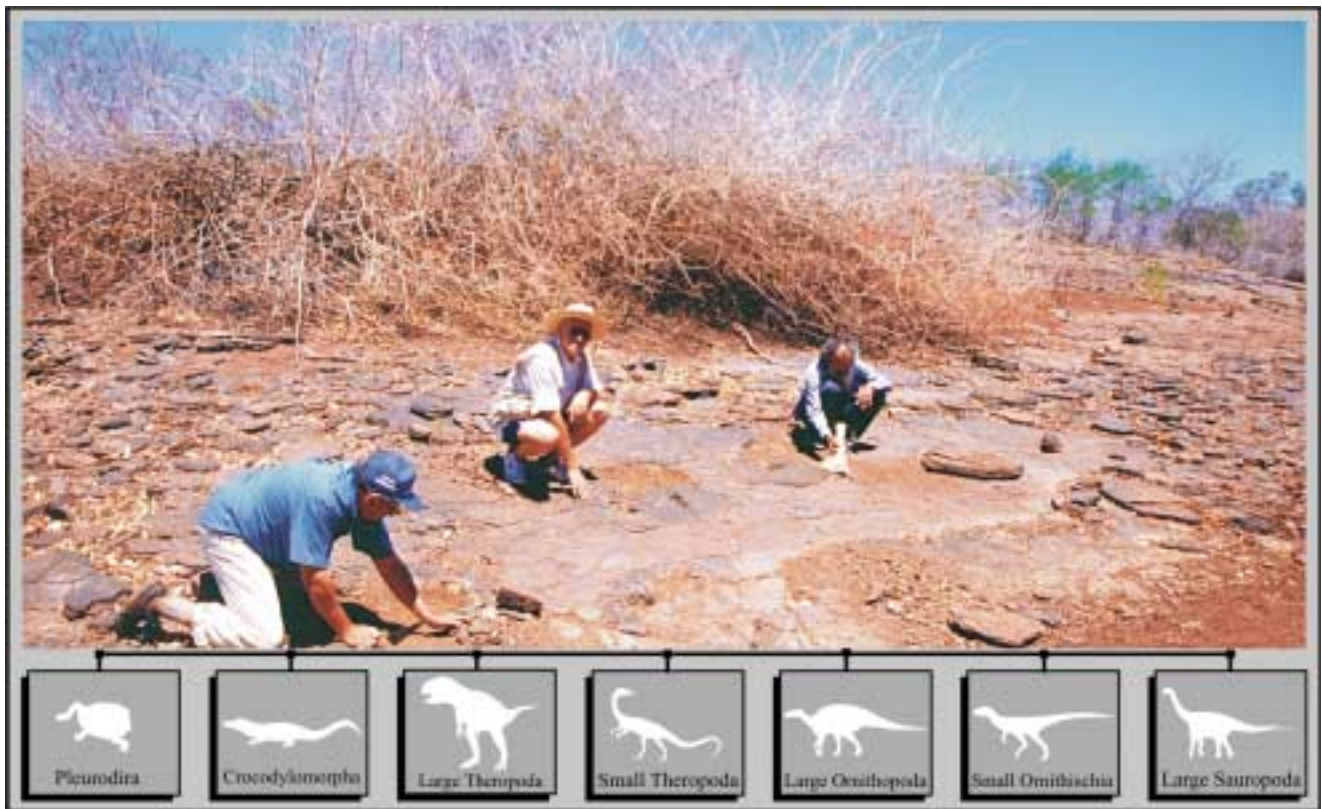


Fig. 19 - A new sauropod trackway at the already known Piau Farm, level 13/site 8. Note the very wide and high displacement rim. The Piau ichnofauna is one of the richest and most diversified of the basin; it contains several forms of large and small theropod, large ornithomimid and small bipedal ornithischian, sauropod, turtle and crocodyloid footprints.

Fig. 19 - Una nuova pista di sauropodo nel già noto sito Piau, livello 13/località 8. Si noti l'ampio e alto bordo di espulsione. L'icnofauna di Piau è una delle più ricche e più diversificate del bacino; contiene piste di diverse forme di teropodi di grandi e piccole dimensioni, grandi ornitomimidi e ornitiscidi di piccole dimensioni, sauropodi, tartarughe e cocodrilli.

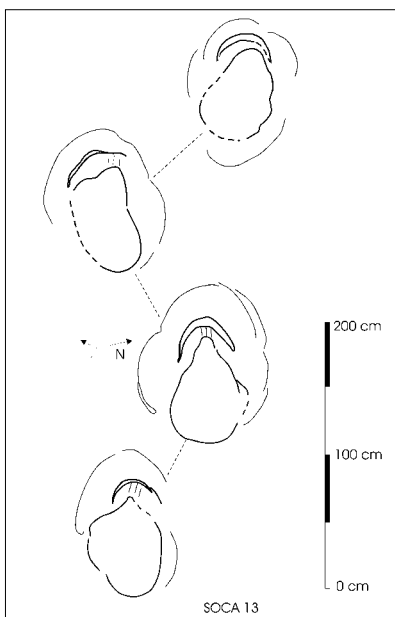


Fig. 20 - The new sauropod trackway at Piau site, very well conserved and recently exposed by de Peixe River erosion. The trackway includes four hand-foot sets.

Fig. 20 - La nuova pista di sauropodo al sito Piau, molto ben conservata e recentemente esposta all'erosione del Fiume Peixe. Affiorano quattro coppie mano-piede.

sta all'erosione del Fiume Peixe. Affiorano quattro coppie mano-piede.



Fig. 21 - The new sauropod trackway at Piau site. The footprints are oval. The hand-prints are almost completely infilled by the anterior part of the high displacement rim of the foot.

Fig. 21 - La nuova pista di sauropodo al sito Piau. Le orme dei piedi sono ovali. Quelle delle mani sono quasi completamente riempite dalla parte anteriore del bordo di espulsione del piede.

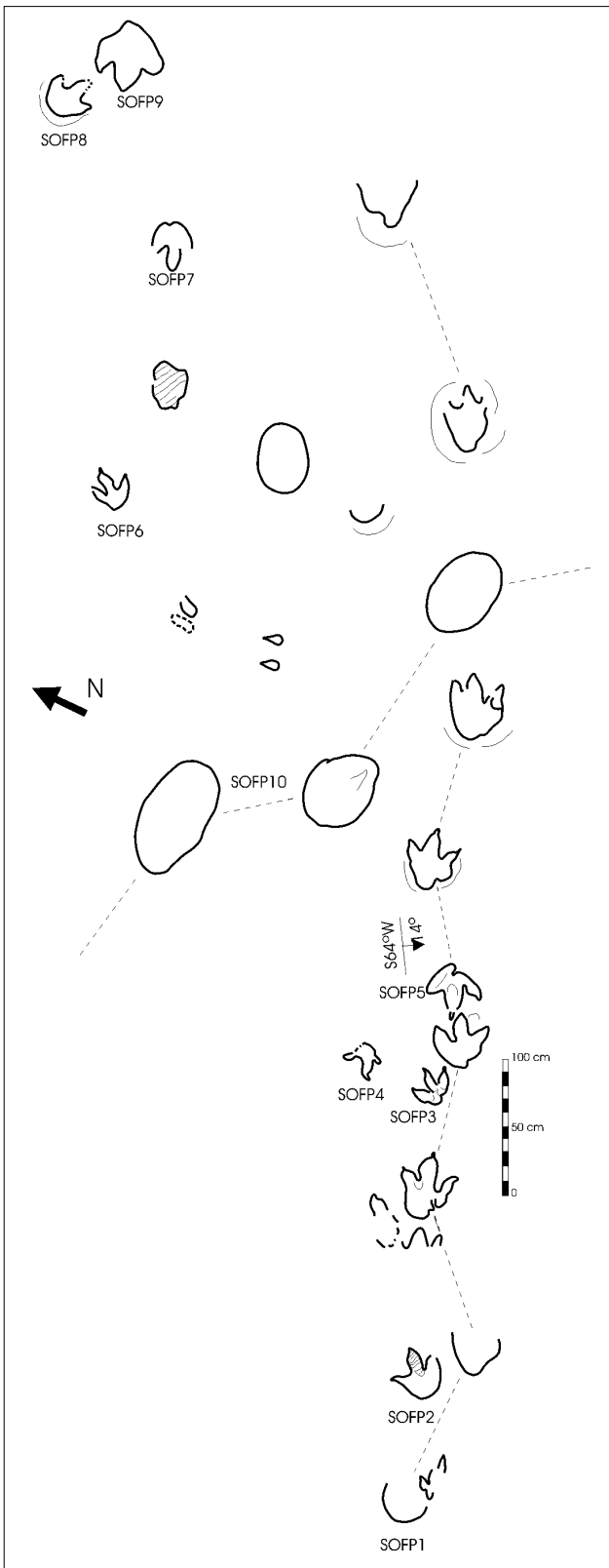


Fig. 22 - Fazenda Paraíso (Sousa). A new map of the rocky pavement of the Piranhas Formation with theropodian tracks.

Fig. 22 - Fazenda Paraíso (Sousa). Un nuovo rilievo della superficie della Formazione Piranhas con una pista e orme di teropodi.



Fig. 23 - The main rocky surface with tracks at Paraíso Farm is situated at the side of the tracks of the narrow-gauge railway Fortaleza-João Pessoa. It contains a good quality trackway of a large theropod and eight isolated footprints, probably all of them attributable to theropods. The whole ichnofauna of the site includes theropod and sauropod tracks.

Fig. 23 - La superficie principale con orme e piste nella Fazenda Paraíso è situata a fianco dei binari della ferrovia a scartamento ridotto Fortaleza-João Pessoa. Comprende una pista di buona qualità di un teropodo di dimensioni particolarmente grandi e otto orme isolate, probabilmente tutte attribuibili a teropodi. Il sito Fazenda Paraíso comprende anche orme di altri teropodi e di sauropodi.



Fig. 24 - A track of a large theropod individual (SOFP 1), imprinted in a terrain that was more waterlogged in some places than in others, at Paraíso Farm.

*Fig. 24 - Un'orma di teropodo (SOFP 1), impressa in un terreno più impregnato d'acqua in certi punti che in altri, nella Fazenda Paraíso.*

terrain that was more waterlogged in some places than in others. There are also eight isolated footprints, probably all of them attributable to theropods (SOFP 2-9). Almost all the tracks are infilled with the coarser material of the upper contiguous layer. One of them (SOFP 9) appears similar to an ornithopodian track because of the roundish hooves, but this is most likely a result of the infilling and not the anatomy of the trackmaker and it also can be attributed to a theropod (Fig. 25). There is also one different trackway (SOFP 10) going ESE, probably a large theropodian under-track.

Some of the theropodian individuals (e. g. SOFP 1, 2, 5, 9, 10) were very large, and their footprints are among the largest of this basin.

Another large theropodian footprint is about 40 m along the railway in the direction of João Pessoa; more isolated, poor quality footprints are scattered in the thorny bush of the farm around a small reservoir,



Fig. 25 - One of the tracks at Paraíso Farm (SOFP 9) could seem an ornithopodian track because of the roundish hooves, but this fact most probably depends on the infilling and not from the anatomy of the trackmaker. It can be attributed to a theropod.

*Fig. 25 - Una delle orme della Fazenda Paraíso (SOFP 9) può sembrare appartenere agli ornitopodi per via degli zoccoli apparentemente rotondi, ma questo aspetto dipende quasi certamente dal riempimento e non dall'anatomia dell'autore dell'orma. Può essere attribuita a teropodi.*

on the north of the main pavement. They are attributed to a sauropod (SOFP 11) and to theropods (SOFP 12, 13).

#### 4.3. Other old sites

New tracks were discovered at the already published sites.

*Serrote do Letreiro (SOSL)* (Antenor Navarro Formation). A new theropod trackway, consisting of three footprints, was discovered near the site of the tracks of a herd of approximately 15 sauropods (Leonardi 1994; Carvalho 2002b). The site Serrote do Letreiro is on the NW margin of the Sousa Basin, on the eastern side of the Lagoa-Pereiros road, about 0.8 km from the main house of the Lagoa dos Estrela Farm and 10.5 km NW of Sousa (06°41'48"S; 38°18'32"W).



Fig. 26 - The low and arid *cuestas* of Piranhas Formation at Mãe d'Água (SSE of Sousa), where new sauropod, theropod and long-heeled ornithopod tracks were found.

Fig. 26 - Le basse e aride *cuestas* della Formazione Piranhas a Mãe d'Água (SSE di Sousa), dove sono state rinvenute nuove orme di sauropodi, teropodi e ornitopodi a tallone allungato.

Mãe d'Água (Piranhas Formation, 7 km SSE of Sousa) (Fig. 26). Aside from the known tracks (Leonardi 1994) some new poor quality tracks were discovered there. These tracks were made by sauropods (Fig. 27), theropods and to a long-heeled ornithopod.



Fig. 27 - An infilled sauropod hind-footprint at Mãe d'Água.

Fig. 27 - Un'orma posteriore di sauropodo, riempita dallo strato superiore, a Mãe d'Água.

Riacho do Cazé (Antenor Navarro Formation, 4.2 NNE of Sousa, 6°43'17"; 38°13'30"W). Some new, poor quality sauropod and theropod footprints (Fig. 28).

Passagem das Pedras (Sousa Formation). New excavations were carried out at this site, where Luciano Jacques de Moraes (1924) discovered the first dinosaur tracks and where the Park Vale dos Dinossauros is now situated. Currently, the excavated part of the trackway *Sousaichnium pricei* Leonardi, 1979 (holotype) SOPP 1, formerly SOPP A, includes 52 footprints (and 25 hand-prints, but of the right side), and is 48 m in length. The paratype of the trackway *Moraesichnium barberenae* (Leonardi 1979) (SOPP 5, formerly SOPP E) consists of 34 excavated footprints on the right side of the river and a further 13 footprints on the left side. The total excavated length of the trackway is now 56 m.

The farms at Saguim de Cima, Várzea da Jurema, Tabuleiro, Catolé da Piedade (WNW of Sousa, in the Sousa Formation); Pau d'Arco (SE of Sousa, in the Piranhas Formation) were explored without results.



Fig. 28 - At Riacho do Cazé (Antenor Navarro Formation) some new sauropod and large theropod poor quality footprints were discovered in very coarse sandstones.

Fig. 28 - Nella località Riacho do Cazé (Formazione Antenor Navarro) sono state rinvenute alcune nuove orme di sauro-podi e di teropodi di grandi dimensioni, in arenarie molto grossolane.

## 5. DISCUSSION - THE TRACKMAKERS

It is not always easy to attribute a track to a particular trackmaker (Figs 3, 9, 12, 15, 18, 19, 23, 26, 28). However, the tracks described above can be attributed, with some likelihood, to the following groups.

In the Cretaceous of South America, the large theropodian tracks pertain most probably to several large predators of the family *Abelisauridae* (Bonaparte & Novas 1985) and then probably to the *Ceratosauria*; the small theropod tracks with the III digit substantially longer than the II and IV, which were classically attributed to the *Coelurosauria*, may more probably be referred to some South American theropodian families that occupied an ecological niche similar to that occupied by the *Coelurosauria* in Laurasia (e.g. *Noasauridae*, Bonaparte & Powell 1980); the sauropod tracks were possibly created by *Dicraeosauridae*, *Rebbachisauridae* or, more probably, by early *Titanosauridae*.

The large bipedal tracks with three roundish hooves are attributable to at least two different forms of graviportal iguanodontids similar, for example, to *Ouranosaurus* Taquet, 1976.

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