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Vertebrate Trace Fossils: the Congo's *Brasilichnium* mammaloid fossil footprints

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ABSTRACT

The ichnogenus *Brasilichnium*, with its ichnospecies type *Brasilichnium elusivum*, was established for a very common and abundant kind of tracks from the Brazilian aeolian Botucatu Formation in Paraná Basin. It is nowadays a recognized ichnogenus on several continents. On the South American continent, it was found in Brazil and Paraguay. On the North American continent, it was found in Mexico and in several localities of the United States. In Asia it was found in Korea and China; in Africa it was found in Tunisia, Namibia and Lesotho whereas in Europe it was found only in Italy. A new occurrence of this ichnogenus (and also of the ichnospecies *Brasilichium elusivum*) is herein announced from Cretaceous arkose sandstones, at Kinshasa, Democratic Republic of Congo. Three slabs with several mammaloid footprints attributable to this ichnogenus were found in Kinshasa, in red sandstone slabs cladding facades of pre-independence (1960) buildings. These slabs were and are quarried at the NW margins of Kinshasa along the left banks of the Congo River, in the districts of Kimbwala and Mbudi. This material can be attributed to the Loia Formation (Berriasian-Aptian). These are the first tetrapod tracks in the Democratic Republic of Congo, and possibly in all of Central Africa. It is important to keep on surveying for tracks in the quarries and on the facades of buildings in Kinshasa, in order to increase the potential use of ichnology to environmental and palaeogeographic reconstructions.

Key Words: *Brasilichnium, ichnofossil, Kinshasa, Cretaceous.*

INTRODUCTION AND AIMS

The ichnogenus *Brasilichnium* Leonardi, 1981b, with its ichnospecies *Brasilichnium elusivum* Leonardi, 1981b, was established for an abundant kind of trackways and footprints from the Botucatu Formation in the Paraná syneclysis (Brazil). The holotype and the two paratypes were some specimens collected in the Corpedras and Santa Águeda quarries, at Ouro ichnosite, Araraquara, São Paulo, Brazil. The holotype (MNRJ 3902-V; ARSB 78)) and the first paratype (MNRJ 3903-V; ARSB 127) are housed in the palaeontological collections of the National Museum of Rio de Janeiro, Vertebrate Section; the second paratype is housed in the collections of the Instituto Geológico de São Pãulo, Brasil. The Botucatu Formation was firstly thought to be Late Triassic or Early Jurassic in ages (for example Leonardi, 1981b; Leonardi & Oliveira, 1990 and by many other geologists and palaeontologists), however, it is now considered as Early Cretaceous (Scherer, 2000, 2002).

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The first specimen of *Brasilichnium elusivum* was found and collected (but not named) on a flagstone on the sidewalks of the city of São Carlos (São Paulo State; Joviano A. de A. Pacheco, 1913). The slab had been quarried near Araraquara at Ouro locality, probably at Santa Águeda quarry. Thousands of such tracks were successively found at Araraquara (São Paulo State; Leonardi 1979, 1980, 1981b), in the quarries of the Ouro region that produced slabs for sidewalk paving. These tracks were also found on the flagstones of the sidewalks of many towns in southern Brazil.

An important diagnostic revision for the Mesozoic ichnogenus *Brasilichnium* and for its ichnospecies *Brasilichnium elusivum* Leonardi, 1981b (Mammalia) was done by Fernandes & Carvalho (2008). This contribution had the distinction of updating and perfecting the formal diagnosis of the ichnogenus and ichnospecies, in particular pointing out that the hind-foot of the animal was tetradactyl and not pentadactyl, and revisiting its heteropody condition.

This ichnogenus is a mammaloid fossil track that is presently found world-wide. The aim of this paper is to announce the discovery of some specimens of the ichnogenus *Brasilichnium* and similar forms found in the Democratic Republic of Congo (DRC), in Kinshasa and, for the first time, in Central Africa. The aim of the paper is also to contribute to the dating of little known rock formations of the DRC, in which until now no other fossils had been discovered.

BRASILICHNIUM: A COSMOPOLITAN ICHNOGENUS

As a matter of fact, ichnites commonly referred to as *Brasilichnium* have been found on several continents: first in the South American countries of Brazil (Pacheco, 1913; Huene, 1931; Leonardi, 1977, 1979, 1980, 1994; Leonardi & Godoy, 1980; Leonardi, 1981a, 1981b; 1994; Leonardi & Sarjeant, 1986; Leonardi & Oliveira, 1990; Marconato & Bertini, 1999; Leonardi & Carvalho, 2002; Leonardi *et alii*, 2007; Buck *et alii*, 2017a-b; D'Orazi Porchetti *et alii*, 2017a-b; Fernandes & Carvalho, 2007, 2008; Fernandes *et alii*, 2003; Francischini *et alii*, 2020) and Paraguay (Leonardi, 1992, 1994), then in North America, Asia, Africa and Europe (Table 1).

For a good summary on the Mesozoic mammalian or mammaloid track record in the world, refer to the one by Mateus *et alii* (2017) which is particularly interesting. The chronological span of all these occurrences encompass the Early Jurassic (Hettangian) to Late Cretaceous

(Campanian).

After the *Brasilichnium elusivum* LEONARDI, 1981 was first described, new ichnospecies of *Brasilichnium*, and other similar kinds of theromorphoid/mammaloid tracks were published. In chronological order of publication, these kinds of tracks are as follows:

1) *Brasilichnium saltatorium* BUCK, GHILARDI, PEIXOTO, FERNANDES & FERNANDES, 2017
2) *Aracoaraichnium leonardii* BUCK, GHILARDI, FERNANDES & FERNANDES, 2017
3) *Koreasaltipes jinjuensis* KIM, LIM, LOCKLEY, XING & CHOI, 2017
4) *Brasilichnium anaiti* D'ORAZI PORCHETTI, BERTINI & LANGER, 2017
5) *Brasilichnium* isp., in a number of other papers (see MATEUS *et alii*, 2017).

Brasilichnium is now an important ichnogenus which also allowed the establishment of the Brasilichnium ichnofacies (Lockley 2011).

The new occurrence of this ichnogenus described herein (and probably of the ichnospecies *Brasilichium elusivum*) in Cretaceous arkose sandstones, at Kinshasa (figure 1 A-B), capital of the Democratic Republic of Congo (DRC), reinforces the idea of the global distribution of this ichnogenus. Similar to the first discovery of this mammal track (LEONARDI, 1977, 1980) which occurred in the sidewalks of some towns of São Paulo State, Brazil, this new occurrence also comes from quarried stones in the DRC capital. The discovery of a few *Brasilichnium* tracks at Kinshasa, was made by the first author in 2004.

GEOLOGICAL SETTING

It is not easy to classify and date the rocks from where the track-bearings sandstone slabs, used for cladding buildings erected in pre-independence years (1960) in downtown Kinshasa (04° 19' 17" S; 15° 18' 29" E; Fig. 1C), were quarried. However, from local general information, these kinds of cladding slabs were quarried in north-western districts of the town, where Pompage, Kinsuka and especially Mbudi and Kimbwala districts are located today.

Classifying and dating this material is also difficult because the survey and the study of the stratigraphic column in the Kinshasa region and surroundings (now absorbed by the megalopolis) dates back from 50-60 years ago or even earlier (CORIN & HUGE, 1948; CAHEN & LEPERSONNE, 1949; EGOROFF, 1955; SEKIRSKY, 1956; LADMIRANT, 1964; LEPERSONNE, 1974, 1978; LINOL *et alii*, 2016; DELVAUX *et alii*, 2019). Also there have been no updates since the independence

TABLE 1.

***Brasilichnium*: a cosmopolitan ichnogenus**

Continent	Country	Locality	Formation	Cronostratigraphy	Literature
South America	Brazil	Paraná Basin	Botucatu	Lower Cretaceous, ~Hauterivian-Barremian	Pacheco, 1913; Huene, 1931; Leonardi, 1977, 1979, 1980, 1994 etc.
South America	Paraguay	Paraná Basin	Misiones	Lower Cretaceous	Leonardi, 1992; 1994
North America	Mexico	El Pelillal, Coahuila	Cerro del Pueblo	upper Campanian	Rodríguez-De La Rosa, 2003; 2004
North America	U.S.A.	Moffat, Colorado	Nugget Sandstones	Lower Jurassic	Engelmann, 2010
North America	U.S.A.	Dinosaur Nat. Mon., Uintah County, Utah	Nugget Sandstones	Lower Jurassic	Engelmann, 2010
North America	U.S.A.	Several other localities of Western U.S.A.	---	---	Lockley, 2011; Lockley & Foster, 2003; Lockley *et alii*, 2011
North America	U.S.A.	Southern Nevada	Aztec Sandstones	Lower Jurassic	Rowland & Mercadante, 2014
Asia	Korea	Near Jinju City, South Korea	Jinju, Sindong Group of Gyeongsang Supergroup	Lower Cretaceous, Aptian	Kim *et alii*, 2017
Asia	China	Shaanxi		Lower Cretaceous	Xing *et alii*, 2018
Africa	Tunisia	Jebel Boulouha West of Tataouine	Kerker Member of the Zebbag Formation	Upper Cretaceous, Cenomanian	Contessi, 2013
Africa	Namibia	Damaraland	Twyfelfontein	Lower Cretaceous	D'Orazi Porchetti & Wagensommer, 2015
Africa	Lesotho	Northern main Karoo Basin	Lesotho	Lower Jurassic Pliensbachian-Toarcian	Bordy *et alii*, 2020
Africa	R.D.Congo	Kinshasa	Loia	Lower Cretaceous, Berriasian-Aptian	Herein
Europe	Italy	Lavini di Marco, Trento	Monte Zugna	Lower Jurassic, Hettangian	Piubelli, 2002 Petti *et alii*, 2020

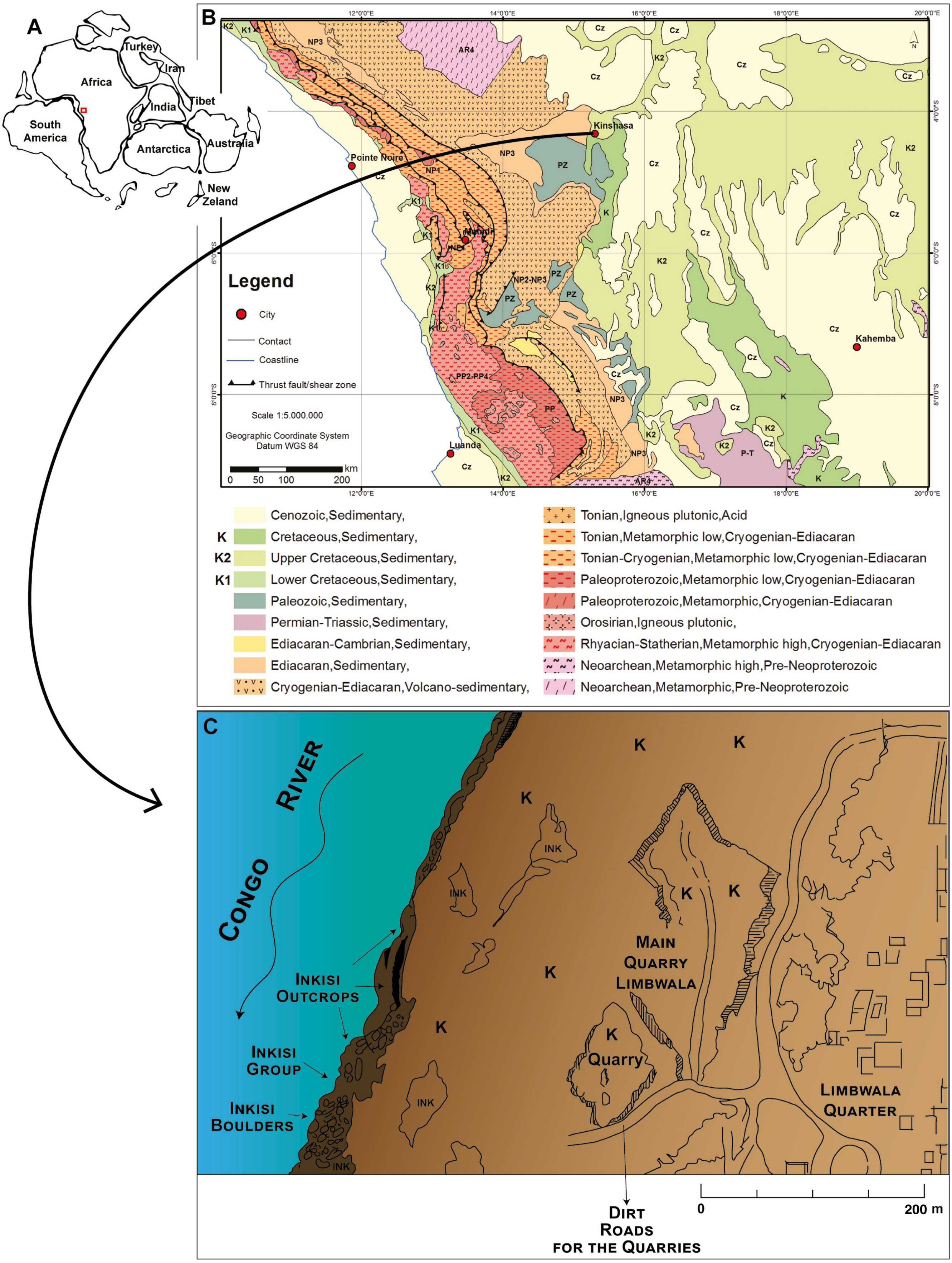

Fig. 1 - Geological context of the Lower Cretaceous ichnosite, in the Gondwana (A) and Kinshasa area (B), including the location area of the main outcrops (C).

occurred in 1960: neither new stratigraphic field survey or dating are available, and no new fossils have been found in the Kinshasa region, in the last five or six decades (cf. Tack *et alii*, 2009; Lateef *et alii*, 2010, p. 22; Mees *et alii*, 2018). "One should thus be aware of the constraints on the level of knowledge." (Lateef *et alii*, 2010).

Newer maps or papers can be useful for a general geologic and stratigraphic update of Congo River Basin (CRV), but none of them takes into account the Kinshasa area in detail. This is the case for Kadima *et alii* (2011), for the *Nouvelle Carte Géologique de la République Démocratique du Congo*, sanctioned by the workshop of July 14-15 (2016), organized by the Congolese Ministry of Mines and also for the map partially published by Schmitt *et alii* (2017). Other papers, while partially dealing also with the Kinshasa area, discuss other geological aspects of it, such as urban sustainability, accelerated erosion (érosion *ravinante*), hydrography, and drinkable water supply (Imwangana, 2010; Lateef *et alii*, 2010).

The quarries from where the cladding slabs were and are quarried at Kinshasa are located on the westernmost margin of the N-S belt, where the Cretaceous blanket of red sandstones, in places silicified, lies on the much older Inkisi Redbeds (Diemo, 2010; Kadima *et alii*, 2011).

The track-bearing slabs very likely come from the Cretaceous sequence (Pascale Lahougue & Damien de Fenfee Delvaux, personal correspondence, April 12, 2018).

The Cretaceous sediments at the NW Kinshasa districts consist of three formations: from the bottom up, the Loia, Bokungu and Kwango Formations, which measure a total thickness of about 750 m, thinning toward the city center, and are topped at Kinshasa with Cenozoic terrains. These Cretaceous rocks are mostly continental. The Loia Formation is ascribed to the Berriasian-Aptian, the Bokungu Formation to the Albian, and the Kwango Formation to the Upper Cretaceous (possibly Cenomanian to Maastrichtian) (Ladmirant, 1964; Lepersonne, 1978; Kadima *et alii*, 2011). The rocks of the quarries situated along the banks of the Congo River seem to belong to the Loia Formation. The sandstones are well cemented, silicified, and are quarried for building purposes. These Cretaceous red, purple or brick-coloured sandstones appear to lay directly (and unconformably) over the Inkisi Redbeds (Kadima *et alii*, 2015), and frequently crop out on the river banks, from Pompage to Kimbwala (Fig. 2).

The *Nouvelle Carte Géologique de la République Démocratique du Congo*, defines the mentioned terrains as "Late Cretaceous continental sedimentary"; however, the scale of this new map is too large, as it is a general map of the country (2,345,410 km^2). The same problem of scale exists for an older *Carte géologique* (Cahen & Lepersonne, 1949; 1:5,000,000); according to which these are Lower Cretaceous. From a different geological map,

Fig. 2 - Boulders and layers of the Redbeds Inkisi (Inkisi Group) in the Congo River banks, underlying the red sandstones of Lower Cretaceous Loia Formation (not seen in the picture), nearside the main quarry to sandstone flagstones, Kimbwala district, Kinshasa.

also 1:5,000,000 (Schmitt *et alii*, 2017; Fig. 1B) the sector referring to the quarries in question can be classified as undifferentiated Cretaceous and/or Upper Cretaceous.

Today the most important, large and active quarry for this kind of red (purple, pinkish, brick-coloured) sandstone slabs for building purposes is located near the banks of the Congo River, in the Kimbwala district (Fig. 1C), about 280 m north of the Mbudi Nature Park and about 1,200 m SW from Inga Avenue and Immotex complex. This large quarry is about 290 m long (approx. N-S) and about 140 m wide (approx. E-W) (Figures 1C and 3). Other smaller quarries working on the same sandstones are scattered along the banks of the river. Both slabs for cladding walls (Fig. 4) and rough blocks of sandstone for building foundations are quarried there.

Instead to the Inkisi Redbeds belong the very large, elongated or rounded, eroded boulders (long up to 4-6 m, up to 1 m or more thick) of red sandstones, although almost black in their varnished surfaces (Fig. 2). These boulders are found on a lower level of the banks of the Congo River and are a product of the erosion of metric thick layers, mainly in the districts of Pompage and Lingwala.

Petrography of sandstones from the Loia Formation

It is not certain that the examined sandstone sample is coming from the same quarry as the track bearing slabs, however, it is from the same formation. The sample is of a well lithified arkose, with coarse sand grains predominating over medium and fine ones (Fig. 5). The majority of the sand grains are of monocrystalline quartz and K-feldspar.

Polycrystalline quartz, plagioclase, slate and volcanic fragments constitute a secondary mode. The rock also contains traces of white mica, epidote, opaque minerals and zircon. The grains show mainly concave-convex and sutured contacts. Authigenic quartz and feldspar overgrowth constitutes crystalline cements which are probably responsible for the cohesion and hardness of the arkose. The boundaries between detrital grains and overgrowths are made very distinct by coatings of iron oxide/hydroxide on the original grains. A carbonate cement, sometimes associated with iron oxide/hydroxide, occurs locally. The carbonate covers and postdates the quartz and feldspar overgrowths. There are also metamorphic lithoclasts of very fine rocks consisting of quartz, white mica, opaque minerals and ferruginous material. They are slates and micaceous quartzites with deformed or recrystallized quartz. Felsic volcanic fragments are rocks with quartz-feldspathic microcrystalline matrix and feldspar microfenocrystals.

Together with the plagioclase and muscovite, both the monocrystalline quartz and the K-feldspars (microcline, orthoclase) record the erosion of a granite source. The presence of fresh feldspars indicates a relatively dry climate in the source area. The roundness of the feldspars suggests a long reworking by the action of weak currents, thus avoiding the feldspar being broken into the silt fraction. Moreover, the iron oxide/hydroxide that coats the detrital grains can be related to oxidizing conditions during deposition of the sediment. The polycrystalline quartz can be related to the low grade metamorphic rock fragments and associated vein quartz. The volcanic fragments record palaeovolcanic activity in the source area.

The quartz and feldspar overgrowths, together with the concave-convex contacts and the scarcity of clay minerals, record pressure–solution processes, probably depending upon mesodiagenesis conditions. The subsequent precipitation of carbonate may have occurred under eodiagenesis conditions.

MATERIAL AND METHODS

The first slab with two footprints (slab Kin 01) was found in 2004 in the stone veneer of a pillar, built with exposed local stone (brick-coloured medium grained sandstone slabs) on the gate of the main inner courtyard of the Mazenod Faculty compound, Kasawubu Avenue, Kintambo district, Kinshasa. This was the very first record (November 20, 2004) of fossil vertebrate tracks in Congo Basin, in Central Africa and particularly in DRC.

After the first finding, a systematic survey of building facades was undertaken by the first author, from 2004 to 2014. It was conducted across the entire city, with different lighting conditions, but with modest outcomes. Little more than two dozen fossil footprints have been found. Instead, most of the sandstone veneer surfaces that were examined, corresponding to many thousands of square meters of the same material, were devoid of fossil tracks. Stone cladding with slabs of local sandstone (Fig. 4) was popular in the DRC capital before the independence of that country (1960) for private and for public buildings in downtown Kinshasa and in other districts inhabited by Belgians. For example, the premises of the Kinshasa University-UNIKIN (*Campus Universitaire de Kinshasa*; formerly the catholic *Université Lovanium*) at Mont Amba district, on *Avenue de l'Université*, are covered by at least 6,800 m^2 of sandstone slabs.

Only the photographic records of those tracks are available. One of us (GL), as a matter of fact, personally examined, measured and photographed the material. The track-bearing slabs, unfortunately, had to be left in place on the facades of the buildings. This was for two well-defined reasons. At Kinshasa there is presently no museum or other scientific institution in which one could lodge the track bearing slabs; also, people are not allowed to carry stones outside the country. At Customs, when leaving the country, the first author had serious problems and incurred fines when the small sandstone samples to make the thin sections were found in his luggage. So, the tetrapod tracks had to be left in their original location. Measurements were taken based on standard procedures proposed by Leonardi (1987).

DESCRIPTION AND DISCUSSION ON THE ICHNOLOGICAL MATERIAL

Tetrapod tracks were only found on three slabs in different locations. Only mammalian tracks were found on the slabs, no other vertebrate or invertebrate traces were discovered.

Description of Kin 01 tracks

Slab Kin 01 (Fig. 6). This slab was found on a pillar of the gate of the main inner courtyard of the Faculty of Mazenod Institute, Kasawubu Avenue, at Kintambo

Fig. 3 - Sandstones slabs of Loia Formation in the main quarry at Kimbwala district, Kinshasa.

Fig. 4 - Example of facade with Cretaceous sandstone slabs, Faculty of Mazenod, apse of the chapel. On this facade veneer of the building was found the slab Kin 03.

quarter, Kinshasa. The slab's dimensions are 35 x 26 cm. The sandstone presents a rather coarse granulometry. It is "*in situ*" on the inner surface of the pillar (toward the interior of the courtyard), and its surface shows small mortar splashes.

Two footprints, named as KIKI 01 and KIKI 02 (independent one from the other; probably both are hind-footprints) are preserved on this slab, as concave epirelief.

Footprint KIKI 01 (Fig. 6 A-B). The first footprint is incomplete. By the shape of the preserved portion (about one half of the area), one can judge that it presented an elliptical outline, meaning that it was a mammaloid track. The longer axis, the transversal or medio-lateral, can be assumed to have been about 5 cm. The shorter axis, very probably the anterior-posterior, is about 3.2 cm. The ratio of length to width of the footprint would be 1.56. No other anatomical details are preserved.

The "upper" margin (as the slab appears on the surface of the pillar and as it is in the Fig. 6 A-B), is oblique in section, is slope-shaped, and probably corresponds to the proximal (posterior) margin of the footprint. The "lower" margin is steep and accompanied by a low and gentle displacement rim, with about 2 cm of maximum width, along the lateral (or medial) preserved side.

Another less probable interpretation would be that the above-mentioned slope is not an indentation due to the sliding of the heel, but the area occupied by the digits. On the other hand, there is no evidence of digit-marks.

Footprint KIKI 02 (Fig. 6 A-D). The second footprint is not in sequence with the first one, i. e. it does not pertain to the same trackway nor to the same trackmaker, either. The anterior-posterior axis (length of the footprint) is 3.85 cm; the transversal axis (width of the footprint) is about 5 cm. The general outline is ellipsoid, like in KIKI 01; but the ratio of length to width is lower (1.3) than in

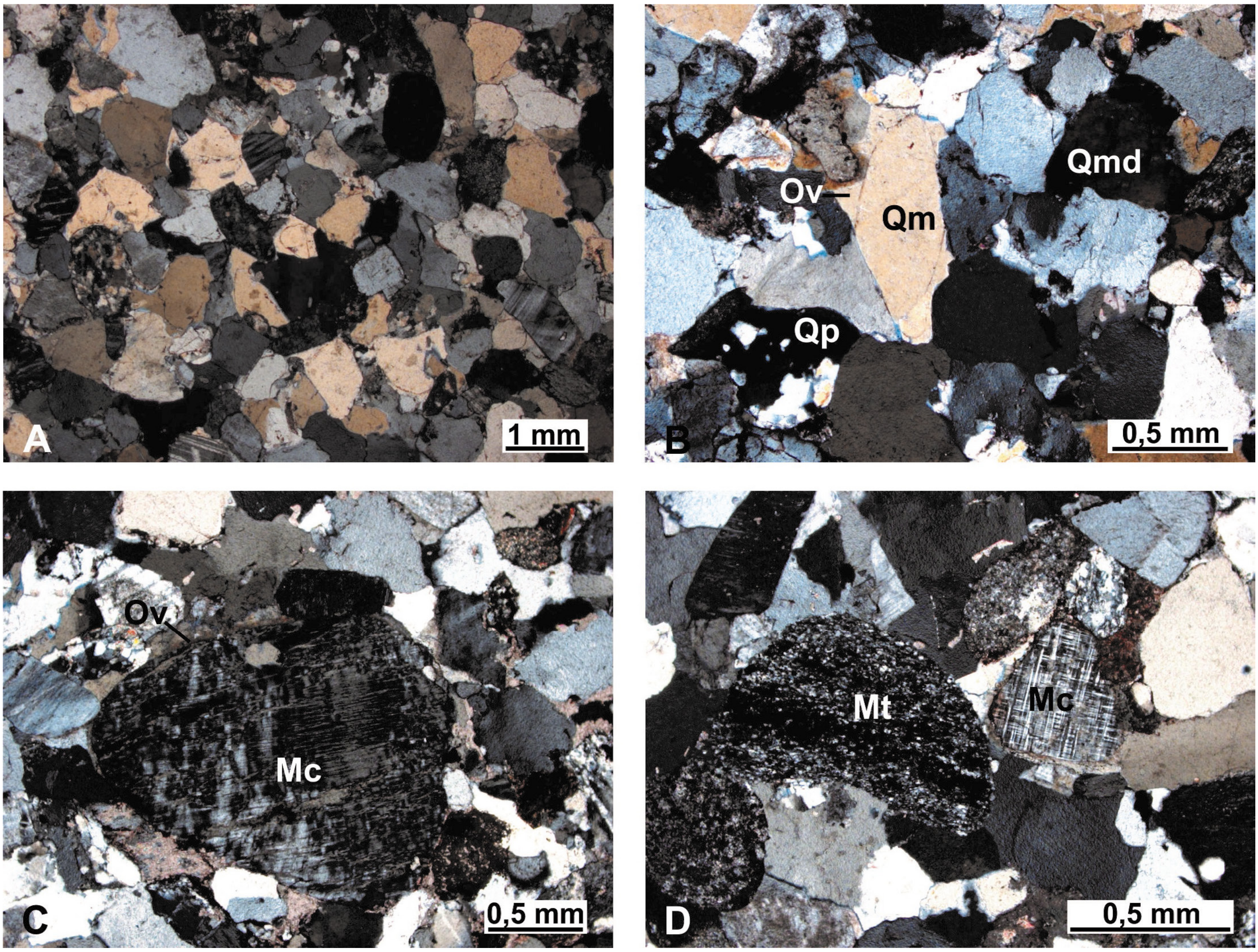

Fig. 5 - A. Rounded quartz and feldspar sand grains with overgrowth in a moderated sorted arkose; B. Monocrystalline (Qm) quartz with overgrowth (Ov), deformed monocrystalline quartz (Qmd) and polycrystalline quartz (Qp) sand grains in arkose; C. Deformed microcline (Mc) sand grain with feldspar overgrowth (Ov); D. Lithoclast of a foliated metamorphic rock rich in opaque minerals (Mt) and a microcline sand grain with overgrowth (Mc).

KIKI 01.

This footprint is complete; however, it is partially filled in by the sandstone of the adjacent upper layer. The infill covers part of the plant but it is thicker inside the three, possibly four, short spatula-shaped digits. Around the footprint there is a low and wide displacement rim.

Discussion on Kin 01 tracks

This kind of elliptic footprints seems to belong to a quadrupedal animal. Both footprints are isolated, and both are judged to be hind-footprints. No correspondence to fore-footprints is visible, so, it can be a case of total overprinting.

Taking into account their preservation, these two footprints could hardly be classified. The fact of the elliptical shape with the major medial-lateral axis (transversal axis), the presence of spatula-shaped toes, in number of three-four, in one of the two footprints (KIKI 02), as well as the roundish shape of the hypexes, all indicate that these two isolated footprints could belong to the ichnogenus *Brasilichnium*, but to a kind with a larger size than those of *Brasilichnium elusivum*; or to an ichnogenus similar to *Brasilichnium*. They can belong to relatively large early mammals, and are similar to *Brasilichnium anaiti*, or to *Aracoaraichnium leonardii*. They are also similar to some theromorphoid or mammaloid tracks already recorded and illustrated but not named in previous papers: the short trackway from plate IV, Figs. 3-4, in Leonardi (1980) (from São Bento-Corpedras quarry, Ouro site, Araraquara, São Paulo, Brazil); the trackway illustrated in Leonardi & Godoy (1980), Fig. 2/A (from São Carlos, São Paulo, Brazil), recorded also in Leonardi & Sarjeant (1986), figs. 1 and 7; the trackway illustrated in a drawing of Leonardi & Godoy (1980), Fig. 2/B, coming from the town of Franca's sidewalks; and in Fig. 4/F. They are like the three different isolated tracks, found in the Araraquara sidewalk flagstones (Leonardi, 1994, plate XXVI, figs. 1-3). Overall, we classify them as *Brasilichnium* isp.

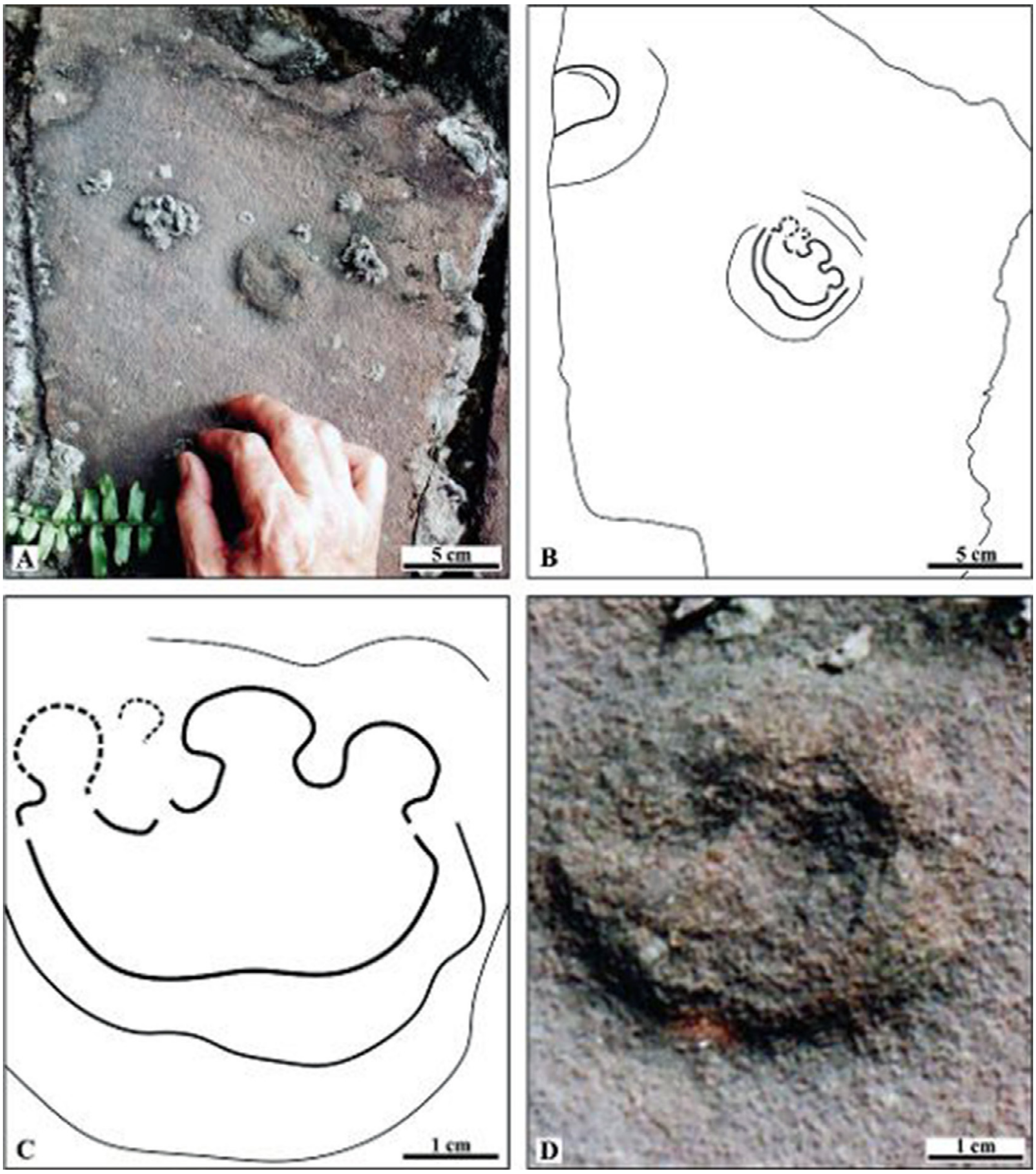

Fig. 6 - A. Slab Kin 01, with two isolated footprints, probably printed by early mammals (KIKI 01 and 02), from the cladding of a pillar of Faculty Mazenod's main patio, Kintambo district, Kinshasa. The tracks are surrounded by mortar splits. B. Interpretative drawing of the slab. C. Detailed drawing of the footprint KIKI 02. D. Picture of the same (Graphic work by Jaime Joachim Dias).

Description of Kin 02 tracks

Slab Kin 02 (Fig. 7). On a small sandstone slab (19 x 19 cm), a set of tracks (KIKI 03-04), was discovered on a wall of the Spiritual Center of Mbiti, at the foot of Mont Gafula, Kinshasa. This is a manus-pes set of the right side, in concave epirelief. In this manus-pes set, the pes (KIKI 03) is elliptical, its transversal axis is about 2.5 cm, and the anterior-posterior axis is about 1.2 cm. So, the transverse axis (medial-lateral) is longer: the ratio of length to width is 2.1. This foot is tetradactyl, with four short toes (toes II-III-IV-V; Fernandes & Carvalho, 2008), without claws, with the fifth toe longer and stronger than the others, in slight abduction. The toes are 0.3-0.5 cm long. The posterior (proximal) side of the pes (downward in Fig. 7 A-B) present a crescent-shaped displacement rim, typical of dune environment and pointing to the dip direction when this specimen was *in situ* in the original fossil dune. Just three millimetres in front of the foot, there is the track of the hand (KIKI 04), very small, rounded, punctiform, with neat heteropody, with no anatomical details and with a diameter of about 2 millimetres.

There are two other less well-preserved tracks beneath the first one (KIKI 05 and KIKI 06) and there is another one on the right (KIKI 07) that are preserved in the same slab (downward in the picture), similar in shape and size, which were possibly left by the same trackmaker. The best-preserved footprints show three or four digits.

Discussion on Kin 02 tracks

The main footprints of the slab Kin 02, i.e. KIKI 03 (pes) and KIKI 04 (manus) (Fig. 7) are a typical hand-foot set of *Brasilichnium*. The set has a strong heteropody, the pes has an elliptical shape. The transversal axis is much longer than the anterior-posterior one, and four toes of which the most lateral (digit V) is the greatest, robust and in abduction. So, also because of the small dimension, the main set of footprints of the slab Kin 02 (KIKI 03 (pes)

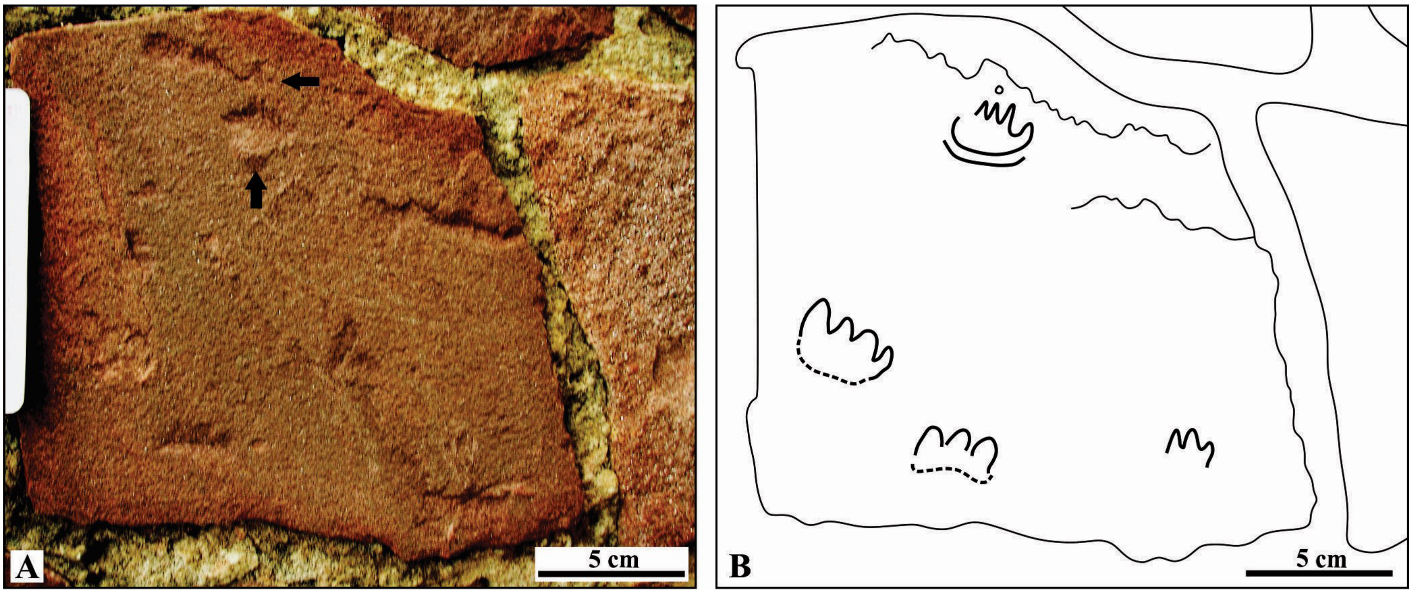

Fig. 7 - A. Slab Kin 02, from the facade of a wall in a building at Mbiti, Kinshasa. *Brasilichnium elusivum*. The horizontal arrow indicates the tiny manus footprint. The vertical arrow indicates the sand crescent-shaped displacement rim. B. Interpretative drawing of the same (Graphic work by Jaime Joachim Dias).

and KIKI 04 (manus); Fig. 7) is attributed to *Brasilichnium elusivum* with certainty.

The crescent-shaped displacement rim of the footprint KIKI 03 (pes) is similar in all details and style to those found in the *Brasilichnium elusivum* tracks of Araraquara and of other Brazilian ichnosites in the megatracksite of the Paraná Basin. This crescent-shaped displacement rim, a semi-circular ridge of sandstone, points with its convex side to the dip of the foresets of a dune.

This peculiar shape and structure of the displacement rim is partly the result of pressure exerted by the foot, oriented backward, and partly by the effect of the force of gravity on the loose sand. In different situations, these crescent-like displacement rims can be long (along the axis parallel to the dip), and some of them can be short, as in this case, indicating different conditions of superficial sand laminae and/or the different speed of the trackmaker and the different pressure of the trackmaker's feet on the sand. From the angle between the axis of this "crescent-shaped" displacement rim and the midline of the trackway, one can determine if the trackmaker was proceeding uphill, downhill, parallel to the strike of the foreset (and to the crest of the dune), or diagonally in comparison with it. For KIKI 03, the trackmaker would be climbing almost directly uphill. The "crescent" here is rather short along its symmetry axis, and its surface inside the footprint is rather steep; so, one can think that the sand was rather wet. Because of this aspect and the other characteristics described above, this hand-foot set is classified as *Brasilichnium elusivum*.

The other three footprints (KIKI 05-07), present in the same slab Kin 02, are less evident because they are less deeply impressed and less complete, but they are rather similar to the footprint KIKI 03, to which they are associated, especially because of the shape and the number of the toes. Despite their lesser quality, they are also tentatively classified as *Brasilichnium elusivum*.

Description and discussion of Kin 03 tracks

Slab Kin 03 (Fig. 8). A relatively large (42 x 43 cm) slab with about 20 poorly preserved hind-footprints (KIKI 08-27) was discovered on the wall of the apse of the chapel inside the Institute St. Eugène de Mazenod, Kasawubu Avenue, at Kintambo district, Kinshasa (Fig. 4). The footprints are preserved as concave epirelief; they are small, about the same size, scattered on the surface, with an elliptical shape. The longer axis (interpreted herein as transversal axis) is

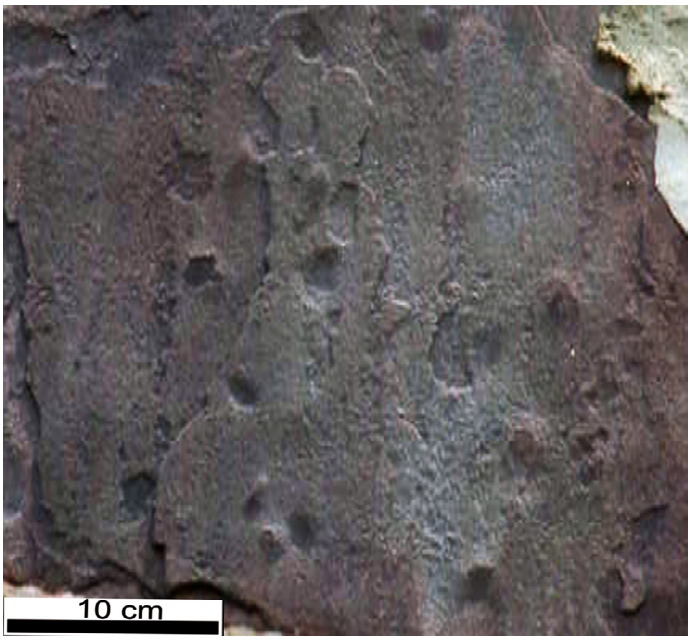

Fig. 8 - Slab Kin 03, from the facing of a building of the Mazenod Faculty, district of Kintambo, Kinshasa. It includes a score of small footprints, probably attributable to *Brasilichnium* isp.

about 2-2.5 cm; and the shorter axis (interpreted as the anterior-posterior axis) is 1-1.6 cm. The average ratio FL/FW is about 1.73. No morphological details are visible, and in particular no digit impressions are preserved. In some cases, there are low and narrow displacement rims on one side of the footprint, however these are not oriented in the same direction, and do not represent the crescent-shaped displacement rims characteristic of dune environment. Rather this fact suggests a humid interdune environment. These tracks are not associated in trackways. Because of the absolute and relative dimension and general aspect it can be assumed that these numerous footprints (about 20) of the slab Kin 03, can be attributed to *Brasilichnium* isp., despite the lack of anatomical details.

THE TRACKMAKER OF *BRASILICHNIUM*: WHY A MAMMAL?

Pacheco (1913), the keen geologist who discovered the first slab with this kind of tracks, who was not a palaeontologist, attributed the trackway to "a reptile"; von Huene (1931) to "more probably a Cynodont"; Mezzalira (1966) to a "?cynodont or archosaur"; Casamiquela (1975) to "a mammaloid"; and Leonardi (1979) wrote that the trackmaker could be "perhaps a therapsid, more probably a small primitive mammal." Announcing the discovery of the ichnosites from the Botucatu Formation at Araraquara (Leonardi, 1980), wrote: "All the other trackways and footprints (PI. IV, figs. 3-12) found until now, are apparently produced by specialized quadrupedal animals autopodia, nearly always presenting a roundish outline, or with a transversal axis longer than the parasagittal. The digits are always very short evidencing, when observable, a phalangeal formula 2-3-3-3-3; their gaits are also advanced, more related to the mammalian than to the reptilian type — among them the gallop and ricochet were observed. Before a systematic study of the material already collected, and of that still to be collected is made, the trackways could tentatively be considered as belonging to Therapsida Broom, 1950, or even in some instances to primitive mammals. The first of these hypothesis is the more likely one, due to the extrapolated size of the animals producing the trackway, which seems too big for Mesozoic mammals." At that time everyone thought that Botucatu Formation was Late Triassic. Today we can say, however, that the Botucatu Formation is Early Cretaceous and that then there were quite large early mammals.

Moreover, although it was later seen that *Brasilichnium* was tetradactyl and not pentadactyl (Fernandes & Carvalho, 2008), the toes, as suggested in Leonardi's paper, were very short, probably all with three phalanges (toes II-III-IV-V; Fernandes & Carvalho, 2008).

Leonardi & Godoy (1980) attributed *Brasilichnium* to the mammaloid kind of tracks. Again, Leonardi (1981b),

Fig. 9 - Environmental reconstruction of the footprint context of Kinshasa Cretaceous deposits (Art by Deverson Silva, Pepi).

in the formal establishment of these ichnogenus and ichnospecies, by means of exclusion, attributed these tracks to the early mammals and formally to the "Class Mammalia Linnaeus 1758". Moreover he made this attribution also for the following anatomical and biomechanical reasons: the trackmaker of this kind of tracks was a quadruped animal, but with a clear tendency to decrease the support on the front of the body, perhaps in an evolutionary trend that would lead him to a hopping bipedal gait, rather typical of the desert environment; posture and gaits not crawling but erect, with the legs held under the body; feet much larger than the hands, unlike the therapsids; pace angulation high for a quadruped and therefore rather narrow trackway, with zero or even negative values of the internal width; foot with elliptical outline, transversal major axis, and anterior-posterior axis slightly inward bent; toes short, clawless; tail drags always absent; besides the walking and running gaits, there are indications of gallop and ricochet gaits.

Leonardi & Sarjeant (1986) defined again these tracks as mammaloid or mammal-like; and they wrote: *"Whether these mammaloid trackways are those of true mammals or those of mammal-like reptiles is a question that cannot be answered satisfactorily, in view of the still-uncertain date of the Botucatu Formation and the small amount of information yet available concerning the morphology of the limbs of protomammals. However, this ichnofauna is giving us the earliest information we have concerning the foot morphology and gait of animals close to the reptile-mammal transition"*.

Subsequently, the other authors who dealt with this subject, including the revision by Fernandes & Carvalho (2008), generally accepted this classification of the trackmaker. Today, the makers of tracks of the ichnogenus *Brasilichnium*, would better be attributed to Mammaliaformes Rowe, 1988, a clade that contains mammals (the crown group, of which, in turn, are part the monotremes, marsupials and placentals) and their extinct relatives; this clade radiated from probainognathian cynodonts (Abdala, 2007).

CONCLUSIONS AND PERSPECTIVES

After a long search in the sandstone slabs of the Loia Formation used for the cladding or veneer of buildings in Kinshasa, DRC, three slabs (Kin 01, 02, 03) with tetrapod fossil tracks were found with a total of 27 fossil footprints, which on the whole are attributable to the ichnogenus *Brasilichnium*. Of these, 25 as mentioned above are herein attributed with greater or lesser certainty to the ichnospecies *Brasilichnium elusivum* and two are attributed to the ichnospecies *Brasilichnium anaiti* (or alternatively to the ichnogenus and ichnospecies *Aracoaraichnium leonardii*), so we classify them as *Brasilichnium* isp. Of these footprints, 26 are tracks of pes, and only one is a tiny print of manus, which forms a manus-pes set along with a correspondent hind-footprint. The rarity of manus tracks is rather common in *Brasilichnium*, because of the strong heteropody with very little hands and also because of the frequent overprinting of the pes print on the manus print (Leonardi, 1981b).

Generally, *Brasilichnium* tracks are typical of an aeolian environment, however, in this case, at least from the petrographic analysis, and with the exception of the slab Kin 02 which seems to come from a dune foreset, the slabs do not seem to pertain to a desert aeolian environment.

The occurrence of these tetrapod tracks in Democratic Republic of Congo, at Kinshasa, is a further constraint to the Cretaceous global distribution of mammals on Earth. These are the first tetrapod tracks found in Democratic Republic of Congo and also in Central Africa. It would be important to continue the search for tracks in the quarries and in the sandstone facades of buildings in Kinshasa, in order to increase the use of ichnology to environmental and palaeogeographic reconstructions (Fig. 9).

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