DEPOSITIONAL SETTINGS OF THE BASAL LÓPEZ DE BERTODANO FORMATION, MAASTRICHTIAN, ANTARCTICA

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ABSTRACT:
In Snow Hill and Seymour islands the lower Maastrichtian, basal part of the López de Bertodano Formation, rests on a high relief, erosive surface elaborated in the underlying Snow Hill Island Formation. Mudstone-dominated beds with inclined heterolithic stratification dominate the basal strata of the López de Bertodano Formation. They consist of rhythmical alternations of friable sandy- and clayey-mudstone couplets, with ripple cross lamination, mud drapes, and flaser bedding. They are characterized by a marked lenticular geometry, reflecting the filling of tide-influenced channels of various scales and paleogeographic positions within a tide-dominated embayment or estuary. Major, sand-rich channel fills, up to 50-m thick, bounded by erosive surfaces probably represent inlets, located on a more central position in the estuary. Minor channel fills, 1- to 3-m thick, associated with offlapping packages with inclined heterolithic stratification probably represent the lateral accretion of point bars adjacent to migrating tidal channels in the upper estuary. Both types of channel fills bear relatively abundant marine fauna, are intensively bioturbated, and are interpreted as a network of subtidal channels. In southwestern Snow Hill Island, the minor offlapping packages have scarce marine fossils and bear aligned depressions interpreted as poor preserved dinosaur footprints. They represent the lateral accretion of point bars adjacent to intertidal creeks, probably located on the fringes of a mud-dominated estuary or embayment. The basal unconformity was produced by subaerial erosion; hence the inferred estuarine settings are consistent with the beginning of a new transgressive sedimentary cycle.

Keywords: *Antarctica; Snow Hill-Seymour islands; Maastrichtian; Dinosaur footprints; Tidal settings.*

RESUMEN: *Ambientes de depositación de la parte basal de la Formación López de Bertodano, Maastrichtiano, Antártida.*. En las islas Snow Hill y Seymour, la Formación López de Bertodano apoya en relación de discordancia erosiva de gran relieve sobre la Formación Snow Hill Island. La parte basal, Maastrichtiano inferior, de la Formación López de Bertodano está dominada por una alternancia rítmica de fangolita arenosa y fangolita arcillosa friables, con estratificación heterolítica inclinada, laminación ondulítica, flaser y cortinas de fangos. Los depósitos presentan a diferentes escalas una marcada geometría lenticular, que refleja el relleno de canales mareales con distintas posiciones paleogeográficas dentro de un engolfamiento o estuario dominado por mareas. Los canales mayores, hasta 50 m de espesor, con superficies erosivas basales y relleno más arenoso, probablemente representan colectores mayores situados en una posición central del estuario. Los canales menores, 1 a 3 m de espesor, asociados con traslape lateral de capas con estratificación heterolítica inclinada, representan estructuras de acreción lateral -migración de barras de punta mareales- adyacentes a canales menores del estuario superior. Ambos tipos de relleno tienen abundante fauna marina y densa bioturbación y se interpretan como un sistema de canales submareales. En el SO de la isla Snow Hill, los canales menores definen capas con estratificación heterolítica inclinada y escasos fósiles marinos, que preservan depresiones alineadas interpretadas como probables icnitas de dinosaurios. Estas capas representan la acreción lateral de barras de punta de canales intermareales menores, probablemente situados en los márgenes fangosos del estuario. La discordancia basal tiene origen subaéreo y en consecuencia los ambientes estuáricos inferidos son consistentes con el inicio de un nuevo ciclo sedimentario transgresivo.

Palabras clave: *Antártida; Snow Hill-Seymour; Maastrichtiano; Icnitas de dinosurios; Ambientes mareales.*

INTRODUCTION

The lower Maastrichtian basal part of the López de Bertodano Formation is well exposed on Seymour and Snow Hill islands, northeastern Antarctic Peninsula (Fig. 1). The section is dominated by thick, friable mudstone-rich deposits, with variable proportions of clay, silt, and sand particles (Macellari 1988). The friable texture and resulting lack of preservation of diagnostic sedimentary structures imposes a homogeneous appearance to these deposits. Consequently, the distinction of sedimentary facies is difficult and the interpretation of the depositional environments problematical.

Based mainly on paleoecological interpretations, two contrasting depositional settings were proposed: a) very shallow marine environment, near a delta or estuary (Macellari 1988); and b) deep water, outer shelf settings (Crame *et al.* 2004). The recognition of large, lenticular bodies of heterolithic mudstones with complex cut and fill structures, interpreted as tide-influenced estuarine channels (Olivero 1998) supported the first interpretation, but the discussion was not completely settled due to the inadequacy of detailed knowledge of sedimentary facies.

The main aim of this study is to analyze the sedimentary facies of the basal López de Bertodano Formation (Fig. 1) and to discuss their significance for the understanding of paleoenvironmental settings. In addition, we report putative dinosaur footprints recorded in the López de Bertodano Formation, Snow Hill Island.

METHODS

This paper is based mainly on the preliminary results of field studies conducted in southwestern Seymour and northeastern Snow Hill islands by three of the present authors in 2004 and 2005 (EBO, JJP, and DRM). The study of sedimentary facies is based on four detailed sedimentary logs of the basal López de Bertodano Formation in Snow Hill and Seymour islands (Fig. 2). Details of sedimentary structures and bedding geometry are mostly visible on fresh exposures at the sea cliff; consequently much of the effort in field research was restricted to this area. The unconformity between the Snow Hill Island and López de Bertodano formations, as well as the erosive basal surfaces of large channels were mapped by walking along the recognized surfaces and recording their geographic position with a GPS navigator. The recorded points were then plotted on published topographic maps of the area (Brecher and Tope 1988, US Geological Survey 1995).

A series of poorly preserved tetrapod footprints were found during the austral summer of 2004 while carrying out sedimentological fieldwork in Snow Hill Island. A new expedition in 2005 resulted in the discovery, in the same horizon, of more material. The detailed mapping of the interpreted tracks was done with a measuring tape and a compass.

GEOLOGICAL AND STRATIGRAPHICAL FRAMEWORK

In the James Ross archipelago, the Upper Cretaceous Marambio Group is about 3 km thick and consists of highly fossiliferous marine, shelf deposits originated in a back-arc basin located to the east of the Antarctic Peninsula (*cf.* Pirrie *et al.* 1997, Olivero and Medina 2000, and references therein).

In the ice-free areas of northeastern Snow Hill and southwestern Seymour islands (Figs. 1, 2), the lower Maastrichtian part of the Group is well exposed (Crame *et al.* 2004), and includes the upper part of the Snow Hill Island Formation and the basal part of the López de Bertodano Formation (Macellari 1988, Pirrie *et al.* 1997). These two units are characterized by monotonous, friable sandy siltstones and mudstones, with abundant concretionary horizons and occasional intercalation of indurate very fine-grained sandstone beds. Due to this homogeneous appearance, all these fine-grained deposits were previously included in the López de Bertodano Formation (*e.g.* Rinaldi *et al.* 1978, Macellari 1988). The differentiation of the Snow Hill Island Formation is based on the recognition of an important unconformity that separates it from the overlying López de Bertodano Formation (Pirrie *et al.* 1997). In this redefined stratigraphy of the studied area, the uppermost part of the Snow Hill Island Formation includes the informal Rotularia Unit 1, and the basal López de Bertodano Formation the Rotularia Units 2 to 5 of Macellari (1988). Absolute dating based on $^{87}Sr/^{86}Sr$ chronostratigraphy suggests an early Maastrichtian age for both stratigraphic units in the studied area (Crame *et al.* 2004), thus supporting previous data based on ammonite biostratigraphy (*cf.* Crame *et al.* 2004, Olivero and Medina 2000, and references therein).

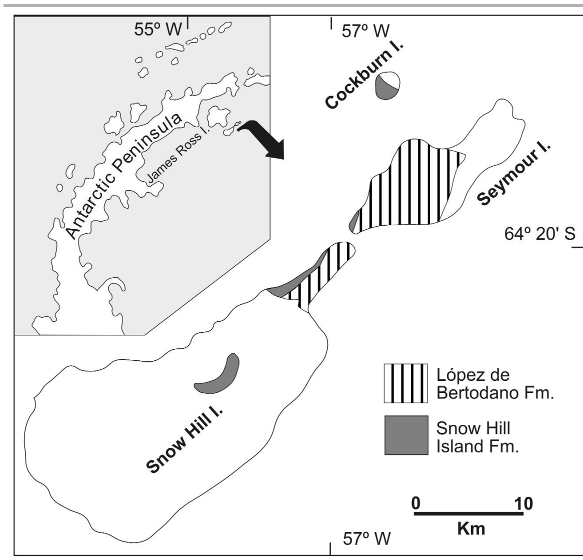

Figure 1: Location map.

SEDIMENTOLOGY OF THE LOPEZ DE BERTODANO FORMATION

The basal unconformity

According to Pirrie *et al.* (1997), in Snow Hill and Seymour islands the base of the López de Bertodano Formation rests on an important unconformity, which erosively cuts more than 60 m of the underlying Snow Hill Island Formation. The results of our field mapping support this conclusion, but we found that the unconformity is located at a lower stratigraphic level, within the upper beds of the Snow Hill Island Formation as originally mapped by Pirrie *et al.* (1997; *cf.* their figure 3 with Fig. 2a). Several erosive surfaces characterized the sedimentary bodies stratigraphically located either above or below the main unconformity (*cf.* Olivero 1998), and recognition of a major sequence boundary requires proper distinction of erosive surfaces generated by autocyclic or allocyclic processes (Fig. 2b).

In our interpretation, the main sequence boundary is coincident with an irregular, high-relief erosive surface locally marked by a basal bed with abundant pebbles of reddish concretions, rounded sandstones, and fossils reworked from the underlying Snow Hill Island Formation, and isolated

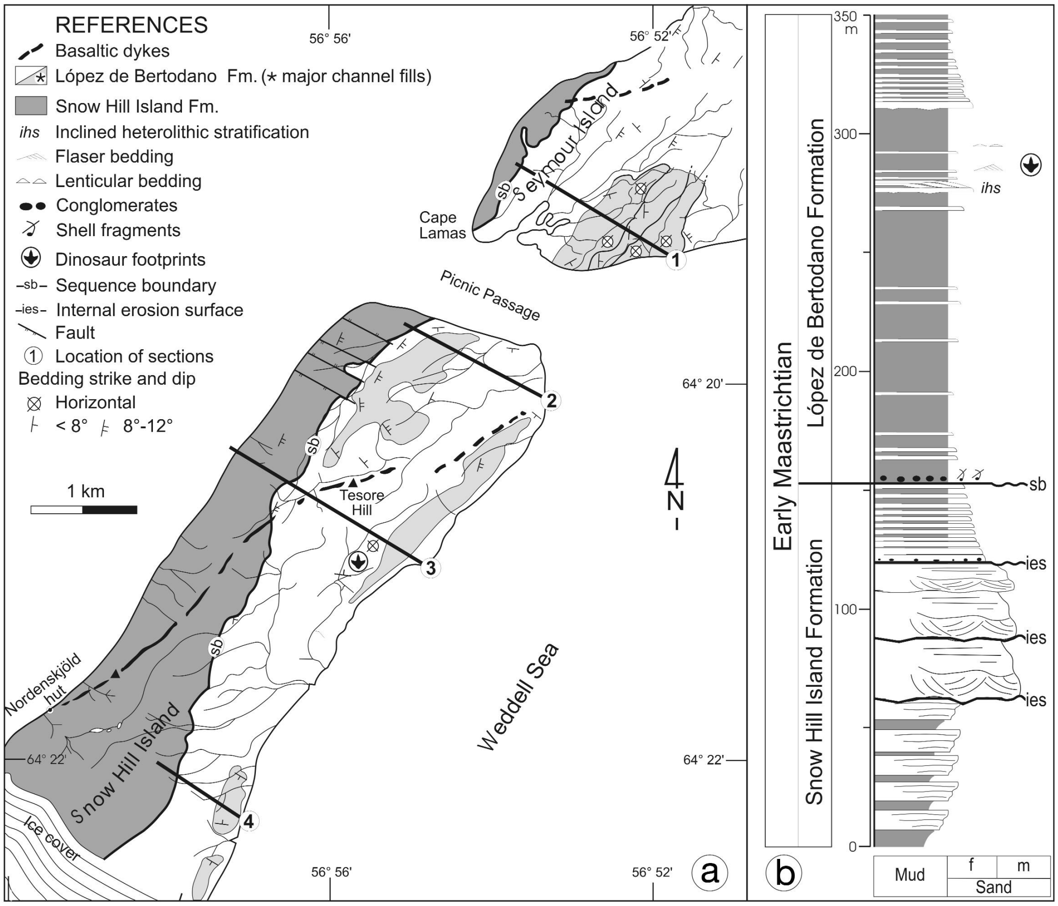

Figure 2: a) Geological sketch of the NE Snow Hill and SW Seymour islands. b) Sedimentary log of the Snow Hill Island and the López de Bertodano formations, Section 3.

pebbles of slates and rhyolites derived from older rocks cropping out along the Antarctic Peninsula (Fig. 3). This bed rests above a slightly angular unconformity that erosively cuts more than 100 m of the underlying Snow Hill Island Formation, being the lowest erosional relief located near the Picnic Passage (Figs. 2a, 4a).

The position of the unconformity is approximately coincident with the level detected by Pirrie *et al.* (1997) in the upper Snow Hill Island Formation, which marks a major compositional break in the palynomorph assemblages. The provenance levels of the upper three palynological samples from this Formation (figure 8 of Pirrie *et al.* 1997) are now reassigned to the basal López de Bertodano Formation. Furthermore, the location of the unconformity proposed in this paper indicates that the outcrop belt of the Snow Hill Island Formation is laterally continuous along Snow Hill and Seymour islands. As this fact eliminates the proposed lateral offset of the outcrop belt between these two islands (Pirrie *et al.* 1997), there is no need to invoke a major extensional fault along the Picnic Passage (Fig. 2a).

Sedimentary facies and architecture

The dominant sedimentary facies of the López de Bertodano Formation are mudstone-dominated heterolithics with inclined bed sets, lenticular sandstone-dominated heterolithics, and fossiliferous conglomerates. Detailed features of individual sedimentary facies and architecture are best seen in fresh exposures at the sea cliffs. Inland, the combination of low-cuesta topography and the friable character of these fine-grained sediments prevent detailed observations. Accordingly, these individual facies are grouped for ease of description in a single facies association dominated by heterolithic mudstones.

The most abundant facies consists of regular alternations of thinly stratified, millimeter- to decimeter-scale, dark-gray mudstones and pale-gray sandy siltstones to very fine-grained sandstones showing variations in thickness of individual laminae or beds that could be arranged in vertically cyclical patterns. Generally, a dense mottling produced by bioturbation resulted in the loss of the original stratification; in less bioturbated areas the sandstone laminae or beds preserve delicate current ripples with mud drapes. Herringbone and flaser bedding are rare. Paleocurrent measurements indicate that major flows were directed to the east, with minor flow reversals (Figs. 4a, 5a-d).

The heterolithic mudstones record thick stratigraphic packages with variable proportions of sand-mud ratios, but they are difficult to map because of the poor quality of the outcrops. Nonetheless, based on a large number of grain-size analyses Macellari (1988) was able to show an intertonguing of silt-rich, clay-rich, and sand-rich units in Seymour Island that he distinguished as the informal units U2, U3, and U4, respectively. The bedding attitude, particularly in the units U3 and U4 and their equivalents in Snow Hill Island, are also highly variable, but two repetitive motifs are evident. In one

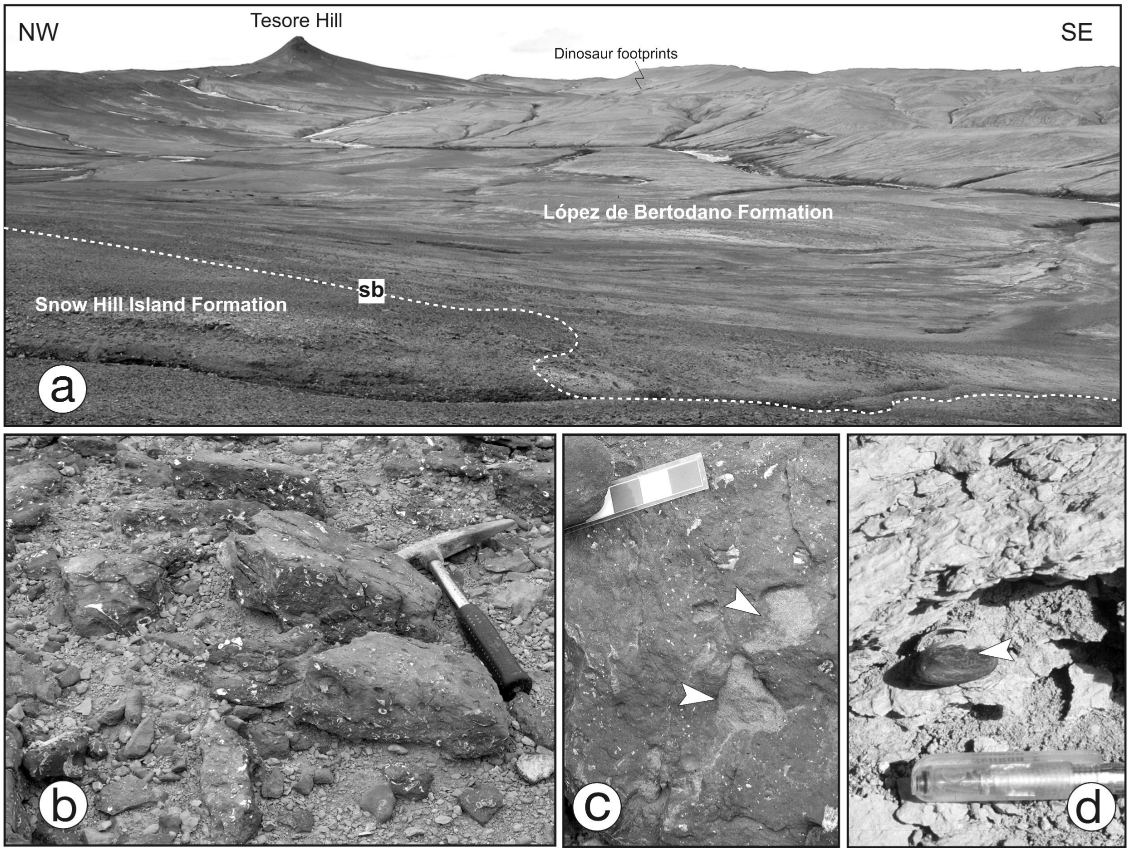

Figure 3: a) Panoramic view of the main unconformity (sb) between the Snow Hill Island and the López de Bertodano formations at Snow Hill Island showing the location of the dinosaur footprints. b) The basal conglomerate of the López de Bertodano Formation in Snow Hill Island. c-d) Detailed photos of the basal conglomerate showing fossil fragments and pebbles; arrows point to reworked sandstone pebbles from the underlying Snow Hill Island Formation (c), and rounded schist pebble derived from the Antarctic Peninsula (d).

motif, lenticular packages of 1- to 3-m thick, are characterized by low dipping to subhorizontal strata, which define low-angle, offlapping bed sets with inclined heterolithic stratification that can be followed laterally for 50- 70-meters. The other motif records large, sometimes deeply incised, concave upward erosion surfaces bounding channel-shaped heterolithic packages, up to 50 m thick (Fig. 4). In the mid and upper parts of unit U4 on Seymour Island these heterolithic packages present multiple erosion surfaces, resulting in complex cut and fill structures (Olivero 1998) characterized by a dominantly aggradational bedding style (Fig. 4b). Other channel-shaped fills, mainly composed of thicker very fine-grained sandstone beds irregularly interbedded with thinner mudstone lenses, form isolated bodies encased in mudstone-rich heterolithic beds (Fig. 4c). The basal contact of these channel-shaped fills is an erosive surface associated with a lag deposit of reworked concretions and shell fragments. The largest channel-form sandstones, about 2-km wide and up to 50-m thick, are preferentially located near the Picnic Passage (Figs. 2, 4a). Because of the dense ichnofabric that has destroyed most original physical structures, it is difficult to discern the bedding style of these channel-form sandstones, but appears to be dominantly accretional.

Just above the basal unconformity of the López de Bertodano Formation in Snow Hill Island an unusual conglomerate facies is locally developed. This facies, exposed in discontinuous patches of reduced extend (2- to 5-m), consists of a hard cemented concentration (20- to 50-cm thick) of pebble- to cobble-sized reworked concretions and sandstone fragments, derived from the Snow Hill Island Formation, occasional pebbles of acidic volcanics and schists, and abundant shell fragments (Figs. 3b-d).

In Seymour Island marine fossil invertebrates are relatively abundant in several stratigraphic horizons within the heterolithic mudstones. In the informal unit U2, abundant specimens of the bivalves *Nordenskjoldia, Eselaevitrigonia, Oistotrigonia*, and *Pinna* are frequently preserved in life position. Relatively large forms of the ammonite *Maorites tuberculatus,* together with *M. densicostatus, Grossouvrites gemmatus,* and *Diplomoceras lambi*, indeterminate gastropods, echinoid spines, and serpulids are also relatively abundant. A more depauperate fauna is present in unit U3, where only serpulids and echinoid spines are abundant throughout its thickness (Fig. 5e). However, gastropods, oysters, and ammonites could be abundant in certain horizons located at the base of the offlapping inclined-bed sets. Unit U4 records a similar pattern, but with increased abundance of *M. tuberculatus, Nordenskjoldia, Pinna,* and cirripeds (*cf.* Macellari 1988, Olivero 1998. Olivero and Medina, 2000, and Crame *et al.* 2004).

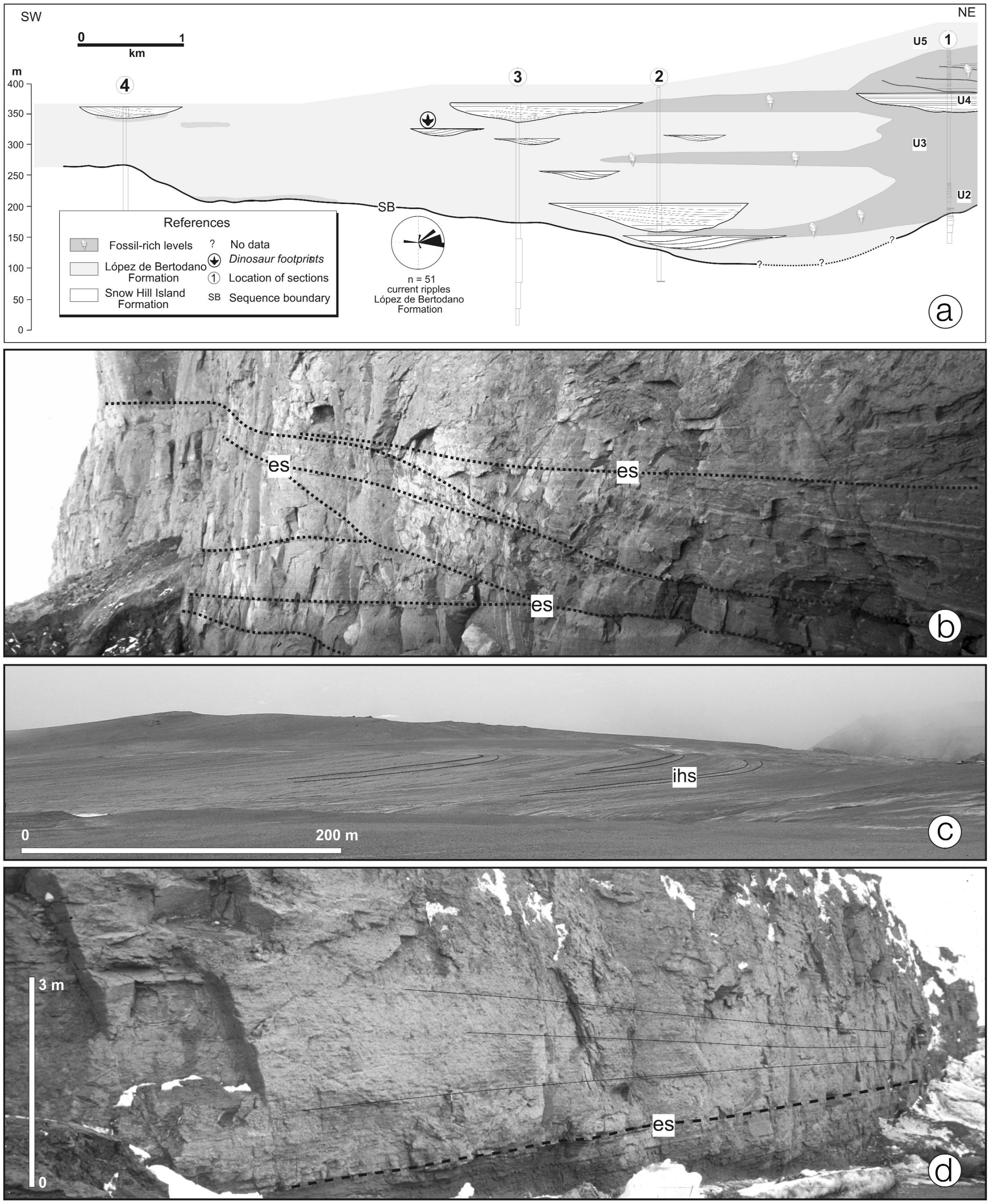

Figure 4: a) Along strike correlation of sections 1 to 4 showing the high-relief sequence boundary, the architecture of sedimentary facies, and the distribution of channels of different scale and fossil-rich horizons in the basal López de Bertodano Formation. Note the concentration of largest channels and fossil horizons near the Picnic Passage, between sections 1 and 3. b) Sedimentary fillings and internal erosion surfaces (es) of the large channel indicated in Section 1, Seymour Island. Height of the cliff is about 50 m. c) Medium-scale, muddy-filled channel with inclined heterolithic stratification (ihs), Section 4, Snow Hill Island. Bedding is gently dipping to the north. d) Small-scale channel filled with offlapping packages (inclined heterolithic stratification). The basal erosion surface (es) and some offlapping beds are indicated.

In northeastern Snow Hill Island, marine invertebrates are restricted to localized stratigraphic horizons and are only abundant in lenticular lag deposits. The basal lags of the two large, isolated channel-form sandstones bear abundant specimens of gastropods, bivalves, and ammonites; the latter dominated by *Maorites tuberculatus*. The discontinuous basal lag resting on the unconformity at the base of the López de Bertodano Formation records abundant specimens of corals, oysters, and the bivalve *Thyasira townsendi* White. Limited horizons within the mud-rich heterolithic beds, which are dominant to the southwest of Snow Hill Island, could record abundant serpulids and echinoid spines. The trace fossils distribution has a similar pattern to that of the megafauna. In the mudrich beds of the López de Bertodano Formation in Seymour and northeastern Snow Hill islands the dominant trace fossils are *Phycosiphon, Nereites missouriensis, Paradictyodora* (*cf.* Olivero *et al.* 2004), and "*Terebellina*", whereas *Neonereites biserialis, Patagonichnus stratiforme*, and *Ophiomorpha* dominate the sandier beds. Bioturbation is scarce or absent in the clay-rich heterolithics exposed

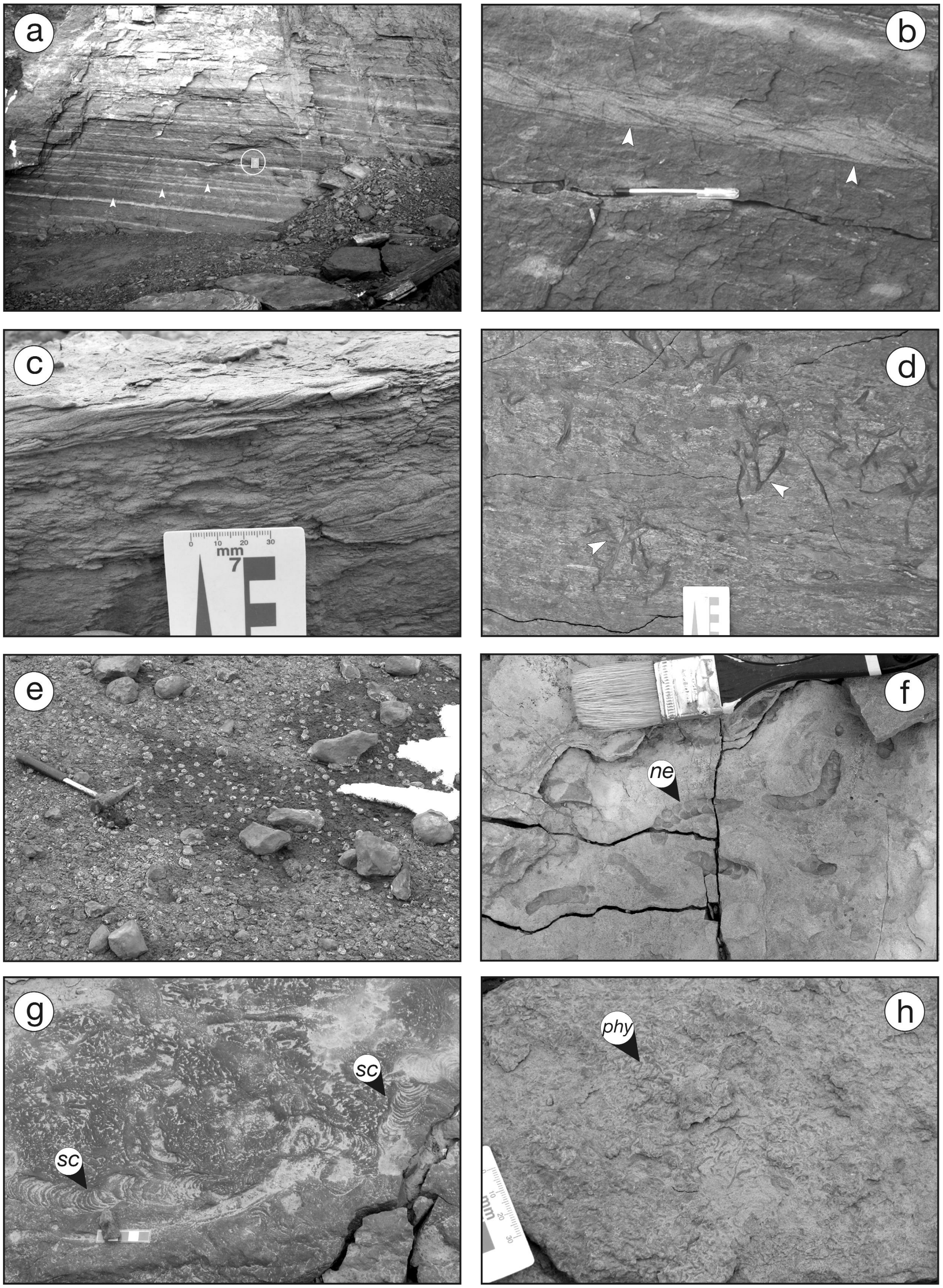

Figure 5: Main sedimentary facies and fossils of the López de Bertodano Formation. a) General view of rhythmic alternation of sandy (light-gray, arrowhead) and muddy (dark-gray) mudstone couplets. Field notebook (encircled) for scale. b) Detailed view of a sandy siltstone bed (arrowhead) with ripple cross-lamination and mud drapes. c) Current ripple cross-lamination in fine-grained sandstones. d) Fully bioturbated siltstone and mudstone couplets. The burrows of *Paradictyodora* isp. (arrow) cross-cut the mottled background, full relief, vertical view. e) Mudstone bed with abundant specimens of *Rotularia* sp. f) *Neonereites biserialis* (*ne*), upper bedding plane view. g) Scolicia isp. (*sc*), full relief, upper view. h) *Phycosiphon* isp. (*phy*), full relief, upper view.

toward the southwest of Snow Hill Island, but sandier beds locally record abundant *Scolicia, Neonereites biserialis,* and *Teichichnus* isp. Large "*Rosselia*"-like traces are relatively abundant at the base of the offlapping, inclined-bed sets (Figs. 5f-h).

Tetrapod footprints

In Snow Hill Island, one thin, very fine-grained, well-cemented sandstone bed bears decimeter-scale depressions surrounded by a raised rim of convoluted sediment. These depressions have been found within one of the offlapping packages with inclined heterolithic stratification (Figs. 2, 3a, 4a), consisting of thin, indurated sandstones and thick, massive, friable mudstones,

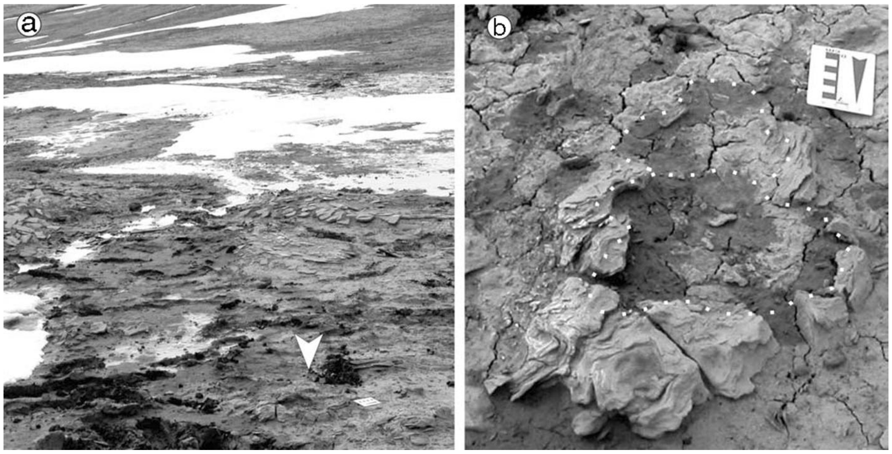

Figure 6: a) General view of the track-bearing surface; the arrow indicates the position of the footprints in b. b) Detailed view of a natural mold of manus-pes pair surrounded by raised rims of convoluted sediment produced by compression of the substrate by the animal; scale bar in cm.

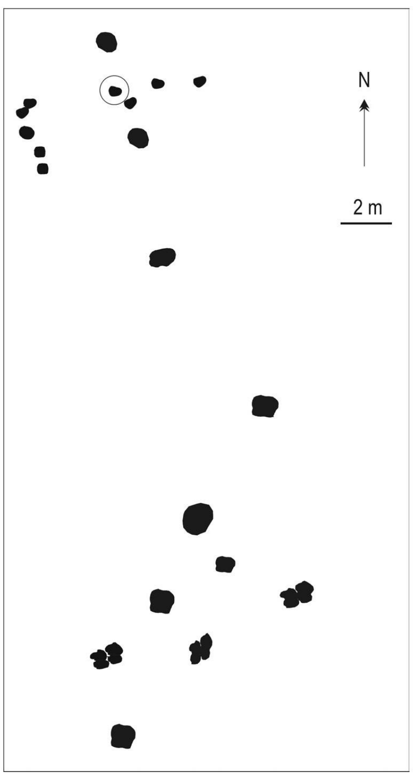

Figure 7: Map of the probable trackways identified on the track-bearing surface; the circle indicates the manus-pes pair in Figure 6 b.

with abundant specimens of the serpulid *Rotularia (Austrorotularia) fallax* (Wilckens). The circular to oval depressions are preserved in a single horizon within a thin, hard-cemented very fine-grained sandstone bed (3 to 5 cm thick) interbedded with friable, clay-rich mudstones. The rounded depressions, at least 3 to 4 cm deep, are not simple holes on the bedding surface, as usually produced by differential weathering in non-uniformly cemented beds. Instead, close inspection of the internal structure shows that the sandy laminae bent downward near the center and it conforms a raised rim of convoluted sediments toward the margin of the depressions (Fig. 6). Because the internal laminae were deformed before cementation of the sandstone bed, deformation by modern cryogenic processes, such as frost heaving, are ruled-out. Most of the depressions are irregularly distributed, but in one case up to seven of them were aligned in almost a straight line (Fig. 7). The bedding plane distribution, the associated deformation pattern, and their relative size suggest that these depressions could be best interpreted as poorly preserved dinosaur tracks and trackways. The putative footprints are preserved as natural molds and the raised rim of convoluted sediment was probably produced by the compression of the substrate by the animals (Fig. 6).

The assemblage includes many isolated prints randomly distributed, of highly variable sizes (from 20 to 60 cm), thus suggesting a trampling surface. Three trackways were identified probably representing both bipedal (one) and quadrupedal (two) progressions (Fig. 7). Seven steps compose a long trackway of a biped, nearly crossing the entire surface from north to south. Each print is slightly anteroposteriorly elongated (approximately 60 cm in length); digits are not distinguishable probably related to the high water content of the sediment during impression. The two remaining trackways apparently correspond to quadrupeds but in only one of them this condition is certain. It includes approximately four manus-pes sets where the pedal prints (approximately 30 cm in length) are larger than those of the manus (approximately 20 cm in length) and partially overprint the posterior half of the former (Figs. 6, 7).

DISCUSSION AND CONCLUSIONS

As previously mentioned, the interpretation of the depositional settings of the basal part of the López de Bertodano Formation in Seymour and Snow Hill islands based on paleoecological analyses is controversial. The depauperate invertebrate macrofauna dominated by the serpulid genus *Rotularia* Defrance and echinoid spines, typical of the basal López de Bertodano Formation, was interpreted to reflect shallow marine depositional settings, with deltaic or estuarine influence (Macellari 1988). On the contrary, Crame *et al.* (2004) interpreted that the lowest, mud-dominated part of the López de Bertodano Formation, with sparse macrofauna, actually represents a deeper-water, outer shelf setting. The later authors considered that the whole formation represents a large-scale shallowing-upwards trend, with most taxa occurring in nearshore, shallow-shelf settings by the latest Maastrichtian, *i.e.* in the upper part of the unit. The homogeneous character of these deposits causes difficulty in the analysis of the sedimentary facies. Nevertheless, the stratal geometry and heterolithic mudstones, with sedimentary structures typical for tidalites (Figs. 5 a-c), suggest shallow-water, tide-influenced depositional settings. The basal strata of the López de Bertodano Formation are characterized by a marked lateral variability originally interpreted as an intertonguing of clayey- and sandy-mudstone bodies, with their main axis aligned parallel to the paleoshore, *i.e.* in a northern direction (Macellari 1988). However, the lateral variability of these strata appears to reflect the lenticular filling of large channels, up to 1 km in width and 50 m in thickness, with their main axis oriented normally to the paleoshore (Olivero 1998). Moreover, these lenticular bodies are bounded by large erosive surfaces; present ample evidence of complex cut and fill structures; and are composed of rhythmical alternations of sandy- and clayey-mudstone couplets, with ripple cross lamination, mud drapes, and flaser bedding (Figs. 2b, 4b, 5a-c). Consequently, these lenticular bodies are best interpreted as the sedimentary filling of large, tide-influenced estuarine channels (*cf.* Olivero 1998). Several of these major channels are indicated in the accompanying map (Figs. 2a, 4a). In addition to the above mentioned features, these large channels are also associated with variable bedding attitudes, with strike orientations almost perpendicular to the regional, NNE bedding strike within the basin. These variable bedding attitudes, which commonly delineate the channel margins, reflect the aggradational character of the sedimentary filling, with successive beds onlapping the channel margins and dipping toward their axis. The variable bedding strike in part also reflects minor scale, offlapping packages of heterolithic mudstones, interpreted as lateral accretion deposits, *i.e.* inclined heterolithic stratification, migrating in a direction oriented normally to the axis of minor channels (Fig. 4c).

The facies association of the López de Bertodano Formation is interpreted to represent sedimentation in tidal-dominated channels of various scales and paleogeographic positions within an embayment or estuary. Sedimentary controls by tidal processes are suggested by the dominance of vertically stacked packages with inclined heterolithic stratification; current ripple cross-lamination with abundant mud drapes; evidence of paleoflow reversals; and the complex, channel-shaped geometry of sedimentary bodies containing marine fossils. No clear examples of tidal cyclicity were recorded, however several thinly laminated, interbedded mudstone/sandstone couplets are arranged in repeated vertically cyclical patterns (Figs. 4, 5), which are suggestive of tidal rhythmites (Nio and Yang 1991, Klein 1998).

The bedding architecture, lithology, and thickness of the fills in the interpreted tidal channels are highly variable, but the recorded motifs appear to characterize tidal processes in different paleogeographic locations. The offlapping packages, 1- to 3-m thick, with inclined heterolithic stratification probably represent the lateral accretion of point bars adjacent to migrating tidal channels. The large, heterolithic channel fills, up to 50-m thick, with complex cut and fill structures and an overall aggradational filling pattern, probably reflect fluctuating sea-level changes and accompanying erosion and deposition by large, subtidal channels (*cf.* Clifton 1994, Eberth 1996). In Seymour and NE Snow Hill islands these two motifs alternate at different stratigraphic levels. As both types of channel fills bear relatively abundant marine fossils and are intensively bioturbated, they are interpreted as subtidal channels, probably representing a network of channels of different sizes.

In southwestern Snow Hill Island, the mud-rich beds with inclined heterolithic stratification are poorly fossiliferous and, except for a few levels, they lack an intense bioturbated ichnofabric. In addition, the topmost bed of one of the offlapping packages appears disturbed by putative dinosaur footprints (Fig. 6). These features strongly suggest that the offlapping packages represent the lateral accretion of point bars adjacent to intertidal creeks, probably located on the fringes of a mud-dominated estuary or embayment.

The footprints represent additional evidence for very shallow water settings, with temporary subaerial exposure, in the basal López de Bertodano Formation. This evidence and the associated sedimentary features strongly suggest that the interpreted track-bearing site represent an intertidal mud flat, dissected by shallow, small tidal creeks. In this scenario, the footprints were made on a thin wet sand layer covered by soupy muds, probably located on the margins of the tidal creek. The poor preservation of these imperfect tracks is probably original and was controlled by the high water content of the soupy substrate. As indicated by the rim of folded sediment around the footprints (Fig. 6), the slumping back of the surrounding sediments into the footprint (*cf.* Lockley 1986, Milàn and Bromley 2006) modified the original track impression.

These small tidal creeks were probably located on the lateral sides of a mud-dominated estuary. Larger channels, with a higher sand-grain content and bounded by extensive erosive surfaces, probably represent major subtidal inlets, located on a more central position in the estuary. The relatively higher abundance of marine fossils in southwestern Seymour Island, compared to stratigraphically equivalent beds in Snow Hill Island is consistent with this scenario. Thus, the main paleoenvironmental settings are interpreted as a relatively large, tide-dominated estuary or embayment. The studied outcrops of Snow Hill Island were probably located on the mud-dominated intertidal flats, along the margin of the estuary, whereas those of the Seymour Island represent subtidal settings located toward the central to outer parts of the estuary. The major unconformity at the base of the López de Bertodano Formation was probably associated with subaerial erosion, as indicated by the erosional downcutting of more than 100 m of sediments of the underlying Snow Hill Island Formation. Consequently, the inferred estuarine settings are totally consistent with the beginning of a new transgressive sedimentary cycle represented by the López de Bertodano Formation.

Even though the dinosaur groups represented by the ichnites can not be assessed, they support the presence of a diverse dinosaur fauna during the latest Cretaceous in the continent. Non-avian dinosaur remains in Antarctica are only known from the Lower Jurassic of the Transantarctic Mountains (Hammer and Hickerson, 1994) and the Upper Cretaceous of the James Ross archipelago. Particularly, the Upper Cretaceous record is rather scarce and fragmentary. The first dinosaur material reported from Antarctica was a single individual of a nodosaurid ankylosaur from shallow marine deposits of the late Campanian Santa Marta Formation, exposed on James Ross Island (Olivero *et al.* 1986, Gasparini *et al.* 1987, Olivero *et al.* 1991, Salgado and Gasparini 2006). Also from James Ross Island, but from a different locality and slightly older levels (Coniacian, Hidden Lake Formation), Molnar *et al.* (1996) described a tibia attributed to a theropod. Additional Cretaceous dinosaur specimens are known from Vega

Island and they include skeletal elements of a hypsilophodontid (early Maastrichtian, Snow Hill Island Formation, Hooker *et al.* 1991) and a single tooth of a hadrosaur (Maastrichtian, López de Bertodano Formation, Case *et al.* 2000). Recently, two additional theropod fragments were recovered from the Maastrichtian of Vega and James Ross islands (J.E. Martin, pers. comm. to EBO, 2005). Therefore, the combination of the known dinosaurs body-fossil record with these new ichnites might suggest a more extensive distribution of dinosaurs in Antarctica than previously assumed. This circumstance could be reflecting opportunistic dispersal of members of the group at the end of the Cretaceous among southern Gondwanan areas via Antarctica, as was previously proposed (Sampson *et al.* 1998), probably during periods of more favorable climatic conditions in the region.

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