Stratigraphy and vertebrate paleoecology of Upper Cretaceous–?lowest Paleogene strata on Vega Island, Antarctica

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ABSTRACT

The Upper Cretaceous (Maastrichtian) Sandwich Bluff Member of the López de Bertodano Formation is well exposed on Vega Island in the James Ross Basin off the northeastern coast of the Antarctic Peninsula. Although this unit is one of the richest sources of end-Cretaceous vertebrate fossils in Antarctica, it is also one of the least sedimentologically and stratigraphically characterized units in the basin. New facies and stratigraphic analyses of the Sandwich Bluff Member and the underlying Cape Lamb Member of the Snow Hill Island Formation were performed in tandem with intensive prospecting for fossil vertebrates and stratigraphic assessment of historic paleontological localities on Vega Island. This effort has led to a revised stratigraphy for the Sandwich Bluff Member and the precise stratigraphic placement of important terrestrial and marine vertebrate fossil localities. Facies analysis reveals a fining and shallowing upward trend through the section that culminates in a newly recognized sequence boundary near the top of the Sandwich Bluff Member, followed by the deposition of a previously unrecognized, 6 m-thick, matrix-supported pebble–cobble conglomerate of probable alluvial origin. Immediately overlying this unit, well-developed *Thalassinoides* burrow networks in fine-grained transgressive sandstones and siltstones indicate a rapid return to marine conditions. A similar stratigraphic pattern is well documented at the top of the López de Bertodano Formation and the base of the overlying (Paleocene) Sobral Formation on Seymour Island in the southern part of the basin. Although no fossils were recovered to constrain the age of the upper 10–15 m of the succession on Vega Island that preserves the newly recognized upper sequence boundary, strata below this level can be confidently placed within the *Manumiella bertodano* interval zone, which extends to a short distance below the K–Pg boundary on Seymour Island. Hence, based on sequence stratigraphic and lithostratigraphic evidence, the uppermost 10–15 m of the succession on Vega Island may encompass the Cretaceous–Paleogene boundary together with a few meters of the Paleocene Sobral Formation.

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1. Introduction

The James Ross Basin (JRB), located off the northeastern margin of the Antarctic Peninsula, provides the most extensive record of Upper Cretaceous strata exposed at present anywhere in Antarctica. Richly fossiliferous, predominantly nearshore shallow marine beds are exposed on James Ross, Vega, Seymour, Snow Hill, Cockburn, Humps, and a few other, smaller islands in the JRB. Sites in this archipelago collectively preserve over 2000 m of exposed Cretaceous strata that range in age from the Albian to the Maastrichtian. These units have yielded an exceptional marine invertebrate record plus a sparse but critical snapshot of Antarctic end-Mesozoic floras and vertebrate faunas (e.g., Olivero et al., 1986; Gasparini et al., 1987; Macellari, 1988; Pirrie, 1989; Zinsmeister et al., 1989; Crame et al., 1991; Olivero et al., 1991; Pirrie et al., 1991; Marenssi et al., 1992; Crame et al., 1996; Zinsmeister and Feldmann, 1996; Pirrie et al., 1997; Rich et al., 1999; Case et al., 2000; Olivero and Medina, 2000; Césari et al., 2001; Marenssi et al., 2001; Chatterjee, 2002; Francis and Poole, 2002; Crame et al., 2004; Clarke et al., 2005; Martin and Crame, 2006; Case et al., 2007; Cerda et al., 2012; Tobin et al., 2012; Bowman et al., 2013; Reguero et al., 2013, in press).

Among the most significant terrestrial vertebrate discoveries from the Upper Cretaceous of the JRB are birds and non-avian dinosaurs (e.g., Chatterjee, 1989; Case et al., 2000; Chatterjee, 2002; Novas et al.,

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2002; Clarke et al., 2005; Case et al., 2007; Tambussi and Acosta Hospitaleche, 2007; Reguero et al., 2013, in press). Although scattered remains of these groups have been found throughout the basin (Gasparini et al., 1987, 1996; Reguero and Gasparini, 2006; Reguero et al., in press), arguably the most productive and important locality for Antarctic Cretaceous dinosaurs (including birds) has been the area encompassing Cape Lamb and Sandwich Bluff on the western half of Vega Island (Hooker et al., 1991; Thomson and Hooker, 1991; Milner et al., 1992; Noriega and Tambussi, 1995; Case and Tambussi, 1999; Case et al., 2000; Case, 2001; Case et al., 2001; Cordes, 2001, 2002; Case et al., 2003; Clarke et al., 2005; Case et al., 2006; Chatterjee et al., 2006; Tambussi and Acosta Hospitaleche, 2007; Reguero et al., 2013, in press). A considerable number of these discoveries are derived from an isolated exposure of the Sandwich Bluff Member of the López de Bertodano Formation that forms the top of the exposed Cretaceous section on the island (Noriega and Tambussi, 1995; Case et al., 2000; Case, 2001; Case et al., 2001, 2003; Clarke et al., 2005; Case et al., 2006; Tambussi and Acosta Hospitaleche, 2007; Reguero et al., in press). Exposed almost exclusively along the flanks of Sandwich Bluff (Figs. 1–2), this section has been proposed to comprise marine and possibly terrestrial facies (Olivero, 2012); however, it is among the least-studied of all stratigraphic units in the JRB.

Previous investigations (Pirrie et al., 1991; Marenssi et al., 2001; Crame et al., 2004) have provided a basic stratigraphic and sedimentological framework for the Sandwich Bluff Member. Nevertheless, the limited understanding of the stratigraphy and depositional setting of this unit is problematic in light of the fact that its fossil vertebrate assemblage includes some of the most evolutionarily and paleobiogeographically significant non-avian dinosaur and bird remains yet recovered from the Cretaceous of Antarctica. Foremost among these are an isolated tooth of

a hadrosaurid ornithopod dinosaur (Case et al., 2000) and the only described partial skeleton of the anseriform bird *Vegavis iaai* (Noriega and Tambussi, 1995; Clarke et al., 2005). Both of these records are important in that they document the presence of these clades in the Antarctic during the Cretaceous; moreover, the hadrosaurid tooth constitutes compelling evidence for Late Cretaceous terrestrial vertebrate dispersal from South America to Antarctica (Case et al., 2000). *Vegavis* is also of paramount importance in that it is the only unquestioned representative of an extant (i.e., crown) avian lineage (Anseriformes, e.g., ducks and geese) yet known from pre-Cenozoic strata anywhere in the world. Its latest Cretaceous occurrence helps to establish that the diversification of Neornithes—the group that includes all modern birds—was underway by this time (Clarke et al., 2005).

The growing significance of the vertebrate fauna of the Sandwich Bluff Member, along with a relative scarcity of high-resolution stratigraphic, taphonomic, and paleoenvironmental information from this unit (Pirrie et al., 1991; Marenssi et al., 2001), prompted the review and investigation reported herein. The results of this study provide a refined stratigraphic framework for Cretaceous deposits on Vega Island. Furthermore, the review and synthesis of the sedimentological and paleontological data shed critical light on paleoecosystems that developed along a polar Gondwanan coastline near the close of the Mesozoic.

2. Geologic background

The James Ross Basin extends several hundred km into the Weddell Sea (del Valle et al., 1992; Hathway, 2000). Cretaceous–Paleogene (K–Pg) exposures in the JRB are limited to a handful of ice-free areas, principally on James Ross, Seymour, Snow Hill, Vega, and a few other, smaller islands (Fig. 1). The JRB developed as a back-arc basin along
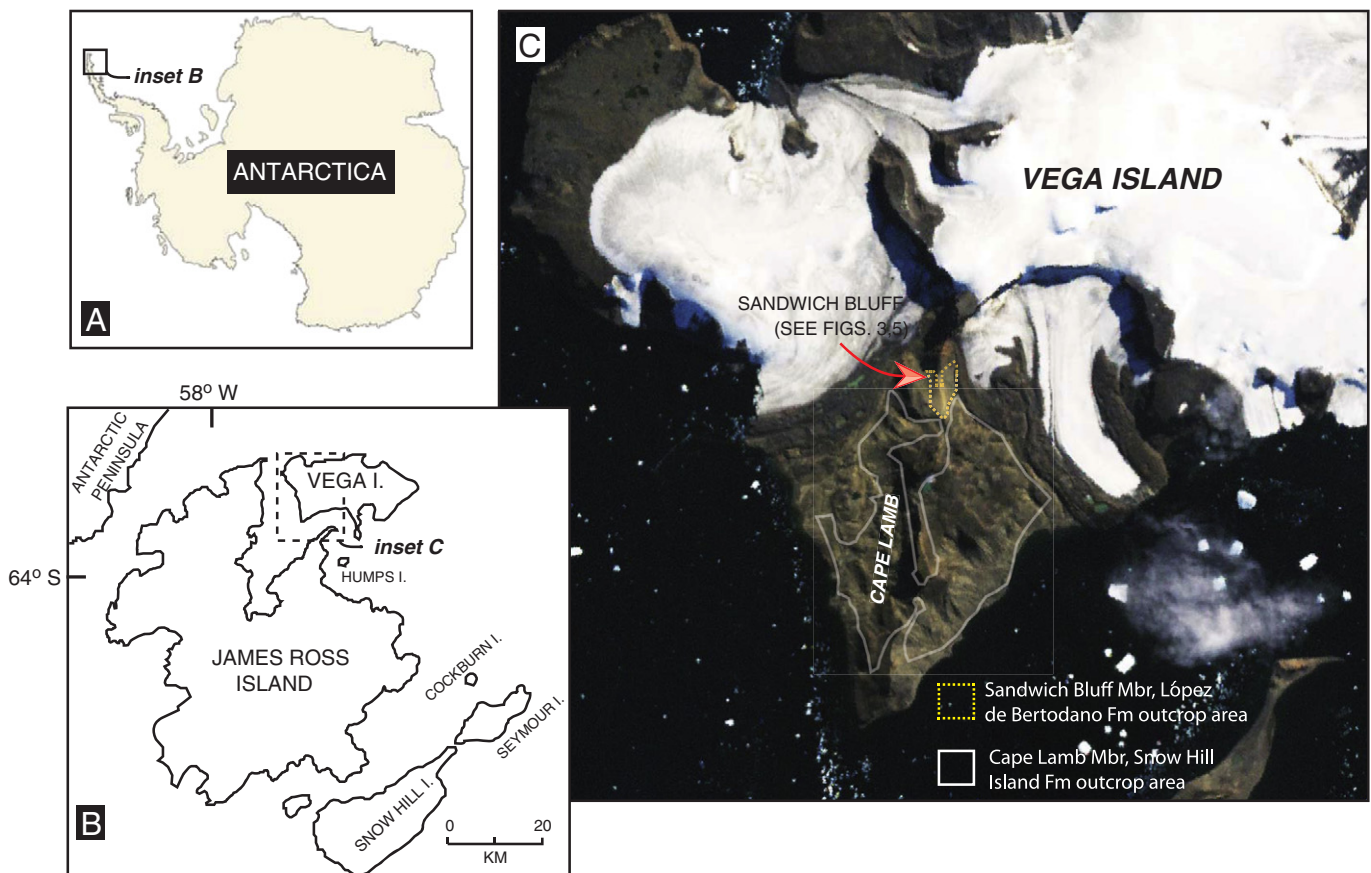
Fig. 1. Location of study area. A) Map of Antarctica showing location of northern Antarctic Peninsula and adjacent James Ross Island Group (box). B) Map of James Ross Island Group showing location of western Vega Island (and northern Naze peninsula of James Ross Island) (box). C) NASA LandSat image of western Vega Island (and northern Naze peninsula) showing outcrop distribution of studied Upper Cretaceous units. Abbreviations: Fm, Formation; I, island; Mbr, Member.
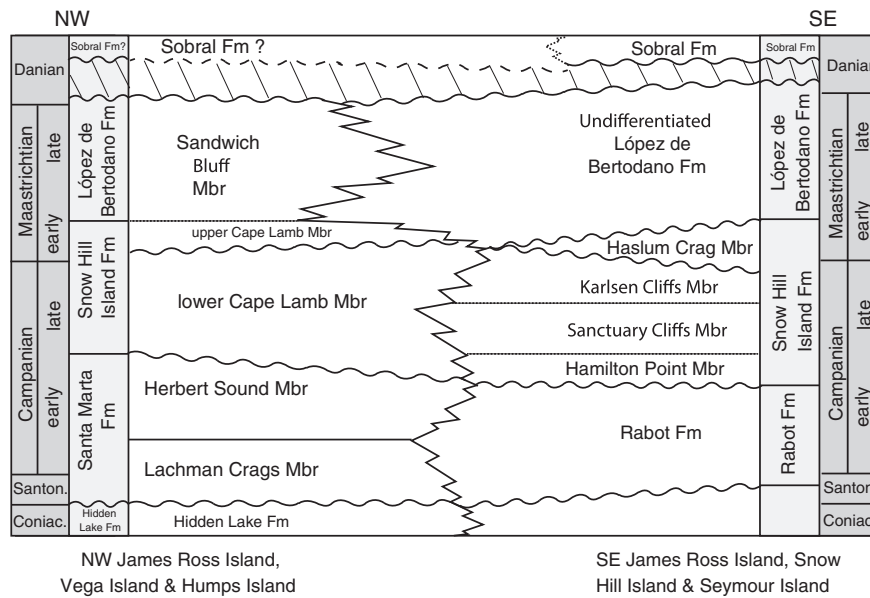
Fig. 2. Generalized Upper Cretaceous stratigraphy of the Marambio Group (adapted from Crame et al., 2004; Olivero, 2012). Abbreviations: Fm, Formation; Mbr, Member; NW, northwest; SE, southeast.

the eastern margin of the Antarctic Peninsula. The magmatic arc was located along the peninsula itself and developed due to southeastward subduction of the proto-Pacific Plate (Hathway, 2000). As much as 5 km of middle Cretaceous to lower Paleogene clastic strata were deposited in the JRB, and are divided into two major depositional cycles: the Gustav Group (Aptian–Coniacian) and the overlying Marambio Group (Santonian–Danian) (Rinaldi et al., 1978; Olivero et al., 1986; Pirrie, 1989; Crame et al., 1991; Pirrie et al., 1991).

Overall basin deepening occurred throughout most of the Late Cretaceous, with a partial basin inversion during the end-Cretaceous to Paleogene that resulted in a shallowing of water depth and the development of a shelf extending >100 km into the Weddell Sea (Pirrie et al., 1991; Hathway, 2000). Superimposed on these regional tectonic controls were the globally high sea levels of the Cretaceous and associated third-order, eustatically controlled sea level cycles, both of which also influenced deposition and stratigraphy in the basin (Olivero, 2012). Constraints on the age, correlation, and paleoenvironmental and paleoclimatic trends within the basin have been provided by various workers (e.g., Olivero et al., 1986; Askin, 1988; Crame et al., 1991; Pirrie et al., 1991; Marenssi et al., 1992; Olivero et al., 1992; Riding et al., 1992; Marenssi et al., 2001; Crame et al., 2004; Olivero et al., 2008; Bowman et al., 2012; Olivero, 2012; di Pasquo and Martin, 2013).
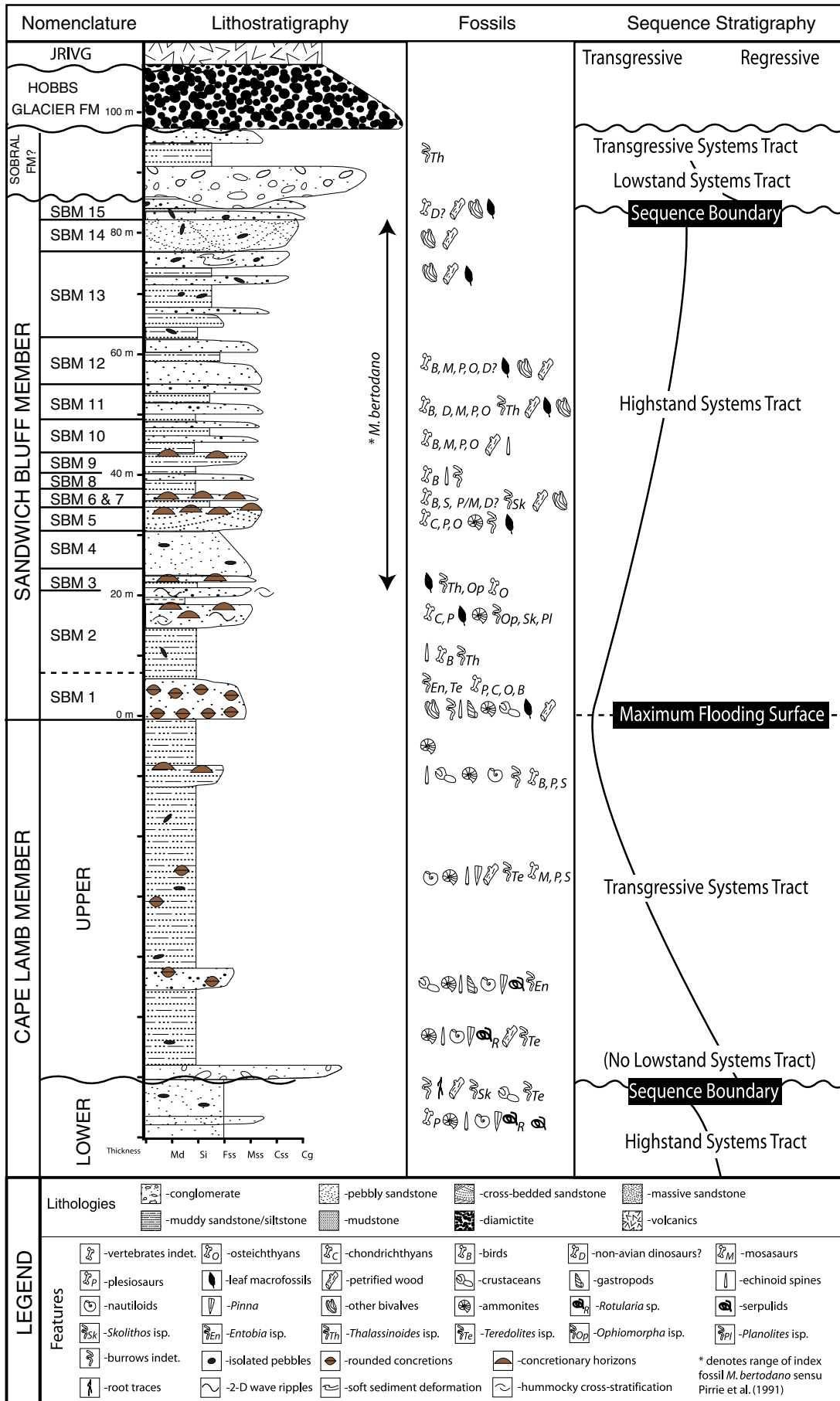
Olivero (2012) recently proposed an overall northwest to southeast deepening trend across the basin, and a subdivision of the Santonian–Maastrichtian strata of the Marambio Group into three major transgressive–regressive cycles. He grouped the Santonian to middle Campanian nearshore Santa Marta and offshore Rabot formations exposed on James Ross Island into the basal N Sequence. Overlying this is the upper Campanian–lower Maastrichtian NG Sequence that comprises proximal offshore deposits of the Cape Lamb Member of the Snow Hill Island Formation on northwestern James Ross, Vega, Humps, and Cockburn islands, along with the more distal offshore Hamilton Point (Olivero, 2012), Sanctuary Cliffs, Karlsen Cliffs, and Haslum Crag members of the Snow Hill Island Formation on southeastern James Ross, Snow Hill, and Seymour islands (Fig. 2). The uppermost, lower Maastrichtian–Danian MG Sequence is interpreted to include the shoreward transgressive shelf deposits of the upper Cape Lamb Member and the overlying nearshore Sandwich Bluff Member of the López de Bertodano Formation on Vega Island, along with undifferentiated

basinward facies of the López de Bertodano Formation on Seymour Island (Olivero, 2012) (Figs. 1–2).

2.1. Vega Island

Upper Cretaceous strata in the JRB have been studied by British, Argentinean, American and various other research groups over the past quarter-century, leading to significant contributions to the understanding of the stratigraphic, paleontological, and paleoclimatic contexts of the Antarctic Peninsula near the end of the Mesozoic (e.g., Olivero et al., 1986; Dettman and Thomson, 1987; Wren and Hart, 1988; Crame et al., 1991; Hooker et al., 1991; Pirrie et al., 1991; Marenssi et al., 1992; Olivero et al., 1992; Riding et al., 1992; Smith, 1992; Wood and Askin, 1992; Case et al., 2000; Marenssi et al., 2001; Francis and Poole, 2002; Crame et al., 2004; Bowman et al., 2012, 2013; di Pasquo and Martin, 2013; Reguero et al., 2013). Much of this work has centered on the lower portions of the stratigraphic section on Vega Island and its rich invertebrate and vertebrate fauna. Cretaceous outcrop on the island is concentrated on Cape Lamb (Fig. 1C). Here, the base of the section is characterized by minor exposures of the middle Campanian Herbert Sound Member of the Santa Marta Formation (Pirrie et al., 1991). Overlying these beds are very extensive, 400 m-thick, fine-grained deposits of the upper Campanian to lower Maastrichtian Cape Lamb Member of the Snow Hill Island Formation (Olivero et al., 1992). Capping the succession is the Maastrichtian Sandwich Bluff Member of the López de Bertodano Formation, a unit that is exposed primarily along the flanks of Sandwich Bluff (Marenssi et al., 2001), in an outcrop area approximately 700 m long by 300 m wide.

To date, most geological investigations of Vega Island have focused on the well-exposed Cape Lamb Member, with relatively little work performed on the underlying Herbert Sound and overlying Sandwich Bluff members. As a result, there is a considerable gap in our knowledge of the stratigraphy of the island — a gap that is all the more significant because the Sandwich Bluff Member is one of the most important localities for high-latitude latest Cretaceous terrestrial plant and vertebrate fossils in the Southern Hemisphere (Reguero et al., 2013). Previous workers (e.g., Pirrie et al., 1991; Marenssi et al., 2001) have investigated the Sandwich Bluff Member; however, these studies have focused on regional stratigraphy and provide only brief descriptions of the

Nomenclature	Lithostratigraphy	Fossils	Sequence Stratigraphy

Transgressive   Regressive

JRIVG

HOBBS GLACIER FM   100 m

SOBRAL FM?

Transgressive Systems Tract

Lowstand Systems Tract

Sequence Boundary

SBM 15

SBM 14   80 m

SBM 13

SBM 12   60 m

SBM 11

SBM 10

SBM 9

SBM 8   40 m

SBM 6 & 7

SBM 5

SBM 4

SBM 3

SBM 2   20 m

SBM 1   0 m

SANDWICH BLUFF MEMBER

Highstand Systems Tract

* *M. bertodano*

Maximum Flooding Surface

CAPE LAMB MEMBER

UPPER

Transgressive Systems Tract

LOWER

(No Lowstand Systems Tract)

Sequence Boundary

Highstand Systems Tract

Thickness   Md   Si   Fss   Mss   Css   Cg

LEGEND

Lithologies

- conglomerate
- pebbly sandstone
- cross-bedded sandstone
- massive sandstone
- muddy sandstone/siltstone
- mudstone
- diamictite
- volcanics

Features

- -vertebrates indet.
- $_O$ -osteichthyans
- $_C$ -chondrichthyans
- $_B$ -birds
- $_D$ -non-avian dinosaurs?
- $_M$ -mosasaurs
- $_P$ -plesiosaurs
- -leaf macrofossils
- -petrified wood
- -crustaceans
- -gastropods
- -echinoid spines
- -nautiloids
- -*Pinna*
- -other bivalves
- -ammonites
- $_R$ -*Rotularia* sp.
- -serpulids
- $_{Sk}$ -*Skolithos* isp.
- $_{En}$ -*Entobia* isp.
- $_{Th}$ -*Thalassinoides* isp.
- $_{Te}$ -*Teredolites* isp.
- $_{Op}$ -*Ophiomorpha* isp.
- $_{Pl}$ -*Planolites* isp.
- -burrows indet.
- -isolated pebbles
- -rounded concretions
- -concretionary horizons
- * denotes range of index fossil *M. bertodano* sensu Pirrie et al. (1991)
- -root traces
- -2-D wave ripples
- -soft sediment deformation
- -hummocky cross-stratification

sedimentology, stratigraphy and paleontology. Moreover, substantial confusion exists concerning the precise age of the Sandwich Bluff Member, the placement of its basal contact, the nature of its uppermost beds, and the location and distribution of critical fossils collected from Sandwich Bluff over the last 25 years. These include the holotypic partial skeleton of *Vegavis* (Clarke et al., 2005) and other significant bird specimens (Case et al., 2006; Chatterjee et al., 2006), as well as rare non-avian dinosaur material (Case et al., 2000).

Age estimates for the Sandwich Bluff Member range from early to late Maastrichtian (Pirrie et al., 1991; Crame et al., 2004; Olivero, 2012). Clarke et al. (2005) and Ksepka and Clarke (in press) reviewed data relevant to dating the *Vegavis*-bearing horizon of the Sandwich Bluff Member, and concurred with most previous authors that this level is most parsimoniously assigned a late Maastrichtian (~68–66 Ma) age. Ksepka and Clarke (in press) attributed remaining uncertainty in age to issues relating to the correlation of the Vega Island section with the better characterized and more securely dated López de Bertodano Formation on Seymour Island (Bowman et al., 2012). Recent biostratigraphic refinement and taxonomic revision of Antarctic records of the dinoflagellate cyst *Manumiella* (Thorn et al., 2009; Bowman et al., 2013) recognized the species *Manumiella bertodano* in the Sandwich Bluff Member of Vega Island. On Seymour Island, this species is restricted to near the top of the upper Maastrichtian López de Bertodano Formation (Bowman et al., 2012). The *Vegavis*-bearing deposits of the Sandwich Bluff Member are situated near the base of a newly proposed biozone (Ksepka and Clarke, in press), thus implying that they too are late Maastrichtian in age.

Pirrie et al. (1991) regarded the occurrence of *Manumiella bertodano* (their 'M. n. species 2') as extending through nearly the entirety of the Sandwich Bluff Member. Nevertheless, based on the stratigraphic section presented by these authors, as well as on correlation with the revised stratigraphic scheme presented below, it appears that they terminated their stratigraphic section at least 10–15 m below the top of the Cretaceous (or Paleocene) succession on Sandwich Bluff, where the slope steepens directly below the cliff-forming Hobbs Glacier Formation. This is relevant because Thorn et al. (2009) and Bowman et al. (2012) considered the upper limit of *M. bertodano* on Seymour Island to be the boundary between Askin's (1988) Zones 3 and 4. This would suggest that the range of this dinoflagellate cyst does not extend to the K–Pg boundary, but instead terminates ~50–100 m below this boundary in the composite regional section. However, since the Sandwich Bluff Member is considerably condensed relative to the López de Bertodano Formation on Seymour Island, it is likely that Zone 4 is thin and possibly still unsampled on Vega Island. It should also be noted that *M. bertodano* was recovered from Zone 4 on Seymour Island, immediately below the K–Pg boundary (e.g., Askin, 1988), but its occurrence there was attributed to reworking (Thorn et al., 2009). In sum, these data favor a late Maastrichtian age assignment for the Sandwich Bluff Member, and are consistent with those presented by Olivero (2012), who correlated this unit with the top of the upper Maastrichtian López de Bertodano Formation on Seymour Island based on sequence stratigraphy.

3. Methods

The research presented herein was conducted during a cruise, sponsored by the United States National Science Foundation, aboard the United States Antarctic Program *R/V Laurence M. Gould* to the JRB during the austral summer of 2011. Fieldwork was carried out primarily from a base camp on the south coast of Vega Island during a two-week period of mostly favorable weather. Prospecting for fossils was conducted throughout each of the Upper Cretaceous units exposed on the island; however, intensive prospecting, conceptually similar to the bone survey

method described by Behrensmeyer and Barry (2005), was conducted only in the Sandwich Bluff Member. This approach involved focused prospecting along the outcrop extent of all of the stratigraphic units of the Sandwich Bluff Member described herein. Significant specimens were collected, and detailed records were also made for fragmentary or already well-represented specimens that were observed in the field but not collected. Records included details of the stratigraphy, facies, taxonomy, and taphonomy of vertebrate sites. Additionally, systematic records were taken, and exemplars collected, at all plant macrofossil, invertebrate, and ichnological localities observed throughout the Upper Cretaceous section. A detailed stratigraphic section, made using a Jacob Staff and Brunton compass, was completed through the upper Cape Lamb Member of the Snow Hill Island Formation and the Sandwich Bluff Member of the López de Bertodano Formation. All collected vertebrate and plant fossils are permanently deposited at the American Museum of Natural History (AMNH), New York, NY, USA and Carnegie Museum of Natural History, Pittsburgh, PA, USA, respectively.

4. Stratigraphy, sedimentology, and paleontology of Upper Cretaceous strata on Vega Island

In this study, a review of the Cape Lamb Member on Vega Island is presented, supplemented with new observations and a detailed review of the vertebrate record and taphonomy of this unit. A more detailed analysis of the overlying Sandwich Bluff Member is also presented, dividing this member into 15 recognizable stratigraphic units with accompanying facies descriptions and paleoenvironmental interpretations.

4.1. Lower Cape Lamb Member
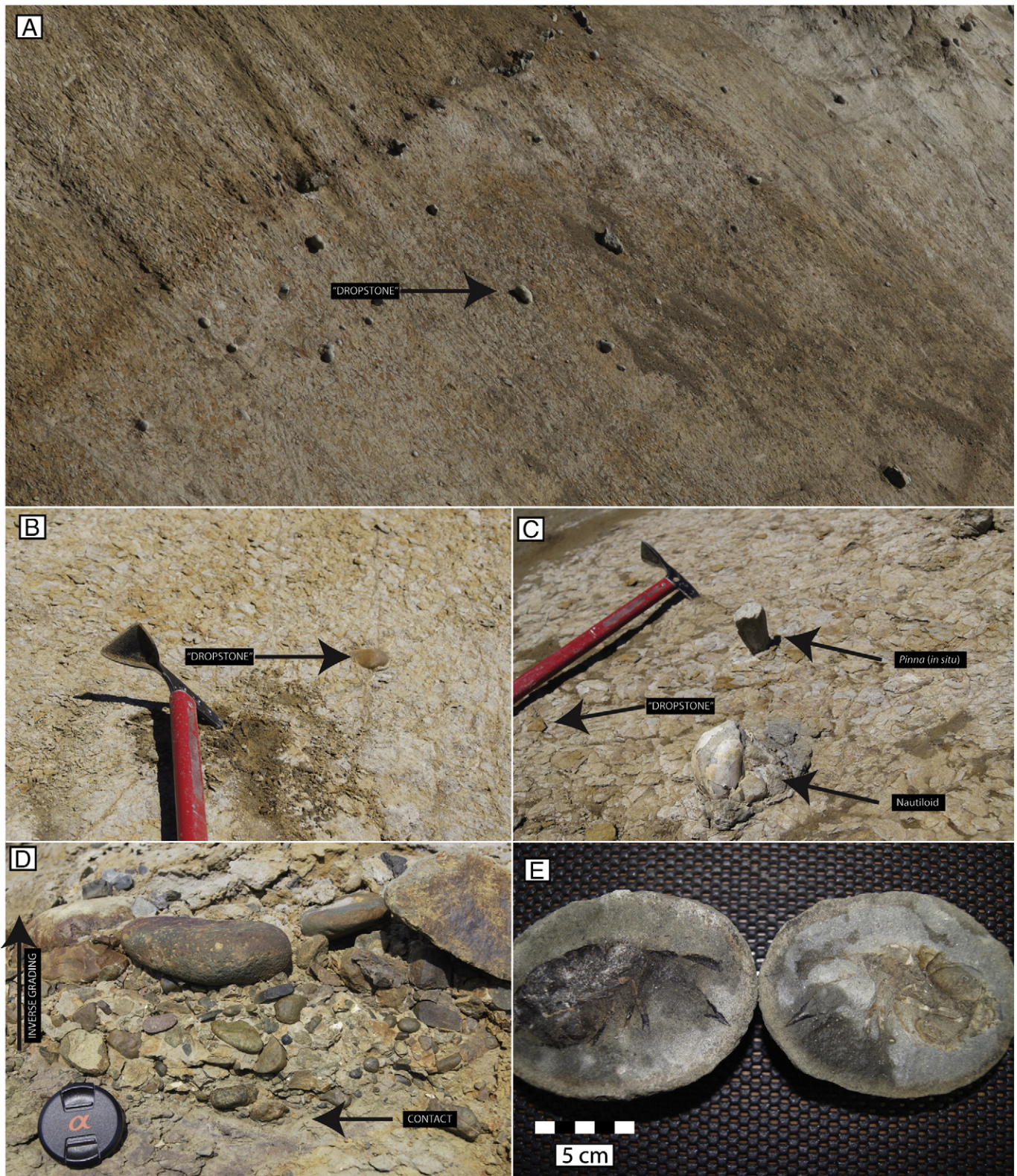
4.1.1. Sedimentology

The term lower Cape Lamb Member is used to refer to the strata situated below the distinctive pebble conglomerate that lie roughly 60 m below the base of the Sandwich Bluff Member (Fig. 3) as defined by Pirrie et al. (1991). This set of strata, which corresponds to Unit K2 of Marenssi et al. (2001), combines Pirrie et al.'s (1991) members A and B and is consistent with Olivero's (2012) usage of the Cape Lamb Member. In the present study, sedimentological observations on the lower Cape Lamb Member are consistent with the much more detailed and extensive investigations published by the above authors; consequently, this paper presents only a summary of this work, with emphasis on new fossil discoveries.

Strata are mostly massive, grayish-green, fine-grained muddy sandstones to sandy mudstones that exceed 200 m in thickness (Fig. 4A). An unusual feature of these otherwise fine-grained strata is the relatively common occurrence of isolated pebbles and cobbles that range from sub-angular to well-rounded (Fig. 4A–C) (see Section 5.2 below). Capping the lower Cape Lamb Member is an extensive, 25–50 cm-thick pebble–cobble conglomerate, which is inversely graded and ranges from matrix- to clast-supported (Fig. 4D). There is evidence of minor (i.e., 10–30 cm) incision into the underlying mudstone, in addition to the presence of oxidized burrows developed on this surface that are infilled with coarser sediment. As described by Pirrie and Marshall (1991), concretions are a particularly noteworthy and abundant component of this member (Fig. 4E). Pirrie and Marshall (1991) classified these concretions into four categories, including (1) spherical and subspherical, (2) sheet, (3) fossil-nucleated, and (4) burrow networks.

The lower Cape Lamb Member is characterized by an extraordinarily abundant and diverse marine invertebrate macrofauna, dominated by ammonoids (most commonly *Gunnarites antarcticus*), nautiloids, bivalves (especially *Pinna*), crustaceans, and serpulid worms (*Rotularia*) (Olivero et al., 1986; Pirrie et al., 1991). Fossil wood with ubiquitous

Fig. 3. Measured section, with sequence stratigraphic interpretation, at Sandwich Bluff (Vega Island) through the upper part of the Cape Lamb Member of the Snow Hill Island Formation and the complete Sandwich Bluff Member of the López de Bertodano Formation. Abbreviations: Cg, conglomerate; Css, coarse-grained sandstone; Fm, Formation; Fss, fine-grained sandstone; JRIVG, James Ross Island Volcanic Group; Md, mudstone; Mss, medium-grained sandstone; SBM, Sandwich Bluff Member; Si, siltstone.

Fig. 4. Sedimentology and taphonomy of the Cape Lamb Member of the Snow Hill Island Formation on Vega Island. A) Finely laminated siltstones of the upper Cape Lamb Member ('dropstone' indicated by arrow is ~8 cm in diameter, for scale). B) Isolated, well-rounded 'dropstone' (indicated by arrow). C) In situ *Pinna* shell with nearby 'dropstone,' demonstrating low energy setting. D) Distinctive, inversely graded pebble to cobble conglomerate at top of sequence boundary. E) Fossil-nucleated concretion with well-preserved crustacean *Hoploparia* sp. Scale bar equals 5 cm in E.

Teredolites borings is common. Araucarian ovuliferous cones have also been reported (Césari et al., 2001). A large proportion of fossils of all types are preserved within carbonate concretions. Pirrie and Marshall (1991) demonstrated that preservation appears to be partly controlled

by rapid early diagenetic concretionary development. Based on isotopic analysis, Pirrie and Marshall (1991) linked sulfate reduction and/or methane oxidation, along with shell dissolution, to rapid cementation and concretion development in the shallow subsurface. Trace fossils

are also abundant throughout the lower Cape Lamb Member, and concretion development probably also played a key role in preserving the ichnofauna of this unit.

4.1.2. Interpretation

The preponderance of evidence suggests that the lower Cape Lamb Member was deposited in an upward-shallowing, mid- to outer-shelf setting, although Olivero (2012) more specifically interpreted it as a progradational deltaic wedge. The present study concurs with Pirrie et al. (1991), Olivero et al. (1992), and Marenssi et al. (2001) that the capping unconformity below the pebble conglomerate represents a sequence bounding unconformity associated with regional sea level fall (Fig. 3). This interpretation is consistent with deposition of the lower Cape Lamb Member during the highstand systems tract. The conglomerate that overlies the sequence boundary has been interpreted as a transgressive lag surface associated with subsequent sea level rise and deposition of the overlying upper Cape Lamb Member (Pirrie et al., 1991; Olivero et al., 1992; Marenssi et al., 2001). In the present study, several exposures were observed with distinct oxidation along the surface immediately below the conglomerate (Fig. 4D), suggesting possible subaerial exposure following the fall in sea level and prior to the subsequent transgression. Marenssi et al. (2001), however, considered this to be a wave ravinement surface that apparently did not become emergent. Either way, this stratum represents a major event in the basin, one that Olivero (2012) interpreted as the boundary between his NG and MG sequences.

4.2. Upper Cape Lamb Member

4.2.1. Sedimentology

The upper Cape Lamb Member is similar in character to the lower Cape Lamb Member. Overall, the beds have the same grayish-green color as in the lower Cape Lamb Member, and consist of generally massive, fine-grained muddy sandstones to sandy mudstones. Isolated and mostly rounded volcanic pebbles and cobbles are commonly present, and are more abundant than in the lower Cape Lamb Member. Concretions are also common, and all four morphotypes described by Pirrie and Marshall (1991) are observed. Little original bedding is preserved, except in concretions, where evidence of planar lamination is commonly still visible despite intense bioturbation.

The invertebrate fauna of the upper Cape Lamb Member is very similar to that of the lower Cape Lamb Member, although Pirrie et al. (1991) noted an important biotic turnover in this interval, particularly in dinoflagellate cysts. An apparent decrease in the abundance and diversity of invertebrates occurs upsection. Ammonoids, nautiloids, crustaceans, bivalves (including *Pinna*), serpulid worms (*Rotularia*), various gastropods, and fossil wood are present, but are noticeably more common closer to the base of the upper Cape Lamb Member. The most notable invertebrate faunal trend is a considerable increase in the abundance of echinoid spines near the top of the unit. Trace fossils, including indistinct burrows, wood borings (*Teredolites*), sponge borings (*Entobia*), and predatory drill holes in bivalves are common.

4.2.2. Interpretation

As above, the basal conglomerate is interpreted to represent a transgressive lag above a sequence boundary, suggesting that a significant lowstand systems tract did not develop between the sequence boundary and subsequent sea level rise (sensu Olivero, 2012). Thus, the upper Cape Lamb Member was deposited in a mid- to outer shelf setting as part of the transgressive systems tract (Fig. 3). This is consistent with the paleoenvironmental interpretations offered by Pirrie et al. (1991) and Marenssi et al. (2001), and accords with the sequence model of Olivero (2012), who proposed that this interval correlates with the lower 950 m of the undifferentiated López de Bertodano Formation on Seymour and Snow Hill islands.

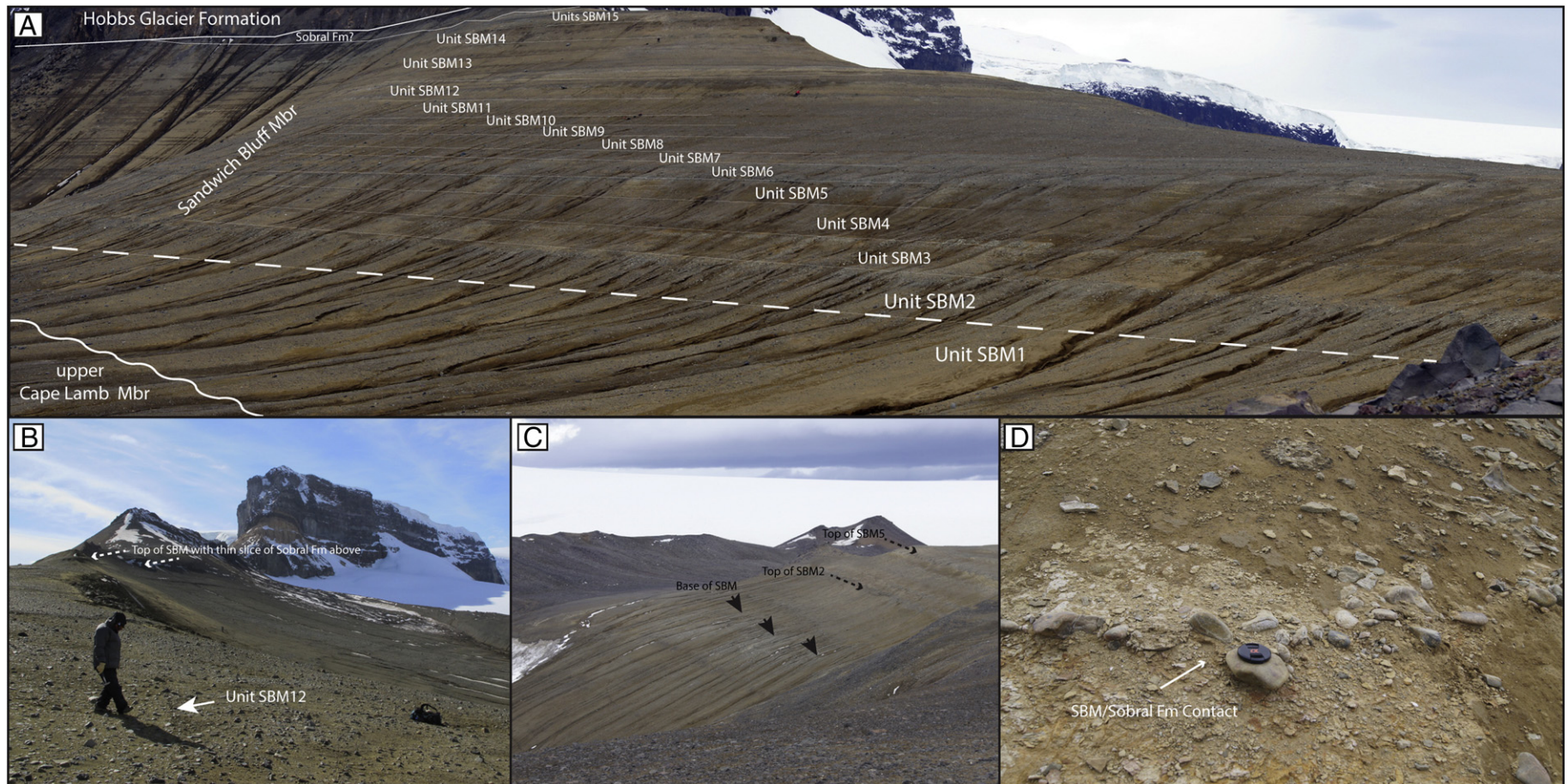### 4.3. Sandwich Bluff Member

4.3.1. Sedimentology

The Sandwich Bluff Member on Vega Island constitutes one of the least documented portions of the Upper Cretaceous stratigraphy in the JRB. Because of this, particular emphasis is placed on the detailed description and interpretation of the stratigraphy and sedimentology of this succession. We recognize and describe 15 discrete units in the Sandwich Bluff Member, termed Unit SBM1–Unit SBM15 (Figs. 3, 5; Table 1).

Pirrie et al. (1991) interpreted the contact between the Cape Lamb Member (their Member 'B') and the Sandwich Bluff Member as unconformable. Nevertheless, the nature of this contact is unclear, and a precise boundary is difficult to discern in outcrop, although when viewed at a distance there is a clear change in weathering profile on the western face of Sandwich Bluff where Pirrie et al. (1991) placed the contact. Neither Marenssi et al. (2001) nor Olivero (2012) recorded an unconformity at this level. Instead, Olivero (2012) logged a conformable contact between the upper Cape Lamb Member and Sandwich Bluff Member here, whereas Marenssi et al. (2001) designated the conglomerate located between the lower Cape Lamb Member and upper Cape Lamb Member as the basal boundary of their unit K3. Hence, unit K3 of Marenssi et al. (2001) includes the upper Cape Lamb Member, plus the Sandwich Bluff Member. To minimize potential confusion, the lithostratigraphic-based subdivision of Pirrie et al. (1991) is followed, and the contact between the upper Cape Lamb Member and the Sandwich Bluff Member is placed at the distinct change in slope and weathering pattern that occurs roughly 372 m above the base of the lower Cape Lamb Member (sensu Pirrie et al., 1991) and ~58 m above the distinctive conglomerate that marks the base of the upper Cape Lamb Member.

When viewed from a distance, there is an apparent change in dip observed between the top of the upper Cape Lamb Member and the Sandwich Bluff Member, which Pirrie et al. (1991) cited as evidence of an unconformable contact (Fig. 5C). It is unclear whether the apparently steeper dip of the underlying upper Cape Lamb beds represents a true depositional dip change (and possible unconformity), or whether this apparent dip is associated with the view angle and topography. However, as is the case in Olivero (2012), a conformable relationship at this boundary is considered more likely because of a lack of significant evidence of the erosion or lithological change that might be expected if there was an angular unconformity. Rather, this contact is characterized only by a slight transition to a coarser-grained, dark green sandy siltstone to silty sandstone that is herein referred to as Unit SBM1. As is the case for the upper Cape Lamb Member, this unit is characterized by feldspatholithic provenance, with abundant plagioclase, volcanic lithic grains, and glauconite. It compares well to the silty mudstone to silty sandstone Facies 5 of Pirrie et al. (1991).

Significantly, SBM1 preserves two distinct concretionary horizons: one that forms the basal-most meter of the unit, and another, 2–3 m-thick horizon near the top. The lower of these concretionary units preserves one of the richest concentrations of fossils (including vertebrates) in the entire succession. Following the terminology proposed by Pirrie and Marshall (1991) for the Cape Lamb Member, a combination of spherical–subspherical and fossil-nucleated concretions are observed in this unit, with rare examples of concretionary burrow networks also present.

The base of the Sandwich Bluff Member preserves a significantly more abundant and seemingly more diverse fauna than is found in the uppermost Cape Lamb Member. The majority of fossils documented at the base of the Sandwich Bluff Member (Unit SBM1) are preserved within concretions (i.e., fossil-nucleated concretions sensu Pirrie and Marshall, 1991). These concretions preserve a diversity of fossils that includes burrow networks, invertebrates, vertebrates, and plants, ranging from fragmentary and isolated materials to complete, articulated specimens. Preservation of fossils in concretions ranges from highly

Fig. 5. Sedimentology and stratigraphy of the Sandwich Bluff Member of the López de Bertodano Formation on Vega Island. A) Photomosaic showing key stratigraphic units through Sandwich Bluff Member. B) View of Sandwich Bluff Member looking south, with Unit SBM13 comprising saddle foreground. C) View of upper Cape Lamb Member and lower part of Sandwich Bluff Member looking towards best-exposed north face. Note apparent change in dip of strata near the top of the upper Cape Lamb Member, which may be a depositional feature or simply an apparent dip associated with topography and perspective. Strata coarsen up only slightly at this contact, suggesting that it is not an angular unconformity. D) Distinctive pebble–cobble conglomerate that may represent a sequence boundary with a Sobral Formation equivalent at top of Sandwich Bluff Member.

Table 1
Stratigraphy and facies of the Upper Cretaceous–?lowest Paleogene succession on Vega Island.

Formation	Unit	Lithofacies	Diagnostic features	Fossils	Interpretation
Herbert Sound Mbr, Santa Marta Fm	Upper	Interbedded silty MDST & thin SS; capped by thick fine-med SS	Overall coarsening up succession; mostly massive; wave & current ripples in capping SS	Bioturbation; rare body fossils; common microfossils	Shallow marine shelf/high clastic input
Cape Lamb Mbr, Snow Hill Island Fm	lCLM	Fine muddy SS to sandy MDST w/'dropstones'	Mostly massive w/intense bioturbation; abund. CaCO$_3$ concretions w/fossils	Bioturbation; plants; abund. invertebrates; vertebrates; microfossils	Shallow marine mid-outer shelf
	uCLM	Basal CG; dominated by fine muddy SS to sandy MS with abund. 'dropstones'	Inversely graded basal CG above erosional unconformity; massive fine-grained strata above this level w/intense bioturbation; abundant concretions w/fossils	Bioturbation; abund. invertebrates; vertebrates; microfossils	Basal trangressive ravinement surface above sequence boundary; shallow marine mid-outer shelf
Sandwich Bluff Mbr, López de Bertodano Fm	SBM1	Very fine silty SS with two distinct concretionary horizons	Volcanic-rich SS w/glauconite; concretions preserve abundant fossils, including birds	Burrows; plant hash; invertebrates; vertebrates; wood	Condensed section at max. flooding surface; marine; mid-outer shelf
	SBM2	Sandy MS that coarsens up into fine SS; capping sheet concretion	Hummocky cross stratification; intra-formational rip-up clasts	*Ophiomorpha*; *Planolites*; *Skolithos*; *Thalassinoides*; ammonoids; echinoids; marine vertebrates; plants	Storm-influenced, shallow marine mid-shelf
	SBM3	Interbedded MS & v. fine SS; concretionary SS cap	Hummocky cross-stratification; intra-formational rip-up clasts	Fish; leaves; plant hash; *Thalassinoides*; *Ophiomorpha*;	Storm-influenced, shallow marine mid-shelf
	SBM4	Repeated, upward fining oxidized fine SS & SLTS	Normal grading; isolated pebbles		Shallow marine mid-shelf
	SBM5	V.fine SS	Distinctive SS sheet concretion	Marine reptiles; sharks; fish; leaves; ammonoids; burrows	Shallow marine mid-inner shelf
	SBM6	Recessive, interbedded fine SS & SLTS	Oxidized horizons	*Skolithos*; in situ, infaunal bivalves within burrows; Dinosaurs?	Shallow marine mid-inner shelf
	SBM7	Interlaminated SS & SLTS	Horizontal bedding; abundant concretions	Sharks; marine reptiles; burrows	Shallow marine mid-inner shelf
	SBM8	Reddish-gray SLTS	Patchy, sheet-like concretions; unit forms saddle between Leal & Sandwich Bluff	Echinoid spines; birds; burrows	Shallow marine mid-inner shelf
	SBM9	Fine SS w/interbedded CS	Normal grading; capped by distinct CS cap	None	Shallow marine mid-inner shelf
	SBM10	Poorly-indurated muddy SS w/CS beds; CG lenses	Top of unit forms distinct bench & marker horizon	Echinoid spines; birds; marine reptiles; fish; wood	Shallow marine inner shelf
	SBM11	Fining-upward SS w/SLTS lamination; isolated pebble lenses	Intraformational SLTS rip-ups	Marine reptiles; birds; fish; dinosaurs; wood; plants; *Thalassinoides*	Shallow marine inner shelf
	SBM12	Well-indurated med SS	Intraformational SLTS rip-ups; large isolated, rounded pebbles	Invertebrates; marine reptiles; birds; plants; wood; fish; dinosaurs?	Shallow, nearshore marine
	SBM13	Alternating beds of gray MS & red muddy SS	Intraformational SLTS rip-ups; isolated pebbles; convoluted bedding; fluid escape structures	Abundant carbonized plant material; bivalves; wood	Shallow, nearshore marine
	SBM14	Well-indurated, med SS	Med-scale trough cross-bedding; upper plane beds	Abundant carbonized wood (logs); bivalves	Shallow, nearshore marine; u.shoreface or delta plain
	SBM15	V. fine SS w/horiz. laminated MS, thin pebble lenses	Isolated pebbles & pebble lenses	Plant hash; wood; bivalves; dinosaurs?	Poss. continental; upper delta plain
Sobral Fm?	SF1	Basal clast supported CG; grades upward into matrix supported CG	Channelized basal contact into underlying unit; both large intra-formational rip-up clasts & rounded volcanic pebbles/cobbles	None	Sequence bounding unconformity; overlain by alluvial CG
	SF2	Muddy SS with shale partings	Bioturbated; weathered upper contact	*Thalassinoides*	Transgressive shallow marine SS

Notes: CG = conglomerate; SS = sandstone; SLTS = siltstone; MS = mudstone; CS = claystone.

weathered, as in the case of marine vertebrates, to fresh and nearly unaltered for many of the invertebrates. Plant material is rare and occurs mostly in the form of fossil wood, whereas invertebrates are common and dominated by crustaceans (e.g., *Hoploparia*), ammonoids (e.g., *Maorites*), and small bivalves and gastropods. Pieces of fossil wood are typically heavily perforated by *Teredolites* borings, and these commonly preserve in situ pholadid bivalves, suggesting that the wood drifted for a time in a shallow marine setting prior to sinking to the sea floor and being buried.

Above this level, concretion development is significantly reduced in the 13 m-thick Unit SBM2, which coarsens up into very fine-grained sandstone that is capped by a distinctive, bench-forming tabular concretionary sandstone horizon (a sheet concretion sensu Pirrie and Marshall, 1991). Vertebrate and invertebrate fossils are also significantly rarer above SBM1. Invertebrates from SBM2 mostly consist of echinoid spines (*Cyathocidaris* sp.) in the lower 10 m and poorly preserved ammonoid shell fragments near the top. Plant hash and isolated, heavily weathered shark vertebrae are also present and typically encased in sandstone concretions (Table 2).

Hummocky cross-stratification and rare intraformational rip-up clasts along with *Planolites*, *Skolithos* and well-developed *Ophiomorpha* and *Thalassinoides* burrows are present in the lower part of the SBM2 concretionary bed and in the overlying, 3-m thick Unit SBM3. Well-preserved angiosperm leaves and seeds were identified and collected from SBM3 (Fig. 6A–B). In addition, well-defined two-dimensional wave ripples are observed within this part of the section. Above this interval, the 7 m-thick, recessive Unit SBM4 is distinguished by its deep red color and repeated, fining-upward, very fine-grained sandstones capped by thin siltstone beds with isolated, sub-rounded pebbles. No fossils were collected from SBM4. Directly overlying this unit is the 3 m-thick marker horizon SBM5, which is characterized by a sandstone sheet concretion that forms numerous mound-like structures that define the top of the unit and form a prominent bench across its entire lateral extent. The only identifiable invertebrate from SBM5 is a small specimen of the ammonoid *Maorites*. Several *Nothofagus*-like leaves were also collected from this unit.

The succeeding strata (SBM6–8) are largely recessive interbedded siltstones and fine sandstones with poorly defined trough cross-stratification. Fossils are rare in this interval, with the exception of bivalves in SBM6 that are preserved in situ within their burrows that were (presumably) excavated into this unit from the overlying SBM7. In addition, there is abundant fossil wood and carbonaceous plant hash.

Unit SBM8 forms the base of the saddle between Sandwich Bluff and Leal Bluff, making it particularly useful for correlation (Fig. 5A, C). Above this level, in SBM9–12, the sedimentology is similar to that observed in SBM6–8; however, an apparent increase in the abundance of vertebrate fossils, including bird material, is observed. The Reptile Horizon of Case et al. (2000), so named for the numerous marine reptile elements it contains, probably corresponds to Unit SBM11. In addition, from this interval upwards, the section is generally more oxidized (i.e., deep red in color); plant hash also becomes more common upwards and the incidence of rounded, mostly isolated volcanic pebbles increases. Moreover, thin (10–15 cm) granule- to pebble-sized conglomerate lenses occur in SBM10–12. In some cases, angular intraformational rip-up clasts are concentrated at the bases of conglomerate lenses. This general depositional pattern continues upsection through SBM13–15, with increasingly abundant, thin pebble conglomerate lenses that typically fine upwards into trough cross-stratified sandstones. The presence of isolated, rounded pebbles also continues to increase upsection. Fluid escape structures (pipes and dishes) and convoluted bedding are observed in this interval as well. Unit SBM14 has rare fossils, whereas pockets of carbonized plant hash, fossil wood and small bivalves are distributed throughout SBM15. Vertebrate fossils, including possible dinosaur bone fragments, also occasionally occur in SBM15.

Directly overlying Unit SBM15 is an erosional unconformity with up to 1.5 m of incision into this unit. Above this surface, a poorly exposed

(due to scree from the overlying upper Neogene Hobbs Glacier Formation) 6 m-thick pebble to cobble conglomerate crops out, particularly on the northeast side of Sandwich Bluff where the slope is steepest (Fig. 5D). The basal 15–20 cm of this unit is clast-supported, whereas the remainder of the unit is predominantly matrix-supported. This conglomeratic unit is deeply erosional and appears to be channelized along its basal contact. Clasts include a variety of intra- and extraformational grain types, with most of the smaller and many of the larger (i.e., >10 cm) clasts composed of sub-angular to well-rounded intraformational sandstone blocks. A fair proportion of the larger clasts are also extraformational; these are primarily volcanic in origin, although some appear to be metasedimentary in composition. At the very top of the conglomeratic incised channel fill is a sharp contact and facies shift back to fine-grained strata (Fig. 3), with 6 m of muddy sandstone beds with well-developed *Thalassinoides* burrows. The top of this unit has been deeply weathered and incised as a consequence of the deposition of the overlying Hobbs Glacier Formation.

4.3.2. Interpretation

The depositional environment at the base of the Sandwich Bluff Member (Unit SBM1) is interpreted as a mid- to outer-shelf setting similar to that of the upper Cape Lamb Member. Since no evidence was found for an unconformable contact, there is little reason to suspect a major change in paleoenvironment across the boundary of the two members. The increase in abundance and apparent diversity of fossils are potentially attributable to a combination of the related factors of sea level and taphonomy. A significant increase in fossil-preserving early diagenetic concretions occurs at the base of SBM1 and may at least partially account for the apparent increase in fossils and biotic diversity at this boundary. Pirrie and Marshall (1991) found that concretionary horizons are typically associated with lithologic boundaries, and that concretion formation is a very early diagenetic phenomenon. Thus, the very slight lithologic change from sandy mudstone in the uppermost Cape Lamb Member to muddy sandstone at the base of the Sandwich Bluff Member supports this model of concretion formation and the diagenetic sequence related to fossil preservation.

The contact between the Cape Lamb Member and the Sandwich Bluff Member is interpreted to correlate with the period of stratigraphic condensation during maximum transgression, which is commonly associated with increased fossil abundance during the development of a condensed section (Vail et al., 1984; Loutit et al., 1988). The elevated concentration of shells and decaying materials, coupled with decreased sedimentation rates, likely triggered the development of early diagenetic concretions (sensu Pirrie and Marshall, 1991). This horizon is interpreted as the maximum flooding surface.

Below the maximum flooding surface at the base of the Sandwich Bluff Member (Unit SBM1), the upper Cape Lamb Member is dominated by massive, heavily bioturbated, organic-rich mudstones and siltstones. Above the condensed section and maximum flooding surface, facies coarsen and shallow upward through the sequence. In SBM2 and 3, hummocky cross-stratification is present, suggesting that, shortly after maximum transgression, sea floor sediments were able to develop and preserve sedimentary structures in a relatively deep-water shelf setting. Although the presence of hummocky cross stratification has traditionally been inferred to be depth-dependent, recent work has shown this to be inaccurate, and has challenged the concept that this type of stratification is diagnostic of deposition within the offshore transition to lower shoreface zones (Peters and Loss, 2012).

Above this point in the Sandwich Bluff Member, hummocky cross stratification is replaced by two-dimensional wave ripples and three-dimensional trough and tabular cross-stratification. Grain size also progressively increases. Coupled with a significant upward increase in the abundance of carbonized plant hash, this suggests increasing terrestrial input and proximity to the shoreline. The deep red, oxidized color associated with several units (e.g., SBM4, 6, 8, and 13) higher in the section also indicates nearshore, well-oxygenated conditions. Repeated fining-

upward cycles with increasing proportions of rounded pebbles further suggest fluctuating energy and pulses of sedimentation, perhaps associated with nearby deltaic input. Finally, the upward increase in the influx of gravel indicates an increasingly continental input. This notion is strongly supported by the work of Pirrie et al. (1991), who found a diminishing percentage of marine microplankton from the base of the Sandwich Bluff Member to near the top, combined with a high abundance of light plant tissues.

The erosional unconformity that is deeply developed into the top of Unit SBM15 reflects the culmination of shallowing within the basin. This deep incision, coupled with subsequent deposition of a thick pebble to cobble conglomerate, is suggestive of a transition from shallow marine to terrestrial depocenters. The base of this erosionally incised conglomerate is interpreted as a likely sequence boundary, with subsequent deposition of the conglomeratic facies by alluvial processes during the succeeding lowstand systems tract. It is also possible that this unit represents incision and infill associated with the development of a submarine channel system that was developed into the shelf immediately following sea level fall. However, the well-rounded nature of the clasts is regarded as being more consistent with the former hypothesis.

Directly above the conglomerate and below the Hobbs Glacier Formation, a 6 m-thick, coarse-grained siltstone and overlying sandstone unit with well-developed *Thalassinoides* burrows likely represents a subsequent marine flooding surface and a rapid return to shallow marine conditions. The sharp contact and facies juxtaposition of marine siltstones with *Thalassinoides* burrows directly above the conglomerate are interpreted as a flooding surface and an overlying transgressive systems tract.

5. Discussion

5.1. A K–Pg boundary section on Vega Island?

In this study, a potential sequence boundary and overlying channel-fill conglomerate at the top of the Sandwich Bluff Member were identified, neither of which had previously been reported. These findings are closely compatible with the conceptual sequence boundary that caps the MG Sequence of Olivero (2012) between the top of the López de Bertodano Formation and the base of the Sobral Formation on Seymour Island. Further, Olivero (2012; see also Fig. 2) projected the up-dip expression of this sequence boundary to a location just above the top of his measured section on Vega Island. Hence, the uppermost ~11–12 m of conglomerate and superjacent fine-grained marine strata that overlie the proposed sequence boundary at the top of the Sandwich Bluff Member potentially correlate to the Paleocene Sobral Formation. If this is accurate, then it suggests that the K–Pg boundary may well crop out on Vega Island, just below this sequence boundary at the top of the Sandwich Bluff Member.

Based on a refined dinoflagellate cyst biostratigraphy of Seymour Island, Bowman et al. (2012) placed the top of the *Manumiella bertodano* interval zone slightly below the K–Pg boundary, with the thin *Manumiella druggii* zone in between. The identification of *M. bertodano* throughout most of the Sandwich Bluff Member supports a late Maastrichtian age for this unit; however, it is not clear from Pirrie et al. (1991) exactly where these authors collected their highest *M. bertodano* specimens. Pirrie et al. (1991) did not mention or record a 6 m thick conglomerate at the top of the Sandwich Bluff Member. This capping unit forms a steep and unstable scree-covered slope that is difficult to access. Therefore, it seems likely that Pirrie et al. (1991) terminated their section just below this interval, and hence did not sample the uppermost portion of the succession that records the upper sequence boundary and thin package of Sobral Formation-equivalent strata proposed herein. This hypothesis must be tested more thoroughly, particularly by palynological analyses; however, based on the data presented herein, as well as existing biostratigraphic

correlations between Vega and Seymour islands, it represents the most likely scenario.

5.2. Origin of 'dropstones' in the Cape Lamb and Sandwich Bluff Members

The presence of 'dropstones' in Upper Cretaceous strata on Vega Island is one of the most puzzling geological phenomena observed in this study. Isolated pebbles and groups of pebbles are commonly found within fine-grained marine mudstones and sandstones of both the Cape Lamb Member and the Sandwich Bluff Member, and range in size from small pebbles to small cobbles. The clasts are typically of intermediate to felsic volcanic composition, including both aphanitic and porphyritic textures, and range from very well-rounded and polished to sub-angular. Their occurrence is not correlated with a specific facies or stratigraphic horizon; rather, they tend to be randomly distributed. The only noticeable trend is their general increase in abundance towards the top of the Sandwich Bluff Member.

As noted by Olivero et al. (1986), at least in the Cape Lamb Member, most of the isolated pebbles and clusters of pebbles are directly associated with in situ *Pinna* shells that are in life position, clearly demonstrating the low-energy nature of marine bottom waters during the time of deposition. Moreover, in areas where these pebbles have been observed, there are no clear vertical changes in the grain size of the entombing mudstones or fine-grained sandstones, which would tend to rule out storm events or turbidites as sources for these clasts. The lack of mass flow deposits in either the Cape Lamb Member or Sandwich Bluff Member precludes other gravitational processes.

Olivero et al. (1986) argued against previous interpretations that these clasts could represent glacial dropstones. Instead, they suggested a mechanism whereby trees rafted from the nearby shoreline were carried into deeper waters, and as their attached root balls began to disintegrate, the pebbles were released (see also Vogt and Parrish, 2012). However, this hypothesis does not sufficiently explain why, if this is an at least reasonably common phenomenon, similar occurrences of isolated pebbles and pebble clusters are not regularly recovered from fine-grained shallow marine deposits elsewhere in the world. It is also difficult to envision this process accounting for the remarkable number of isolated pebbles observed in both the Cape Lamb and Sandwich Bluff Members.

Olivero et al. (1986) noted the lack of striations on the clasts as one critical piece of evidence against the glacially-derived hypothesis, and also asserted that, during the latest Campanian–Maastrichtian, the climate of the Antarctic Peninsula was too warm to have supported glaciations. However, recent work on dinoflagellate cysts by Bowman et al. (2013) suggests that periodic winter ice was very likely present in peninsular Antarctica during this time.

In addition to these two hypotheses, various other scenarios might explain the existence of isolated pebbles in low-energy marine settings. One possibility is that the pebbles represent gastroliths ('stomach stones') of marine reptiles, likely plesiosaurs, which either died or regurgitated these stones in the shallow marine settings of the Cape Lamb and Sandwich Bluff Members. Gastroliths have been found associated with a number of Antarctic plesiosaur skeletons (e.g., Martin et al., 2007b; Thompson et al., 2007; O'Gorman et al., 2012, 2013), and occur in extremely high concentrations in at least some specimens (e.g., the skeleton described by Thompson et al. (2007) was associated with more than 2600 gastroliths). It is possible that, as is the case with some extant marine tetrapods (e.g., penguins, pinnipeds (Taylor, 1993; Wings, 2007)), plesiosaurs may have routinely ingested and regurgitated gastroliths (originally collected from estuarine or fluvial environments) throughout their lives (O'Gorman et al., 2012, 2013). This would have had the effect of scattering these stones across the seafloor. Furthermore, due to decomposition and scavenging, floating plesiosaur carcasses probably often shed gastroliths before sinking and coming to rest on the seabed (Taylor, 1993; Everhart, 2000; Thompson et al., 2007). Consequently, one might expect these 'stomach stones' to occur throughout the Cape Lamb and Sandwich Bluff Members, rather

Table 2

Late Cretaceous vertebrate taxa from Vega Island. Stratigraphic provenance provided in parentheses; source(s) of record(s) in brackets. Abbreviations: CLM, Cape Lamb Member of the Snow Hill Island Formation (undifferentiated); lCLM, lower Cape Lamb Member; uCLM, upper Cape Lamb Member; SBM, Sandwich Bluff Member of the López de Bertodano Formation. Numbers following 'SBM:' correspond to stratigraphic subunits of the Sandwich Bluff Member defined herein (Unit SBM1–Unit SBM15). 'SBM' records where numbers are not provided are those for which the subunit(s) that yielded the taxon in question are not known (i.e., the taxon is known only to have come from the Sandwich Bluff Member).

CHONDRICHTHYES
  Elasmobranchii
    Neoselachii
      Squalea
        Hexanchiformes
          Hexanchidae
            Notidanodon dentatus (SBM) [Martin and Crame, 2006]
            cf. *Notidanodon dentatus* (SBM: 1) [this paper]
          Hexanchidae indet. (uCLM) [Martin, 2008]
        Squalea indet. (SBM) [Martin and Crame, 2006]
      Elasmobranchii indet. (uCLM; SBM: 1, 2, 5, 7) [this paper]
  Holocephali
    Chimaeriformes
      Chimaeroidei
        cf. *Callorhinchus* sp. (CLM; SBM: 3) [MacPhee et al., 2011; this paper]
  ?Chondrichthyes indet. (CLM) [this paper]
OSTEICHTHYES
  Actinopterygii
    Teleostei
      Euteleostei
        cf. Sphenocephalidae
          cf. Sphenocephalidae indet. (CLM) [Martin and Crame, 2006]
  Osteichthyes indet. (SBM: 1, 5, 10–12) [this paper]
SAUROPTERYGIA
  Plesiosauria
    Elasmosauridae
      Aristonectes parvidens (SBM) [O'Gorman et al., 2010]
      Mauisaurus sp. (uCLM) [Martin et al., 2007b; Martin, 2008]
      Elasmosauridae indet. (lCLM; CLM) [Thompson et al., 2007; O'Gorman et al., 2008, 2012]
    Plesiosauria indet. (lCLM; uCLM; SBM: 1, 2, 5, 7, 10–12) [del Valle et al., 1977; O'Gorman et al., 2010; this paper]
LEPIDOSAURIA
  Mosasauridae
    Mosasaurinae
      '*Liodon*' sp. (CLM, SBM) [Martin et al., 2002; Martin, 2006; Fernández and Gasparini, 2012]
      cf. '*Liodon*' sp. (CLM) [Fernández and Gasparini, 2012]
      Mosasaurus cf. *lemonnieri* (CLM) [Martin et al., 2002]
      Mosasaurus sp. (SBM) [Martin, 2006]
    Plioplatecarpinae
      Plioplatecarpus sp. (SBM) [Martin et al., 2002; Martin, 2006]
      cf. *Plioplatecarpus* sp. (CLM) [Fernández and Gasparini, 2012]
    Tylosaurinae
      Taniwhasaurus antarcticus (CLM) [Martin et al., 2007a; Fernández and Gasparini, 2012]
      cf. *Taniwhasaurus antarcticus* (CLM) [Fernández and Gasparini, 2012]
    Mosasauridae indet. (SBM: 1, 2, 5, 7, 10–12) [this paper]
DINOSAURIA
  Ornithischia
    ?Ankylosauria
      ?Ankylosauria indet. (SBM) [Case et al., 2003]
    Ornithopoda
      Ornithopoda gen. et sp. nov.? ('hypsilophodontid'; CLM) [Hooker et al., 1991; Thomson and Hooker, 1991; Milner et al., 1992]
        Hadrosauridae
          Hadrosauridae indet. (SBM: 11) [Case et al., 2000]
  Saurischia
    Theropoda
      Theropoda indet. (SBM) [Case et al., 2003]
  ?Dinosauria indet. (SBM: 7?, 12, 15) [this paper]
    Aves
      Neornithes
        Anseriformes
          Vegavis iaai (SBM: 1) [Noriega and Tambussi, 1995; Clarke et al., 2005]
        ?Gaviiformes
          Polarornis sp. nov. (SBM: 1) [Chatterjee et al., 2006]
          cf. *Polarornis gregorii* (SBM: 8) [this paper]
        ?Charadriiformes gen. et sp. nov. (CLM) [Cordes, 2001, 2002]

Table 2 (*continued*)

        ?Charadriiformes indet. (CLM; SBM) [Case and Tambussi, 1999; Case, 2001; Case et al., 2001]
        ?Cariamiformes indet. (SBM: 1) [Case et al., 2006; Tambussi and Acosta Hospitaleche, 2007; but see Cenizo, 2012]
        Ornithurae indet. (uCLM; SBM: 12) [this paper]
        Aves indet. (SBM: 1, 2, 7, 10–12) [this paper]

than being exclusively associated with plesiosaur body fossils in these units.

Another alternative, which would support Bowman et al.'s (2013) winter ice hypothesis, is that the pebbles and cobbles were derived from ice rafts that floated out of nearby rivers during winter months. This phenomenon is not well-documented in modern fluviomarine systems, but it has been observed by several workers (Bennett et al., 1996). This could account for the well-rounded nature of many of the observed pebbles, and would also explain their lack of glacial striations. Although the true nature of the 'dropstones' in the Cape Lamb and Sandwich Bluff Members remains unresolved, rafting represents a plausible hypothesis in light of new evidence for winter ice in the Latest Cretaceous of Antarctica (Bowman et al., 2013).

5.3. Vertebrate paleontology and paleoecology of the Cape Lamb Member

The fossil vertebrate record from exposures of the Cape Lamb Member on Vega Island is dominated by aquatic taxa (Table 2). Fishes are represented by fragmentary, mostly isolated specimens pertaining to both Chondrichthyes (cartilaginous fishes) and Osteichthyes (bony fishes). Elasmobranch material from the Cape Lamb Member includes a tooth of a hexanchid shark (Martin, 2008) in addition to taxonomically indeterminate specimens. The hexanchid tooth was found in association with the skeleton of an elasmosaurid plesiosaur, suggesting that the shark to which it belonged may have scavenged the carcass of this marine reptile. The occurrence of holocephalans in the Cape Lamb Member is documented by partial jaws and tooth plates of the chimaeroid cf. *Callorhinchus* sp. collected during the course of this study. Along with other cf. *Callorhinchus* remains from the Sandwich Bluff Member (Fig. 6D), these fossils constitute the first records of Chimaeriformes from Upper Cretaceous sediments on Vega Island. Antarctic Cretaceous chimaeriforms were previously known only from the Herbert Sound Member of the Santa Marta Formation on James Ross Island (Kriwet et al., 2006) and the undifferentiated upper López de Bertodano Formation of Seymour Island (Stahl and Chatterjee, 1999, 2002; Otero et al., 2013). An additional fish specimen from the Cape Lamb Member discovered during this study is an incomplete vertebral series of an as-yet unidentified taxon that is tentatively assigned to Chondrichthyes (AMNH FF 20374; Fig. 6E).

Bony fishes are only sparsely represented in the Late Cretaceous vertebrate assemblage of Vega Island. The Cape Lamb Member has yielded perhaps the most diagnostic Cretaceous osteichthyan fossil yet found on the island, an articulated partial skeleton. Housed in the collection of the British Antarctic Survey (BAS), the fossil consists of the posterior part of the postcranium of a diminutive fish recovered from Hill 177 on False Island Point. The specimen was briefly described and figured by Martin and Crame (2006), who tentatively referred it to an indeterminate member of the teleost group Sphenocephalidae.

Marine reptile fossils have been frequently recovered from Cretaceous strata on Vega Island, with remains of plesiosaurs considerably outnumbering those of mosasaurs. In the Cape Lamb Member, the latter are represented by specimens pertaining to the clade Mosasaurinae: a fragmentary skeleton assigned to *Mosasaurus* cf. *lemonnieri* and a partial tooth referred to '*Liodon*' (=*Leiodon*') sp. (Martin et al., 2002). Materials referred to the tylosaurine *Taniwhasaurus antarcticus* (Martin et al., 2007a; Fernández and Gasparini, 2012) and the plioplatecarpine cf. *Plioplatecarpus* sp. (Fernández and Gasparini, 2012) have also been reported. The Cape Lamb Member has also produced multiple partial
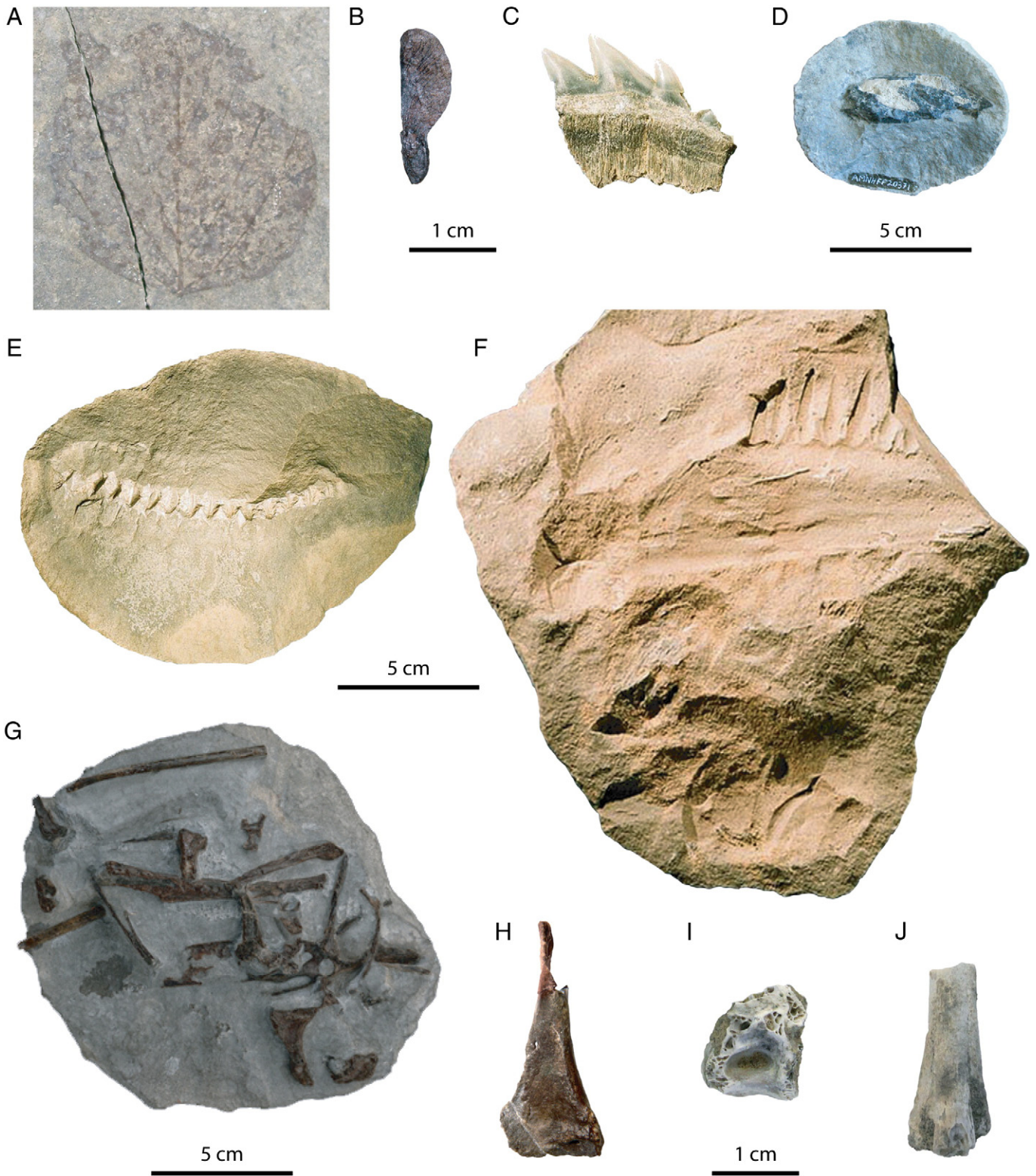
Fig. 6. Representative Upper Cretaceous plant and vertebrate fossils from the Cape Lamb Member of the Snow Hill Island Formation and the Sandwich Bluff Member of the López de Bertodano Formation (SBM), Vega Island. Stratigraphic provenance in parentheses; numbers following 'SBM:' correspond to SBM subunits defined herein (Unit SBM1–Unit SBM15). A) leaf of unidentified angiosperm (SBM: 3). B) winged seed of cf. Sapindaceae (SBM: 3). C) tooth of hexanchiform shark cf. *Notidanodon* (AMNH FF 20375) in labial view, anterior to right (SBM: 1). D) palatine tooth plate of chimaeriform cf. *Callorhinchus* sp. (AMNH FF 20371) in occlusal view (SBM: 3). E) articulated vertebral series of unidentified? chondrichthyan (AMNH FF 20374) in medial view of parasagittal cross section (Cape Lamb Member). F) natural mold of mandible and partial cervical series of unidentified plesiosaur (AMNH FARB 30877) in lateral view (upper Cape Lamb Member). G) holotypic partial postcranial skeleton of anseriform bird *Vegavis iaai* (Museo de La Plata specimen 93-I-3-1) (SBM: 1). H) partial coracoid of unidentified bird recovered from concretion (AMNH FARB 30898) in dorsal view (SBM: 1). I) thoracic vertebra of unidentified ornithurine bird (AMNH FARB 30920) in left lateral view (upper Cape Lamb Member). J) distal tarsometatarsus of unidentified ornithurine (cf. *Vegavis*?) (AMNH FARB 30913) in dorsal view (SBM: 12). Scale bars equal 1 cm in A–C, H–J; 5 cm in D–G.

skeletons of elasmosaurid plesiosaurs (e.g., Martin et al., 2007b; Thompson et al., 2007; Martin, 2008; O'Gorman et al., 2008, 2012), at least one of which (that of an articulated, beautifully-preserved juvenile) appears referable to the genus *Mauisaurus* (Martin et al., 2007b). As is the case for several other Antarctic Cretaceous marine reptile taxa, *Mauisaurus* exhibits a distinctive paleobiogeographic distribution: its closest known relatives occur in contemporaneous deposits elsewhere in southern Gondwana. Specifically, this elasmosaurid is otherwise documented only from latest Cretaceous beds in New Zealand (Hector, 1874; Hiller et al., 2005) and Patagonia (Gasparini et al., 2003b, 2007; Otero et al., 2010). The distribution of *Mauisaurus* is therefore suggestive of endemism in southern Gondwanan marine reptile faunas during the Late Cretaceous (Gasparini et al., 2003b; Martin et al., 2007b; Martin, 2008). Interestingly, this distribution is consistent with that observed for the Weddellian Biogeographic Province, originally conceived on the basis of Late Cretaceous–Paleogene molluscan paleobiogeography (Zinsmeister, 1979).

Undoubtedly the most informative marine reptile specimens collected during the 2011 expedition are two partly articulated plesiosaur partial skeletons preserved in concretions of the upper Cape Lamb Member. Although some skeletal elements are preserved only as natural molds (the bones having weathered away prior to discovery), one of these finds (AMNH FARB 30877) is particularly significant, as it includes much of the skull and mandible (Fig. 6F). Interestingly, the dentition of this specimen appears to differ from that of *Aristonectes parvidens* (=‘*Morturneria seymourensis*’), the only Antarctic Cretaceous plesiosaur for which cranial remains have yet been described (Chatterjee and Small, 1989; Gasparini et al., 2003a). Thus, the new specimen is either the first Antarctic specimen of *Mauisaurus* to preserve skull material or, alternatively, it pertains to a plesiosaur species that has not previously been recorded from the continent. We also discovered, but did not collect, a third articulated plesiosaur skeleton in the upper Cape Lamb Member. The abundance of well-preserved, partial to nearly complete skeletons of these aquatic reptiles in strata of this unit is consistent with its having been deposited in a nearshore marine setting.

A single non-avian dinosaur specimen has been discovered in the Cape Lamb Member of Vega Island: a partial skeleton of a medium-sized (~5 m total length) ornithopod, discovered on the western face of Cape Lamb by a BAS expedition during the austral summer of 1989 (Hooker et al., 1991; Thomson and Hooker, 1991; Milner et al., 1992). The skeleton, only briefly described to date, was initially reported as that of a ‘hypsilophodontid’; nevertheless, that purported clade has since been shown to constitute a paraphyletic assemblage of non-iguanodontian and basal iguanodontian (i.e., non-hadrosaurid) taxa. Consequently, pending its detailed description, the specimen is best regarded as that of a non-hadrosaurid ornithopod of uncertain affinities. Given that ornithopods of this evolutionary grade are viewed as entirely terrestrial animals, the skeleton was presumably derived from a carcass that washed into the ocean from a continental environment, drifted for some distance, and ultimately came to rest on the seafloor.

Several avian fossils have been discovered in sediments of the Cape Lamb Member; nevertheless, as is the case for the ornithopod, none have been fully described to date. Two of these specimens, an isolated tarsometatarsus (Case and Tambussi, 1999) and a largely complete postcranial skeleton (Cordes, 2001, 2002), have been assigned to Charadriiformes (extant shorebirds), many of which occupy coastal and near-coastal environments today. In the absence of detailed published descriptions, these preliminary systematic referrals cannot be confirmed. Illustrations provided by Cordes (2001) do allow the partial skeleton to be confidently referred to Ornithurae, the clade that encompasses crown birds (Neornithes) and their closest relatives. The open ilioischiadic fenestra and apparent lack of an ossified supratendinal bridge of the tibiotarsus would suggest placement of the specimen outside Neognathae, and possibly outside Neornithes as well. These are plesiomorphic character states that are seen in non-neornithine

Ornithurae such as *Ichthyornis* (Clarke, 2004), the nearest well-preserved taxon to the crown clade. The isolated tarsometatarsus is described as relatively elongated with hypotarsal crests but not enclosed canals. Assuming this is the case, it would show morphologies consistent with a phylogenetic placement within or very close to the crown clade. A third avian specimen, consisting of an isolated partial thoracic vertebra (AMNH FARB 30920), was discovered in the upper Cape Lamb Member during the 2011 expedition (Fig. 6I). Its weakly heterocoelous centrum is consistent with its belonging to an ornithurine that is closer to the crown clade than *Ichthyornis*, or perhaps even a member of Neornithes. These Cape Lamb Member fossils are significantly older than the remainder of the bird material from Vega Island, and as such, detailed descriptions of their morphologies are needed.

5.4. Vertebrate paleontology and paleoecology of the Sandwich Bluff Member

Similar to vertebrate materials recovered from the Cape Lamb Member, most fossils of these animals collected from the Sandwich Bluff Member consist of fragmentary, isolated teeth and bones, many of which have yet to be fully studied and described. The vertebrate assemblages of the two units appear broadly comparable to one another, though with a notably greater abundance, and possibly diversity, of terrestrial taxa in the Sandwich Bluff Member (Table 2). This is consistent with the hypothesis, outlined above, that the Sandwich Bluff Member represents a proximal nearshore paleoenvironment, with a postulated sequence boundary and a short period of alluvial deposition representing the base of a Sobral Formation equivalent prior to a return to shallow marine conditions.

Both chondrichthyan and osteichthyan fishes have been recovered from most units of the Sandwich Bluff Member (SBM1–3, 5, 7, and 10–12 [and possibly other units as well, though not by our expedition — the precise stratigraphic positions of many fossils from this member have not been reported in the literature]). Most fish remains from the Sandwich Bluff Member consist of isolated teeth or vertebrae, though a few examples of associated materials have also been observed (e.g., short sequences of articulated shark vertebrae). The only fish fossils from this member that have been identified to low taxonomic levels are an isolated tooth of the hexanchid shark *Notidanodon dentatus* (Martin and Crame, 2006) and a palatine tooth plate of the chimaeroid cf. *Callorhinchus* sp., the latter of which (AMNH FF 20371; Fig. 6D) was discovered in the course of this study in Unit SBM3. Two additional teeth of cf. *N. dentatus* (Fig. 6C) were collected from SBM1 during the 2011 expedition.

Marine reptiles are also abundant in the Sandwich Bluff Member, with their fossils occurring in SBM1, 2, 5, 7, and 10–12, at least. Similar to the situation in the Cape Lamb Member, plesiosaur material is seemingly more common than that of mosasaurs, although a considerable diversity of the latter is also evident in the Sandwich Bluff Member. O'Gorman et al. (2010) reported a vertebra of the aberrant elasmosaurid plesiosaur *Aristonectes parvidens* from a high stratigraphic level of this unit. Furthermore, Martin (2006) described specimens of three mosasaur genera from the Sandwich Bluff Member: the mosasaurines ‘*Liodon*’ sp., *Mosasaurus* sp. and the plioplatecarpine *Plioplatecarpus* sp. The occurrence of a plioplatecarpine is of particular paleoecological interest, as members of this clade have frequently been interpreted as inhabitants of very shallow aquatic environments adjacent to coastlines, such as reefs, estuaries, or even freshwater habitats (Lingham-Soliar, 1992; Holmes et al., 1999; Caldwell, 2005).

Non-avian dinosaur fossils are extremely rare in the Sandwich Bluff Member. Case et al. (2003) reported, but did not describe, non-avian theropod and putative ankylosaurian material from this unit; in lieu of published illustrations or descriptions, however, these records cannot be substantiated. Our 2011 expedition also recovered a few fragments

from this member (specifically from SBM12, 15, and possibly 7) that have been tentatively identified as pertaining to non-avian dinosaurs.

At present, an isolated tooth of a hadrosaurid ornithopod from the Reptile Horizon of the Sandwich Bluff Member (likely equivalent to Unit SBM11; see above) constitutes the only indisputable non-avian dinosaur occurrence in this member (Case et al., 2000). Although hadrosaurid fossils are occasionally encountered in marine deposits (e.g., Horner, 1979; Fiorillo, 1990; Prieto-Márquez et al., 2006), these animals are regarded as predominantly terrestrial (Ostrom, 1964; Horner et al., 2004). Consequently, the occurrence of a hadrosaurid tooth in sediments of the Sandwich Bluff Member further establishes the proximity of the depositional environment of this unit to the Late Cretaceous coastline. This tooth is also of considerable paleobiogeographic interest. Hadrosaurids originated in the northern continents during the Early or middle Cretaceous (see Horner et al., 2004). The Campanian–Maastrichtian occurrence of these dinosaurs in southern South America has been regarded as strong biotic support for a hypothesized land bridge or island chain linking the Americas for a short period during the Late Cretaceous (Juárez Valieri et al., 2010; Prieto-Márquez and Salinas, 2010; Dalziel et al., 2013a,b). Furthermore, because hadrosaurids almost certainly dispersed to Antarctica from South America, the Maastrichtian record of these ornithopods in the JRB suggests that some form of subaerial connection existed between these continents during and/or slightly prior to this time (Case et al., 2000).

Paradoxically, although bird fossils are rare in many Late Cretaceous contexts, they are among the most abundant and well-preserved vertebrate remains known from the Sandwich Bluff Member. Avian material from this member includes at least two partial skeletons in concretions from SBM1 (Noriega and Tambussi, 1995; Clarke et al., 2005; Chatterjee et al., 2006) in addition to dozens of isolated bones from a variety of units (minimally SBM1, 2, 7, 8, and 10–12) (Fig. 6G, H, J; Table 2; see also Case et al., 2006; Tambussi and Acosta Hospitaleche, 2007). All previously reported bird remains from the Sandwich Bluff Member have been proposed to belong to taxa within the crown avian radiation, Neornithes. Nevertheless, as is the case for many vertebrate fossils from Vega Island, most of these specimens have yet to be formally described or illustrated, and as such, their phylogenetic affinities and associated evolutionary and paleoecological implications are presently difficult to ascertain. Of the avian material from Sandwich Bluff, only the holotypic partial skeleton of *Vegavis* (Fig. 6G; recovered from SBM1) has been analyzed in detail (Noriega and Tambussi, 1995; Clarke et al., 2005); these studies have firmly established this taxon as a member of the clade Anseriformes, as a relative of ducks and geese. Clarke et al. (2005) noted significant proportional differences between *Vegavis* and another stem anseriform, the wader *Presbyornis*, and a more recent reevaluation of the holotype coupled with the study of new, isolated *Vegavis* remains from the Sandwich Bluff Member suggests a diving ecology. Consequently, the probable habits of this bird are consistent with this unit having been deposited in a nearshore marine setting. Moreover, if the taxonomic assignments of purported Sandwich Bluff Member 'charadriiform' material (Case, 2001; Case et al., 2001) and a proposed new species of the putative loon *Polarornis* (Chatterjee et al., 2006) are confirmed, the records of these taxa would be consistent with this paleoenvironmental interpretation as well. An isolated femur, initially reported as having been derived from the Cape Lamb Member (Case et al., 2006), but more recently stated to have come from "near the base of [the] Sandwich Bluff Member… at a level equivalent to that of *Vegavis*…" (Tambussi and Acosta Hospitaleche, 2007, pg. 607; i.e., Unit SBM1), was referred to Cariamiformes, the clade that includes the extant seriemas of South America (Cariamidae) as well as the extinct 'terror birds' (Phorusrhacidae). Known cariamiforms are terrestrial raptors (Mayr, 2009); consequently, if this purported occurrence of the clade in the Sandwich Bluff Member is substantiated, this bone (or the carcass that contained it) would presumably have originated in a continental setting and washed into the shallow marine environment represented

by this unit. However, Cenizo (2012) suggested, and we concur, that rather than belonging to a cariamiform, this femur probably pertains to an unidentified foot-propelled diving bird.

All Cretaceous birds from Vega Island, and indeed from the JRB in its entirety, have been well supported (Noriega and Tambussi, 1995; Clarke et al., 2005), or at least proposed (e.g., Case and Tambussi, 1999; Cordes, 2001; Chatterjee, 2002; Cordes, 2002; Case et al., 2006; Chatterjee et al., 2006; Coria et al., 2007; Tambussi and Acosta Hospitaleche, 2007) as representatives of the crown clade (Neornithes). In our view, all of these remains are referable to Ornithurae, and some (e.g., *Vegavis*) are also part of the crown clade. Cape Lamb Member and Sandwich Bluff Member deposits on Vega Island have produced at least three associated ornithurine skeletons thus far. Although a few other Late Cretaceous localities have also yielded ornithurine-dominated avifaunas (e.g., Longrich, 2009; Longrich et al., 2011), none of these has produced multiple associated skeletons belonging to this clade.

The recovery of neornithines from the Late Cretaceous of Antarctica has led to the hypothesis that this important group, or at least major clades within it (e.g., Neognathae), may have originated on this continent during this interval (Case, 2001; Chatterjee, 2002). It has even been proposed that the high-latitude paleoenvironments of Antarctica may have acted as a refugium for neornithines, enabling these birds to endure the K–Pg extinction event while contemporaneous avian groups that inhabited lower latitudes (e.g., Enantiornithes) did not (Chatterjee, 2002). Global sampling of Late Cretaceous birds remains sparse, however (Clarke et al., 2005), and the evaluation of these intriguing hypotheses must await further discoveries of phylogenetically informative avian material from this interval.

6. Conclusions

Systematic vertebrate paleontological surveys and stratigraphic assessments of new and historic Upper Cretaceous fossil localities were conducted on Vega Island during the austral summer of 2011. Faunal study, coupled with detailed facies analysis of the Cape Lamb Member and Sandwich Bluff Member, provides new insights into the taphonomy and paleoecology of high-latitude paleoecosystems on the Antarctic Peninsula at the end of the Mesozoic. Whereas the Cape Lamb Member is characterized by a fully marine paleoecosystem with rare but significant terrestrial vertebrates, the Sandwich Bluff Member records a progradational, nearshore marine to possibly terrestrial, upward-coarsening siliciclastic succession that is highlighted by a rich fossil bird record and a variety of other terrestrial and nearshore marine taxa. Detailed stratigraphic analysis of the Sandwich Bluff Member reveals 15 distinct depositional units, beginning with a basal, exceptionally fossiliferous concretionary horizon that is identified as a condensed section (a maximum flooding surface) that was deposited during the maximum transgression of a third-order sea level cycle. Above this level, the section rapidly coarsens and shallows upwards, culminating in a previously unrecognized sequence boundary and the subsequent deposition of a 6 m-thick sequence of conglomeratic alluvial strata. Above this is a 6 m-thick succession of bioturbated marine siltstones and sandstones. Collectively, this 12 m-thick package of strata immediately below the Neogene Hobbs Glacier Formation is here interpreted to correlate with the Paleocene Sobral Formation, a unit that was previously known only on Seymour Island in the southern part of the James Ross Basin. If confirmed by biostratigraphic (especially palynologic) and chronostratigraphic data, this discovery would place the K–Pg boundary near the top of the Sandwich Bluff Member on Vega Island.

References

Askin, R.A., 1988. Campanian to Paleocene palynological succession of Seymour and adjacent islands, northeastern Antarctic Peninsula. In: Feldmann, R.M., Woodburne, M.O. (Eds.), Geology and Paleontology of Seymour Island, Antarctic Peninsula. Geol. Soc. Am. Mem., 169, pp. 131–153.

Behrensmeyer, A.K., Barry, J.C., 2005. Biostratigraphic surveys in the Siwaliks of Pakistan: a method for standardized surface sampling of the vertebrate fossil record. Palaeontol. Electron. 8 (24 pp., http://palaeoelectronica.org/paleo/2005_1/behrens15/issue1_05.htm).

Bennett, M.R., Doyle, P., Mather, A.E., 1996. Dropstones: their origin and significance. Palaeogeogr. Palaeoclimatol. Palaeoecol. 121, 331–339.

Bowman, V.C., Francis, J.E., Riding, J.B., Hunter, S.J., Haywood, A.M., 2012. A latest Cretaceous to earliest Paleogene dinoflagellate cyst zonation from Antarctica, and implications for phytoprovincialism in the high southern latitudes. Rev. Palaeobot. Palynol. 171, 40–56.

Bowman, V.C., Francis, J.E., Riding, J.B., 2013. Late Cretaceous winter sea ice in Antarctica? Geology 41, 1227–1230.

Caldwell, M.W., 2005. The squamates: origins, phylogeny, and paleoecology. In: Currie, P. J., Koppelhus, E.B. (Eds.), Dinosaur Provincial Park: A Spectacular Ancient Ecosystem Revealed. Indiana University Press, Bloomington, pp. 235–248.

Case, J.A., 2001. Latest Cretaceous record of modern birds from Antarctica: center of origin or fortuitous occurrence? North American Paleontological Conference 2001 Abstracts. University of California, Berkeley.

Case, J.A., Tambussi, C.P., 1999. Maestrichtian record of neornithine birds in Antarctica: comments on a Late Cretaceous radiation of modern birds. J. Vertebr. Paleontol. 19 (supplement to 3), 38A.

Case, J.A., Martin, J.E., Chaney, D.S., Reguero, M., Marenssi, S.A., Santillana, S.M., Woodburne, M.O., 2000. The first duck-billed dinosaur (family Hadrosauridae) from Antarctica. J. Vertebr. Paleontol. 20, 612–614.

Case, J.A., Marenssi, S.A., Martin, J.E., Reguero, M.A., Santillana, S.N., Rinaldi, C.A., Woodburne, M.O., 2001. Late Cretaceous vertebrate fauna from Antarctica. 31st International Geological Congress, Rio de Janeiro, Brasil, August 2000.

Case, J.A., Martin, J.E., Chaney, D.S., Reguero, M., 2003. Late Cretaceous dinosaurs from the Antarctic Peninsula: remnant or immigrant fauna? J. Vertebr. Paleontol. 23 (supplement to 3), 39A.

Case, J., Reguero, M., Martin, J., Cordes-Person, A., 2006. A cursorial bird from the Maastrichtian of Antarctica. J. Vertebr. Paleontol. 26 (supplement to 3), 48A.

Case, J.A., Martin, J.E., Reguero, M., 2007. A dromaeosaur from the Maastrichtian of James Ross Island and the Late Cretaceous Antarctic dinosaur fauna. In: Cooper, A.K., Raymond, C.R., ISAES Editorial Team (Eds.), Antarctica: A Keystone in a Changing World — Online Proceedings for the Tenth International Symposium on Antarctic Earth Sciences: U.S. Geological Survey, Washington, D.C, pp. 1–4.

Cenizo, M., 2012. Review of the putative Phorusrhacidae from the Cretaceous and Paleogene of Antarctica: new records of ratites and pelagornithid birds. Pol. Polar Res. 33, 239–258.

Cerda, I.A., Paulina Carabajal, A., Salgado, L., Coria, R.A., Reguero, M.A., Tambussi, C.P., Moly, J.J., 2012. The first record of a sauropod dinosaur from Antarctica. Naturwissenschaften 99, 83–87.

Césari, S.N., Marenssi, S.A., Santillana, S.N., 2001. Conifers from the Upper Cretaceous of Cape Lamb, Vega Island, Antarctica. Cretac. Res. 22, 309–319.

Chatterjee, S., 1989. The oldest Antarctic bird. J. Vertebr. Paleontol. 9 (supplement to 3), 16A.

Chatterjee, S., 2002. The morphology and systematics of Polarornis, a Cretaceous loon (Aves: Gaviidae) from Antarctica. In: Zhou, Z., Zhang, F. (Eds.), Proceedings of the 5th Symposium of the Society of Avian Paleontology and Evolution, Beijing, 1–4 June 2000. Science Press, Beijing, pp. 125–155.

Chatterjee, S., Small, B.J., 1989. New plesiosaurs from the Upper Cretaceous of Antarctica. Geol. Soc. Lond., Spec. Publ. 47, 197–215.

Chatterjee, S., Martinioni, D., Novas, F., Mussel, F., Templin, R., 2006. A new fossil loon from the Late Cretaceous of Antarctica and early radiation of foot-propelled diving birds. J. Vertebr. Paleontol. 26 (supplement to 3), 49A.

Clarke, J.A., 2004. Morphology, phylogenetic taxonomy, and systematics of Ichthyornis and Apatornis (Avialae: Ornithurae). Bull. Am. Mus. Nat. Hist. 286, 1–179.

Clarke, J.A., Tambussi, C.P., Noriega, J.I., Erickson, G.M., Ketchum, R.A., 2005. Definitive fossil evidence for the extant avian radiation in the Cretaceous. Nature 433, 305–309.

Cordes, A.H., 2001. A Basal Charadriiform Bird from the Early Maastrichtian of Cape Lamb, Vega Island, Antarctic Peninsula. (Master's thesis) South Dakota School of Mines and Technology, Rapid City.

Cordes, A.H., 2002. A new charadriiform avian specimen from the early Maastrichtian of Cape Lamb, Vega Island, Antarctic Peninsula. J. Vertebr. Paleontol. 22 (supplement to 3), 46A.

Coria, R.A., Tambussi, C., Moly, J.J., Santillana, S., Reguero, M., 2007. Nuevos restos de Dinosauria del Cretácico de las islas James Ross y Marambio, Península Antártica. VI Simposio Argentino y III Latinoamericano sobre Investigaciones Antárticas, 10 al 14 de Septiembre de 2007. Dirección Nacional del Antártico/Instituto Antártico Argentino, Buenos Aires (4 pp.).

Crame, J.A., Pirrie, D., Riding, J.B., Thomson, M.R.A., 1991. Campanian–Maastrichtian (Cretaceous) stratigraphy of the James Ross Island area, Antarctica. J. Geol. Soc. Lond. 148, 1125–1140.

Crame, J.A., Lomas, S.A., Pirrie, D., Luther, A., 1996. Late Cretaceous extinction patterns in Antarctica. J. Geol. Soc. Lond. 153, 503–506.

Crame, J.A., Francis, J.E., Cantrill, D.J., Pirrie, D., 2004. Maastrichtian stratigraphy of Antarctica. Cretac. Res. 25, 411–423.

Dalziel, I.W.D., Lawver, L.A., Norton, I.O., Gahagan, M., 2013a. The Scotia Arc: genesis, evolution, global significance. Annu. Rev. Earth Planet. Sci. 41, 767–793.

Dalziel, I.W.D., Lawver, L.A., Pearce, J.A., Barker, P.F., Hastie, A.R., Barfod, D.N., Schenke, H.-W., Davis, M.B., 2013b. A potential barrier to deep Antarctica circumpolar flow until the late Miocene? Geology 41, 947–950.

del Valle, R.A., Medina, F., Gasparini de Brandoni, Z., 1977. Nota preliminar sobre el hallazgo de reptiles fósiles marinos del suborden Plesiosauria en las islas James Ross y Vega, Antártida. Contrib. Cient. Inst. Antart. Argent. 212, 1–13.

del Valle, R.A., Elliot, D.H., MacDonald, D.I.M., 1992. Sedimentary basins on the east flank of the Antarctic Peninsula: proposed nomenclature. Antarct. Sci. 4, 477–478.

Dettman, M.E., Thomson, M.R.A., 1987. Cretaceous palynomorphs from the James Ross Island Area, Antarctica. A pilot study. Br. Antarct. Surv. Bull. 77, 13–59.

di Pasquo, M., Martin, J.E., 2013. Palynoassemblages associated with a theropod dinosaur from the Snow Hill Island Formation (lower Maastrichtian) at the Naze, James Ross Island, Antarctica. Cretac. Res. 45, 135–154.

Everhart, M.J., 2000. Gastroliths associated with plesiosaur remains in the Sharon Springs Member of the Pierre Shale (Late Cretaceous), western Kansas. Trans. Kans. Acad. Sci. 103, 64–75.

Fernández, M.S., Gasparini, Z., 2012. Campanian and Maastrichtian mosasaurs from Antarctic Peninsula and Patagonia, Argentina. Bull. Soc. Geol. Fr. 183, 93–102.

Fiorillo, A.R., 1990. The first occurrence of hadrosaur (Dinosauria) remains from the marine Claggett Formation, Late Cretaceous of south-central Montana. J. Vertebr. Paleontol. 10, 515–517.

Francis, J.E., Poole, I., 2002. Cretaceous and early Tertiary climates of Antarctica: evidence from fossil wood. Palaeogeogr. Palaeoclimatol. Palaeoecol. 182, 47–64.

Gasparini, Z., Olivero, E., Scasso, R., Rinaldi, C., 1987. Un ankylosaurio (Reptilia, Ornithischia) Campaniano en el continente Antartico. Anais do X Congresso Brasileiro de Paleontologia, 1, pp. 131–141.

Gasparini, Z., Pereda-Suberbiola, X., Molnar, R.E., 1996. New data on the ankylosaurian dinosaur from the Late Cretaceous of the Antarctic Peninsula. Mem. Qld. Mus. 39, 583–594.

Gasparini, Z., Bardet, N., Martin, J.E., Fernández, M.S., 2003a. The elasmosaurid plesiosaur Aristonectes Cabrera from the latest Cretaceous of South America and Antarctica. J. Vertebr. Paleontol. 23, 104–115.

Gasparini, Z., Salgado, L., Casadío, S., 2003b. Maastrichtian plesiosaurs from northern Patagonia. Cretac. Res. 24, 157–170.

Gasparini, Z., Salgado, L., Parras, A., 2007. Late Cretaceous plesiosaurs from northern Patagonia, Argentina. Geol. J. 42, 185–202.

Hathway, B., 2000. Continental rift to back-arc basin: Jurassic–Cretaceous stratigraphical and structural evolution of the Larsen Basin, Antarctic Peninsula. J. Geol. Soc. Lond. 157, 417–432.

Hector, J., 1874. On the fossil Reptilia of New Zealand. Trans. N. Z. Inst. 6, 333–358.

Hiller, N., Mannering, A., Jones, C., Cruickshank, A., 2005. The nature of Mauisaurus haasti Hector, 1874 (Reptilia: Plesiosauria). J. Vertebr. Paleontol. 25, 588–601.

Holmes, R., Caldwell, M.W., Cumbaa, S.L., 1999. A new specimen of Plioplatecarpus (Mosasauridae) from the lower Maastrichtian of Alberta: comments on allometry, functional morphology, and paleoecology. Can. J. Earth Sci. 36, 363–369.

Hooker, J.J., Milner, A.C., Sequeira, S.E.K., 1991. An ornithopod dinosaur from the Late Cretaceous of west Antarctica. Antarct. Sci. 3, 331–332.

Horner, J.R., 1979. Upper Cretaceous dinosaurs from the Bearpaw Shale (marine) of south-central Montana with a checklist of Upper Cretaceous dinosaur remains from marine sediments in North America. J. Paleontol. 53, 566–577.

Horner, J.R., Weishampel, D.B., Forster, C.A., 2004. Hadrosauridae, In: Weishampel, D.B., Dodson, P., Osmólska, H. (Eds.), The Dinosauria, Second edition. University of California Press, Berkeley, pp. 438–463.

Juárez Valieri, R.D., Haro, J.A., Fiorelli, L.E., Calvo, J.O., 2010. A new hadrosauroid (Dinosauria: Ornithopoda) from the Allen Formation (Late Cretaceous) of Patagonia, Argentina. Rev. Museo Argent. Cienc. Nat. 12, 217–231.

Kriwet, J., Lirio, J.M., Nuñez, H.J., Puceat, E., Lécuyer, C., 2006. Late Cretaceous Antarctic fish diversity. In: Francis, J.E., Crame, J.A. (Eds.), Cretaceous-Tertiary High-Latitude Palaeoenvironments, pp. 83–100.

Ksepka, D., Clarke, J.A., 2014. Phylogenetically vetted and stratigraphically constrained fossil calibrations within Aves. Palaeontol. Electron. (in press).

Lingham-Soliar, T., 1992. A new mode of locomotion in mosasaurs: subaqueous flying in Plioplatecarpus marshi. J. Vertebr. Paleontol. 12, 405–421.

Longrich, N.R., 2009. An ornithurine-dominated avifauna from the Belly River Group (Campanian, Upper Cretaceous) of Alberta, Canada. Cretac. Res. 30, 161–177.

Longrich, N.R., Tokaryk, T., Field, D., 2011. Mass extinction of birds at the Cretaceous–Paleogene (K–Pg) boundary. Proc. Natl. Acad. Sci. 108, 15253–15257.

Loutit, T.S., Hardenbol, J., Vail, P.R., Baum, G.R., 1988. Condensed sections: the key to age-dating and correlation of continental margin sequences. In: Wilgus, C.K., Hastings, B.S.,

Posamentier, H.W., Van Wagoner, J.C., Ross, C.A., Kendall, C.G.St.C. (Eds.), Sea-Level Changes—An Integrated Approach. SEPM Special Publication, 42, pp. 183–213.

Macellari, C.E., 1988. Stratigraphy, sedimentology, and paleoecology of Upper Cretaceous/Paleocene shelf-deltaic sediments of Seymour Island (Antarctic Peninsula). In: Feldmann, R.M., Woodburne, M.O. (Eds.), Geology and Paleontology of Seymour Island, Antarctic Peninsula. Geol. Soc. Am. Mem., 169, pp. 25–53.

MacPhee, R., Clarke, J., Gorscak, E., Lamanna, M., O'Connor, P., Meng, J., Roberts, E., Sertich, J., Salisbury, S., 2011. New fossil vertebrate discoveries from the Late Cretaceous of James Ross and Vega islands, West Antarctica. 11th International Symposium on Antarctic Earth Sciences, Programme and Abstracts, p. 265.

Marenssi, S.A., Lirio, J.M., Santillana, S.N., 1992. The Upper Cretaceous of southern James Ross Island, Antarctica. In: Rinaldi, C.A. (Ed.), Geología de la Isla James Ross. Instituto Antártico Argentino, Buenos Aires, pp. 89–99.

Marenssi, S.A., Salani, F.M., Santillana, S.N., 2001. Geología de cabo Lamb, Isla Vega, Península Antártica. Contrib. Cient. Inst. Antart. Argent. 530, 1–43.

Martin, J.E., 2006. Biostratigraphy of the Mosasauridae (Reptilia) from the Cretaceous of Antarctica. In: Francis, J.E., Pirrie, D., Crame, J.A. (Eds.), Cretaceous-Tertiary High-Latitude Palaeoenvironments, James Ross Basin, Antarctica. Geological Society of London Special Publications, 258, pp. 101–108.

Martin, J.E., 2008. Plesiosaurs from the Late Cretaceous deposits of Antarctica. Geol. Soc. Am. Abstr. Programs 40, 331.

Martin, J.E., Crame, J.A., 2006. Palaeobiological significance of high-latitude Late Cretaceous vertebrate fossils from the James Ross Basin, Antarctica. In: Francis, J.E., Pirrie, D., Crame, J.A. (Eds.), Cretaceous-Tertiary High-Latitude Palaeoenvironments, James Ross Basin, Antarctica. Geological Society of London Special Publications, 258, pp. 109–124.

Martin, J.E., Bell Jr., G.L., Case, J.A., Chaney, D.S., Fernández, M.A., Gasparini, Z., Reguero, M., Woodburne, M.O., 2002. Mosasaurs (Reptilia) from the Late Cretaceous of the Antarctic Peninsula. In: Gamble, J.A., Skinner, D.N.B., Henrys, S. (Eds.), Antarctica at the Close of a Millennium, Eighth International Symposium on Antarctic Earth Sciences. Royal Society, New Zealand Bulletin, 35, pp. 293–299.

Martin, J., Kihm, A., Fernández, M., Reguero, M., Case, J., 2007a. A juvenile mosasaur (*Taniwhasaurus antarcticus*) from the Late Cretaceous of Antarctica. J. Vertebr. Paleontol. 27 (supplement to 3), 112A.

Martin, J.E., Sawyer, J.F., Reguero, M.A., Case, J.A., 2007b. Occurrence of a young elasmosaurid plesiosaur skeleton from the Late Cretaceous (Maastrichtian) of Antarctica. In: Cooper, A.K., Raymond, C.R., ISAES Editorial Team (Eds.), Antarctica: A Keystone in a Changing World — Online Proceedings for the Tenth International Symposium on Antarctic Earth Sciences. U.S. Geological Survey, Washington, D.C, pp. 1–4.

Mayr, G., 2009. Cariamae (seriemas and allies). In: Mayr, G. (Ed.), Paleogene Fossil Birds: Berlin. Springer, Berlin Heidelberg, pp. 139–152.

Milner, A.C., Hooker, J.J., Sequeira, S.E.K., 1992. An ornithopod dinosaur from the Upper Cretaceous of the Antarctic Peninsula. J. Vertebr. Paleontol. 12 (supplement to 3), 44A.

Noriega, J.J., Tambussi, C.P., 1995. A Late Cretaceous Presbyornithidae (Aves: Anseriformes) from Vega Island, Antarctic Peninsula: paleobiogeographic implications. Ameghiniana 32, 57–61.

Novas, F.E., Cambiaso, A., Lirio, J.M., Nuñez, H.J., 2002. Paleobiogeografía de los dinosaurios polares de Gondwana. Ameghiniana 39, 15R.

O'Gorman, J., Concheyro, A., Olivero, E., Reguero, M.A., Moly, J., Marenssi, S., Gasparini, Z., 2008. Un elasmosaurido (Plesiosauria, Plesiosauroidea) del Cretácico Superior de Isla Vega, Antártida. In: Calvo, J.O., Porfiri, J.D., Juárez Valieri, R., dos Santos, D. (Eds.), Libro de Resúmenes, III Congreso Latinoamericano de Paleontología de Vertebrados. Universidad Nacional del Comahue, Neuquén, p. 181.

O'Gorman, J.P., Gasparini, Z., Reguero, M., 2010. *Aristonectes parvidens* Cabrera (Sauropterygia, Plesiosauria) from Cape Lamb, Vega Island (Upper Cretaceous), Antarctica. XXXI Scientific Committee on Antarctic Research (SCAR) Open Science Conference, August 3–6, 2010, Buenos Aires, p. 557 (abstract).

O'Gorman, J.P., Olivero, E.B., Cabrera, D.A., 2012. Gastroliths associated with a juvenile elasmosaur (Plesiosauria, Elasmosauridae) from the Snow Hill Island Formation (upper Campanian–lower Maastrichtian), Vega Island, Antarctica. Alcheringa 36, 531–541.

O'Gorman, J.P., Salgado, L., Cerda, I.A., Gasparini, Z., 2013. First record of gastroliths associated with elasmosaur remains from La Colonia Formation (Campanian–Maastrichtian), Chubut, Patagonia Argentina, with comments on the probable depositional palaeoenvironment of the source of the gastroliths. Cretac. Res. 40, 212–217.

Olivero, E.B., 2012. Sedimentary cycles, ammonite diversity and palaeoenvironmental changes in the Upper Cretaceous Marambio Group, Antarctica. Cretac. Res. 34, 348–366.

Olivero, E.B., Medina, F.A., 2000. Patterns of Late Cretaceous ammonite biogeography in southern high latitudes: the Family Kossmaticeratidae in Antarctica. Cretac. Res. 21, 269–279.

Olivero, E.B., Scasso, R.A., Rinaldi, C.A., 1986. Revision of the Marambio Group, James Ross Island, Antarctica. Contrib. Cient. Inst. Antart. Argent. 331, 1–28.

Olivero, E.B., Gasparini, Z., Rinaldi, C.A., Scasso, R., 1991. First record of dinosaurs in Antarctica (Upper Cretaceous, James Ross Island): palaeogeographical implications. In: Thomson, M.R.A., Crame, J.A., Thomson, J.W. (Eds.), Geological Evolution of Antarctica. Cambridge University Press, Cambridge, pp. 617–622.

Olivero, E.B., Martinioni, D.R., Mussel, F.J., 1992. Upper Cretaceous sedimentology and biostratigraphy of western Cape Lamb (Vega Island, Antarctica). Implications on sedimentary cycles and evolution of the basin. In: Rinaldi, C.A. (Ed.), Geología de la Isla James Ross. Instituto Antártico Argentino, Buenos Aires, pp. 147–166.

Olivero, E.B., Ponce, J.J., Martinioni, D.R., 2008. Sedimentology and architecture of sharp-based tidal sandstones in the upper Marambio Group, Maastrichtian of Antarctica. Sediment. Geol. 210, 11–26.

Ostrom, J.H., 1964. A reconsideration of the paleoecology of hadrosaurian dinosaurs. Am. J. Sci. 262, 975–997.

Otero, R.A., Soto-Acuña, S., Rubilar-Rogers, D., 2010. Presence of *Mauisaurus* Hector (Plesiosauroidea, Elasmosauridae) in the Late Cretaceous (Maastrichtian) of central Chile. Acta Palaeontol. Pol. 55, 361–364.

Otero, R.A., Rubilar-Rogers, D., Yury-Yañez, R.E., Vargas, A.O., Gutstein, C.S., Mourgues, F.A., Robert, E., 2013. A new species of chimaeriform (Chondrichthyes, Holocephali) from the uppermost Cretaceous of the López de Bertodano Formation, Isla Marambio (Seymour Island), Antarctica. Antarct. Sci. 25, 99–106.

Peters, S.E., Loss, D.P., 2012. Storm and fair-weather wave base: a relevant distinction? Geology 40, 511–514.

Pirrie, D., 1989. Shallow marine sedimentation within an active margin basin, James Ross Island, Antarctica. Sediment. Geol. 63, 61–82.

Pirrie, D., Marshall, J.D., 1991. Field relationships and stable isotope geochemistry of concretions from James Ross Island, Antarctica. Sediment. Geol. 71, 137–150.

Pirrie, D., Crame, J.A., Riding, J.B., 1991. Late Cretaceous stratigraphy and sedimentology of Cape Lamb, Vega Island, Antarctica. Cretac. Res. 12, 227–258.

Pirrie, D., Crame, J.A., Lomas, S.A., Riding, J.B., 1997. Late Cretaceous stratigraphy of the Admiralty Sound region, James Ross Basin, Antarctica. Cretac. Res. 18, 109–137.

Prieto-Márquez, A., Salinas, G.C., 2010. A re-evaluation of *Secernosaurus koerneri* and *Kritosaurus australis* (Dinosauria, Hadrosauridae) from the Late Cretaceous of Argentina. J. Vertebr. Paleontol. 30, 813–837.

Prieto-Márquez, A., Weishampel, D.B., Horner, J.R., 2006. The dinosaur *Hadrosaurus foulkii*, from the Campanian of the East Coast of North America, with a reevaluation of the genus. Acta Palaeontol. Pol. 51, 77–98.

Reguero, M.A., Gasparini, Z., 2006. Late Cretaceous–Early Tertiary marine and terrestrial vertebrates from James Ross Basin, Antarctic Peninsula: a review. In: Rabassa, J., Borla, M.L. (Eds.), Antarctic Peninsula and Tierra del Fuego: 100 Years of Swedish–Argentine Scientific Cooperation at the End of the World. Taylor and Francis, London, pp. 55–76.

Reguero, M., Goin, F., Acosta Hospitaleche, C., Dutra, T., Marenssi, S., 2013. Late Cretaceous/Paleogene West Antarctica Terrestrial Biota and its Intercontinental Affinities: Dordrecht. Springer, Dordrecht, Netherlands (120 pp.).

Reguero, M.A., Tambussi, C.P., Coria, R.A., Marenssi, S.A., 2014. Late Cretaceous dinosaurs from the James Ross Basin, West Antarctica. Geol. Soc. Lond., Spec. Publ. 381. http://dx.doi.org/10.1144/SP381.20 (in press).

Rich, T.H., Vickers-Rich, P., Fernandez, M., Santillana, S., 1999. A probable hadrosaur from Seymour Island, Antarctic Peninsula. In: Tomida, Y., Rich, T.H., Vickers-Rich, P. (Eds.), Proceedings of the Second Gondwana Dinosaur Symposium. National Science Museum of Tokyo, Tokyo, pp. 219–222.

Riding, J.B., Keating, J.M., Snape, M.G., Newham, S., Pirrie, D., 1992. Preliminary Jurassic and Cretaceous dinoflagellate cyst stratigraphy of the James Ross Island Area, Antarctic Peninsula. Newsl. Stratigr. 26, 19–39.

Rinaldi, C.A., Massabie, A., Morelli, J., Rosenman, H.L., del Valle, R., 1978. Geologia de la isla Vicecomodoro Marambio. Contrib. Cient. Inst. Antart. Argent. 217, 1–44.

Smith, S.W., 1992. Microplankton from the Cape Lamb Member, López de Bertodano Formation (Upper Cretaceous), Cape Lamb, Vega Island. Antarct. Sci. 4, 337–353.

Stahl, B.J., Chatterjee, S., 1999. A Late Cretaceous chimaerid (Chondrichthyes, Holocephali) from Seymour Island, Antarctica. Palaeontology 42, 979–989.

Stahl, B.J., Chatterjee, S., 2002. A Late Cretaceous callorhynchid (Chondrichthyes, Holocephali) from Seymour Island, Antarctica. J. Vertebr. Paleontol. 22, 848–850.

Tambussi, C.P., Acosta Hospitaleche, C.I., 2007. Antarctic birds (Neornithes) during the Cretaceous–Eocene times. Rev. Asoc. Geol. Argent. 62, 604–617.

Taylor, M.A., 1993. Stomach stones for feeding or buoyancy? The occurrence and function of gastroliths in marine tetrapods. Philos. Trans. R. Soc. Lond. B 341, 163–175.

Thompson, W.A., Martin, J.E., Reguero, M., 2007. Comparison of gastroliths within plesiosaurs (Elasmosauridae) from the Late Cretaceous marine deposits of Vega Island, Antarctic Peninsula, and the Missouri River area, South Dakota. In: Martin, J.E., Parris, D.C. (Eds.), The Geology and Paleontology of the Late Cretaceous Marine Deposits of the Dakotas. Geological Society of America Special Paper, 427, pp. 147–153.

Thomson, M.R.A., Hooker, J.J., 1991. First hypsilophodontid dinosaur from Antarctica. Abstracts of the Sixth International Symposium on Antarctic Earth Sciences, 6, pp. 594–595.

Thorn, V.C., Riding, J.B., Francis, J.E., 2009. The Late Cretaceous dinoflagellate cyst *Manumiella*—biostratigraphy, systematics and palaeoecological signals in Antarctica. Rev. Palaeobot. Palynol. 156, 436–448.

Tobin, T.S., Ward, P.D., Steig, E.J., Olivero, E.B., Hilburn, I.A., Mitchell, R.N., Diamond, M.R., Raub, T.D., Kirschvink, J.L., 2012. Extinction patterns, $\delta18O$ trends, and magnetostratigraphy from a southern high-latitude Cretaceous–Paleogene section: links with Deccan volcanism. Palaeogeogr. Palaeoclimatol. Palaeoecol. 350–352, 180–188.

Vail, P.R., Hardenbol, J., Todd, R.G., 1984. Jurassic unconformities, chronostratigraphy, and sea-level changes from seismic stratigraphy and biostratigraphy. In: Schlee, J.S. (Ed.), Interregional Unconformities and Hydrocarbon Accumulation. American Association of Petroleum Geologists Memoir, 36, pp. 129–144.

Vogt, P.R., Parrish, M., 2012. Driftwood dropstones in Middle Miocene Climate Optimum shallow marine strata (Calvert Cliffs, Maryland Coastal Plain): erratic pebbles no certain proxy for cold climate. Palaeogeogr. Palaeoclimatol. Palaeoecol. 323–325, 100–109.

Wings, O., 2007. A review of gastrolith function with implications for fossil vertebrates and a revised classification. Acta Palaeontol. Pol. 52, 1–16.

Wood, S.A., Askin, R.A., 1992. Dinoflagellate cysts from the Marambio Group (Upper Cretaceous) of Humps Island. Antarct. Sci. 4, 327–336.

Wren, J.H., Hart, G.F., 1988. Paleogene dinoflagellate cyst biostratigraphy of Seymour Island, Antarctica. Geol. Soc. Am. Mem. 169, 321–447.

Zinsmeister, W.J., 1979. Biogeographic significance of the late Mesozoic and early Tertiary molluscan faunas of Seymour Island (Antarctic Peninsula) to the final breakup of Gondwanaland. In: Gray, J., Boucot, A. (Eds.), Historical Biogeography, Plate Tectonics and the Changing Environment. Proceedings of the 37th Annual Biology Colloquium and Selected Papers. Oregon State University Press, Corvallis, pp. 349–355.

Zinsmeister, W.J., Feldmann, R.M., 1996. Late Cretaceous faunal changes in the high southern latitudes: a harbinger of global biotic catastrophe? In: MacLeod, N., Keller, G. (Eds.), Cretaceous-Tertiary Mass Extinctions: Biotic and Environmental Changes. Norton, New York, pp. 303–325.

Zinsmeister, W.J., Feldmann, R.M., Woodburne, M.O., Elliot, D.H., 1989. Latest Cretaceous/ earliest Tertiary transition on Seymour Island, Antarctica. J. Paleontol. 63, 731–738.