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High-resolution chronostratigraphy of the Cerro Barcino Formation (Patagonia): Paleobiologic implications for the mid-cretaceous dinosaur-rich fauna of South America

J. Marcelo Krause [a,b,c,*], Jahandar Ramezani [d], Aldo M. Umazano [e,f], Diego Pol [a,b], José L. Carballido [a,b], Juliana Sterli [a,b], Pablo Puerta [a], N. Rubén Cúneo [a,b], Eduardo S. Bellosi [b,g]

[a] Museo Paleontológico Egidio Feruglio, Avenida Fontana 140, 9100 Trelew, Chubut, Argentina
[b] Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Godoy Cruz 2290, C1425FQB Buenos Aires, Argentina
[c] Universidad Nacional de Río Negro, Av. Roca 1242, 8332 General Roca, Río Negro, Argentina
[d] Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, USA
[e] INCITAP (CONICET-UNLPam), Mendoza 109, 6300 Santa Rosa, La Pampa, Argentina
[f] Facultad de Ciencias Exactas y Naturales, Universidad Nacional de La Pampa, Avenida Uruguay 151, 6300 Santa Rosa, La Pampa, Argentina
[g] Museo Argentino de Ciencias Naturales, Avenida Ángel Gallardo 470, 1405 Buenos Aires, Argentina

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ABSTRACT

The Cretaceous Cerro Barcino Formation (Chubut Group) of Central Patagonia, Argentina has yielded a remarkable fossil vertebrate fauna, which form important components of the South American "mid-Cretaceous" fauna, including titanosauriform sauropod dinosaurs, theropod dinosaurs, crocodyliforms, turtles, and lepidosauromorphs. However, a lack of robust chronostratigraphic framework for its fossil occurrences has so far hampered a full realization of their paleobiologic significance. This contribution presents new stratigraphic, sedimentologic, and U-Pb isotopic age data from 11 localities throughout the Patagonian Somuncurá-Canadón Asfalto Basin and analyzes the evolutionary characteristics of the Cerro Barcino fauna within the biostratigraphic context of the Cretaceous of Gondwana.

Four new high-precision $^{206}Pb/^{238}U$ zircon dates by the CA-ID-TIMS method range from 118.497 $\pm$ 0.063 Ma to 98.466 $\pm$ 0.048 Ma (2σ internal errors) and limits the Puesto La Paloma, Cerro Castaño and Las Plumas members of the Cerro Barcino Formation largely to the Aptian, Albian and Cenomanian stages of the Cretaceous, respectively. Accordingly, the majority of the Cerro Barcino vertebrates fall within a ~118–110 Ma time interval in the latest Early Cretaceous, which makes them the oldest documented component of the "mid-Cretaceous" faunal assemblage of Gondwana. Paleobiologic analyses of the latter assemblage suggests a ~10 m.y. period of faunistic stability characterized by only minor evolutionary novelties or faunal turnovers.

1. Introduction

The extensive Cretaceous exposures along the extra-Andean Patagonia, Argentina, have yielded diverse assemblages of continental vertebrate fossils, but this record is highly biased toward Late Cretaceous rocks of northwestern Patagonia (Novas, 2009). Particularly, the vertebrate fossil record of the Chubut Group in Somuncurá-Canadón Asfalto Basin (Fig. 1) was for many years limited to a single dinosaur taxon: the titanosauriform sauropod *Chubutisaurus insignis* (del Corro, 1975). Collecting efforts by multiple workers since 2005 have greatly increased our knowledge of the vertebrate fauna, yielding a total of seven named species representative of other major clades of reptiles that thrived during the Cretaceous of South America. The diverse fossil record of Chubut Group in the Somuncurá-Cañadón Asfalto Basin is presently characterized by: Theropoda (*Tyrannotitan chubutensis* Novas et al., 2005), Sauropoda (*Chubutisaurus insignis* del Corro, 1975; *Patagotitan mayorum* Carballido et al., 2017), Crocodyliform (*Barcinosuchus gradilis* Leardi and Pol, 2009), Lepidosauromorpha (*Kaikaifilusaurus minimus* Apesteguía and Carballido, 2014), and Testudinata (*Chubutemys copelloi* Gaffney et al., 2007; Sterli et al., 2015; *Prochelidella cerrobarcinae* de la Fuente et al., 2011). Additional theropod and sauropod dinosaur remains, which have not been formally named due to their fragmentary nature and their lack of autapomorphic characters, were also described from this unit (Rauhut et al., 2003; Gianechini et al., 2011) and are important representatives of certain taxonomic groups (e.g., abelisaurids, titanosauriforms). In addition to vertebrate bone remains, the Chubut

* Corresponding author at: Museo Paleontológico Egidio Feruglio, Avenida Fontana 140, 9100 Trelew, Chubut, Argentina.
E-mail address: mkrause@mef.org.ar (J.M. Krause).

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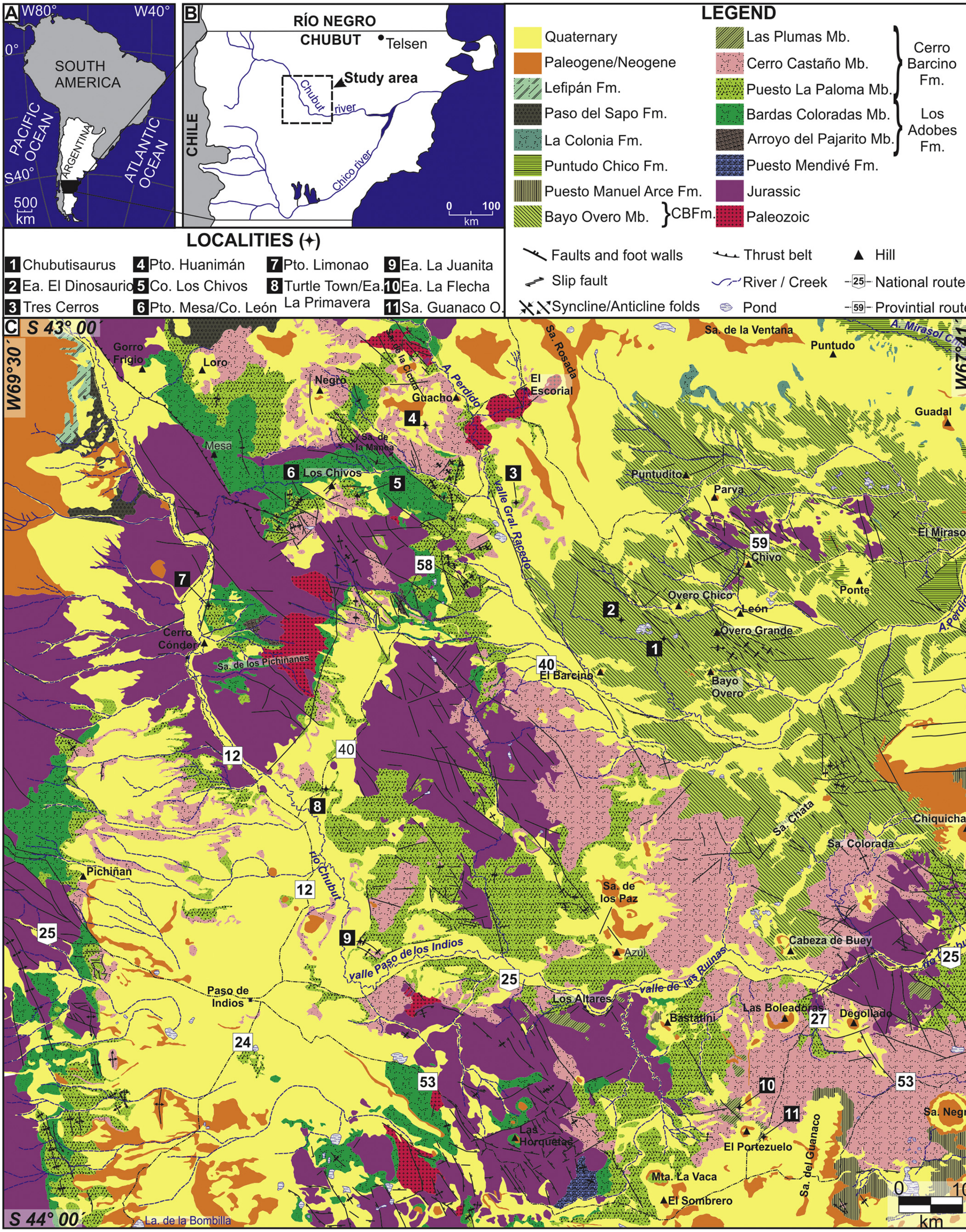

Fig. 1. Location map and geology of the study area (revised after Proserpio, 1987; Anselmi et al., 2000, 2004; Silva Nieto et al., 2005; Krause et al., 2014b, and Umazano et al., 2017). A – Geographic location in South America with the Chubut Province shown in black. B – Outline of the study area within the Chubut Province. C – Geologic map of the Cretaceous units cropping out in the study area; studied localities are numbered. Ea. – Estancia, Pto. – Puesto, Co. – Cerro, Sa. – Sierra, CBFm – Cerro Barcino Formation.

Group contains rhizolith balls (Genise et al., 2010), dinosaurian egg-shells (Argañaraz et al., 2013), vertebrate and invertebrate burrows (Perez et al., 2013a,b), mammal-like footprints (Perez et al., 2013b), and cupressaceae (Brea et al., 2016; Nunes et al., 2019) and angiosperm woods (Nunes et al., 2018).

In spite of its rich fossil record, the Chubut Group has two longstanding problems that hampers a comprehensive analysis of its fauna: 1) a poorly defined lithostratigraphy, including nomenclatural differences between adjacent geological map sheets, which complicates the correlation of fossiliferous horizons, and 2) a lack of absolute age constraints, which preclude a full understanding of the significance of its vertebrate fauna in relation to the geologic time scale and within the context of the Cretaceous South American Gondwanan faunal assemblages.

The aim of this paper is to constrain the chronostratigraphy of the predominantly alluvial/tuffaceous Cerro Barcino Formation and to critically review the significance and phylogenetic affinities of its fossil vertebrate fauna within the context of the evolutionary history of each group in the Cretaceous of Gondwana. Here we present new stratigraphic and sedimentologic observations combined with high-precision U-Pb geochronologic data from 11 key outcrops of the fossil-rich Cerro Barcino Formation of the Chubut Group throughout the Somuncurá-Cañadón Asfalto Basin. These data highly improve the basin-wide correlation of the Cerro Barcino Formation and its members, provide new insights into their depositional history and establish a robust chronostratigraphic framework, in which their fossil record can be interrogated. Our integrated approach allows a critical review of the significance and taxonomic affinities of the Cerro Barcino vertebrate fauna within the context of the evolutionary history of each group and in connection to other "mid-Cretaceous" assemblages previously proposed by Leanza et al. (2004). This further constrains in space and time the establishment of the "mid-Cretaceous" vertebrate fauna in Patagonia (Novas, 2009).

2. Geological setting and stratigraphy

This study encompasses an area of approximately 1500 km^2 in the north-central part of Chubut Province (Fig. 1A–C), extending from the eastern portion of the Paso de Indios (Silva Nieto et al., 2005) and the western portion of the Los Altares (Anselmi et al., 2004) to the northern area of the El Sombrero (Anselmi et al., 2000) geological maps. Fig. 2 illustrates the stratigraphic subdivisions of the Chubut Group adapted in this contribution. The studied units are those mapped as the Puesto La Paloma, Cerro Castaño, Bayo Overo and the Las Plumas members of the Cerro Barcino Formation as part of the upper Chubut Group. The first two members are mostly exposed in the western-central part of the study area between the Valle General Racedo and the Chubut river (Fig. 1C), which includes the localities Puesto Limonao, Estancia La Juanita, Turtle Town-Estancia La Madrugada, Puesto Mesa-Cerro León, Cerro Los Chivos, Puesto Huanimán, and Tres Cerros, herein grouped under "western localities" (Fig. 1C). The Puesto Limonao section also exposes the uppermost Los Adobes Formation (Bardas Coloradas Member) of the basal Chubut Group. The Bayo Overo Member is exposed in the "eastern localities", Estancia El Dinosaurio and Chubutisaurus (Fig. 1C). Two "southern localities" of Estancia La Flecha and Sierra del Guanaco Oeste expose the overlying Las Plumas Member. Various stratigraphic schemes have been proposed for the Chubut Group by workers focused on different regions (see Supplementary materials). Following Silva Nieto et al. (2017), we consider the Bayo Overo Member an undifferentiated correlative of the Puesto La Paloma and Cerro Castaño members that crops out in the eastern areas of the Somuncurá-Cañadón Asfalto Basin. The focus of this research has been stratigraphic sections of the predominantly alluvial/tuffaceous Cerro Barcino Formation containing fossil vertebrates, where lithostratigraphic units previously mapped as the Puesto La Paloma, the Cerro Castaño and the Las Plumas members can be recognized. We thus refer to the Bayo Overo Member only in the Eastern localities (Chubutisaurus and El Dinosaurio) where the latter three members cannot be easily differentiated in the outcrop.

The Chubut Group is a continental succession of alluvial/fluvial and lacustrine deposits with frequent pyroclastic input, which ranges in thickness from hundreds to thousands of meters. It is characterized by laterally extensive outcrops in both the Somuncurá-Cañadón Asfalto and the San Jorge basins of the Chubut Province in the Argentine Patagonia (Lesta, 1968; Lesta and Ferello, 1972; Chebli et al., 1976; Codignotto et al., 1978; Sciutto, 1981; Proserpio, 1987; Figari and Courtade, 1993; Cortiñas, 1996; Figari, 2011; Ranalli et al., 2011; Sylwan et al., 2011; Allard et al., 2015; Figari et al., 2015). The exact tectonic setting of the Chubut Group deposits has been a matter of debate (e.g., Barcat et al., 1989; Fitzgerald et al., 1990), but the most recent interpretations

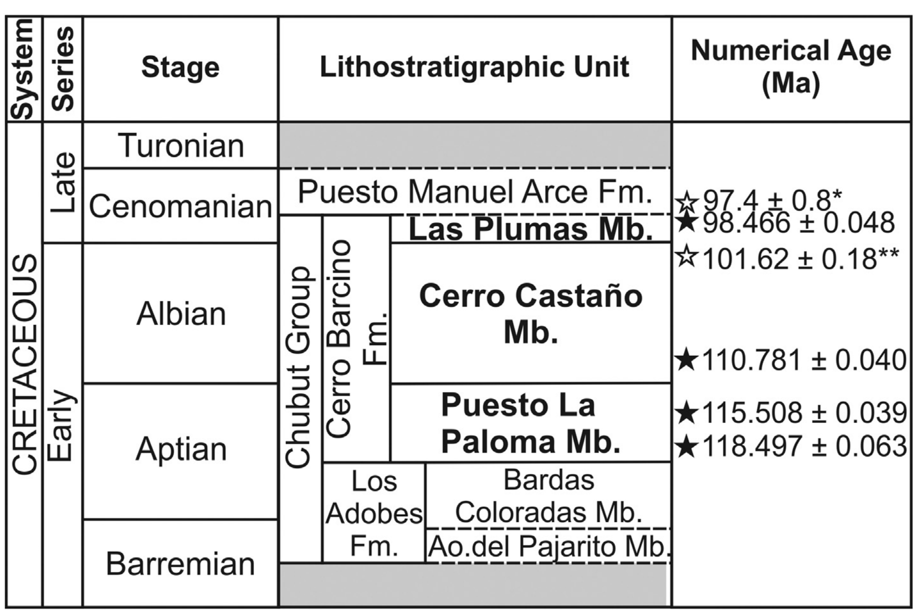

Fig. 2. Calibrated chronostratigraphy of the Chubut Group in the study area based on U-Pb ages of this study (solid stars) and previously published data (open stars). The Bayo Overo Member is considered correlative of the Puesto La Paloma and Cerro Castaño members, following Silva Nieto et al. (2017). *Suárez et al. (2014); **Carballido et al. (2017). Dashed lines correspond to boundaries with uncertain ages; shading signifies depositional hiatus.

involve a Cretaceous episode of Andean arc expansion and foreland basin formation, possibly by synorogenic reactivation of older (Jurassic) structures (Gianni et al., 2015; Echaurren et al., 2016).

In the Somuncurá-Cañadón Asfalto Basin, the Chubut Group is commonly underlain by an irregular paleo-relief surface of predominantly Lower Jurassic volcanic rocks (Musacchio and Chebli, 1975; Codignotto et al., 1978) and, locally, continental sedimentary beds (e.g., Cañadón Calcáreo Formation) with Late Jurassic radioisotopic ages (Cúneo et al., 2013), as well as by units assigned to the lower Cretaceous (Volkheimer et al., 2009) (see also Hauser et al., 2017 for details). The studied Cretaceous succession is covered by various Paleogene–Quaternary, continental and marine successions (Musacchio and Chebli, 1975), or by Cenozoic basalts (Ardolino and Franchi, 1993).

The age of the Chubut Group in the Somuncurá-Cañadón Asfalto Basin has been postulated based mainly on paleontological evidence, with only limited radioisotopic data available from the unit. Codignotto et al. (1978) suggested a Barremian–Cenomanian age for the Chubut Group based on previous paleontological results (e.g., Chebli et al., 1976; Musacchio and Chebli, 1975; Musacchio, 1995). Palynological data obtained at Cerro Solo (~ 20 km to the south of Puesto Huanimán; Fig. 1C) from the Arroyo del Pajarito Member (Los Adobes Formation), suggested a late Aptian to early Albian age for the lowermost unit of the Chubut Group (Llorens and Marveggio, 2009; Marveggio and Llorens, 2011, 2013). Charophyte (Musacchio, 1972, 1995; De Sosa Tomas et al., 2017) and ostracod (Musacchio and Chebli, 1975; Musacchio, 1995) associations recovered near Paso de Indios (Fig. 1C), suggested an Aptian to early Albian age for lower Cerro Barcino Formation, including both Puesto La Paloma and Cerro Castaño members.

The sparse radioisotopic dates from the Chubut Group have generally lacked sufficient stratigraphic context or geographic extent. Bridge et al. (2000) reported $^{40}Ar/^{39}Ar$ dates from tuffs and ignimbrites of the Chubut Group (Castillo, Bajo Barreal and Laguna Palacios formations) in the San Jorge Basin that ranged from 104.8 Ma to 85.1 Ma (Albian–Santonian), but no analytical methods or supporting isotopic data were presented. The majority of modern U-Pb geochronology cited herein has been carried out on detrital zircons from (tuffaceous) sedimentary beds by in situ techniques such as secondary ion mass spectrometry (SIMS) or laser ablation-inductively coupled plasma mass spectrometry (LA-ICPMS). Recent SIMS U-Pb zircon geochronology from the upper Chubut Group by Suárez et al. (2014) produced a weighted mean $^{206}Pb/^{238}U$ date of 97.4 $\pm$ 1.6 Ma (2σ internal error) from a vitric lapilli tuff of the Puesto Manuel Arce Member collected from eastern Sierra del Guanaco, about 13 km to the ESE of our western Sierra del Guanaco locality (Fig. 1C). A detrital zircon provenance study of the Chubut Group fluvial sandstones in the vicinity of Telsen to the northeast of the Somuncurá-Cañadón Asfalto Basin by Navarro et al. (2015) produced maximum depositional ages of 109 $\pm$ 1 Ma and 106 $\pm$ 1 Ma. The only published high-precision U-Pb ID-TIMS zircon date from the Chubut group known to us is from the uppermost section of the Cerro Castaño Member at the Estancia La Flecha locality (Figs. 1C and 3), where the giant titanosaur *Patagotitan mayorum* was discovered. This weighted mean $^{206}Pb/^{238}U$ date of 101.62 $\pm$ 0.18 Ma (2σ total uncertainty; Carballido et al., 2017) from a tuffaceous siltstone serves as an Albian (or younger) age constraint for the top of the Cerro Castaño Member in the southern Somuncurá-Cañadón Asfalto Basin.

3. Methods

3.1. Sedimentary sections and sampling

In order to establish a chronostratigraphic framework for the Chubut Group and its fossil record, 11 stratigraphic sections were measured: The Tres Cerros, Puesto Huanimán, Cerro Los Chivos, Puesto Mesa/Cerro León, Puesto Limonao, Turtle Town/Estancia La Madrugada, and Estancia La Juanita as part of the western localities; Estancia El Dinosaurio and *Chubutisaurus* of the eastern localities; and Estancia La Flecha and the Sierra del Guanaco Oeste representing the southern localities. The western localities expose the Puesto La Paloma and Cerro Castaño members and the correlative Bayo Overo Member outcrop in the eastern localities, while the overlying Las Plumas Member is exposed in the southern localities (Figs. 1, 2, 3 and 4A–I). Stratigraphic and sedimentological measurements were made with the aid of a Jacob's staff and global positioning system (GPS) and included lithology, mean grain size, sedimentary structures, bounding surfaces, bed geometry, and pedogenic features. Initial correlations were made using regional facies associations defining stratigraphic intervals, lithostratigraphic contacts, and a prominent white tuffaceous marker bed within the Cerro Castaño Member (Umazano et al., 2017). Tuff samples were collected for radioisotopic dating from sections at the Puesto Limonao, Cerro Los Chivos, Puesto Huanimán and the Sierra del Guanaco Oeste (Fig. 1C).

Several of the measured sections, as well as the paleontological material referred to herein, have been previously analyzed in detail and published elsewhere (e.g., Rauhut et al., 2003; Novas et al., 2005; Leardi and Pol, 2009; Genise et al., 2010; Carballido et al., 2011; de la Fuente et al., 2011; Argañaraz et al., 2013; Sterli et al., 2015; Carmona et al., 2016). In addition, Umazano et al. (2017) provide a detailed sedimentary analysis of most of the sections stated here.

3.2. U-Pb geochronology

Four samples of tuff (tuffaceous sand to mud/siltstone) were collected from stratigraphically well-constrained outcrops of the Cerro Barcino Formation and one sample from the Los Adobes Formation for U-Pb geochronology by the chemical abrasion isotope dilution thermal ionization mass spectrometry (CA-ID-TIMS) method, following the procedures described in Ramezani et al. (2011). These include tuffaceous beds from the lower Puesto La Paloma Member at Puesto Limonao (LF022616-2; ~8.4 m above the contact with the underlying Los Adobes Formation), from the upper Puesto La Paloma Member at Cerro Los Chivos (ULPCh; ~4 m below the contact with the overlying Cerro Castaño member), from the middle Cerro Castaño Member at Puesto Huanimán (MCCHm; ~25 m above the base of the Cerro Castaño Member), and from the lower Las Plumas Member at Sierra del Guanaco Oeste (~28 m above the top of the Cerro Castaño Member).

Details of U-Pb analytical procedures, data reduction, date calculation and age interpretation, as well as complete isotopic data are given in the Supplementary materials (Table S1). The calculated weighted mean $^{206}Pb/^{238}U$ dates along with their detailed uncertainties are presented in Table 1 and the date distribution plots of Fig. 5. Date uncertainties throughout the text are reported at 95% confidence level and follow the notation $\pm X/Y/Z$ Ma, where X is the internal (analytical) uncertainty in the absence of all external errors, Y incorporates X in addition to the U-Pb tracer calibration error and Z includes the latter as well as the U decay constant errors of Jaffey et al. (1971). Tracer calibration uncertainties (Y) must be taken into account for comparison between U-Pb age data produced by different techniques (e.g., ID-TIMS versus SIMS). The Cretaceous subdivisions of GTS2012 (Ogg and Hinnov, 2012) and ICS (Cohen et al., 2013) are followed in this paper.

4. Results

Unambiguous correlation of fluvial strata across a wide geographic area is inherently difficult due to well-documented lenticular and repetitive nature of fluvial facies, as well as lateral discontinuity of fluvial units (e.g., Miall, 1983). A similar problem exists with the recognition of various members of the Cerro Barcino Formation and their stratigraphic and geographic extents across the Somuncurá-Cañadón Asfalto Basin. This is indeed evident in inconsistencies in lithostratigraphic subdivisions among adjacent geological maps of the area (e.g., Proserpio, 1987; Anselmi et al., 2000, 2004; Silva Nieto et al., 2005). This research is aimed at constructing a regional stratigraphic framework based on detailed examination of sedimentary facies and associated fossil

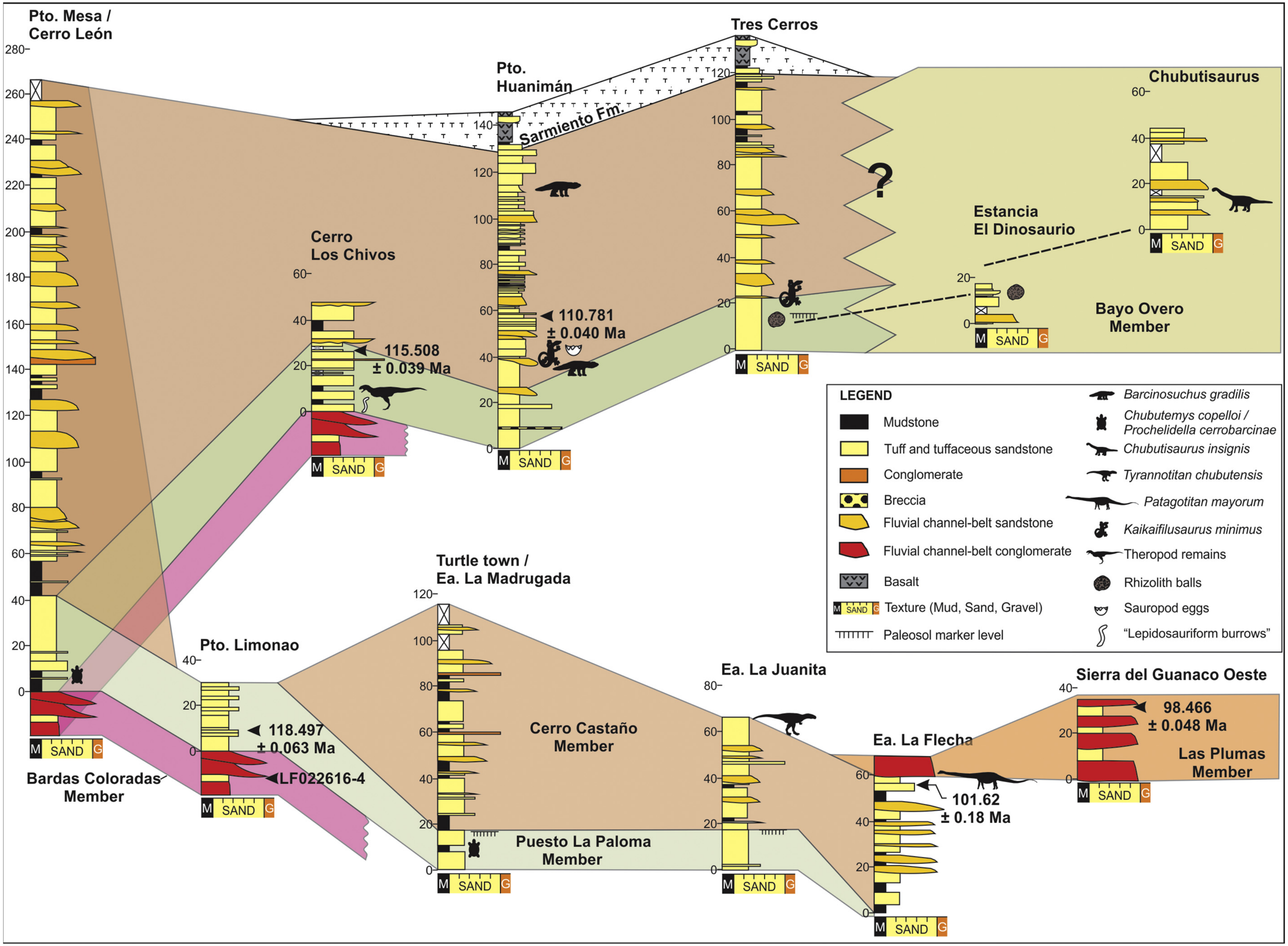

Fig. 3. Stratigraphic columns of the investigated Chubut Group successions, showing horizons corresponding to fossil discoveries (silhouettes) and dated tuff layers (arrows). The stratigraphic relationship between Chubutisaurus and Estancia El Dinosaurio sections is based on bed-level correlation along ~4 km of outcrops, whereas the lateral equivalence between the Puesto La Paloma/Cerro Castaño and the Bayo Overo members is proposed based on correlation of rhizolith-bearing strata. Stratigraphy and age of the Cerro Castaño Member in Estancia La Flecha locality are respectively based on Carmona et al. (2016) and Carballido et al. (2017). Age of sample LF022616-4 is discussed in the Supplementary materials. Ea. – Estancia; Pto. – Puesto.

Fig. 4. Outcrop photos of the Cerro Barcino Formation. A – The Puesto La Paloma (PLP) and Cerro Castaño (CC) members' boundary strata at Estancia La Juanita section. B – Cerro Castaño Member at Puesto Huaniman showing the lower tuff marker bed (LTMB). C – Puesto La Paloma and Cerro Castaño members and their boundary at Tres Cerros. D – Rhizolith ball near the contact between the Puesto La Paloma and the Cerro Castaño members at Tres Cerros locality (see Genise et al., 2010 for comparison). E – Three-order rhizolith system at the top of the Puesto La Paloma Member at Puesto Mesa-Cerro León locality. Unfolded portion of measuring tape is 10 cm long. F – General aspects of the paleosol marker near the Puesto La Paloma-Cerro Castaño boundary at Tres Cerros locality. Thickness of purple mottled horizon is ~50 cm. G – Bayo Overo Member in the vicinity of the Chubutisaurus locality. The human scale (circled) is 1.8 m tall. H – Las Plumas Member in the Sierra del Guanaco Oeste section. Dated tuff location marked by red rectangle. I – Dated tuff layer underneath a 1.5 m-thick conglomerate of the Las Plumas Member. Hammer scale is 33 cm long. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

contents at each selected section in order to resolve the outstanding correlation inconsistencies. High-precision U-Pb ash bed geochronology is an essential tool in examining the validity of correlations that underpin the new stratigraphic framework and unravelling the detailed depositional history of the Chubut Group. Main stratigraphic and sedimentologic characteristics of the studied localities, as well as the results of U-Pb geochronologic analyses, are provided in the following sections (Figs. 1–6).

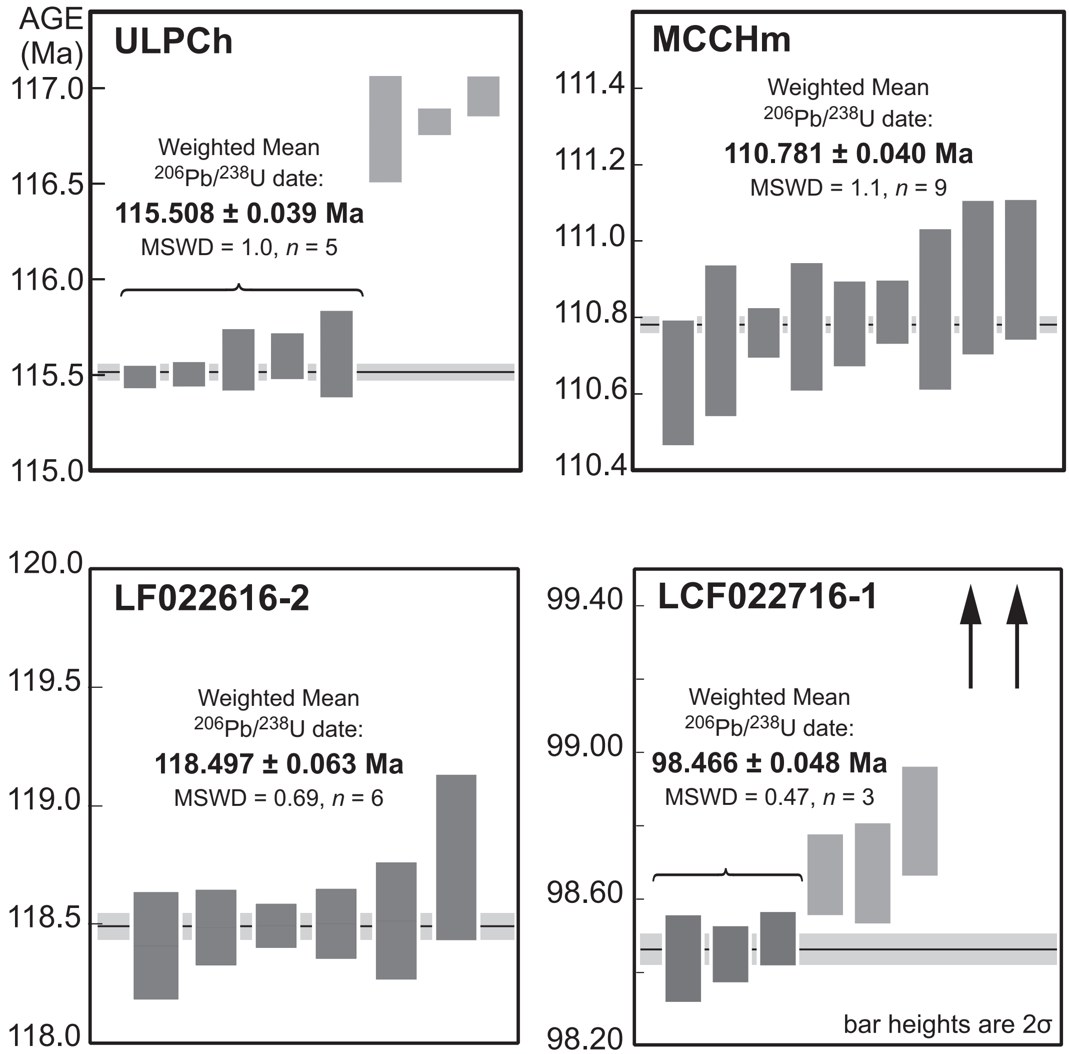

Fig. 5. Date distribution plot of analyzed zircons from the tuff beds of the Cerro Barcino Formation. Bar heights are proportional to 2σ analytical uncertainty of individual zircon dates; solid bars are analyses used in age calculation. Horizontal lines and shaded bands signify the calculated weighted mean dates and their uncertainty at 95% confidence level, respectively. Arrows point to older (detrital) analyses that plot outside the diagram. See Supplementary materials Table S1 for complete U-Pb data and Table 1 for the details of calculated dates and their uncertainties.

4.1. Western localities

4.1.1. Tres Cerros

The Puesto La Paloma Member (23 m thick), with an unexposed base, consists by sheet-like, fine-grained, tuffaceous sandstones (Figs. 3 and 4C). The beds are usually massive, but occasionally plane-parallel lamination can be recorded. This section is interpreted as the record of volcaniclastic non-channelized fluvial systems (Umazano and Krause, 2013; Umazano et al., 2014, 2017). Upward the Puesto La Paloma Member, a series of stacked hydromorphic paleosols, characterized by root

Table 1
Summary of calculated U-Pb ages and their uncertainties.

Sample	Location	Member	Latitude (S)	Longitude (W)	$\frac{^{206}Pb}{^{238}U}$ age	Uncertainty (2σ)			MSWD	*n*
						X	*Y*	*Z*		
LCF022716-1	La Coste Farm	Las Plumas	44°03′6.87″	68°05′5.61″	98.466	0.048	0.056	0.12	0.47	3
MCCHm	Huanimán	Cerro Castaño	43°08′26.77″	68°43′18.58″	110.781	0.040	0.067	0.14	1.1	9
ULPCh	Los Chivos	Puesto La Paloma	43°13′12.42″	68°50′36.84″	115.508	0.039	0.066	0.14	1.0	5
LF022616-2	Limonao Farm	Puesto La Paloma	43°21′18.85″	69°07′25.20″	118.497	0.063	0.095	0.16	0.69	6

Notes:
Latitude/longitude relative to WGS84 datum.
X: internal (analytical) uncertainty in the absence of all external or systematic errors.
Y: incorporates the U-Pb tracer calibration error.
Z: includes *X* and *Y*, as well as the uranium decay constant errors.
MSWD: mean square of weighted deviates.
n: number of analyses included in the calculated weighted mean date.

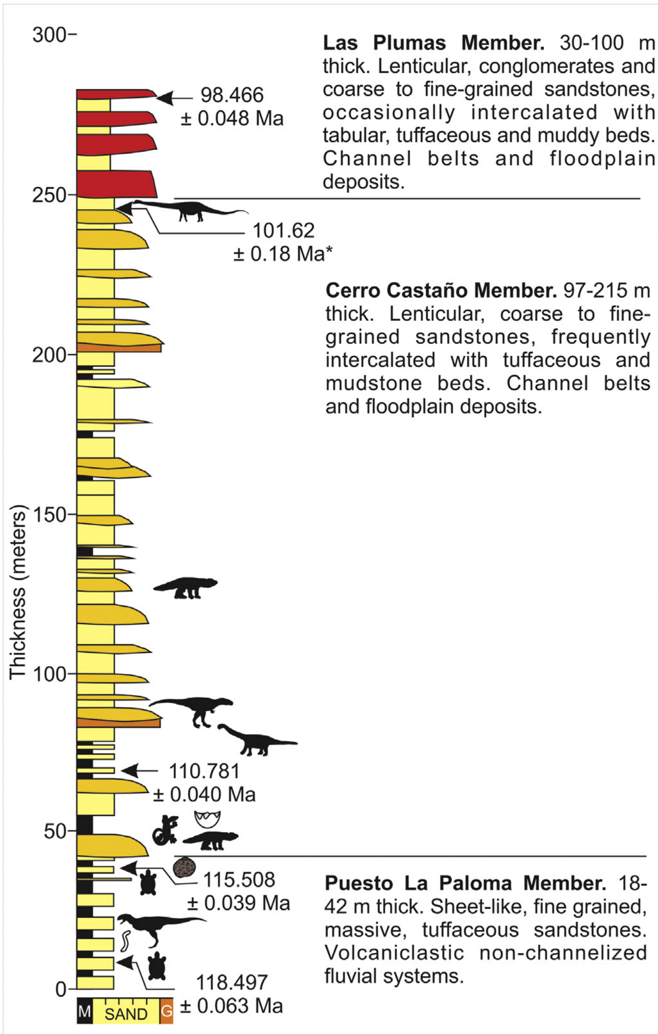

Fig. 6. Composite stratigraphic column and depositional facies of the Puesto La Paloma and Cerro Castaño members, showing stratigraphic position of vertebrate remains, trace fossils and dated tuff layers. *Carballido et al. (2017). For references see Fig. 3.

traces, burrows, mottles and rhizolith balls, have been recognized (Krause et al., 2014a) (Fig. 4D and F).

The Cerro Castaño Member (97 m thick), with an erosional upper contact, comprises lenticular, coarse- to fine-grained sandstones that are frequently intercalated with tabular, tuffaceous strata (Fig. 3). The lenticular bodies display a fining-upward trend and exhibit erosive bases commonly covered by stratified breccias, which pass upward to cross-bedded and rippled sandstones. The tabular beds are constituted, in decreasing order of abundance, by tuffaceous sandstones, tuffaceous mudstones, tuffs, sands and, very rarely, conglomerates. Most of these strata are massive, and occasionally show plane-parallel or ripple lamination, cross-beddings along with root and invertebrate trace fossils. Fossil vertebrate remains recorded at this locality (*Kaikaifilusaurus minimus* Apesteguía and Carballido, 2014) are included in the tuffaceous beds, occurring about 3 m above the contact Puesto La Paloma-Cerro Castaño members. Within a fluvial paleoenvironment scheme, the lenticular sandstone bodies represent low-sinuosity, perennial channel-belts and the tuffaceous beds with paleosols and trace fossils represent a floodplain setting with sheet-flood and shallow lacustrine deposits (Umazano and Krause, 2013; Umazano et al., 2014, 2017).

4.1.2. Puesto Huanimán

This section exposes a ~100 m-thick succession of the Cerro Castaño Member underlain by strata of the Puesto La Paloma Member. The Cerro Castaño Member unconformably underlies the Oligocene Sarmiento Formation (Fig. 3). The Puesto La Paloma Member is ~33 m thick, with an unexposed base, and composed of fine-grained sandstones or tuffaceous sandstones sheets, in alternation with fine-grained, massive tuffs and stratified breccias (Figs. 3 and 4B). The sandstones display two major facies: i) tangential or low-angle cross-bedded sands of aeolian dune origin showing large vertebrate footprints (Perez et al., 2013b; Umazano et al., 2014, 2017); ii) massive sands with rare intercalations of trough cross-bedding or ripples, which suggest unconfined fluvial flows of volcaniclastic origin (Umazano et al., 2014, 2017). In this paleoenvironmental context, the breccias are interpreted as related to the non-channel fluvial systems; while massive tuffs are assigned to ash-fall deposits (Umazano et al., 2014, 2017).

The Cerro Castaño Member is mainly composed of lenticular, fine- to coarse-grained sandstones and tabular tuffaceous, fine- to medium-grained sandstones, and subordinate tuffs and mudstones (Figs. 3 and 4B). The lower Cerro Castaño Member has produced remains of the peirosaurid crocodilian *Barcinosuchus gradilis* Leardi and Pol, 2009, a sphenodontid identified as *Kaikaifilusaurus minimus* (Apesteguía and Carballido, 2014) and sauropod eggs (Argañaraz et al., 2013), most of them occurring in a 7–12 m-thick interval above the base of the Cerro Castaño Member. The depositional paleoenvironment was fluvial and included main channel belts, levees, subsidiary channels and a distal floodplain (Argañaraz et al., 2013). The abundance of tuffaceous material suggests a high volcanic influx during sedimentation.

A prominent white tuff in the lower Cerro Castaño Member forms a regional marker bed that can be followed throughout the region (Umazano et al., 2017). Our new U-Pb date of 110.781 ± 0.040/0.067/0.14 Ma from this tuff indicates that the Cerro Castaño Member is predominantly post-Aptian in age.

4.1.3. Cerro Los Chivos

This section is similar to that studied by Rauhut et al. (2003) and referred to as "Cerro Chivo". However, what has been conventionally mapped as Cerro Chivo (e.g., Proserpio, 1987; Anselmi et al., 2004) is located around 25 km ESE from our section (see mid-central area in Fig. 1C). Cerro Los Chivos exposes a complete succession of the Puesto La Paloma Member up to 31 m-thick (Fig. 3), overlain by the Cerro Castaño Member (not studied in detail here). The former consists predominantly of sheet-like, tuffaceous strata, interpreted as fluvio-aeolian deposits (Villegas et al., 2014). In this context, the massive tuffaceous sandstones and the laminated tuffaceous mudstones of the Puesto La Paloma Member represent proximal and distal deposits, respectively, of unconfined volcaniclastic sheet-floods. Subordinate planar-tabular, cross-bedded, tuffaceous sandstones attributed to aeolian dunes, and laminated tuffs interpreted as sub-aerial ash-falls, are present. From the lower section, several vertebrate burrows probably excavated by lepidosauriform reptiles were recovered (Perez et al., 2013a). From the northern flank of Cerro Los Chivos, at El Jujeño locality, theropod remains were recovered from the lower Puesto La Paloma Member, around 9 m above the Bardas Coloradas Member (Rauhut et al., 2003: fig. 2) (Fig. 3).

The Cerro Castaño Member at Cerro Los Chivos is >150 m thick and is intruded by a volcanic neck and several magmatic dikes (Proserpio, 1987). Typically, there is an alternation of sandstone-dominated channel bodies with tractive structures, and commonly massive, tabular, tuffaceous sandy and muddy beds, deposited within a fluvial depositional system. The new U-Pb date of 115.508 ± 0.039\0.066\0.14 Ma from a tuff ~4 m below the Puesto La Paloma – Cerro Castaño member boundary approximates the lower age limit of the Puesto La Paloma Member.

4.1.4. Puesto Mesa-Cerro León

This section is equivalent to those named as "Los Chivos Hill section" in de la Fuente et al. (2011) and is renamed according a more specific location and for distinguishing for the "Cerro Chivo section" from the same area (Rauhut et al., 2003).

The Puesto La Paloma Member (42 m thick), overlying to the Bardas Coloradas Member, is composed of sheet-like, fine to medium-grained tuffaceous sandstones bearing frequent fossil tree trunks, along with subordinate tuffs, tuffaceous mudstones and limestones (Fig. 3). The 7.20 m thick lower section comprises tuffaceous mudstone strata with a silicified limestone intercalation near the top, with remains of the chelid turtle *Prochelidella cerrobarcinae* (de la Fuente et al., 2011) (Fig. 3). The mudstone beds are usually massive in their lower parts, but plane-parallel lamination or ripples can be recognized upward the beds. Three-order rhizolith systems were recognized in the laminated facies (Fig. 4E). Above of 2 m covered, there is a 4.5 m thick middle section composed of tuffaceous sandstones with planar tabular cross-bedding at the base, and low-angle cross-bedding with reverse intralamina grading. The upper section is mainly composed of massive or plane-parallel laminated tuffaceous sandstones; with very scarce intercalations of massive tuffs. Whereas the lower section would represent shallow lakes, the middle and upper sections would record aeolian dune sedimentation and unconfined fluvial systems affected by explosive volcanism respectively (Umazano, 2010; de la Fuente et al., 2011; Umazano and Krause, 2013; Umazano et al., 2014, 2017).

The Cerro Castaño Member (215 m thick), with an erosional upper contact, is mainly composed of lenticular, coarse to fine-grained sandstones interbedded with sheet-like, tuffaceous strata (Fig. 3). The lenticular bodies show the same fining-upward trend and basal contact features as in those channeled beds at Tres Cerros section, although without rippled sandy facies on top. Occasionally, lenses of cross-bedded conglomerates and laminated or massive tuffaceous mudstones can be recognized within the lenticular sandstone beds. On the other hand, the sheet-like strata also show similar features as those observed in the Tres Cerros section. The lenticular, sandstone bodies record permanent fluvial channel-belts and the sheet-like strata represent floodplain deposits (Umazano et al., 2012, 2014, 2017; Umazano and Krause, 2013).

4.1.5. Puesto Limonao

The exposed Puesto La Paloma Member is 30 m-thick and is underlain by the Bardas Coloradas Member of the Los Adobes Formation (Fig. 3). The lower (8.1 m) and the upper (14 m) sections of the Puesto La Paloma Member show similar sedimentological features. Both sections consist of massive, fine to medium-grained, (tuffaceous) sandstones. The middle section, which is 7.6 m-thick, mostly consists of fine to medium-grained tuffs with massive aspects or plane parallel lamination. There are decimetric intercalations of fine-grained sandstones with ripples. The sedimentological features from both lower and upper sections are compatible with unconfined current flows with pyroclastic influx, which agree with the regional paleoenvironmental scenario interpreted for this unit (Umazano et al., 2017). The middle section mostly records volcanic ash-falls and scarce fluvial reworking by current flows. The top of the Puesto La Paloma Member at this locality has been eroded and covered with quaternary deposits.

Our new weighted mean U-Pb date of 118.497 $\pm$ 0.063/0.095/0.16 Ma from a tuff bed near the base of the Puesto La Paloma Member at Puesto Limonao (see Supplementary Data) places an unequivocal Aptian upper age limit on the Cerro Barcino Formation. The contact between the latter and the underlying Los Adobes Formation at Puesto Limonao appears conformable and marked by a ~2 m-thick, pebble-rich, brown sandstone. This suggests a possible Aptian age for the upper Los Adobes Formation, as well.

4.1.6. Turtle Town-Estancia La Madrugada

The Puesto La Paloma Member (17 m thick), with an unexposed base, contains sheet-like strata composed of massive and laminated, fine-grained tuffaceous sandstones, and tuffs with accretionary lapilli (Fig. 3). The middle section bears chelid (Gaffney et al., 2007) and meiolaniform (*Chubutemys copelloi* Gaffney et al., 2007; Sterli et al., 2015) turtles, at approximately 9.5 m below the contact Puesto La Paloma-Cerro Castaño members. The lower and upper sections would represent ash falls and unconfined current flows with pyroclastic influx respectively; while the middle section suggest ponded areas (Umazano, 2010; Umazano and Krause, 2013; Umazano et al., 2014, 2017; Sterli et al., 2015). A sequence of strongly-developed hydromorphic paleosols was recognized in the contact between the Puesto La Paloma and Cerro Castaño members in this locality and in other two, suggesting a lapse of increased landscape stability and negligible sedimentation before the establishment of a channelized fluvial system (Umazano et al., 2017).

The Cerro Castaño Member (98 m thick), with eroded top, includes in this area, lenticular, coarse to fine-grained sandstones enclosed by sheet-like, tuffaceous strata (Fig. 3). The lenticular bodies exhibit a roughly similar fill to those outcropping at Tres Cerros section, although highly bioturbated basal surfaces can be occasionally present. The sheet-like, tuffaceous strata are similar to those described from previous localities and would record floodplain deposits (Umazano et al., 2012, 2014, 2017; Umazano and Krause, 2013). The lenticular bodies represent channeled, perennial fluvial belts, although the occurrence of highly bioturbated basal surfaces suggests important fluctuations in water discharge (Umazano et al., 2012, 2014, 2017; Umazano and Krause, 2013).

4.1.7. Estancia La Juanita

The Puesto La Paloma Member (18 m thick), with an unexposed base, consists of sheet-like strata commonly composed of fine-grained tuffaceous sandstones with paleosols bearing root traces (Figs. 3 and 4A). The beds are usually unstructured or, less frequently, show plane-parallel lamination or cross-bedding. As in previous cases for equivalent deposits, this succession is interpreted as volcaniclastic unconfined fluvial systems (Umazano, 2010; Umazano and Krause, 2013; Umazano et al., 2014, 2017). A sequence of strongly-developed, hydromorphic paleosols locate within the upper Puesto La Paloma Member (Krause et al., 2014a,b) (Fig. 3).

The Cerro Castaño Member (50 m thick), with an erosional upper contact, is composed of medium to fine-grained sandstone bodies with channeled geometry, which are interbedded with sheet-like tuffaceous strata (Fig. 3). Both channeled and sheet-like bodies are similar to those described from the preceding locality (Fig. 3). There are two fossil-bearing, massive tuffaceous sandstones, located in the upper section, approximately 43 m and 48 m above the Puesto La Paloma-Cerro Castaño boundary, from where two specimens of the carcharodontosaurid theropod *Tyrannotitan chubutensis* Novas et al., 2005 were recovered. The channeled bodies and sheet-like strata were probably deposited in fluvial channel-belts and floodplains, respectively (Umazano et al., 2012, 2014, 2017; Umazano and Krause, 2013).

4.2. Eastern localities

4.2.1. Estancia El Dinosaurio

The succession includes the middle section of the Bayo Overo Member (16 m thick), and is a fining upward one. This is composed of coarse- to very fine-grained sandstones in the lower section, and tuffs and mudstones in the upper (Genise et al., 2010) (Fig. 3). This succession is tentatively correlated to the upper Puesto La Paloma Member (Fig. 3). The lower includes lenticular, coarse-grained, trough cross-bedded sandstones with erosive base, and tabular, fine-grained, laminated or massive sandstones containing rhizoliths and burrows. Calcareous, pedogenic horizons are common within this member. The upper section is composed of thinner and tabular beds of fine- to very fine-grained tuffs and mudstones with plane-parallel lamination, burrows and calcareous concretions. Between two sections, a complete profile of a paleosol occurs, which contains abundant calcareous rhizolith balls (Genise et al., 2010). This succession originated in a fluvial system, including floodplain and channel belts, with a significant pyroclastic supply. The tuffaceous paleosol (Andisols) containing the rhizolith balls suggest periods of non-deposition in the floodplain (Genise et al., 2010).

4.2.2. Chubutisaurus

The exposed succession belongs to the Bayo Overo Member and has 42 m thick (middle section). This section is tentatively correlated to the upper Puesto La Paloma Member or alternatively to the lower Cerro Castaño Member (Fig. 3). It is composed of sandstones, tuffaceous sandstones and conglomerates (Figs. 3, 4G). The section includes lenticular, normally graded, trough cross-bedded conglomerates and sandstones with intraformational clasts, interpreted as fluvial channel belt deposits. In some cases, epsilon cross-bedded strata are present, suggesting high sinuosity channels with attached margin bars. From one of these bodies, in the lower part, theropod teeth (del Corro, 1966) and dinosaur bones (*Chubutisaurus insignis* del Corro, 1975) were recovered along with fragmented plant remains. Alternating between lenticular deposits and tabular strata of fine to medium-grained, there are tuffaceous sandstone beds with plane-parallel lamination. Subordinately, there are medium-grained, massive sandy beds containing pedogenic features (e.g. carbonate nodules, root traces, mottles, burrows). These beds are interpreted as developed in floodplain settings.

4.3. Southern localities

4.3.1. Estancia La Flecha

This section exposes a 60 m-thick succession of the Cerro Castaño Member, overlain by the lower (<10 m) conglomerates of the Las Plumas Member (Fig. 3). The former consists of an intercalation of sandy mudstones, tuffaceous sandstones and fluvial channel sandstones, interbedded with tuffs. The sedimentary facies suggest a floodplain setting with meandering channels (Carmona et al., 2016). The fossil-rich horizons of the upper Cerro Castaño Member at this section, known as the La Flecha Quarry, are where the remains of the titanosaur *Patagotitan mayorum* (Carballido et al., 2017) were discovered. In stratigraphic equivalent beds Nunes et al. (2018, 2019) described the oldest record of an angiosperm tree found in South America.

Carballido et al. (2017) reported a U-Pb CA-ID-TIMS zircon age of 101.62 ± 0.11/0.14/0.18 Ma from a tuffaceous siltstone from the La Flecha Quarry about 4.5 m below the base of the Las Plumas Member. This date along with our new U-Pb date from Cerro Los Chivos (see Section 4.1.3) suggest that the bulk of the Cerro Castaño Member and its fossil contents are Albian in age.

4.3.2. Sierra del Guanaco Oeste

The Las Plumas Member of the Cerro Barcino Formation crops out in this section with an exposed thickness of ~35 m on the east side of Provincial Route 27 (Figs. 1C, 4H–I). The member consists of maroon, polymictic conglomerates, sandstones and minor tuffs with prominent graded bedding that occur in distinct, fining-upward cycles which indicate a high-energy fluvial channel depositional setting. Nearby exposures indicate that the unit is immediately underlain by strata of the Cerro Castaño Member, although the contact is not exposed at the roadside section.

Our new U-Pb zircon date of 98.466 ± 0.048/0.056/0.12 Ma from a tuff located ~28 m above the base of the Las Plumas Member (Fig. 4H–I) suggests that this unit is for the most part Cenomanian (or younger) in age. The latter age is stratigraphically consistent with the previously reported U-Pb date of Carballido et al. (2017) from the uppermost Cerro Castaño Member at the nearby La Flecha section (see Section 4.3.1). The combined ages places the Cerro Castaño–Las Plumas member boundary in the southern region approximately at the Albian-Cenomanian boundary.

5. Discussion

5.1. Age of the Cerro Barcino Formation and its regional correlation

The revised stratigraphic correlation schemes that form the basis of our new chronostratigraphic framework for the Cerro Barcino Formation in the Somuncurá-Cañadón Asfalto Basin have been described in the Supplementary materials. Our set of new high-precision U-Pb zircon dates from tuffs, together with that reported by Carballido et al. (2017), are fully consistent with stratigraphic superposition and provide reliable temporal constraints on the corresponding lithostratigraphic units. Accordingly, the deposition of the Puesto La Paloma Member was essentially limited to the Aptian and its contact with the overlying Cerro Castaño Member roughly coincides with the Aptian-Albian stage boundary (~113 Ma). Similarly, the Cerro Castaño–Las Plumas members contact approximates the Albian-Cenomanian stage boundary, confining the Cerro Castaño Member largely to the Albian (Fig. 2). An Aptian–early Albian (~118.5–110.8 Ma) age for the combined Puesto La Paloma–Cerro Castaño interval in the west-central Somuncurá-Cañadón Asfalto Basin is consistent with previous biostratigraphic (Musacchio, 1972; Musacchio and Chebli, 1975; De Sosa Tomas et al., 2017) and magnetostratigraphic age estimates (Somoza, 1994; Geuna et al., 2000).

A U-Pb zircon age of 114.67 ± 0.18 Ma (CA-ID-TIMS method) from the Punta del Barco Formation of the Baqueró Group in the Santa Cruz Province to the south (Césari et al., 2011) correlates this unit with the lower fossiliferous interval of the Cerro Castaño Member. The Punta del Barco Formation is important to understanding the Lower Cretaceous flora of South America and reconstructing the paleoecology of Patagonia in that time. Suárez et al. (2014) reported U-Pb zircon dates by the SIMS method from a tuff from the Bajo Barreal Formation of the upper Chubut Group in the San Jorge Basin (Codo del Río Senguerr area). Eighteen out of 20 analyses gave a weighted mean $^{206}Pb/^{238}U$ date of 99.3 ± 1.4 Ma, whereas the youngest 3 analyses gave 93.3 ± 2.8 Ma (Suárez et al., 2014). Since the possibility of significant Pb loss in SIMS zircon analyses cannot be verified or discounted (see Wu et al., 2016), it is not clear which date best represents the depositional age of the Bajo Barreal tuff. The Bajo Barreal Formation and its dinosaur fauna (see Section 5.2) should thus be considered between latest Albian to early Turonian in age and a possible correlative of the Las Plumas and/or the Puesto Manuel Arce Formation. Farther north in the Neuquén Basin, U-Pb dating of detrital zircon (LA-ICPMS method) from the basal Candeleros Formation of the Upper Cretaceous Neuquén Group produced maximum depositional ages as young as 98.6 ± 2.5 Ma (Late Albian-Cenomanian) in southern Mendoza Province, and as old as 104.3 ± 2.5 Ma (Late Albian) in Neuquén Province (Tunik et al., 2010). This indicates a possible correlation with the upper Cerro Castaño and/or the Las Plumas Member of the Cerro Barcino Formation, as well as the Bajo Barreal Formation in the San Jorge Basin. The Candeleros Formation has a rich vertebrate record including diplodocoid sauropods and lepidosauriform reptiles (see Section 5.2).

It will be difficult to predict the age of the onset of Chubut Group deposition in the absence of any direct geochronologic constraints from its basal Los Adobes Formation. This problem is exacerbated by the generally poor calibration of the global Early Cretaceous time scale. Our geochronology from the overlying Puesto La Paloma Member indicates that the Los Adobes Formation has to be older than ~119 Ma, thus early Aptian or older in age.

Our results constrain the age of the Cerro Barcino Formation to a maximum of ~118.5 Ma (or slightly older), thus implying that this unit could be no older than late Aptian. In this sense, the microflora assigned to the underlying Los Adobes Formation (Arroyo del Pajarito Member) and presumed to be late Aptian–early Albian age (Llorens and Marveggio, 2009; Marveggio and Llorens, 2011, 2013) deserve a particular revision. The exact age of the Arroyo del Pajarito Member could have significant implications for the tectonosedimentary development of the Somuncurá-Cañadón Asfalto and adjacent basins.

Finally, our results are consistent with a progression toward younger "mid-Cretaceous" depocenters in the east, where Las Plumas Member and the overlying Puesto Manuel Arce Formation were deposited. This is in agreement with the scheme of Chebli et al. (1976) who based on structural relationships and field evidence postulated that the northern and north-western outcrops are increasingly older than those of the eastern localities.

5.2. Vertebrate fauna of the Cerro Barcino Formation and their paleobiologic implications

Several clades of vertebrates are represented in the rich fossil record of the Cerro Barcino Formation. At present, the documented fossil record of the Formation includes tetanuran (*Tyrannotitan*) and ceratosaurian theropods (abelisaurids, ?*Genyodectes*), non-titanosaur titanosauriform sauropods (*Chubutisaurus*), peirosaurid crocodylliforms (*Barcinosuchus*), eilenodontine sphenodontians (*Kaikaifilusaurus*), and meiolaniform (*Chubutemys copelloi*) and chelid (*Prochelidella cerrobarcinae*) turtles (see below). Except for *Kaikaifilusaurus*, *Patagotitan* and *Tyrannotitan* this assemblage is restricted to a time interval of ~118–110 Ma (Aptian-Albian) recorded in the Puesto La Paloma Member to the lower Cerro Castaño Member in the Somuncurá-Cañadón Asfalto Basin and correlative stratigraphic levels elsewhere (Figs. 3 and 6). A detailed analysis of sedimentary architecture and facies by Umazano et al. (2017) characterized the Puesto La Paloma Member depositional paleoenvironment as a predominantly unconfined flood plain fluvial system with local lacustrine (calcareous) and/or aeolian sedimentation and with strong pedogenic influences. In contrast, the lower part of the Cerro Castaño Member represents a more channelized, meandering, perennial fluvial system with weakly developed hydromorphic paleosols. This change in fluvial style has been attributed to either a reduction in pyroclastic influx or a change from semi-arid, seasonal climate to one of higher humidity and weaker seasonality, or both (Umazano et al., 2017).

Our new chronostratigraphic framework allows the paleobiology and phylogenetic relationships of these fauna to be examined at much higher resolution and in greater detail within both regional and global contexts. The following describes the major tetrapod groups of the Cerro Barcino Formation and their new paleobiologic interpretations based on the results of this study.

5.2.1. Theropoda

The most complete theropod found so far in the Cerro Barcino Formation is *Tyrannotitan chubutensis*. This theropod was originally interpreted as a basal and the oldest member of Carcharodontosauridae (Novas et al., 2005), a group of Tetanurae that includes the largest known predatorial dinosaurs that was poorly known until recently. Numerous discoveries made in the last years revealed an outstanding diversity of this clade of large bodied allosauroids. Basal forms of Carcharodontosauridae are now known to be worldwide distributed (Brusatte et al., 2009) and their origins certainly date back to the earliest Cretaceous (Ortega et al., 2010; Brusatte et al., 2012) and possibly even to the Late Jurassic (Rauhut, 2011). Most phylogenetic analyses have depicted *Tyrannotitan* clustered with the Late Cretaceous *Giganotosaurus* (Coria and Salgado, 1995), *Mapusaurus* (Coria and Currie, 2006), and *Carcharodontosaurus* (Sereno et al., 1996; Brusatte and Sereno, 2008), forming a clade of gigantic and derived carcharodontosaurids exclusively known from Gondwana (Carcharodontosaurinae sensu Brusatte and Sereno, 2008; Ortega et al., 2010; Benson et al., 2010; Brusatte et al., 2012; Canale et al., 2015). Furthermore, within this clade, *Tyrannotitan* was recently depicted as more closely related to the two other South American forms (*Giganotosaurus* and *Mapusaurus*) than to the African *Carcharodontosaurus* (Novas et al., 2013; Canale et al., 2015). Within this context, the new geochronological data from the Cerro Barcino Formation provide a minimum age of diversification (Albian) of derived carcharodontosaurids from Gondwana (Carcharodontosaurinae) that is younger than previously thought, given most previous studies regarded an Aptian diversification event of this clade (e.g., Novas et al., 2005, 2013; Benson et al., 2010). Therefore, derived carcharodontosaurids (Carcharodontosaurinae) are now restricted from the Albian to the Cenomanian/Turonian of South America and Africa, having relatively short but conspicuous appearance in the Cretaceous fossil record of Gondwana.

Theropod remains from the Cerro Barcino Formation also include abelisaurid known only from fragmentary postcranial remains (Rauhut et al., 2003) and isolated teeth (Gianechini et al., 2011). These abelisaurid remains are not diagnostic at the species level, but have a series of features (e.g., vertebrae with elongated transverse processes with thickened distal end and centrodiapophyseal lamina; see Rauhut et al., 2003) that indicate abelisaurids were present in the Puesto La Paloma Member (Figs. 3 and 6; Table 2). Our age constraints place their presence at least 5 m.y. later than interpreted by Rauhut et al. (2003): Hauterivian–Barremian, but still well before they became the dominant clade of carnivorous dinosaurs in the post-Turonian assemblages of Gondwana (Novas et al., 2005). The early (pre-Turonian) evolutionary history of Abelisauridae was poorly known until recently. However, an increasing number of recent discoveries have shed light on the early diversity of Abelisauridae, including a possible basal abelisaurid from the Middle Jurassic of Patagonia (Pol and Rauhut, 2012) and numerous remains from the Aptian through the Cenomanian of Patagonia and Africa (Lamanna et al., 2002; Calvo et al., 2004; Sereno et al., 2004; Sereno and Brusatte, 2008; Canale et al., 2009). The abelisaurid remains from the Cerro Barcino Formation (Rauhut et al., 2003; Gianechini et al., 2011) add to this early diversity of the group, indicating abelisaurids were important components of the Gondwanan theropod faunas previous to the Turonian extinction or diversity decrease of other theropod clades (such as spinosaurids and carcharodontosaurids; see Novas et al., 2005, 2013).

A possible additional component of the theropod fauna of the Cerro Barcino Formation is the ceratosaurid *Genyodectes serus* (Woodward, 1901). Its taxonomic validity and affinities, as well as its stratigraphic provenance, have been uncertain for many years. Rauhut (2004) redescribed these remains, rediagnosed this species, and considered it as related to *Ceratosaurus* from the Late Jurassic of North America (a position corroborated in a recent phylogenetic analysis; Pol and Rauhut, 2012). Rauhut (2004) noted this taxon probably come from outcrops of the Cerro Barcino Formation based on the geographic provenance data of this specimen and the current knowledge of outcrops of the Cerro Barcino Formation located south of Paso de Indios town in Chubut Province. No other remains of ceratosaurid theropods are currently known from the Cretaceous of South America and therefore *Genyodectes* likely represents a survivor lineage of a worldwide distributed but yet poorly known clade of ceratosaurian theropods.

5.2.2. Sauropoda

Despite sauropod fossils are the most commonly found fossils in the Cerro Barcino Formation (Figs. 3 and 6; Table 2), most remains of this group are isolated and poorly preserved specimens (Rauhut et al., 2003; Cladera et al., 2004). The recently described *Patagotitan mayorum* and the holotype of *Chubutisaurus insignis* are the most complete specimens recovered so far. *Chubutisaurus* is composed by presacral and caudal vertebrae and forelimb and hindlimb elements (Carballido et al., 2011). Although some authors considered *Chubutisaurus* as a basal titanosaur (e.g., Wilson, 2002), recent phylogenetic analyses recovered *Chubutisaurus* as a basal (non-titanosaur) titanosauriform (e.g., Bonaparte et al., 2006), a position better supported with the recent description of new elements with plesiomorphic characters (e.g., large ischium peduncle; Carballido et al., 2011). Similarly, other fragmentary specimens recovered from this unit identified as titanosaurs (Rauhut et al., 2003) can be equally regarded as non-titanosaur titanosauriforms (given their fragmentary nature and the lack of derived features exclusive of Titanosauria).

Table 2
Summary of the tetrapod taxa found in Aptian-Turonian units from Patagonia.

Age	Aptian-Albian	Albian	Lower Cenomanian	Cenomanian-Turonian
Formation taxa	Lohan Cura	Cerro Barcino	Candeleros	Bajo Barreal (Lower Member)
Abelisauridae		Abelisauridae indet. (Rauhut et al., 2003)	*Ekrixinatosaurus novasi*	Abelisauridae indet. (Lamanna et al., 2002) *Xenotarsosaurus bonapartei*
Carcharodonto-sauridae		*Tyrannotitan chubutensis*	*Giganotosaurus carolinii*	Carcharodontosauridae indet. (Casal et al., 2009)
Coelurosauria		Coelurosauria indet. (Dromeosauridae?) (Gianechini et al., 2011)	*Buitreraptor gonzalezorum* (Dromeosauridae) *Bicentenaria argentina* (basal Coelurosauria)	*Aniksosaurus darwini* (basal Coelurosauria)
Ceratosauria		*Genyodectes serus*		
Ornithopoda				*Notohypsilophon comodorensis*
Non-titanosaur titanosauriforms	*Ligabuesaurus leanzai*	*Chubutisaurus insignis*		
Titanosauria		*Patagotitan mayorum*	*Andesaurus delgadoi*	*Epachthosaurus sciuttoi*
Basal Rebbachisauridae	*Comahuesaurus windhauseni*			
Limaysaurinae			*Rayososaurus agrioensis* *Limaysaurus tessonei*	*Katepensaurus goicocheai*
Eilenodontinae sphenodontians		*Kaikaifilusaurus minimus*	*Kaikaifilusaurus calvoi*	
Serpentes			*Najash rionegrina*	
Peirosauridae		*Barcinosuchus gradilis*	Peirosauridae indet.	
Uruguaysuchidae			*Araripesuchus patagonicus* *A. butreraensis*	
Chelidae	*Prochelidella* spp.	*Prochelidella cerrobarcinae*	*Prochelidella* spp.	*Prochelidella argentinae* *Bonapartemys bajobarrealis*
Basal Meiolaniformes		*Chubutemys copelloi*		

Titanosauriform origins certainly date back at least to the Late Jurassic, based on the brachiosaurid *Giraffatitan* and *Brachiosaurus* records from Tendaguru (Africa) and Morrison (North America). Furthermore, track evidences suggest the group may have originated in the Middle Jurassic (Day et al., 2002). Titanosauria is the most successful clade of titanosauriforms, which appears in the fossil record by Barremian–Albian times (Mannion and Calvo, 2011; D'Emic, 2013). The single putative pre-Cenomanian titanosaur from Patagonia is *Patagotitan mayorum*, from the uppermost section of the Cerro Castaño Member (Late Albian). Besides this taxon there are no other undisputed records of pre-Cenomanian titanosaurs and the late Early Cretaceous sauropod fauna from Patagonia seems to be dominated by non-titanosaur titanosauriforms. In addition to the Albian titanosauriforms from the Cerro Barcino Formation mentioned above, other titanosauriforms have been described from the Lohan Cura Formation (late Aptian–early Albian; *Ligabuesaurus*, *Agustinia*; Bonaparte, 1999; Bonaparte et al., 2006). Although these taxa have been regarded as titanosaurs (Upchurch et al., 2004; Apesteguía, 2007), they likely represent non-titanosaur titanosauriforms, or even a rebbachisaurid in the case of *Agustinia* (see Salgado et al., 2006; Bellardini and Cerda, 2017). The phylogenetic position of *Agustinia* is debated and its inclusion within Titanosauria has been questioned in recent studies (see Salgado et al., 2006; Mannion and Calvo, 2011). *Amargatitanis*, originally described as a titanosaur from the La Amarga Formation (Barremian; Apesteguía, 2007) was recently interpreted as a dicraeosaurid sauropod (Gallina, 2016). Therefore, the Late Aptian–Late Albian age herein obtained for the Cerro Barcino sauropods reinforces the hypotheses that non-titanosaur titanosauriforms dominated the sauropod fauna of Patagonia until the Cenomanian. It should be noted that within a phylogenetic framework these non-titanosaur titanosauriforms (e.g., *Chubutisaurus*, *Ligabuesaurus*) are closely related outgroups of Titanosauria and there are few morphological changes separating them from basal titanosaurs such as *Andesaurus*. Some of these morphological differences include a subtle change in the articulation morphology of anterior caudal vertebrae from anteriorly concave and posteriorly flat centra (in *Chubutisaurus*) to incipient procoelous in *Andesaurus* (anteriorly concave and posteriorly slightly convex), as well as a reduction in the ischia blade observed in *Andesaurus* and most derived titanosaurs. Therefore, the late Aptian–early Albian *Chubutisaurus* and Cenomanian *Andesaurus* are morphologically more similar to each other than is *Andesaurus* to the more derived titanosaurs from the post-Turonian of Patagonia. The presence of the giant titanosaur, *Patagotitan mayorum*, in the upper section of the Cerro Barcino Formation (Late Albian) indicates that a clade of large bodied titanosaurs evolved just prior to the Late Cretaceous (Carballido et al., 2017) but peaked in their diversity by the early Late Cretaceous.

Rebbachisaurid diplodocoids, which are diverse in the Candeleros Formation (Neuquén Basin) and present but less diverse in the Bajo Barreal Formation (San Jorge Basin, Chubut Province) (Calvo and Salgado, 1995; Gallina and Apesteguía, 2005; Ibiricu et al., 2012, 2013, 2014, 2015; Casal et al., 2016), have not yet been reported from the Cerro Barcino Formation. However, the specimen MPEF PV 1698 (Rauhut et al., 2003) seems to represent a fragmentary and poorly preserved rebbachisaurid (JLC pers. Obs.). The age of the Candeleros and Bajo Barreal faunas have been presumed Cenomanian in previous contributions. The uncertainty in the radioisotopic age of the Bajo Barreal Formation places this unit anywhere between the latest Albian and the early Turonian (see Section 5.1), which does not provide a better resolution that its late Albian–Turonian age based on a pollen assemblage recovered from subsurface beds correlated to the lower Bajo Barreal Formation (Archangelsky et al., 1994). Similarly, only a broad age range of latest Albian to Cenomanian can be assigned to the Candeleros Formation and its fauna.

The basal rebbachisaurids *Comahuesaurus* and *Lavocatisaurus* were described from Lower Cretaceous (Lohan Cura and Rayoso formations) in the Neuquén Basin to the north (Salgado et al., 2004; Carballido et al., 2012; Canudo et al., 2018). These formations are considered to be Aptian-Albian in age based on its stratigraphy (e.g., below the Candeleros Formation) and tectonosedimentary aspects (e.g., Leanza et al., 2004), although its unconformable contacts renders any age assignment highly speculative. Both rebbachisaurids retains few plesiomorphic characters that support their more basal position (outside the derived clade of Limaysaurinae).

5.2.3. Crocodyliforms

The only diagnostic remain of a crocodyliform from the Cerro Barcino Formation is *Barcinosuchus gradilis* (Leardi and Pol, 2009) (Figs. 3 and 6; Table 2). The holotype and only known material consists of fragmentary cranial material and associated postcranial remains. This taxon has been interpreted as a member of Peirosauridae through a phylogenetic analysis, a position supported by the presence of hypapophysis up to the first four dorsal vertebrae (Leardi and Pol, 2009). Peirosaurids (and their putatively related taxa from Africa and Madagascar traditionally referred as trematochampsids) are rather generalized basal mesoeucrocodylians with ziphodont dentition that occupied carnivorous niches in multiple vertebrate assemblages of the Cretaceous of Gondwana (Pol and Gasparini, 2007). Although there are Albian–Cenomanian records from Africa (*Hamadasuchus*; Larsson and Sues, 2007), definitive South American records of Peirosauridae were restricted to Turonian (Barrios et al., 2015) or post-Turonian rocks of Patagonia and Brazil. The new geochronological data of the Cerro Barcino Formation indicates *Barcinosuchus* predates by at least 15 million years other named peirosaurid taxa from South America (likely being one of the oldest records of the group worldwide). *Barcinosuchus* provides the first well-constrained minimum age for the initial diversification of this important clade of Cretaceous crocodyliforms. Fragmentary remains of crocodyliforms found in the Albian-Cenomanian Candeleros Formation (Carignano et al., 2002) of possible peirosaurid affinities suggests this group likely was component of the crocodyliform fauna of South America since the Albian through the latest Cretaceous.

5.2.4. Lepidosauromorpha

Lepidosauriform reptiles were reported from the Puesto Huanimán and Tres Cerros localities of the Cerro Barcino Formation (Apesteguía and Carballido, 2014), including isolated lower and upper jaws and an almost complete skull (Figs. 3 and 6; Table 2). All these specimens belong to a single taxon, *Kaikaifilusaurus minimus* (Apesteguía and Carballido, 2014). The genus *Kaikaifilusaurus* was originally described from the Candeleros Formation and constrained to the late Albian-early Cenomanian (Tunik et al., 2010; Di Giulio et al., 2012). *Kaikaifilusaurus* is clustered within Eilenodontinae, a group of large bodied forms that belongs to the derived eupropalinal lineage of sphenodontians (Apesteguía and Carballido, 2014). Although derived sphenodontians are recorded since the late Jurassic in other regions of the world, the Patagonian record was previously restricted to the late Cretaceous (Apesteguía and Novas, 2003). The early Albian age of the lower Cerro Castaño Member that yielded remains of *Kaikaifilusaurus minimus* (Figs. 3 and 6) has important implications for understanding the evolution of this group in Patagonia. First, it represents the oldest record of the derived clade of eupropalinal sphenodontians in Patagonia, corroborating the hypothesis that this group achieved a worldwide distribution during the late Jurassic-early Cretaceous but only survived in the southern hemisphere due to regional extinctions (Apesteguía and Novas, 2003). Second, the Cerro Barcino species of *Kaikaifilusaurus* predates the record of this genus in the (latest Albian-) to early Cenomanian Candeleros Formation (Di Giulio et al., 2012) by at least 10 million years, indicating this genus of eilenodontine sphenodontians formed a common element of the Patagonian faunas across the Early-Late Cretaceous boundary (Apesteguía and Carballido, 2014).

5.2.5. Testudinata

Two testudinatan species, *Chubutemys copelloi* and *Prochelidella cerrobarcinae*, have been recovered from the Puesto La Paloma Member, lower Cerro Barcino Formation, which belong to two different lineages of turtles (Figs. 3 and 6; Table 2). *Chubutemys copelloi* (Gaffney et al., 2007; Sterli et al., 2015) represents the most basal taxon of the extinct clade Meiolaniformes, as shown by two different phylogenetic analyses of the group (Gaffney et al., 2007; Sterli et al., 2015). Meiolaniformes is a recently defined clade that includes Meiolaniidae (horned terrestrial turtles) and related forms that are distributed in Gondwana (South America and Australasia) and Eurasia (Sterli and de la Fuente, 2013). The Aptian age of *Chubutemys copelloi* places this taxon as one of the oldest members of Meiolaniformes and, together with *Otwayemys cunicularius* from the Aptian of Australia (Gaffney et al., 1998), provides the minimum age of diversification of this clade in the late early Cretaceous (Sterli et al., 2015). The age of these taxa and their phylogenetic position indicated in a recent biogeographic analysis that Meiolaniformes originated in southern Gondwana at some point between the middle Jurassic (when this lineage split from other testudinatans) and their first record in the late early Cretaceous (Sterli and de la Fuente, 2013).

Prochelidella cerrobarcinae, instead, belongs to the pleurodiran group Pan-Chelidae (de la Fuente et al., 2011), an extant Gondwanan clade with exclusive South American and Australasian records. *Prochelidella cerrobarcinae* has been recovered within the crown-group Chelidae (Sterli et al., 2013) and the Aptian age of the fossiliferous levels of the Puesto La Paloma Member presented in this contribution depicts this taxon as the oldest undisputed member of this important clade of Gondwanan turtles. Other fossil remains from the “mid-Cretaceous” of Patagonia (Lohan Cura Formation; de Lapparent de Broin and de la Fuente, 2001) and Australia (Griman Greek Formation; Smith, 2010) have been interpreted as the oldest chelids, but their inclusion in the crown-group Chelidae has not been tested within a phylogenetic framework. Therefore, the radiometric dates provided in this study give critical information for determining the minimum age of diversification of the living lineages of pan-chelid turtles in the fossil record, which is also relevant for calibrating molecular clock studies of this group (e.g., Near et al., 2005; Sterli et al., 2013; Joyce et al., 2013). Summarizing, the testudinatan record of the Cerro Barcino Formation includes the oldest members of two important clades of turtles (Meiolaniformes and Pan-Chelidae) and the new dates presented here constrain their minimum age of diversification and the timing of their early evolutionary stages.

5.3. Significance of the Cerro Barcino vertebrate fauna in the Cretaceous of Gondwana

Considering the abundance of vertebrates in the Cerro Barcino Formation, this assemblage represents the most diverse continental vertebrate fauna from the “mid-Cretaceous” of Patagonia and one of the most diverse from this time period in South America. The high-precision geochronology presented in this contribution renders the Cerro Barcino assemblage perhaps the best calibrated terrestrial vertebrate fauna from the “mid-Cretaceous” of Gondwana. Tying diverse fossil assemblages to radioisotopic dates independent of uncalibrated biostratigraphy or magnetostratigraphy is critical to assessing the significance of fossil taxa, understanding the timing of evolutionary events and exploring the provinciality of vertebrate assemblages. Even though the Cretaceous land vertebrate assemblages of South America are dominated by the Patagonian record and the number of discoveries have increased significantly in the last two decades, progress in refining their temporal context has been much delayed. Drawing from our new geochronology and considering the significance of the Cerro Barcino fauna with respect to the Cretaceous fauna of Patagonia, two basic paleobiologic interpretations arise.

First, the Cerro Barcino fauna suggests the presence of a stable “mid-Cretaceous” (Aptian–early Albian) vertebrate fauna in Patagonia (Table 2). There is a strong identity in the faunal components of the Cerro Barcino and other vertebrate assemblages of Patagonia that range from the Aptian–Albian to the Cenomanian–Turonian proceeding from the Lohan Cura and correlative formations. Almost all the reptilian clades recorded in the Cerro Barcino Formation are also present in the late Albian-Cenomanian Candeleros Formation (Tunik et al., 2010; Di Giulio et al., 2012) and in the lower member of the Bajo Barreal Formation (Ibiricu et al., 2012), which is interpreted to be latest Albian to early Turonian. Furthermore, two of these groups are also present in the older (Aptian–Albian) Lohan Cura Formation (Martinelli and Vera, 2007; see Table 2). Although many groups are absent in the Lohan Cura Formation, the scarcity of diagnostic remains from this unit precludes assessing whether these absences are just artifacts of preservation. In particular, there is a strong similarity in some of the taxa recorded in the Cerro Barcino and Candeleros faunal assemblages, such as the presence of species of the same genera of sphenodontians and chelid turtles (*Kaikaifilusaurus* and *Prochelidella*, respectively). The two groups of sauropods (Titanosauriformes and Rebbachisauridae) are the only members of these faunal assemblages that show some degree of distinction (Table 2). Among titanosauriforms, the late Aptian–early Albian taxa from Patagonia are non-titanosaurians and the only rebbachisaurid known was recently regarded as the sister taxa of the derived clade Limaysaurinae + Nigersaurinae (Carballido et al., 2012). Despite these taxonomic nomenclatural differences, in both titanosauriforms and rebbachisaurids, the distinction between the late Aptian–early Albian forms and the late Albian–Cenomanian taxa is limited to minor anatomical changes (see above). In summary, the mid-Cretaceous age of the Cerro Barcino fauna reported here, and its strong similarities with the mainly Cenomanian faunal assemblages of Patagonia (Table 2), indicate that the "mid-Cretaceous" fauna of Patagonia was relatively uniform during the Aptian–Cenomanian. During this time no major evolutionary novelties or faunal turnovers are recorded. Such similarity, in turn, casts doubts on the validity of the distinction between the Lohan Curan (Aptian–Albian) and Limayan (Cenomanian–Turonian) as two different tetrapod assemblages of Patagonia (Leanza et al., 2004). Further data, however, are needed to thoroughly test the distinction between these two tetrapod assemblages.

Second, the "mid-Cretaceous" fauna of Patagonia is composed of a mixture of existing (Jurassic) lineages and groups that originated in the late Early Cretaceous (Aptian–Albian). Out of the eight taxonomic groups recorded in the Cerro Barcino Formation, four groups date back to the Jurassic (e.g., titanosauriforms, ceratosaurids, abelisaurids, eilenodontines). However, four clades (pan-chelids, meiolaniforms, peirosaurids, derived carcharodontosaurids) are inferred to have originated at this time (Aptian–Albian). In fact, the significance of the Cerro Barcino vertebrate fauna lies in its oldest records of these four clades, constraining the origin of the faunal assemblage that characterizes the "mid-Cretaceous" of Patagonia. However, it is important to note that the scarce pre-Aptian record of Cretaceous vertebrates in South America and other regions of Gondwana (see also Novas et al., 2013) obscures the exact origins of the "mid-Cretaceous" fauna. Further collecting efforts and discoveries in the earliest Cretaceous will be critical for understanding the origins of some groups that at the moment have their first occurrence in the lower Cerro Barcino Formation. In particular, some of these groups (e.g., meiolaniforms, abelisaurids, derived carcharodontosaurids) have basal ghost lineages that extend back to the earliest Cretaceous or even back to the Jurassic and recent findings suggest the possible presence of these groups prior to the Aptian (Coria et al., 2010, 2017; Canale et al., 2017).

Finally, the Cerro Barcino record is key to our understanding of the dynamics of the turnover between the "mid-Cretaceous" and the post-Turonian vertebrate assemblages, previously identified as a major faunal change in Patagonia (Novas et al., 2005, 2013; Coria and Salgado, 2005). As previously noted, this notion is mainly based on the extinction of carcharodontosaurids, rebbachisaurids, and non-saltasaurine titanosauriforms (Novas et al., 2005, 2013; Coria and Salgado, 2005). The taxonomic composition of the Cerro Barcino fauna includes at least four important lineages that survived the Cenomanian-Turonian faunal turnover (pan-chelids, meiolaniforms, peirosaurids, abelisaurids). This lends support to the hypothesis that the distinction of the post-Turonian Cretaceous fauna of Patagonia was largely shaped by local extinctions and diversification of pre-existing groups rather than by initiation of new lineages (although some theropod groups diversify at this time; Novas et al., 2013). A similar faunal turnover has been recognized in North America, Europe and Africa (Lucas and Hunt, 1989; Le Loeuff, 1991; Jacobs et al., 1993; Sereno et al., 1998; Sereno, 1999), although poor age resolution at this time hampers a thorough examination of their presumed synchronicity.

5.4. Correlation with the mid-Cretaceous record of North America

The transcontinental correlations of vertebrate fauna have been based traditionally on biochronologic age assignments to vertebrate assemblages, which in many cases result in a circular paradigm. Chronostratigraphies based on radioisotopic age data provide the means for independent temporal correlation of fauna and can support reliable analyses of their paleobiology and biogeography in deep time. Our results point out to the contemporaneous relationship between the Cerro Barcino vertebrate assemblages of Patagonia and the rich fossil records of the Cedar Mountain Formation and the lower Dakota Formation (sandstone) of the North American Western Interior Basin.

Somewhat similar to the Chubut Group, the terrestrial Cedar Mountain Formation has a significant volcanic component and overlies via an unconformity the paleo-erosional surface of the Jurassic (Morrison Formation) and older strata (e.g., Kirkland et al., 1999). $^{40}Ar/^{39}Ar$ geochronology of ash beds from the upper Mussentuchit Member of the Cedar Mountain Formation in eastern Utah (Iguanodontid dinosaurs quarry) produced a range of Cenomanian plateau ages from 98.5 ± 1.2 Ma (2σ) to 97.2 ± 1.2 Ma (Garrison et al., 2007), although the use of K decay constants of Steiger and Jäger (1977) necessitates a recalculation of these age data. Detrital zircon U-Pb LA-ICPMS geochronology from the same member in the Dinosaur National Monument (Utah) by Chure et al. (2010) yielded a maximum depositional age of 104.46 ± 0.95 Ma (Albian) for a bone bed containing brachiosaurid sauropod dinosaur remains. Geochronology from the lower Yellow Cat Member of the Cedar Mountain Formation is presently limited to Barremian-Aptian detrital zircon dates (LA-ICPMS method) from the above areas reported in a conference abstract (Britt et al., 2007) and without supporting data. The dinosaur fauna of the Cedar Mountain Formation are dominated by polacanthid and nodosaurid ankylosaurs, iguanodontid ornithopods, basal titanosauriforms (including both brachiosaurids and somphospondilian sauropods; e.g., Mannion et al., 2013), and large dromaeosaurid theropods (e.g., Kirkland et al., 1999; Chure et al., 2010).

The lower Dakota Formation (sequence 2) of Albian age is well-known for its dinosaur ichnofauna that is dominated by deinonychosaurian theropod tracks and is best displayed at Dinosaur Ridge, Colorado (Lockley et al., 2016). The lower, dinosaur track-rich interval of the Dakota Formation (sequences 2 and 3) in Southwestern United States has high-precision U-Pb zircon dates (CA-ID-TIMS method) that ranges from ~104.6 Ma to 97.6 Ma (Barclay et al., 2015; Lockley et al., 2018 and references therein), indicating an Albian-Cenomanian time period.

Regarding to the trans-American Cretaceous sauropod record, the main difference relates to the total absence of rebbachisaurid diplodocoids in North America and of brachiosaurids in Patagonia. Rebbachisauridae was traditionally considered a clade with a Gondwanan distribution, although the recent revision of "Amphicoelias" fragillimus suggested that, at least in the Late Jurassic, this clade could have extended as far as the western Laurasia. If true, the total absence of such forms from the Cretaceous strata indicates a local extinction of this lineage during the Jurassic-Cretaceous transition. A similar case is the absence of brachiosaurids sauropods from the Cretaceous of Patagonia. The presence of basal somphospondylians during the late Early Cretaceous in both hemispheres indicates that these forms reached a global distribution before they were completely replaced by more derived forms of Titanosauria during the Late Cretaceous.

6. Conclusions

Extensive and detailed stratigraphic investigations combined with sedimentary facies analyses and high-precision U-Pb geochronology of tuffaceous beds are used to construct a robust chronostratigraphic framework for the Cerro Barcino Formation of the Cretaceous Chubut Group and its rich vertebrate fossil record throughout the Somuncurá-Cañadón Asfalto Basin of central Patagonia. Accordingly, the depositions of the Puesto La Paloma and Cerro Castaño members, respectively, were largely restricted to the Aptian and the Albian stages of Early Cretaceous, with the overlying Las Plumas member extending into the Cenomanian. These indicate a pre-late Aptian age for the onset of the Chubut Group accumulation to the east of the Andean Cretaceous proto-arc.

The main concentration of the Cerro Barcino fossil remains occurs in a discrete stratigraphic interval that encompasses the Puesto La Paloma Member and the lower section of the Cerro Castaño Member, spanning a nearly 8 m.y. interval (~118–110 Ma) that straddles Aptian-Albian boundary.

The new chronostratigraphy of the "mid-Cretaceous" Cerro Barcino vertebrate fauna makes it perhaps the best calibrated terrestrial vertebrate fauna from the "mid-Cretaceous" of Gondwana. Our analysis of the Cerro Barcino vertebrate record in connection to coeval Aptian to Cenomanian assemblages in the region highlights a stable mid-Cretaceous Patagonian fauna with no major evolutionary novelties or faunal turnovers. Although multiple vertebrate lineages appear in the fossil record during this time interval, their earlier origins cannot be ruled out because of the current scarcity of the early Cretaceous discoveries. Radioisotopic age calibration allows direct temporal correlation between the Cerro Barcino faunal record and that of the Cedar Mountain and lower Dakota formations of the North American Western Interior Basin.

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