

Burdigalian deposits of the Santa Cruz Formation in the Sierra Baguales, Austral (Magallanes) Basin: Age, depositional environment and vertebrate fossils

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ABSTRACT. A succession of marine and continental strata on the southern flank of Cerro Cono in the Sierra Baguales, northeast of Torres del Paine, can be correlated with stratigraphic units exposed along the southern border of the Lago Argentino region in Santa Cruz Province, Argentina. These include the Estancia 25 de Mayo Formation and the basal part of the Santa Cruz Formation. The lithological correlation is also confirmed by detrital zircon ages (maximum age of 18.23±0.26 Ma) and a rich assemblage of terrestrial vertebrate fossils, biostratigraphically equivalent to a post-Colhuehuapian, pre-Santacrucian South American Land Mammal Age (SALMA) fauna, suggesting a range of 19 to 17.8 Ma. Similar ages have been obtained from the basal part of the Santa Cruz Formation at Estancia Quién Sabe in southwestern Argentina, supporting the assumption of a regional continuity between these deposits. A measured lithostratigraphic column is presented and the depositional environment is interpreted as a coastal plain with small, meandering rivers and ephemeral floodplain lakes. The sedimentation coincides with intensified uplift of the Patagonian Andes during the 'Quechua Phase' of Andean tectonism, which is reflected by a change in paleocurrent directions from northwest to east-northeast.

Keywords: Burdigalian, Santa Cruz Formation, Santacrucian SALMA, 'Notohippidian' fauna, Meandering rivers, Andean uplift.

RESUMEN. Depósitos burdigalianos de la Formación Santa Cruz en Sierra Baguales, Cuenca Austral (Magallanes): Edad, ambiente de deposición y vertebrados fósiles. Una sucesión de estratos marinos y continentales en el flanco meridional del cerro Cono, en la sierra Baguales, al noreste de Torres del Paine, se correlaciona con estratos al sur de la región de lago Argentino en la Provincia de Santa Cruz, República Argentina. Estas unidades incluyen la Formación Estancia 25 de Mayo y la parte basal de la Formación Santa Cruz. La correlación litológica es, además, confirmada por datación de circones detríticos (edad máxima de $18,23 \pm 0,26$ Ma) y un variado ensamble de vertebrados fósiles terrestres de edad post-Colhuehuapense a pre-Santacrucense en la escala de Edades Mamífero Sudamericanas (EMAS), con un rango temporal de entre 19 a 17,8 Ma. Edades similares han sido reportadas para la parte basal de la Formación Santa Cruz, en estancia Quién Sabe, en el suroeste de Argentina, ratificando la continuidad regional entre estos depósitos. Se presenta una columna estratigráfica y se interpreta el ambiente de deposición como una llanura costera con pequeños ríos sinuosos y lagos efímeros. La edad de sedimentación coincide con el solevantamiento de los Andes Patagónicos durante la 'Fase Quechua', lo que se ve reflejado por un cambio en la dirección de las paleocorrientes desde el noroeste hacia el este-noreste.

Palabras clave: Burdigaliano, Formación Santa Cruz, EMAS Santacrucense, Fauna 'Notohippidense', Ríos sinuosos, Solevantamiento de los Andes.

1. Introduction

The Early Miocene represents one of the most interesting and well documented geological and biological periods in South America. Important climate changes related to an increase in the global temperature (Zachos *et al.*, 2008), eustatic sea-level fluctuations (Miller *et al.*, 2005), and large scale geotectonic events leading to the main uplift of the Andes (Ramos and Alemán, 2000), left a strong imprint on the southern biota (Pascual and Odreman Rivas, 1971, Pascual *et al.*, 1996; Ortiz-Jaureguizar and Cladera, 2006). General information of this epoch largely comes from Argentinian Patagonia, where widespread marine and continental sedimentary deposits represent the main component of the Neogene stratigraphic succession (Feruglio, 1938, 1944, 1949a, 1949b, 1950; Hatcher, 1900; Pascual *et al.*, 1996; Nullo and Combina, 2002; Malumíán and Náñez, 2011). Outcrops of contemporaneous Early Miocene rocks in southern Chubut and the Santa Cruz Province of Argentina have yielded a wealth of beautifully preserved fossils, making this epoch also a cornerstone of the many evolutionary hypotheses proposed since the pioneering work of the well-known Argentinean palaeontologists Florentino and Carlos Ameghino at the end of the 19th century (Ameghino, 1887, 1889, 1900-1902, 1902, 1904, 1906). Within this vast paleontological record, fossil mammals take a prominent place, bearing incomparable testimony to the past austral faunal diversity (Ameghino, 1887, 1889, 1906; Hatcher, 1903; Scott, 1932; Simpson, 1940).

Patagonian late Early Miocene fossil mammals were first brought to the public attention by Captain

Bartholomew James Sulivan and Charles Darwin (Owen, 1846; Darwin, 1862), and subsequently thousands were collected during multiple expeditions led by South American, North American and European explorers (Marshall, 1976; Madden and Scarano, 2010; Vizcaíno *et al.*, 2012a). After more than a century of intense research, new specimens and detailed stratigraphic information are still actively recorded from these rich Patagonian strata (Bown and Fleagle, 1993; Kramarz *et al.*, 2005; Madden *et al.*, 2010a; Vizcaíno *et al.*, 2012b), making them some of the finest worldwide paleontological records ever documented (Simpson, 1940; Pascual and Odreman Rivas, 1971).

In comparison, the study and collection of fossil mammals in Chilean Patagonia have been less intense and largely discontinued (Marshall and Salinas, 1990a, b; Flynn *et al.*, 2002; De la Cruz and Suárez, 2006), lacking precise taxonomic identifications and resulting in an imperfect knowledge of the extent, age, local emplacement, and regional lithostratigraphical affinities of the Neogene host sequences. These difficulties have restricted our understanding of the past biological diversity in Chilean Patagonia, also reducing our capacity to correlate local geo-paleontological information at a more extensive international level. The need to overcome some of these limitations is one of the main aspects addressed in the present communication.

2. An overview of the Pansantacrucian fossil faunas

There is little doubt that it was the pioneering work of Florentino and Carlos Ameghino that

led to the worldwide renown of the austral South American Neogene sedimentary sequences and their rich fossiliferous heritage. For a period of 16 years (1887-1903) the Ameghino brothers -Carlos in the field and Florentino in the laboratory- prospected, collected and described thousands of fossils from Patagonia, identifying more than two hundred new species and establishing the basis for the present chrono-biostratigraphic scale for the South American Cenozoic (Ameghino, 1887, 1889, 1900-1902, 1902, 1904, 1906; Pascual *et al.*, 1965, 1996; Pascual and Odreman Rivas, 1971). The vast geo-paleontological knowledge gained by F. Ameghino in his study of the Patagonian fossils certainly transcended the merely descriptive, becoming one of the most remarkable examples of early South American evolutionary, chronostratigraphic, anthropological and biogeographic scientific thought (Ingenieros, 1951; Morrone, 2011; Ranea, 2011; Salgado, 2011). This legacy was not free of controversies, with heated scientific disagreements and clashing ambitions between Ameghino and local and international colleagues making a deep impact on modern paleontological thinking, with important repercussions even today (Quintero Toro, 2009 and references therein; Fernicola, 2011a, b).

Following Ameghino's (1889, 1902, 1906) original framework, Simpson (1940) defined two formal and consecutive faunal intervals: the Colhuehuapian (early Burdigalian, ~20 Ma), and the Santacrucian (late Burdigalian, ~17-16 Ma) 'mammal units', presently referred to as South American Land Mammal Ages, or SALMAs (Pascual *et al.*, 1965, 1996). Ortiz-Jaureguizar (1986) quantified the direct links between these faunal intervals and grouped them into a single major evolutionary unit, the Pansantacrucian faunistic sub-cycle, a term that will be frequently used in this paper (Fig. 1).

The Colhuehuapian SALMA, initially described by Ameghino (1902) as 'étage Colpodonien', was redefined, based on the rich vertebrate collections from the Lower Fossil Zone of the Colhue-Huapi member of the Sarmiento Formation at Gran Barranca (Chubut Province, Argentina), presently considered to be the type locality for the Colhuehuapian Age (Simpson, 1940; Madden and Scarano, 2010; Madden *et al.*, 2010b; Fig. 1). Apart from Gran Barranca, currently known Colhuehuapian faunas are almost totally restricted to scattered localities in the northern half of Patagonia (*i.e.*, Sacanana, Cerro Bandera, Barda Negra, Paso Córdova, Bryn Gwyn; Fig. 1),

in the Neuquén, Río Negro, and Chubut Provinces of Argentina (Simpson, 1932; Marshall *et al.*, 1983; Kramarz *et al.*, 2005). Recent geochronological studies highlighted the brief temporal extension of the Colhuehuapian SALMA, confined to ~20 Ma by direct dating at Gran Barranca (Ré *et al.*, 2010).

The Santacrucian SALMA represents one of the best known Neogene faunal intervals ever described (Simpson, 1940; Marshall *et al.*, 1983; Vizcaíno *et al.*, 2012a). First defined as the 'piso Santacruciano' by F. Ameghino based on the extensive collections made by his brother Carlos in the Santa Cruz Province (Ameghino, 1887, 1889, 1906), its classic localities within the Santa Cruz Formation stretch along the Atlantic coastal cliffs from Monte León National Park to Río Gallegos (Ameghino, 1906; Marshall, 1976; Tauber, 1997; Kay *et al.*, 2008; Fleagle *et al.*, 2012; Fig. 1). Tephrostratigraphic correlations and radiometric dates from the Santa Cruz Formation in localities such as Corriguen Aike, Monte León and Cerro Observatorio (not Monte Observación, see Vizcaíno *et al.*, 2012a), suggest a core age of 17.8 to ~16.0 Ma for these deposits, and by extension for the typical Santacrucian SALMA (Marshall *et al.*, 1986; Bown and Fleagle, 1993; Fleagle *et al.*, 1995; Tejedor *et al.*, 2006; Parras *et al.*, 2012; Perkins *et al.*, 2012). However, different scholars have pointed out that typical Santacrucian mammals do occur in slightly older inland horizons, indicating that the Santacrucian SALMA probably extends to somewhat earlier ages. These include Andean and central Patagonian outcrops, as for example the upper succession of the eolian-volcaniclastic Pinturas Formation in the valley of the Pinturas River (Kramarz and Bellosi, 2005), and exposures at Lake Posadas/Puyrredón (Hatcher, 1903; Blisniuk *et al.*, 2006), Río Chalia/Sehuén (Hatcher, 1903), Estancia El Carmen, Lake Cardiel, and Gobernador Gregores (Bown and Fleagle, 1993; De Barrio *et al.*, 1994; Kramarz and Bellosi, 2005; Fleagle *et al.*, 2012). Other localities with potential Santacrucian fossils are El Trébol and Camerón (Bordas, 1939), Meseta Latorre (Brandmayr, 1945), and the Cerro Boleadoras Formation in the valley of the Jeininemi and Zeballos Rivers, south of Lake General Carrera/Buenos Aires (Ugarte, 1956; Vucetich, 1994; Scillato-Yané and Carlini, 1998. Fig. 1).

Two other post-Colhuehuapian and pre-Santacrucian faunal intervals have also been proposed since the beginning of the 20th century: the 'Notohippidian'

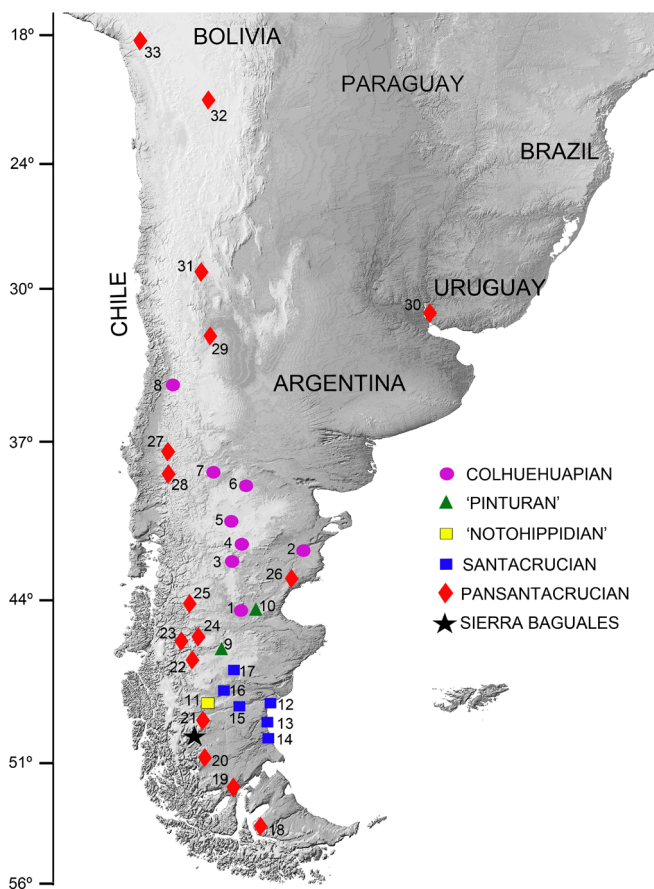


FIG. 1. Pansantacrucian faunal sub-cycle fossil localities reported from the Southern Cone of South America. *Colhuehuapian Age faunas*: 1. Gran Barranca, Lower Fossil Zone-C.H. Member, ARG.; 2. Bryn Gwyn, ARG.; 3. La Curandera, ARG.; 4. El Pajarito, ARG.; 5. Sacanana, ARG.; 6. Paso Córdoba, ARG.; 7. Cerro Bandera, Barda Negra and Cerro Bayo Mesa, ARG.; 8. Las Leñas, CH. *'Pinturan' Sub-age? faunas*: 9. Upper Pinturas River valley, ARG.; 10. Gran Barranca, Upper Fossil Zone-C.H. Member, ARG. *'Notohippidian' Stage fauna*: 11. Karaiken, ARG. *Santacrucian Age faunas*: 12. Monte León and Cerro Observatorio localities, ARG.; 13. Campo Barranca to Corriguen Aike and surroundings, ARG.; 14. Monte Tigre, Cabo Buen Tiempo and Killik Aike Norte fossil zones, ARG.; 15. Santa Cruz River valley, ARG.; 16. Sehuén and Chafia River valleys, ARG.; 17. Middle Patagonian sites: Gobernador Gregores, Lake Cardiel, Estancia El Carmen. *Unspecified, potential, tentatively assigned or time inclusive Pansantacrucian faunas*: 18. Río Cóndor, CH.; 19. Laguna del Toro, Lago Blanco and Palomares hills, CH.; 20. Meseta Latorre, ARG.; 21. Cerro Centinela and Estancias Quién Sabe, La Josefina and Bon Accord, ARG.; 22. Lake Posadas-Puyrredón, ARG.; 23. Pampa Guadal and Pampa Castillo, Meseta Cosmelli, CH.; 24. Jeinimeni River valley, CH.-ARG., and Cerro Boleadoras Formation, ARG.; 25. Alto Río Cisnes, CH.; 26. El Trébol y Cameron, ARG.; 27. Laguna del Laja sub-basin, C.M. Form., CH.; 28. Lonquimay sub-basin, C.M. Form., CH.; 29. Divisadero Largo, ARG.; 30. 'Palmirensé' stage, UY.; 31. Manantiales basin, ARG.; 32. Cerdas, BOL.; 33. Chucal, CH. *Star*: Study site in Sierra Baguales, Magallanes, Chile. See specific references for the locations in the text. Abbreviations: **ARG.**: Argentina; **CH.**: Chile; **UY.**: Uruguay; **BOL.**: Bolivia. **C.H.**: Colhue-Huapi Member. **C.M.**: Cura-Mallín Formation.

('étage Notohippidien' of Ameghino, 1900-1902, 1906), and the 'Pinturan' ('faune Astrapothericuléen' of Ameghino, 1906).

The Pinturan fauna (Pinturan association *sensu* Kramarz and Bellosi, 2005) was recognized in elements of the old 'Astrapothericulan' fauna of

Ameghino (1906), a composite fossil assemblage recovered in the headwaters of the Pinturas River, lacking an accurate geographic and stratigraphic position (Ameghino, 1900-1902, 1906). Kramarz and Bellosi (2005) restricted the Pinturan association to fossils collected exclusively from the lower

and middle successions of the Pinturas Formation (Bown and Lariestra, 1990; Bown and Fleagle, 1993; Fig. 1), and characterised it by its more ancestral constitution, bearing more primitive elements than those of the classic Santacrucian localities along the Atlantic Coast. While most researchers have traditionally considered the Pinturas ('Astrapothericulan') fossils to be simply a local Santacrucian age fauna (Pascual and Odreman Rivas, 1971; Marshall *et al.*, 1983; Pascual *et al.*, 1985, 1996), other scholars have suggested that it could represent an independent biochronologic unit ('Pinturan' age/sub-age), placed between the Colhuehuapian and the Santacrucian SALMAs (Ameghino, 1906; Kraglievich, 1930; Castellanos, 1937; Brown and Fleagle, 1993; Kramarz and Bellosi, 2005; Kramarz *et al.*, 2010). However, direct $^{40}\text{Ar}/^{39}\text{Ar}$ dating from the Pinturas Formation bracketed between 17.99 and 16.80 Ma (Perkins *et al.*, 2012), demonstrated that this lithostratigraphic unit is partially coeval with the Santa Cruz Formation in the coastal localities. A newly recognised faunal horizon in the uppermost portion of the Colhue-Huapi Member (Upper Fossil Zone-UFZ) of the Sarmiento Formation at Gran Barranca, has also been referred to the 'Pinturan' sub-age (Kramarz *et al.*, 2010, Fig. 1). Considering the available information, Kramarz *et al.* (2010) suggested a time span of 18.75 to 16.50 Ma for the 'Pinturan' sub-age.

The 'Notohippidian' fauna were described initially as typifying the 'étage Notohippideen' by Ameghino (1900-1902, 1906), based upon a diverse collection of fossils made by his brother Carlos during a single expedition in 1890. Ameghino stated that the most important horizons of these fauna were at Karaiken, at the northeastern border of Lago Argentino (Fig.1). Kraglievich (1930) renamed this stage as the 'Karaikense', also including the 'Astrapothericulan' fauna within it. While initially proposed as a pre-Santacrucian transitional fauna (Ameghino 1900-1902, 1906; Simpson, 1940), the majority of subsequent researchers also considered the 'Notohippidian' fauna as simply a local assemblage of basal Santacrucian taxa (Feruglio, 1949b; Pascual and Odreman Rivas, 1971; Marshall and Pascual, 1977; Marshall *et al.*, 1983; Pascual *et al.*, 1996, 2002). An estimated age for the whole

exposed sequence at Karaiken based on the $^{40}\text{Ar}/^{39}\text{Ar}$ dating of two tephra horizons and sedimentary accumulation rates, indicate a range between ~18.5 and ~15.7 Ma (Marshall *et al.*, 1986; Perkins *et al.*, 2012). A 'Notohippidian' assignation was also given to a small collection of fossil mammals made south of the town of Calafate, at the Estancia Quién Sabe and Cerro Centinela, very close to the Chilean border (Feruglio, 1944, 1949b; Marshall and Pascual, 1977; Scillato-Yané, 1981; Ribeiro and Bond, 1999; Abello, 2007¹; González Ruiz and Scillato-Yané, 2009). Furque and Camacho (1972) placed all these localities within the westernmost inland facies of the Santa Cruz Formation.

Outside Patagonia, Pansantacrucian faunas have been recognized in the Divisadero Largo area near Mendoza, Argentina (Mariño Formation of the Bermejo-Vinchina Basin: Cerdeño and Vucetich, 2007, Fig. 1); the Manantiales Basin (Chinches Formation) in San Juan, northern Argentina (López *et al.*, 2011); the Bolivian locality of Cerdas (Croft *et al.*, 2009); the Biblián Formation in the Cuenca Basin, and the Loma Blanca Formation in the Catamayo Basin of south-central Ecuador (Madden *et al.*, 1989, 1994); as well as the Cerro La Cruz (Castillo Formation) in the Lara State of Venezuela (Sánchez-Villagra *et al.*, 2004; Rincón *et al.*, 2010). Bostelmann *et al.* (2011) alluded that part of the Late Oligocene Fray Bentos Formation in south-western Uruguay could also contain younger facies with associated Colhuehuapian/Santacrucian faunas.

In Chile, almost all recorded Pansantacrucian faunas have been assigned indiscriminately to the Santacrucian SALMA, an assertion that undoubtedly requires a detailed revision. These faunas include from north to south: **a.** the Chucal fauna of the Chucal Formation in the Lauca Basin, northern Chile, dated between 19 and 17.5 Ma (Charrier *et al.*, 2002; Croft *et al.*, 2004, 2007); **b.** the enigmatic and imperfectly known Friasian fauna (Río Frías Formation) of Alto Río Cisnes, in the Aysén Region (Ameghino, 1906; Roth, 1908; Kraglievich, 1930; Marshall, 1990; Marshall and Salinas, 1990a; Flynn and Swisher, 1995; Bostelmann *et al.*, 2012); **c.** the undated Pampa Castillo and Pampa Guadal faunas, in the northern portion of the Austral Basin, south of Lake General Carrera (Flynn *et al.*, 2002;

¹ Abello, A. 2007. Sistemática y bioestratigrafía de los Paucituberculata (Mammalia, Marsupialia) del Cenozoico de América del Sur. Ph.D. Thesis (Unpublished), Universidad Nacional de La Plata, Facultad de Ciencias Naturales y Museo: 381 p.

De la Cruz and Suárez, 2006; Bostelmann and Buldrini, 2012); and **d.** a handful of spatially unconnected mammal fossil-bearing deposits assigned to the Palomares Formation of the Austral Basin at Puerto Natales, Sierra Baguales, Laguna del Toro, Lake Blanco and Tierra del Fuego in the Magallanes Region (Keidel and Hemmer, 1931; Decat and Pomeyrol, 1931; Hemmer, 1935a; Simpson, 1941; González and Tapia 1952a²; Marshall and Salinas, 1990b). Other localities undoubtedly containing Pansantacrucian faunas in Chile are the largely undescribed ‘Las Leñas’ fauna of central Chile, the only to have been formally considered as a Colhuehuapian age fauna (Flynn *et al.*, 1995); and the Early Miocene basal sections of the Cura-Mallín Formation in the Laguna del Laja (Flynn *et al.*, 2008; Luna *et al.*, 2011; Shockey *et al.*, 2012) and Lonquimay sub-basins (Marshall *et al.*, 1990; Suárez *et al.*, 1990; Suárez and Emparan, 1995; Croft *et al.*, 2003; Buldrini and Bostelmann, 2011). Recently, Kramarz *et al.* (2010) alluded that the late Early Miocene faunas of Chucal and Laguna del Laja could be referred to the ‘Pinturan’ sub-age. Similarly, Chick *et al.* (2010) commented on the potential ‘Pinturan’ age for the fauna of Pampa Castillo based on the evolutionary stage of the fossil rodent assemblage.

While both the Chucal and Laguna del Laja faunas are currently being intensively investigated, the remaining Neogene Chilean localities/faunas have received only marginal attention, with no active prospecting and almost all its paleontological content remaining virtually unpublished. Especially dramatic is the situation of the faunas in Magallanes, which have never been investigated in detail and are only known through poorly recorded casual findings (Hemmer, 1935a; Simpson, 1941; Marshall and Salinas, 1990b). In the following paragraphs we document a new Neogene terrestrial fauna of Magallanes, recovered from late Early Miocene fluvio-lacustrine successions at Sierra Baguales in the northeastern Última Esperanza Province. We provide a detailed lithostratigraphic section, an interpretation of the depositional environment, direct age constraints, and a preliminary description of the vertebrate fossil content, with some comments on its biostratigraphic and geochronologic importance.

3. Previous work and regional stratigraphy

Recent field campaigns have shown that the Cenozoic (and almost surely the latest Cretaceous) stratigraphic succession in Sierra Baguales mirrors the sequence located south of Lago Argentino, in Argentina, allowing a direct correlation of those better known units with the Chilean succession. Moreover, the Sierra Baguales strata clearly represent the continuity of these units across the international border, which presents an opportunity to clarify and unify the diverse nomenclature used for the same stratigraphic units both within and between the two countries (Table 1).

The Río Baguales Formation (Cecioni, 1957) was described in detail by Le Roux *et al.* (2010), who tentatively assigned its upper part to the Chattian-Aquitania (28.4-20.4 Ma) but mentioned Late Eocene sharks, rays and chimeroid fishes in its basal portion. It is here reconsidered and correlated with the Man Aike Formation of southwestern Argentina (Piatnitzky, 1938; Feruglio, 1938; Furque, 1973; Marensi *et al.*, 2002). The latter formation was initially assigned to the Late Cretaceous (Maastrichtian) and subsequently dated as late Middle to Late Eocene based on its marine micropaleontological content (Malumián, 1990; Concheyro, 1991; Camacho *et al.*, 2000; Malumián and Nández, 2011), fossil invertebrates and direct ⁸⁷Sr/⁸⁶Sr dating (Casadio *et al.*, 2009). Pérez Panera (2013) suggested an Early to Middle Eocene age for the subsurface deposits of this formation. A well-represented fossil record of cartilaginous fishes (Chondrichthyes) in the Río Baguales Formation presents a rich Middle to Late Eocene assemblage with narrow affinities to paleoichthyofaunas recovered from the North Atlantic, as well as reworked Early to Middle Eocene, Paleocene and Maastrichtian fragments (Otero *et al.*, in press). Zircons from the Río Baguales Formation have also yielded a latest Middle Eocene age of 40.48±0.37 Ma (Le Roux, 2012). The Man Aike Formation was named initially by Piatnitzky (1938) and Feruglio (1938), but re-defined and separated from the Calafate Formation by Furque (1973), whereas the Río Baguales Formation was first referred to as such by Cecioni (1957) and Hoffstetter *et al.* (1957). As a general rule in lithostratigraphy, the name first

² González, E.; Tapia, G. 1952a. Informe Geológico Preliminar en el Anticlinal Manzano y Área de los Cerros Palomares-Estancia Río Verde. Informe (Unpublished) N° I.0100.0049, Empresa Nacional del Petróleo (ENAP): 146 p. Punta Arenas.

TABLE 1. PROPOSED SUBDIVISION AND NOMENCLATURE OF LITHOSTRATIGRAPHIC UNITS IN SIERRA BAGUALES, AS CORRELATED WITH THEIR ARGENTINIAN COUNTERPARTS.

Cenozoic stratigraphic units (Northwestern Magallanes, Chile)	Cenozoic stratigraphic units (Lago Argentino, Argentina)	Age (Ma)	Depositional Environment
Santa Cruz Formation (=Palomares Formation?)	Santa Cruz Formation	19-18 (19-15 in Argentina)	Continental fluvial
Estancia 25 de Mayo Formation	Estancia 25 de Mayo Formation (Ex Centinela Formation)	20-19	Shallow marine
La Cumbre Sill	-	21?	Olivine-rich gabbro (intrusive)
Río Leona Formation (=El Salto Formation?)	Río Leona Formation	24?-22?	Continental fluvial
La Cumbre Sill	-	-	Olivine-rich gabbro (intrusive)
Man Aike Formation (Río Baguales Formation)	Man Aike Formation	40-36?	Estuarine

given to a unit has preference over names assigned later, unless duplicated in other, different units, so that the name Man Aike Formation should take preference in this case.

In Argentina, the Man Aike Formation is unconformably overlain by the continental Río Leona Formation (Feruglio, 1944, 1949b; Furque, 1973; Malumián, 1990; Marensi *et al.*, 2000, 2005), attributed to the early Chattian by Barreda *et al.* (2009), based on the distribution and content of its palynomorph assemblage. In Sierra Baguales, the Man Aike Formation is capped by a thick olivine-bearing gabbro sill (Le Roux *et al.*, 2010), here preliminarily named the La Cumbre Sill. The latter is overlain by continental deposits previously referred to as the Las Flores Formation (Cecioni, 1957; Le Roux *et al.*, 2010). Nevertheless, this unit seems to include sedimentary sequences comparable to the upper member of the Río Turbio Formation in the Cancha Carrera and Río Turbio areas of Argentina (Hünicken, 1955; Nullo and Combina, 2002). Tracing the north-south trend of the Oligocene-Miocene continental sedimentary sequences, it is reasonable to consider that the Río Leona and Río Guillermo Formations probably represent the same depositional interval. A direct zircon U-Pb (SHRIMP-RG) age of

21.7 Ma from volcanic ash at Cancha Carrera (Fosdick *et al.*, 2011) indicates an Early Miocene age for the Río Guillermo/Río Leona Formation, challenging the current view of an exclusively Paleogene age for these rocks (Nullo and Combina 2002; Barreda *et al.*, 2009; Pérez Panera, 2013; but see Panti, 2011). As Cecioni (1957) mentioned the presence of plant fossils, in particular *Nothofagus*, Hoffstetter *et al.* (1957) correlated the Las Flores Formation with the continental, *Nothofagus*-bearing El Salto Formation north of the Gulf of Skyring and assigned it to the Oligocene. However, the Río Leona Formation was already named as 'Estratos de Río Leona' by Feruglio in 1938 (and subsequently redefined by Furque and Camacho, 1972), whereas the El Salto Formation was only later named by González and Tapia (1952b)³. Consequently, the name Río Leona Formation should also take preference over the El Salto Formation if these correlations should prove to be correct in future research.

In Sierra Baguales, the Río Leona Formation is at least partially capped by an olivine-bearing gabbro sill, which field observations have shown to be transgressive and thus probably belonging to the La Cumbre intrusive. A recently published age of 19.7 Ma from a possibly related dacite flow

³ González, E.; Tapia, G. 1952b. Levantamiento Geológico Estructural en el Área de Estancia El Salto-Sección Las Coles. Informe (Unpublished) N°1.0100.0043, Empresa Nacional del Petróleo (ENAP): 32 p. Punta Arenas.

collected at the foot of Cerro Ciudadela, east of the Baguales River (Fosdick *et al.*, 2011), might indicate a late Early Miocene age for this magmatic event. The basalt flows are overlain by a marine succession that undoubtedly represents the Early Miocene 'Patagonian/Superpatagonian' transgression of Ameghino. This unit was previously known as the Centinela Formation and recently renamed the Estancia 25 de Mayo Formation by Cuitiño and Scasso (2010), as the early name duplicates that of a previously named Ordovician unit in northwestern Argentina (Harrington and Leanza, 1957). In Sierra Baguales, this marine unit overlies the La Cumbre Sill and contains a diverse assemblage of marine invertebrates including facies with oyster reefs, soft-bottom bivalves, gastropods, and crab fossils. As this unit was previously not formally recognised in the area, the name Estancia 25 de Mayo Formation is retained here.

The Estancia 25 de Mayo Formation is apparently absent east of the Fitz-Roy Channel, where the Río Leona Formation is overlain unconformably by the continental Palomares Formation, assumed to be of Early to Middle Miocene age (González and Tapia, 1952b)³. Unlike the Río Leona Formation, the latter unit contains characteristic Pansantacrucean vertebrate fossils (Hemmer, 1935a, b; Simpson, 1941; Thomas, 1949; Marshall and Salinas, 1990b) and thus probably correlates with the basal part of the Santa Cruz Formation in Sierra Baguales. Nevertheless, besides the Palomares Formation other assumed Early Miocene deposits have been considered as temporal and stratigraphic equivalents of the Santa Cruz Formation in Magallanes. This includes the Laurita and El Salto Formations (north and central Magallanes), and the Río Cóndor Formation in Tierra del Fuego (Marshall and Salinas, 1990b). Except for the El Salto Formation, none of these units has yet been dated radiometrically, and their paleontological content is virtually unknown. Although Marshall and Salinas proposed a direct correlation between the El Salto and Palomares Formations with the Los Dos Mellizos and Bon Accord Members of the Santa Cruz Formation, respectively (Marshall and Salinas 1990b), the available evidence is presently inconclusive to support this assumption. The lack of detailed lithostratigraphic studies in the Magellanian units coupled with the dubious taxonomic assignments given to the few described vertebrate fossils precludes a definitive conclusion about the

relationships between those units. Future work in the eastern part of the Magallanes Region is required to clarify these suggested correlations. Nevertheless, as the Santa Cruz Formation was first referred to by Ameghino (1889) as the 'Piso Santacruceño' (Marshall, 1976; Vizcaíno *et al.*, 2012a) and later formalized by Zambrano and Urien (1970), this name is retained here instead of Palomares, which was first used by Keidel and Hemmer in 1931.

4. Lithostratigraphy of the Santa Cruz Formation

The Santa Cruz Formation is exposed along the southern flank of Cerro Cono (Fig. 2), where it overlies the Estancia 25 de Mayo Formation with a conformable, gradational contact. We measured a 91 m thick stratigraphic section (Fig. 3) along a traverse that includes the following coordinates from base to top: S50°42'03.6'/W72°24'32.9'; S50°42'5.2'/W72°24'30.7'; S50°42'04.4'/W72°24'16.8'; S50°41'57'/W72°24'15.6'. True thicknesses (rounded to the nearest 10 cm) were determined with a tape measure and Brunton compass, applying corrections incorporating the traverse orientation, slope angle and spatial orientation of the strata. The following subdivision (from bottom to top of section) is generally based on fining-upward successions with prominent basal sandstones or conglomerates. Many minor fining-upward cycles are present, but due to the nature of the outcrops are not always clearly exposed.

Unit 1 has a total thickness of 32.7 m. Overlying an erosional contact at the base is a 0.7 m thick, reddish brown, trough cross-laminated, medium- to coarse-grained sandstone, in which the troughs are up to about 1 m wide. The sandstone is poorly sorted with sub-rounded chert clasts together with clay pellets and lenses. It grades into a 1.5 m thick, medium- to very coarse-grained sandstone with wider trough cross-laminae. Overlying this sub-unit with an erosional contact is a low-angle and trough cross-bedded conglomerate with quartz and chert clasts up to 2 cm in diameter, grading upward into high-angle cross-bedded conglomerate with a medium-grained sandstone matrix. This fining-upward sub-unit is 0.5 m thick. It is followed by a 0.3 m thick, poorly sorted, coarse to very coarse sandstone with low-angle and trough cross-lamination. Above this sub-unit is a 0.3 m thick, matrix-supported, trough cross-bedded conglomerate with sub-rounded clasts up to 1.5 cm in diameter, overlain by a 1.9 m thick, trough

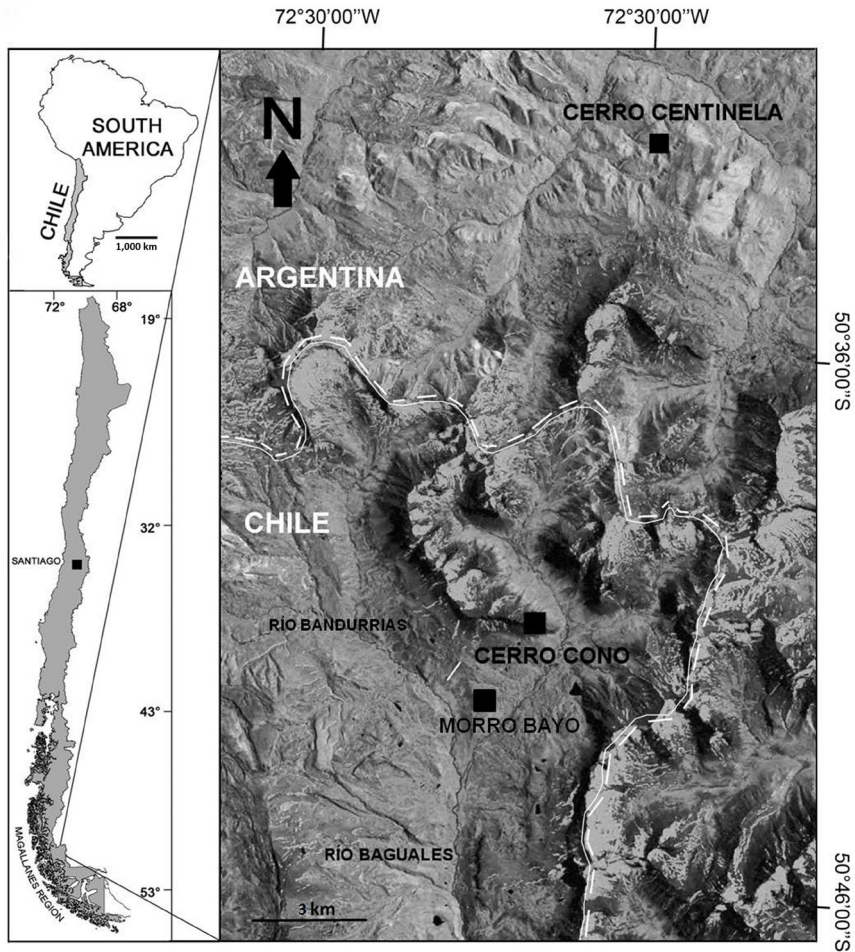


FIG. 2. Location of Sierra Baguales and places mentioned in text.

cross-laminated, medium- to very coarse-grained sandstone containing scattered quartz and chert clasts with a maximum diameter of 1 cm. At the top of unit 1 is a coarse-grained sandstone with epsilon cross-lamination and scattered clasts up to 1 cm in diameter, reaching a thickness of 0.4 m. The troughs in this basal, sandy part of unit 1 are up to 3 m wide, indicating currents generally flowing to the north-northeast, but varying between northwest and east. This sandstone package grades into a 19 m thick covered interval probably consisting of mudstone. The top of unit 1 reaches a total thickness of 8.1 m, consisting of dark, greyish green mudstone grading upward into blocky weathering, light green mudstone with medium- to coarse sandstone grains and vertebrate fragments. It has intercalations of light brown siltstone beds with a clay-rich matrix.

Unit 2 has an erosional basal contact overlain by a 0.5 m thick, dark brown, medium-grained sandstone showing high-angle planar cross-lamination and minor trough cross-lamination indicating northwest- to east-flowing currents. *Scoyenia* trace fossils within the sandstone consist of round, vertical tubes 4-7 mm in diameter (*Skolithos* Haldeman, 1840), as well as sinuous, short tubes along bedding planes (*Planolites* Nicholson, 1873). The sandstone fines upward into a 1.7 m thick interval of buff-weathering siltstones, which in turn grade into a 5.5 m thick greyish brown mudstone containing very fine-grained sandstone and siltstone lenses as well as scattered vertebrate fossil fragments. This is followed by greenish grey mudstone with dispersed clasts and vertebrate fragments, with a thickness of 9.9 m. The total thickness of unit 2 is 17.6 m.

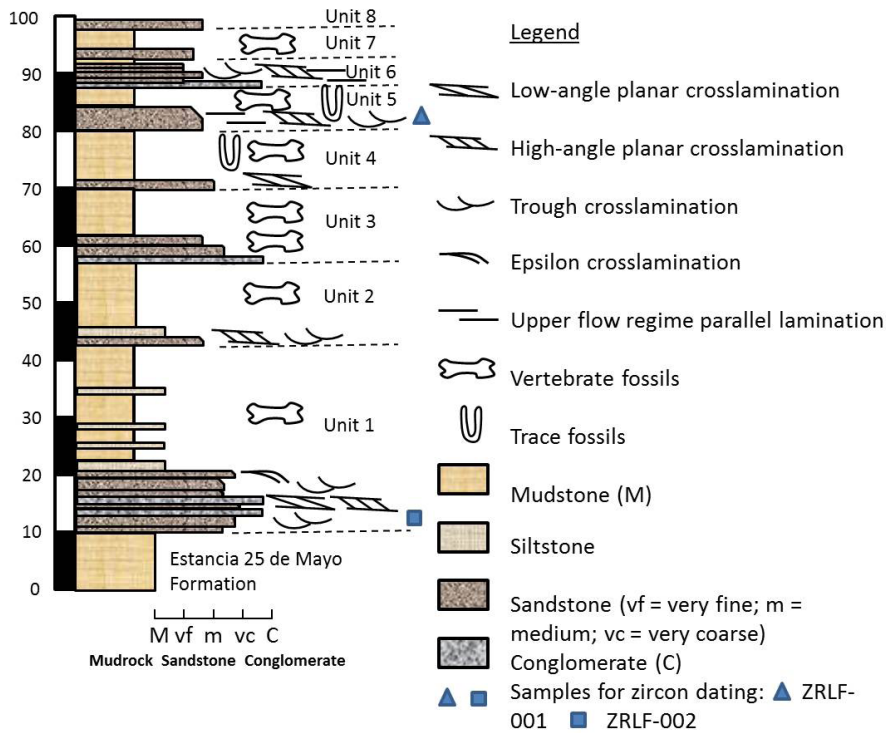


FIG. 3. Measured lithostratigraphic column of the basal part of the Santa Cruz Formation.

Unit 3, with a total thickness of 13.3 m, has a 1.0 m thick conglomerate at the base with small (up to 1 cm), multi-coloured chert and quartz clasts, grading towards the east into sandy conglomerate. The conglomerate fines upward into 1.6 m of fine-grained, olive green sandstone with vertebrate fragments, in turn overlain by a 1.4 m thick, brown, pebbly sandstone with fossil wood fragments. This sandstone grades into a 9.3 m thick unit of brownish, greenish and reddish grey mudstone with small, scattered pebbles and sand grains, as well as vertebrate fragments.

Unit 4 starts with a 1.9 m thick, whitish, medium-grained sandstone at the base, which is low-angle planar cross-laminated. It grades upward into a 3.1 m thick, greenish mudstone. Locally, a small lens (up to 0.4 m thick) of coarse-grained, greenish white sandstone with a sharp basal contact separates this mudstone from overlying, red, sandy mudstone reaching a thickness of 3.8 m and containing mm-scale bifurcating traces. The unit is capped by a 1.6 m thick, greenish mudstone. Vertebrate fragments are present throughout unit 4, which has a total thickness of 10.8 m.

Unit 5 is 8.6 m thick and commences with a 4.6 m thick, yellowish, clay-rich, fine- to medium-grained sandstone with upper flow regime horizontal lamination, rare trough cross-lamination and high-angle cross-lamination. Soft-weathering concretions within this sandstone contain mm-thick, upward-branching traces (probably due to hymenopterids). This sandstone grades into a 4.0 m thick interval of chocolate-brown and reddish mudstone with cm-scale, fine to medium sandstone lenses.

Unit 6 has an erosional basal contact and a total thickness of 4.6 m, which can be subdivided into 5 fining-upward sub-units (6a-e) separated by sharp to erosional contacts. It commences with a 0.3 m thick, clast-supported conglomerate with subangular quartz and chert pebbles up to 2.5 cm in diameter in a fine to medium sandstone matrix. High-angle planar and trough cross-bedding are prominent. This bed fines upward into a 0.8 m thick, matrix-supported, low-angle planar cross-bedded conglomerate with subrounded quartz and chert clasts, grading into poorly sorted, coarse to medium sandstone with upper flow regime parallel lamination at the top. This is cut by a reddish, medium-grained sandstone with scattered

clasts up to 0.5 cm in diameter, showing low-angle planar cross-lamination. It has a thickness of 0.85 m. Sub-unit 6b, 0.55 m thick, is a medium to coarse-grained sandstone with subrounded quartz and chert grains, showing high-angle planar cross-lamination and upper flow regime parallel lamination. It overlies with an erosional contact by sub-unit 6c, a very coarse to coarse, poorly sorted, fining-upward sandstone with scattered, subrounded clasts and low-angle planar cross-lamination, with a thickness of 0.45 m. Sub-unit 6d is 0.6 m thick, fining upward from poorly sorted, medium sandstone with isolated clasts and mudstone pellets up to 0.5 cm in diameter, to fine-grained, well sorted, massive sandstone with locally reddish colours. Sub-unit 6e is a 0.75 m thick sandstone similar to the top of unit 6, containing scattered, small pebbles and vertebrate fragments. It grades upward into a 0.3 m thick bed of maroon mudstone.

Unit 7 is a 5.0 m thick, fining-upward cycle consisting of a 1.1 m thick, yellowish green, fine- to medium-grained sandstone with a clay-rich matrix, overlain by a 1.5 m thick, red mudstone with blocky weathering and small biotite flakes. This mudstone grades into light greyish green mudstone reaching a thickness of 1.6 m, and finally a 0.8 m thick interval of buff-weathering mudstone with minute blocky weathering. Thin (<0.25 m) beds of mudstone with coarser blocky weathering occur within this part of the cycle.

Unit 8 consists of yellowish, medium- to coarse-grained, poorly sorted sandstone with a clay-rich matrix. It has a preserved thickness of 1.4 m at the top of the measured section.

Higher up on Cerro Cono, the Santa Cruz Formation is unconformably overlain by Plio-Pleistocene basalts, which form the watershed and frontier between Chile and Argentina in this area (Fig. 2).

5. Sandstone and conglomerate petrography

Two thin sections were made of a conglomerate and pebbly sandstone, from units 1 and 5, respectively. Zircons were separated from the same samples for U-Pb dating.

The conglomerate (sample ZRLF-002, unit 1) consists of clast-supported, sub- to well-rounded pebbles up to 60 mm in diameter in a coarse to very coarse sandstone matrix. There is very little cement (which is composed of Si, where present), so that

the sample has a high porosity. The pebbles are composed of quartzite with sutured grain contacts, pure quartz apparently derived from a porphyritic rhyolite, and devitrified glass (palagonite) with a spherulitic texture.

The pebbly sandstone (sample ZRLF-001, unit 5) is very poorly sorted with sub-angular grains, classifying as a lithic arkose. Pebbles are up to 60 mm in diameter, including fine-grained, well-sorted quartz wacke, metamorphic quartzite with sutured contacts, and chert. The medium- to very coarse-grained sand fraction contains quartz, plagioclase with Karlsbad twins, volcanic rock fragments with plagioclase laths, clinopyroxene (including titanite), and rare, untwinned and slightly weathered K-feldspar. The fresh appearance of the plagioclase and volcanic fragments, together with the presence of pyroxene, suggest a relatively short distance of transport from a tectonically active source area rich in newly formed basalts. Like the conglomerate, this rock is also very porous, indicating a high-energy environment where finer sediments such as clay could not settle out. Some pores have a lining or are filled with well-developed zeolite crystals, suggesting low-grade metamorphism.

6. Depositional environment

There can be little doubt that the Santa Cruz Formation in this area was deposited in a continental, fluvial environment, as indicated by the abundance of terrestrial vertebrate fragments, *Scoyenia* including probable hymenopterid traces, multi-coloured (often reddish), blocky-weathering mudstones (Fig. 4) with occasional mud-cracks, and sandstones showing sedimentary structures such as trough, epsilon and high-angle planar cross-lamination (Fig. 5), with a more or less consistent paleocurrent direction towards the east-northeast.

Although fossil leaves and wood are absent or at least very rare in the Santa Cruz Formation, a fairly large diversity of microfossil remains have been found, amongst others arthropod appendages and butterfly wing scales, as well as fungi and acritarchs. Normally, pollen and spores are scarce in oxidized deposits (Traverse, 1988), but in spite of this we have identified a mixture of herbaceous species, shrubs, tree ferns, and trees, including the families Poaceae Barnhart, 1895, Asteraceae Berchtold and Presl, 1820, Chenopodiaceae Ventenat, 1799, Proteaceae De Jussieu, 1789, Nothofagaceae Kuprianova, 1962,

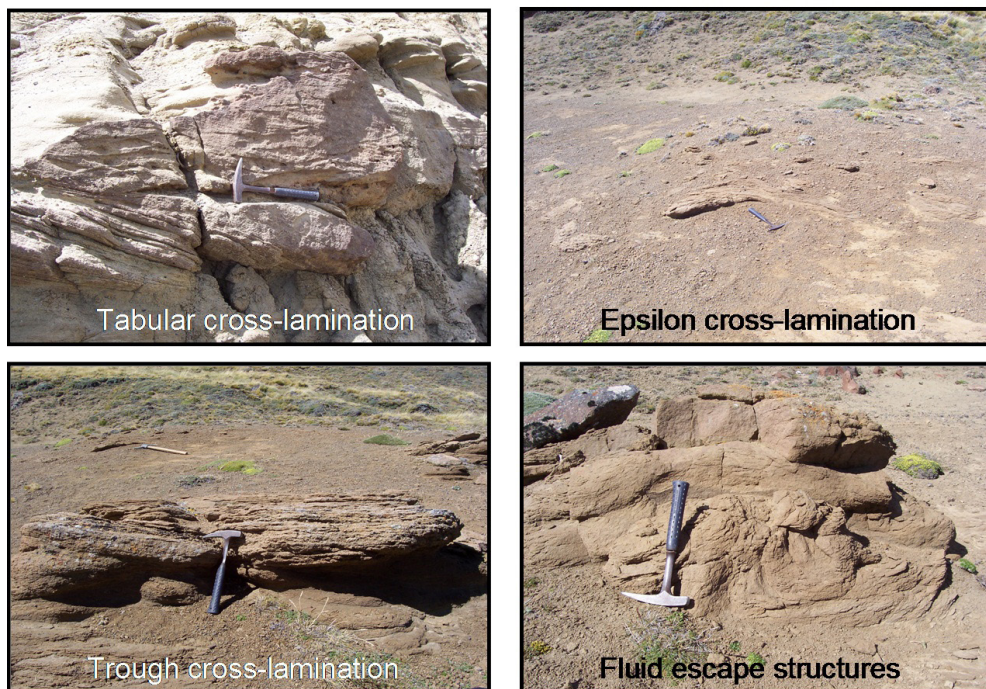


FIG. 4. Typical sedimentary structures in sandstones of the Santa Cruz Formation.



FIG. 5. Multi-colored mudstones of the Santa Cruz Formation on the southern flank of Cerro Cono.

Podocarpaceae Endlicher, 1847, Onagraceae De Jussieu, 1789, Myrtaceae De Jussieu, 1789, and Cyatheaaceae Kaulfuß, 1827.

The lenticular nature of the sandstones, their fine to medium grain-size, relatively small-scale fining-upward cycles, and the presence of epsilon cross-lamination in places suggest deposition on point bars in slightly meandering river channels, as supported by the comparatively thick overbank mudstones. Although outcrops of the latter are mostly covered, it is probable that some of the thicker mudstone/shale units represent ephemeral floodplain lakes. The Skolithos ichnofacies Seilacher, 1967 is normally considered to represent shallow marine deposits, but *Skolithos* is also characteristic of the shore zones of ephemeral lakes and river floodplains (Frey *et al.*, 1984).

Paleocurrent directions were recorded wherever possible, using high-angle planar and trough cross-lamination (Fig. 6). The measurements were tilt-corrected by rotating the strikes and dips of the containing strata to the horizontal, using the spreadsheet program of Le Roux (1991). Vector mean, magnitude and sinuosity values were subsequently calculated according to the methodology of Le Roux (1992, 1994). For the Santa Cruz Formation as a whole, the vector mean is 60° , with a vector magnitude of 86.4% and a sinuosity index of 1.28. The latter suggests

ivers with a medium sinuosity, although this might be due to the fact that relatively few measurements ($n=80$) could be taken.

7. Vertebrate fossil content and age of the Santa Cruz Formation in Sierra Baguales

Well preserved Cenozoic fossils are abundantly exposed in the sedimentary successions of Sierra Baguales, including the Man Aike Formation (marine vertebrates, invertebrates, traces and leaf impressions), Río Leona Formation (leaf impressions and wood fragments) and Estancia 25 de Mayo Formation (marine invertebrates and traces) (Hoffstetter *et al.*, 1957; Torres *et al.*, 2009; Le Roux *et al.*, 2010; Sallaberry *et al.*, 2010). Nevertheless, the first and only mention on the occurrence of fossil mammals in the area was made by Marshall and Salinas (1990b), based on a few fragmentary specimens held in the private collection of the late Mr. Oscar Vidal, at that time the owner of the Estancia La Cumbre. In that contribution, Marshall and Salinas identified and figured the remains of an astrapotheriid ungulate (referred to as *Astrapotherium magnum*), and part of the maxillary of a 'notohippine' 'Notohippidae' considered as an unknown ungulate by the authors (fossil identified by E. Bostelmann based on figure 13 of Marshall and Salinas, 1990b). During the last two seasons we collected fossil vertebrates in the Santa Cruz Formation on the southern slopes of Cerro Cono, in a small area of about 0.8 km², north of the confluence of the Baguales and Bandurrias Rivers (Fig. 2). All the remains were located between the 1,100 and 1,200 m altitude line, forming discrete patches in exposed ravines and buttes, of which the most relevant is Morro Bayo (Figs. 2, 7). The materials are mostly composed of isolated pieces (bone fragments, teeth, osteoderms, vertebrae), and associated cranial and postcranial elements. Most of the bones were collected on surface having been eroded from soft mudstone, thus lacking a precise stratigraphic position, although field work has shown their occurrence in all the exposed sedimentary units within the column (units 1 to 8). A few disarticulated but associated elements were also exhumed *in situ* from units 5 to 8, including maxillary and mandibular fragments, aggregated teeth, and cranial-postcranial portions.

Generally speaking, the bones present two distinct types of preservation. The vast majority

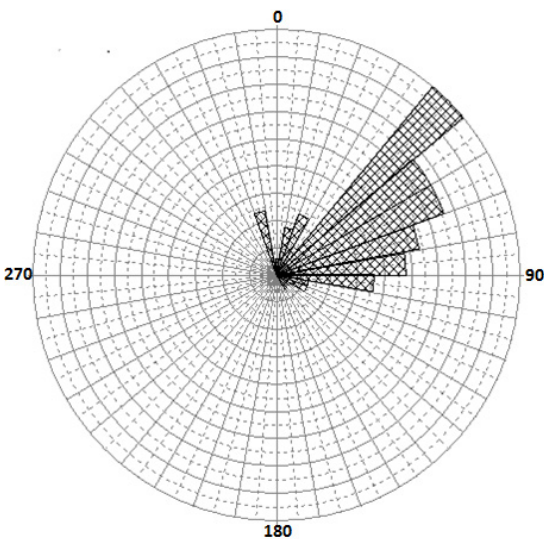


FIG. 6. Rose diagram of measured paleocurrent directions ($n=80$) in the Santa Cruz Formation.



FIG. 7. Morro Bayo, one of the most prominent sites with fossil vertebrates in the Santa Cruz Formation at Sierra Baguales.

show varied grades of integrity, with angular borders and little mechanical attrition and weathering. The occurrence of associated elements with high structural density, such as cranial portions, hemi-mandibles, and teeth, suggests an autochthonous/parautochthonous origin for all these materials, with limited transport and quick burial. A second fraction of the bones includes more reworked material, with rounded borders, intense abrasion, and extensive fractures, suggesting a parautochthonous/allochthonous origin. However, both types of preservation were detected in remains assigned to the most commonly recovered species within the column, leading us to suppose that the provenance of all the materials was relatively proximal.

So far, more than 200 specimens belonging to 23 vertebrate species have been identified. Almost all of the remains correspond to terrestrial fossil mammals, for which a preliminary taxonomic classification is given below (Table 2, Figs. 8 and 9). A detailed assessment of all the materials will be published as a separate paper devoted to the taxonomic identification and regional biostratigraphic context of the fauna. The majority of the specimens (including one potential holotype) were deposited in the Vertebrate Palaeontology collection of the Museo Nacional de Historia

Natural, in Santiago (SGO.PV. codes). The remaining materials are temporarily housed in the Vertebrate Palaeontology collection of José Luis Oyarzún in Puerto Natales, Magallanes (CPJLO codes), waiting for their final transfer to the future regional museum. The anatomical terminology used for each of the different taxonomic groups follows the proposed nomenclature of the corresponding references. Upper case and lower case letters denote the position of the teeth, with I/i referring to upper or lower incisors respectively, C/c to canines, P/p to premolars, and M/m to molars and molariforms. Quotation marks emphasize informal units or non-monophyletic groups.

Among the large mammals collected, the most abundant remains belong to a medium-sized astrapotheriid (Order Astrapotheria, Lydekker, 1894), from which some isolated teeth (*i.e.*, SGO.PV. 22.260, 22.261, CPJLO 051, 052; Fig. 8A and B) are here assigned to *Astrapothericulus iheringi* (Ameghino 1899). This species, easily characterized by its dental morphology, features: **1.** rugous and prominent basal cingula on the cheek teeth; **2.** upper premolars with V-shaped oriented labial cingula on the base of a bucal enamel fold; **3.** upper molars with a prominent parastyle engrossed in the base of the tooth, with a well-developed antero-lingual

TABLE 2. SYSTEMATIC LIST OF MAMMALIAN TAXA RECORDED IN THE SANTA CRUZ FORMATION AT SIERRA BAGUALES, ÚLTIMA ESPERANZA, MAGALLANES, CHILE.

Class Mammalia Linnaeus, 1758
 Infraclass Eutheria Gill, 1872
 Order Astrapotheria Lydekker, 1894
 Family Astrapotheriidae Ameghino, 1887
 Genus *Astrapothericulus* Ameghino, 1899
Astrapothericulus iheringi (Ameghino, 1899)
 Astrapotheriinae indet.
 Order Notoungulata Roth, 1903
 Family Toxodontidae Gervais, 1847
 Genus *Nesodon* Owen, 1846
Nesodon sp.
 Genus *Adinotherium* Ameghino, 1887
Adinotherium sp.
 Family ‘Notohippidae’ Ameghino, 1894
 ‘Notohippinae’ aff. *Notohippus toxodontoides* Ameghino, 1891
 Order Litopterna Ameghino, 1889
 Family Proterotheriidae Ameghino, 1887
 Genus *Paramacrauchenia* Bordas, 1939
Paramacrauchenia scamnata (Ameghino, 1902)
 Proterotheriinae indet.
 Order Cingulata Illiger, 1811
 Family Dasypodidae Gray, 1821
 Genus *Proeutatus* Ameghino, 1891
Proeutatus sp. nov.
Proeutatus sp.
 Family Glyptodontidae Gray, 1869
 Propalaeophlorinae indet.
 Order Pilosa Flower, 1883
 Family Megalonychidae Gervais, 1855
 Megalonychidae indet.
 Tardigrada indet.
 Order Rodentia Bowdich, 1821
 Caviioidea indet.
 Family Neoepiblemidae Kraglievich, 1926
 Genus *Perimys* Ameghino, 1887
Perimys incavatus Ameghino, 1891
 Family Echimyidae Miller and Gidley, 1918
 Genus *Adelphomys* Ameghino, 1887
Adelphomys candidus Ameghino, 1887

fosette; 4. complete basal cingula in lower molars; and 5. absence of an accessory cuspule in the central valley of the upper molars (Kramarz, 2009). The genus *Astrapothericulus* is restricted to the Colhuehuapian through basal Santacrucian (‘Notohippidan’ stage) SALMAs of Patagonia (Kramarz, 2009), and south central Chile (Luna *et al.*, 2011). Our find extends the geographic

distribution of this species in the country by almost 1,500 km to the south, also making this occurrence the southernmost record for the genus *Astrapothericulus*. Well preserved post-cranial remains, including an associated femur, tibia and radius (CPJLO 069A-E), are also assigned to *Astrapothericulus iheringi*. A few large upper canines which exceed the normal mean of a typical medium-sized astrapotheriid (*i.e.*, CPJLO 086), are referred to an unknown Astrapotheriinae. While it is very likely that all these remains also belong to *Astrapothericulus*, the absence of diagnostic dental elements associated with these fragments prevents their specific identification. Given that the size range of the Sierra Baguales specimens of *Astrapothericulus iheringi* is slightly above the mean for the genus in northern localities (Kramarz, 2009), we prefer to be conservative and preliminarily recognize the existence of only one medium-sized species in the deposits. Nevertheless, it should be emphasized that Early Miocene astrapotheriids include a great diversity of taxa ranging from gigantic to small forms, this being the period of greatest known diversity of the order (Kramarz and Bond, 2010, 2011).

A second large taxon is represented by isolated and fragmentary molars (*i.e.*, CPJLO 089, 090, 101) belonging to a ‘Nesodontinae’ Toxodontidae Gervais 1847, which we refer to the genus *Nesodon* Owen 1846; a typical indicator of the Santacrucian land mammal age in South America (Ameghino, 1904; Scott, 1912; Madden, 1990⁴; Croft *et al.*, 2004). Due to the disproportionate number of named species within this genus, an exhaustive revision of the more abundant and typological Argentinean materials would be necessary before a specific assignment can be made for the Magallanean specimens. The Baguales material represents one of the earliest occurrences of the genus *Nesodon* in the fossil record, otherwise restricted to the ‘Pinturan’ through Colloncuran ages of Argentina and Chile (Ameghino, 1906; Flynn *et al.*, 2002; Croft *et al.*, 2003, 2004; Kramarz and Bellosi, 2005; Bond and Kramarz, 2008).

Medium-sized mammals in Sierra Baguales include members of the Orders Notoungulata Roth 1903, and Litopterna Ameghino 1889. Notoungulates

⁴ Madden, R.H. 1990. Miocene Toxodontidae (Notoungulata, Mammalia) from Colombia, Ecuador and Chile. Ph.D. Thesis (Unpublished), Duke University: 407 p.

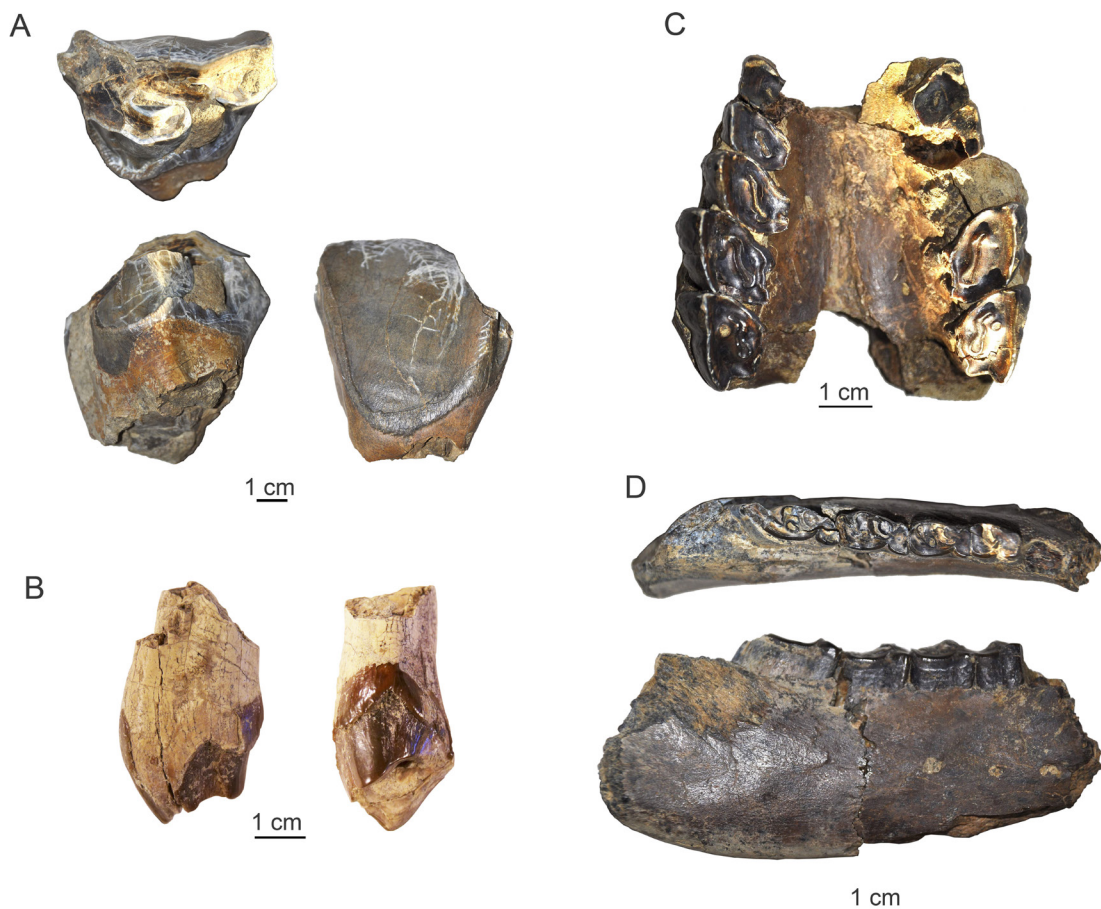


FIG. 8. Selected specimens of large and medium mammals of the Sierra Baguales fauna. *Astrapothericulus iheringi* Ameghino 1899: **A.** CPJLO 055, isolated left upper second molar (M2) in occlusal, lingual, and labial views; **B.** SGO.PV. 22.260, isolated right third upper premolar (P3) in anterior and lingual views. ‘Notohippinae’ aff. *Notohippus toxodontoides*; **C.** CPJLO 030A, maxillary portion with left P3, M2-M3 and right P3-M3 series, in occlusal view; **D.** CPJLO 030B, right dentary fragment with p4-m3, in occlusal and labial views. **C** and **D** belong to the same individual.

are represented by abundant mandibular fragments with their associated dentitions (CPJLO 008, 009) and maxillary portions (SGO.PV. 22.310, 22.315; CPJLO 018, 030A-C; Fig. 8C and D) of a notohippine ‘Notohippidae’ Ameghino 1894, which can be assigned either to *Argyrohippus boulei* Ameghino 1901, or *Notohippus toxodontoides* Ameghino 1891a. The fragmentary nature of the type material upon which Ameghino created *Notohippus toxodontoides* prevents any definitive distinction between both entities, so that a complete revision of these genera will be required to demonstrate their taxonomic validity (as partially commented on by Ribeiro and Bond, 1999). Notohippines were abundant towards the end of the Oligocene and beginning

of the Miocene in Patagonia, having their last appearance in the fossil record during the ‘étage Notohippidien’ (Ameghino, 1900-1902, 1906; Marshall, 1976; Marshall and Pascual, 1977). The Sierra Baguales remains represent the first documented occurrence of Neogene notohippids in the Chilean fossil record, and also the southernmost presence of this paraphyletic ‘family’ in South America.

Isolated teeth and incomplete hemi-mandibles with their dentitions (*i.e.*, SGO.PV., 22.335, 22.336, CPJLO 111, 112, 113) can be assigned to a medium-sized ‘Nesodontinae’, which we tentatively identify as *Adinotherium* Ameghino 1887, based on certain specific attributes of the occlusal morphology of

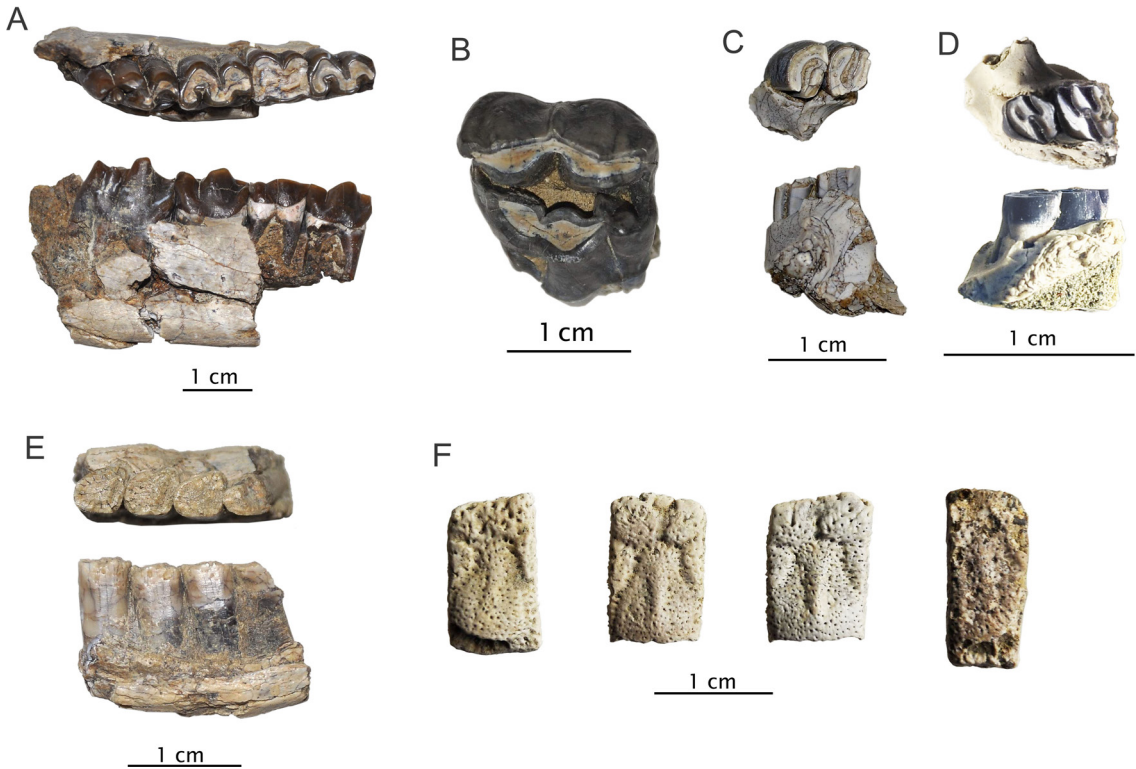


FIG. 9. Selected specimens of medium and small mammals of the Sierra Baguales fauna. *Paramacrauchenia scamnata* Ameghino 1902: **A.** CPJLO 001, left dentary fragment with p4-m3, in occlusal and lingual views; **B.** CPJLO 003, right M1 or M2? in occlusal view. *Perimys incavatus* Ameghino 1891; **C.** right maxillary fragment with P4 and M1, in occlusal and labial views. *Adelphomys candidus* Ameghino 1887; **D.** CPJLO 130, left maxillary fragment with DP4 and M1, in occlusal and lingual views. *Proeutatus* sp. nov.; **E** SGO.PV. 22.300, right dentary fragment with the last four molariforms (m7-m10?), in occlusal and labial views; **F.** Isolated osteoderms in dorsal view.

the teeth and the advanced stage of hypsodonty. As in the case of *Nesodon*, *Adinotherium* represents a classic Santacrucian representative ungulate, quite common in the type sections of the Santa Cruz Formation. In Chile, the occurrence of *Adinotherium* has been mentioned for the Pampa Castillo (Flynn *et al.*, 2002) and Pampa Guadal localities (De la Cruz and Suárez, 2006; Bostelmann and Buldrini, 2012) south of Lake General Carrera, and also from the upper Río Cisnes (Bostelmann *et al.*, 2012) and the Chucal fauna (Croft *et al.*, 2004).

Litopterns in the Sierra Baguales fauna include two different members of the family Proterotheriidae Ameghino 1887. The smallest is represented by two isolated upper molars and both dentaries of a young animal (CPJLO 001, 002, and 003; Fig. 9A and B), all assignable to *Paramacrauchenia scamnata* (Ameghino, 1902); a monotypic form previously

known exclusively from Colhuehuapian age localities in central Patagonia (Soria, 2001; Kramarz and Bond, 2005; Villafañe, 2009). Diagnostic characters observed in the Sierra Baguales specimens include on the upper molars: **1.** a reduced metaconule positioned at the union of the protocone and the hipocone; **2.** an open lingual side of the antero-lingual cingulum, without contact with the protocone; and **3.** small entoconids merged to bigger, medially positioned hipoconulids on the lower molars. Our record is the first mention of this genus and species outside the limits of Argentina and obviously the first for Chile. The second taxon is represented exclusively by a mandibular fragment with one well-preserved molar (CPJLO 004). It belongs to a form somewhat larger than *Paramacrauchenia scamnata*, which is easily distinguished because of the shape of its dental cusps. Although the

preserved tooth presents clear characters, a formal generic designation is not recommended due to the fragmentary nature of the material.

The Superorder Xenarthra Cope 1889, which presently includes sloths, anteaters and armadillos, is represented in the Sierra Baguales fauna by at least two different species of ground sloths, two different armadillos, and one glyptodont (Fig. 8). The identified sloth remains include isolated post-cranial bones such as caudal vertebrae, astragalus, metacarpals, some phalanx (*i.e.*, CPJLO 117, 119), and part of a small dentary with three broken molariforms (CPJLO 116). Unfortunately, this kind of skeletal element tends to be common within the sloth lineage and does not allow a refined taxonomic characterisation for each of the species, although the dentary and astragalus could be tentatively referred to an undetermined Megalonychidae Gervais 1855. The Order Cingulata Illiger 1811 (armadillos, glyptodonts, and relatives), is represented by a small eutatine Dasypodidae Bonaparte 1838, of which a mandibular and cranial fragment as well as two dozen isolated osteoderms were collected (SGO.PV. 22.300; Fig. 9E and F). While the general morphology of the teeth and the external ornamentation of the osteoderms suggest a direct resemblance with the genus *Proeutatus* Ameghino 1891b, the extremely small size -similar to the euphractine *Paraeutatus distans* Scott 1903- distinguishes the Sierra Baguales specimens from all previously known Pansantacrucian species of the genus, suggesting the presence of a new species in the Baguales record.

The second armadillo is represented only by isolated osteoderms (CPJLO 048), clearly belonging to a large member of the genus *Proeutatus*. The taxonomy of the many known different species of this genus is currently under revision by Argentinean colleagues (González Ruiz, 2010⁵; J.C. Fernicola, personal communication, 2012) making it recommendable to wait for the results before assigning a specific epithet to the Sierra Baguales specimens. In Chile, the genus *Proeutatus* has been mentioned without a detailed description from Early/Middle Miocene deposits of the Alto Río Císnes (Scillato-Yané *et al.*, 1989; González Ruiz, 2010⁵; Bostelmann *et al.*, 2012), and Pampa Castillo (Flynn *et al.*, 2002), both in the Aysén Region (Fig. 1).

Curiously, so far we have recovered only three isolated osteoderms of the usually abundant members of the glyptodont subfamily Propalaeohoplophorinae Ameghino 1891a, a frequent component in all Early Miocene Patagonian faunas.

Rodents are mostly represented in our assemblage by maxillary and mandibular remains of the neopiblemid *Perimys incavatus* Ameghino 1902 (*i.e.*, CPLJO 042, Fig. 9C), a common Colhuehuapian age-representative taxon (Ameghino, 1902, 1904; Kramarz, 2002; Vucetich *et al.*, 2010). Some diagnostic characters observed in our materials include: **1.** upper cheek teeth with rounded margins on the anterior laminae, and absence of enamel on the labial walls of M1 and M2; and **2.** lingual walls of m1 and m2 covered by enamel. This species has been recovered abundantly at the type locality of the Colhuehuapian SALMA at Puesto Almendra in Gran Barranca (Fig. 1), and also on Cerro Centinela in the Santa Cruz Province, Argentina (Kramarz, 2002; Vucetich *et al.*, 2010). The genus *Perimys* represents one of the most common hypselodont rodents in all the Early Miocene Pansantacrucian faunas of Patagonia, and while its occurrence in Chile has been cited previously for Pampa Castillo in the Aysén Region based on an unclear number of species (Chick *et al.*, 2010; Flynn *et al.*, 2002), this is the first time that *P. incavatus* is mentioned for a locality outside Argentinean Patagonia.

Isolated elements characterize the remaining rodents in the Sierra Baguales fauna. An incomplete upper molar is preliminarily referred to an unspecified member of the superfamily Cavoidea. A partially preserved right maxillary with an associated deciduous premolar and first molar (CPJLO 130; Fig. 9D) could be referred to an 'adelphomyine' Echimyidae Miller and Gidley 1918, from the '*Protacaremys-Adelphomys*' lineage (Kramarz 2001; Vucetich *et al.*, 2010). The extended procotone with a wide anteroloph forming a right angle in its antero-labial side, the prolonged hypoflexus, short labial flexus and loss of the metafossesets (at least in the DP4), allow us to recognize this specimen as *Adelphomys candidus* Ameghino 1887; a well known monotypic Santacrucian 'adelphomyine' (Kramarz, 2001, 2004). Another small rodent is represented by a partial dentary and some pieces of its incisor enamel band. Although

⁵ González Ruiz, L.R. 2010. Los Cingulata (Mammalia, Xenarthra) del Mioceno Temprano y Medio de Patagonia (Edades Santacrucense y 'Friasense'), revisión sistemática y consideraciones bioestratigráficas. PhD. Thesis (Unpublished), Universidad Nacional de La Plata, Facultad de Ciencias Naturales y Museo: 471 p.

clearly distinguishable, the fragmented nature of the remains prevents any possibility of a more refined taxonomic identification for this specimen.

During our field season in 2012, remains of at least 3 different bird species were collected from the Santa Cruz Formation in Sierra Baguales. The most notable is represented by a poorly preserved large bone, potentially belonging to a predatory bird (CPJLO 135). If this assignment is confirmed by detailed anatomical studies, this will become the first record of 'terror birds' in Chile. Finally, some isolated vertebrae are referred to an undetermined teleostid fish, but more diagnostic materials are needed to support a taxonomic identification for all these specimens.

In spite of the limited taxonomic sampling, a preliminary correlation can be proposed based on the species identified to date. The recovered fauna clearly suggest an Early Miocene (Burdigalian) age for this part of the Santa Cruz Formation, roughly ranging from 20 to 17.8 Ma (Colhuehuapian to basal Santacrucian age). The occurrence of typical Colhuehuapian species such as *Paramacrauchenia scamnata* and *Perimys incavatus* coupled with some Colhuehuapian- 'Notohippidian' taxa such as *Astrapothericulus iheringi*, supports a more close affinity with faunas older than the Santacrucian SALMA at their classic localities along the Atlantic Coast. The presence of species whose biochrones include both the Colhuehuapian and the Santacrucian, such as *Proeutatus* sp., as well as species whose initial biochrones fall within the 'Pinturan' (such as *Nesodon* sp.), lead us to believe that the mammal assemblage identified corresponds to a transitional faunal group between those of the classic Colhuehuapian localities (Gran Barranca, Bryn Gwyn, Sacanana, Cerro Bandera, Barda Negra, Paso Córdova, etc.) and those of the biostratigraphically 'higher' deposits of the Early Miocene continental series.

A preliminary correlation is suggested with the basal part of the Santa Cruz Formation south of Lago Argentino, which has been dated at 18.8 Ma by zircons from intercalated tuff in the Estancia Quién Sabe area (Cuitiño *et al.*, 2012). This formation is very similar in outcrop appearance to that in Sierra Baguales, consisting of multi-coloured mudstones intercalated with cross-laminated sandstones. The underlying, shallow marine/estuarine Estancia 25 de Mayo Formation was dated at 19.14 Ma by zircons from pyroclastic beds and 20.05-19.1 Ma by

$^{87}\text{Sr}/^{86}\text{Sr}$ ratios (Cuitiño *et al.*, 2012). On the basis of the recovered fossil assemblage, the age of the Early Miocene continental deposits in Sierra Baguales can thus be considered to lie somewhere between 19 and 18 Ma (post-Colhuehuapian- pre-Santacrucian), which is confirmed by our zircon dating of the rocks.

8. U-Pb dating of detrital zircons

The same samples described in section 4 (ZRLF-001 and ZRLF-002) were dated by detrital zircons using SHRIMP U-Pb at the Australian National University.

In sample ZRLF-002, the youngest spot age is 88.4 Ma, with scattered, older spot ages ranging to 3,114 Ma. Sample ZRLF-001, on the other hand, shows a peak of 14 grains between 18-19 Ma, the 22 grains in this cluster having a weighted mean $^{206}\text{Pb}/^{238}\text{U}$ age of 18.23 ± 0.26 Ma (Fig. 10). A subordinate cluster occurs between 80 and 110 Ma.

The fact that sample ZRLF-002, stratigraphically below ZRLF-001 in unit 5, does not show any signs of the cluster around 18-19 Ma, suggests that the basal part of the sedimentary succession may have been deposited before 18.23 Ma. However, if the upper part of the succession is younger than 18.23 Ma and the lower part older, it seems probable that this date lies very close to the real age of the formation, about 19-18 Ma.

9. Discussion

Our investigations in Sierra Baguales have demonstrated the occurrence of Neogene sedimentary units in the northwestern portion of the Magallanes Region, an area previously regarded by most researchers as underlain only by marine units of Cretaceous-Paleogene age, capped by Plio-Pleistocene volcanics and Quaternary fluvio-glacial deposits (however, see Furque, 1973 or Marshall and Salinas, 1990b). At the same time, our field work has encompassed much of the Cenozoic succession in the northern half of the region, along with dramatically increasing our knowledge on the paleontological diversity of this part of the country (Torres *et al.*, 2009; Le Roux *et al.*, 2010; Sallaberry *et al.*, 2010; Otero *et al.*, 2012a; Otero *et al.*, 2012b, in press).

Like much of Patagonia, the Neogene successions exposed in Sierra Baguales are composed of a marine unit, the Estancia 25 de Mayo Formation ('Patagonian Sea'), transitionally overlain by a continental

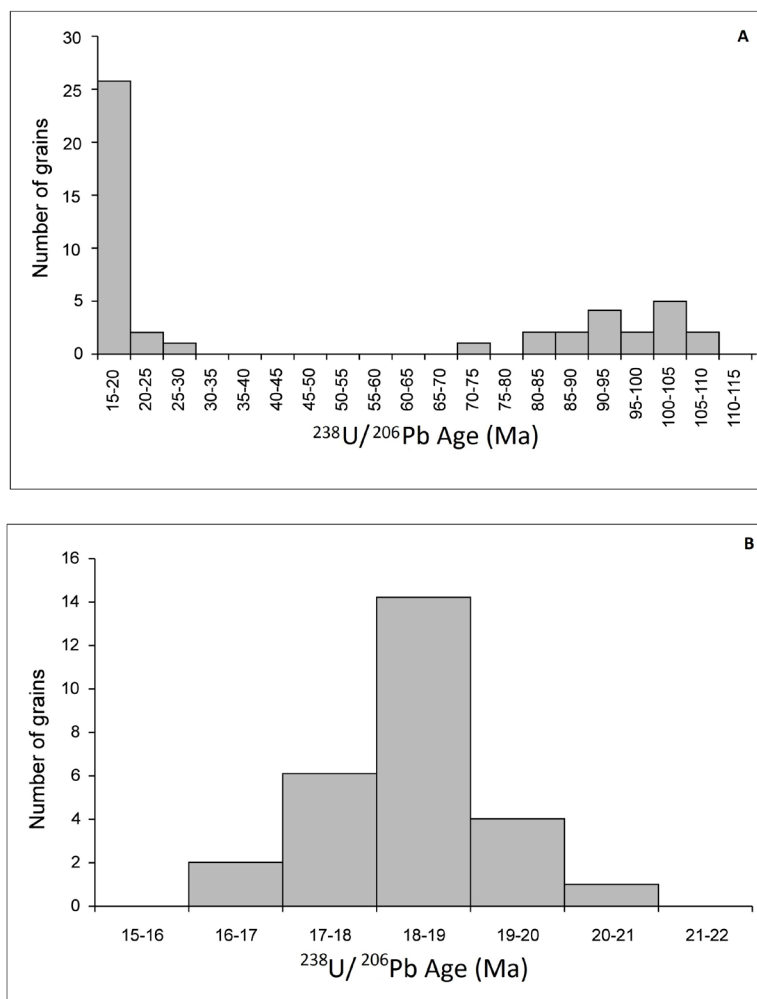


FIG. 10. Histograms showing distribution of zircon ages in sample ZRLF-0001.

unit known as the Santa Cruz Formation, widely represented across southern Patagonia (Feruglio, 1944, 1949a, 1949b, 1950; Marshall, 1976; Nullo and Combina, 2002). The likely possibility that the Río Leona Formation could also belong to the Neogene series (see Fosdick *et al.*, 2011) while coherent, needs to be carefully investigated and corroborated. In the area south of Lago Argentino, Furque (1973) divided the Santa Cruz Formation into three members based on their lithological attributes, from base to top being the Los Dos Mellizos, Bon Accord, and Los Huelguistas Members (Furque and Camacho, 1972; Furque, 1973). Our preliminary stratigraphic correlation suggests a closer affinity of the Chilean succession with the Los Dos Mellizos Member,

although a more integrated study is needed on both sides of the border to confirm this assumption.

The deposition of the Santa Cruz Formation in Sierra Baguales represents the beginning of the continental synorogenic sedimentation immediately after the eastward withdrawal of the 'Patagonian' sea, at around 19 Ma (Feruglio, 1949b; Cuitiño and Scasso, 2010; Cuitiño *et al.*, 2012). Direct dating of these units south of Lago Argentino (W. Zinsmeister, written communication, 1985, in Marshall and Salinas, 1990a, p. 69; Cuitiño *et al.*, 2012), Sierra Baguales (this study), and the Cordillera Chica in Argentina (Fosdick *et al.*, 2011), indicates that this process started around 18.8 Ma, one million years before the deposition of the Santa Cruz Formation

in its classic Atlantic Coast localities, dated between 17.8 and 16.0 Ma (Marshall *et al.*, 1986; Fleagle *et al.*, 1995; Flynn and Swisher, 1995; Tejedor *et al.*, 2006; Perkins *et al.*, 2012). The base of the southern Lago Argentino-Sierra Baguales deposits also seems to predate those of the Pinturas Formation along the upper course of the Pinturas River in northwestern Santa Cruz Province, whose lower and upper sections were dated using the $^{40}\text{Ar}/^{39}\text{Ar}$ method between 17.99 and 16.80 Ma (Fleagle *et al.*, 2005; Perkins *et al.*, 2012). An older date of <18.98 Ma obtained as a weighted mean of three fusions on plagioclase (minimum age) from the lower section at Cerro de los Monos was most likely contaminated by older plagioclase, which makes it less reliable (Perkins *et al.*, 2012, p. 39 and Table 2.2). In addition, an 18.75 Ma age has been proposed for the 'Pinturan' fauna recovered from the Upper Fossil Zone (UFZ) of the Colhue-Huapi Member in Gran Barranca (Kramarz *et al.*, 2010). This age has been suggested considering a diverse set of chronological markers including an $^{40}\text{Ar}/^{39}\text{Ar}$ date of 19.29 Ma from a tuff below the UFZ, and the paleomagnetic assignation of the deposits to Chron C6n (Ré *et al.*, 2010). However, none of these markers corresponds to a direct radiometric dating of the UFZ, and the recent chronologies obtained in the Pinturas Formation (Perkins *et al.*, 2012) show that a younger age for the assemblage in Gran Barranca cannot be discarded. It is clear that important uncertainties still remain about the exact age of the 'Pinturan' fauna and their relation with the typical Santacrucian mammals (Fleagle *et al.*, 2012). A post-Colhuehuapian- pre-'Pinturan' age for the fauna in Sierra Baguales is supported by the transitional character exhibited by the various species of fossil mammals recovered from the area, including typical Colhuehuapian forms along with others whose first occurrences are located later in the 'Pinturan'/Santacrucian period.

In his 1900-1902 papers, Florentino Ameghino named the 'étage notohippidien' as a new interval to differentiate fossils collected in southwestern Santa Cruz during 1889-1890, and presenting a 'less advanced' evolutionary state than his 'Santacrucian' stage faunas (Ameghino 1900-1902, p. 179). He stated that the most relevant site was at Karaiken, in the vicinity of Lago Argentino, and provided a list of species without details on their stratigraphic provenance. Later, in 1906, Ameghino made some changes to this original list without elaborating on the reasons

behind it (Ameghino, 1906). Marshall and Pascual (1977) conducted an extended discussion about the nature of these fossils, concluding that Ameghino's 'Notohippidian' concept probably represents a mix of different species from distinct localities and diverse stratigraphic levels. While referring to the fossiliferous outcrops at Karaiken, Marshall and Pascual (1977) also recognized two faunal intervals (NF1 and NF2) separated by sterile siltstones and sandstones with intercalated tephra horizons. The lower level (NF1) was described as having abundant specimens of advanced notohippids and was therefore recognized as Ameghino's 'Notohippidian' fauna, while the upper level (NF2) was considered to include only typical Santacrucian age taxa. The observations of Marshall and Pascual (1977) provided major support for the mixed-fauna hypothesis involving the 'Notohippidian' stage, which was tacitly accepted by the majority of subsequent paleontologists. Direct $^{40}\text{Ar}/^{39}\text{Ar}$ dating on plagioclase of two superimposed tephra horizons at Karaiken yielded ages of 17.71 and 16.71 Ma, respectively (Marshall *et al.*, 1986; Perkins *et al.*, 2012), being somewhat younger than the date obtained in Sierra Baguales. Although both tephra seem to be located a few meters above the strata hosting the 'Notohippidian' fauna *sensu* Marshall and Pascual (1977), sedimentary accumulation rates estimated for the whole exposure showed that it is highly probable that this unit may reach ~18.5 Ma at its base (Perkins *et al.*, 2012, Fleagle *et al.*, 2012). The age constraints obtained at Karaiken evidently suggest a close temporal link between all the faunas displaying advanced notohippids in the area, which would be temporally bracketed between 18.8 Ma (the base of the Santa Cruz Formation at Estancia Quién Sabe) and 17.71 Ma (the date of the tephra above the supposed 'Notohippidian' assemblage at Karaiken).

To this temporal and faunal period belongs the mammalian fossil assemblage collected by Feruglio (1949b) south of Lago Argentino, and by Pascual and Odreman Rivas in 1968 at Cerro Centinela, Argentina, located just 18.7 km north of the Sierra Baguales deposits. These poorly known faunas (Marshall and Pascual, 1977; Scillato-Yané, 1981; Marshall and Salinas, 1990b; Abello, 2007¹; González Ruiz and Scillato-Yané, 2009) were assigned to the 'Notohippidian' stage by Marshall and Pascual (1977) and Scillato-Yané (1981). These authors established a direct link between the continental Miocene series south of Lago Argentino and those exposed at Karaiken

based on the evolutionary degree showed by its caenolestoid marsupials, sloths, and the common occurrence of notohippine notohippids.

The fauna of Cerro Centinela have never been published on extensively and therefore their taxonomic affinities are still somewhat uncertain. This prevents any current attempt to make a full correlation with the fauna of Sierra Baguales, although some preliminary observations allow us to establish some degree of similarity between them (see list of identified taxa in Marshall and Pascual, 1977, p. 95; E. Bostelmann, personal observation). Common shared species between Sierra Baguales and Cerro Centinela presently include *Proeutatus* nov. sp., *Propalaeohoplophorinae* indet., the advanced notohippines, *Adelphomys candidus*, and *Perimys incavatus*. Based on our observations, up to six other species could also be present in both assemblages, but careful taxonomic identification- currently under way- is needed to sustain this assumption. A similar condition can be proposed for the scattered fossils mentioned by Feruglio (1949b), Furque (1973), and Marshall and Salinas (1990b), collected at Estancia Bon Accord and Estancia Quién Sabe (Fig. 1), directly to the southeast of the town of Calafate. Nevertheless, the active tectonic history of this part of the basin highlights the need for more and better direct dating of the rocks, in conjunction with detailed stratigraphic studies of all the continental successions located in the area surrounding Lago Argentino and in northwestern Magallanes, in order to provide a better control on the age, stratigraphy and taphonomic attributes of all the local fossil faunas.

In summary, and taking into account the geological and paleontological data collected in Sierra Baguales, we consider that the base of the Miocene continental deposits and their paleontological content exposed at Cerro Centinela (and almost surely at Estancias Bon Accord, Quién Sabe, and La Josefina; Marshall and Salinas, 1990b; González Ruiz and Scillato-Yané, 2009) are synchronous and syngenetic with the units in Sierra Baguales. They compose a particular faunal assemblage of marked transitional (evolutionary) and/or provincial (biogeographic) character, probably older than those exposed in the upper Pinturas River and surely older than the classic outcrops of the Santa Cruz Formation along the Atlantic Coast and the eastern Gallegos River. These assemblages could also be correlated with

the fossil content of the lower NF1 at Karaiken, but detailed prospection in this iconic place is needed to confirm this assumption. Certainly, the possibility exists that the Sierra Baguales and Cerro Centinela fauna represent a reliable fossil assemblage, which would allow a recharacterisation of Ameghino's classic 'Notohippidian' fauna. Our current work in the Sierra Baguales area is aimed at getting more stratigraphically controlled specimens, which would prove to be of invaluable assistance in sustaining this exciting possibility.

The age of the Santa Cruz Formation has important implications with regard to the timing of uplift of the Patagonian Andes. Le Roux *et al.* (2010) reported that the estuary system of the Middle-Late Eocene Río Baguales Formation (here renamed the Man Aike Formation) prograded towards the northwest. The east-northeasterly direction of paleocurrents in the overlying Santa Cruz Formation therefore indicates an important eastward change in the regional paleoslope, which can probably be related to uplift of the Patagonian Andes to the southwest. This is supported by the sandstone petrography, which indicates a relatively nearby, tectonically active source area rich in newly formed basalts.

Based on lithostratigraphic correlation with the Santa Cruz and Estancia 25 de Mayo Formations, exposed northward across the border in Argentina, the measured part of our synorogenic stratigraphic section in the Sierra Baguales area was deposited between 19 and 18 Ma. These findings thus indicate that uplift of the austral segment of the Andes commenced or intensified at this time. This estimation agrees with the proposed timing for the beginning of the 'Quechua Phase' of Andean tectonics around 19-18 Ma (Malumián and Ramos, 1984; Ramos, 1989; Marshall and Salinas, 1990a; Ramos and Kay, 1992; Flynn *et al.*, 2002). Additionally, this interpretation is supported by the synchronous acceleration of exhumation rates across the Patagonian Andes (Thomson *et al.*, 2001), estimated to have occurred between 17-14.24 Ma by Blisniuk *et al.* (2006), and between 22-18 Ma by Fosdick *et al.* (2013) in the retro-foreland region. The dynamic Oligocene-Miocene tectonic configuration of the Patagonian Andes generated by: **1.** changes in the subduction velocity, convergence rate, and obliquity of the Nazca and South American plates (Pardo-Casas and Molnar, 1987); and **2.** an increase in compression and shortening related to the collision of an unstable oceanic spreading center

(quadruple junction) at 18-17 Ma (Breitsprecher and Thorkelson, 2009; Eagles *et al.*, 2009), followed by the subduction and northward migration of the Chile Ridge (Cande and Leslie, 1986; Lagabrielle *et al.*, 2004), seem to be the primary factors triggering the uplift, concomitant widening and foreland propagation of the fold-and-thrust belt during Early Miocene times (Ramos and Ghiglione, 2008). The resulting effects of these remarkable geological processes on the past configuration of the ecosystems and biogeographic patterns of the austral biota are the subjects of our present and future investigations in Aysén and Magallanes.

10. Conclusions

A new fossil vertebrate assemblage is described for Chilean Patagonia, which corresponds to the first well-documented Neogene fauna of the Magallanes Region. Presently, 23 species have been identified at a preliminary taxonomic level, including large, medium and small taxa. The fossil-bearing sedimentary units are clearly of fluvial and fluvio-lacustrine origin, having been deposited after the regression of the 'Patagonian' sea at the western margin of the foreland. These rocks are recognized as forming part of the Santa Cruz Formation, widely distributed in Argentinean Patagonia and Tierra del Fuego. The presence of mammal species whose biochrons include both the Colhuehuapian and Santacrucian SALMAs, allows us to constrain an age between 19 to 18 Ma for this apparently transitional taxonomic assemblage. The age assigned to this fauna is also supported by detrital zircon dating of the deposits around 18.23 Ma, and the estimation of sediment accumulation rates and radiometric dating at localities north and south of the study site. The taxonomic identities of some of the species preliminarily correlate with other described faunas south of the town of Calafate at Cerro Centinela, Estancia Quién Sabe, and possibly with the type locality of the 'Notohippidian' fauna at Karaiken. The relationship between the Sierra Baguales fossils and other localities assigned to the Palomares Formation in central and eastern Magallanes needs to be tested with new and representative collections at those sites, where presently almost nothing is known. Finally, the study of fossil mammals from the Sierra Baguales helps in refining the timing of the beginning of Andean

uplift, triggered by important changes in the slab subduction dynamics as resulting from the collision of an active spreading center at 19-18 Ma.

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