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Late Cenozoic glaciations in Patagonia and Tierra del Fuego: an updated review

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The Patagonian glaciations developed from the latest Miocene (*c.* 6 Ma) in multiple events of varied duration and intensity. Most of the present glacial landscape is the result of the glacial modelling during the Pleistocene, since the Great Patagonian Glaciation (GPG; *c.* 1 Ma). The Patagonian Andes were covered by a continuous mountain ice sheet, from 37°S to Cape Horn (56°S), in at least five major glaciations over more than 15 cold events over the last million years. Before GPG, the glaciers were restricted to isolated ice caps along the mountain ranges. The present drainage network was developed after the Last Glacial Maximum [LGM; *c.* 25 calibrated kiloyears before present (cal. ka BP)], particularly those cases with drainage reversal, when the glaciers began to melt as a result of global climatic changes. The environmental impact of glaciations extended not only all over Patagonia, but to the Pampas as well.

ADDITIONAL KEYWORDS: glaciations – Late Cenozoic – Patagonia – Quaternary – South America.

Las glaciaciones patagónicas se desarrollaron desde el final del Mioceno (ca. 6 Ma) en múltiples eventos, de variada duración e intensidad. La mayoría del paisaje andino actual es el resultado del modelado glaciario durante el Pleistoceno, desde la Gran Glaciación Patagónica (GGP; ca. 1 Ma). Los Andes Patagónicos fueron cubiertos por un manto de hielo de montaña continuo, desde 37°S hasta el Cabo de Hornos (56°S) a lo largo de por lo menos 5 glaciaciones mayores durante más de 15 eventos fríos en el último millón de años. Antes de la GGP, los glaciares estaban restringidos a casquetes glaciarios aislados a lo largo de las cadenas montañosas. El sistema de redes de drenaje actual, en especial en lo que hace a la inversión del drenaje, se desarrolló luego del Último Máximo Glacial (UMG; ca. 25 cal. ka A.P.), cuando los glaciares comenzaron a retirarse debido a cambios climáticos globales. El impacto ambiental de las glaciaciones se extendió, no sólo a toda la Patagonia, sino también a la región pampeana.

PALABRAS CLAVE: Cenozoico Tardío – Cuaternario – Glaciaciones – Patagonia – Sud America.

INTRODUCTION

Continental and alpine-type glaciations of varied ages and extent are both very well represented in Patagonia and Tierra del Fuego. Morphological evidence of ancient glaciations is widespread in both the mountains and the lowlands along the present Atlantic coast near the Magellan Straits and Bahía Inútil (Fig. 1, number 25). Till deposits interbedded with basalt flows indicate the occurrence of glaciation already at the end of the Miocene (*c.* 6–5 Ma; Rabassa, 2008).

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There are still many questions concerning the age of the glaciations and their geographical extension. The landforms of the older glaciations, even those of the Great Patagonian Glaciation (GPG; Mercer, 1976; *c*. 1 Ma), are very well preserved, as a result of the persistent arid conditions in the Patagonian tablelands during the entire Pleistocene. A detailed overview of the physical geography of Patagonia is given by Coronato *et al*. (2008a) and recent reviews of Patagonian glaciations have been presented by Rabassa (2008), Rabassa *et al*. (2008) and Coronato & Rabassa (2011).

The first observations of glacial boulders found scattered over the landscape were made by Charles Darwin (1842) in the Río Santa Cruz valley (Fig. 1, number 20). Almost a century later, Carl Caldenius (1932) mapped four major glacial boundaries east of the Patagonian Andes (Fig. 2) from 41°S to Cape Horn (see Fig. 2), at the southernmost tip of South America (56°S). Caldenius mistakenly considered the glacial stages as retreat phases of the last glaciation and named them 'Initioglacial', 'Daniglacial', 'Gotiglacial' and 'Finiglacial', following the Scandinavian model. He also described 'Post-Finiglacial' moraines, which were assigned a post-Last Glacial Maximum (LGM) age (Coronato, Martínez & Rabassa, 2004a; Coronato, Meglioli & Rabassa, 2004b; Rabassa, 2008).

Pliocene and pre-Pliocene glacial deposits have been investigated by Mercer (1976), Wenzens (1999, 2000, 2006) and Rabassa, Coronato & Salemme (2005), among others, whereas the relationship of the Pleistocene glaciations with the Pampean biostratigraphical stages was discussed by Rabassa *et al*. (2005) and Rabassa & Coronato (2009). Holocene glaciations, including the Little Ice Age, have been studied by Glasser *et al*. (2004, 2008), Wenzens (2005) and Kilian *et al*. (2007), among others.

This article is an updated review of Patagonian glaciations following Coronato *et al*. (2004a, b), Coronato & Rabassa (2007a, b, 2011), Rabassa (2008) and Martínez *et al*. (2011). The Patagonian glacial boundaries are depicted following Caldenius (1932; Fig. 2) and later authors, but were redrawn using digital terrain models [Shuttle Radar Topography Mission (SRTM) 90 m; freely available on http://srtm/csi.cgiar.org] and based on new field information. This study contributes to the understanding of the palaeo-Patagonian ice fields as a unique source of ice from which many outlet glaciers flowed to the east and west, although each behaved slightly differently depending on the local conditions, giving rise to differing capabilities of landscape sculpturing.

The GPG (Mercer, 1976) was dated in Lago Buenos Aires (Fig. 1, number 11; e.g. Singer, Ackert & Guillou, 2004a) and the Río Gallegos valley (Fig. 1, number 21; Meglioli, 1992; Ton-That *et al*., 1999). This glacial event may be clearly identified in the field, and thus considered to be a key reference to following glaciations. The Pre-GPG and Post-GPG boundaries, as well as the LGM and its readvance phases during overall glacial retreat (LGM-late glacial), are depicted.

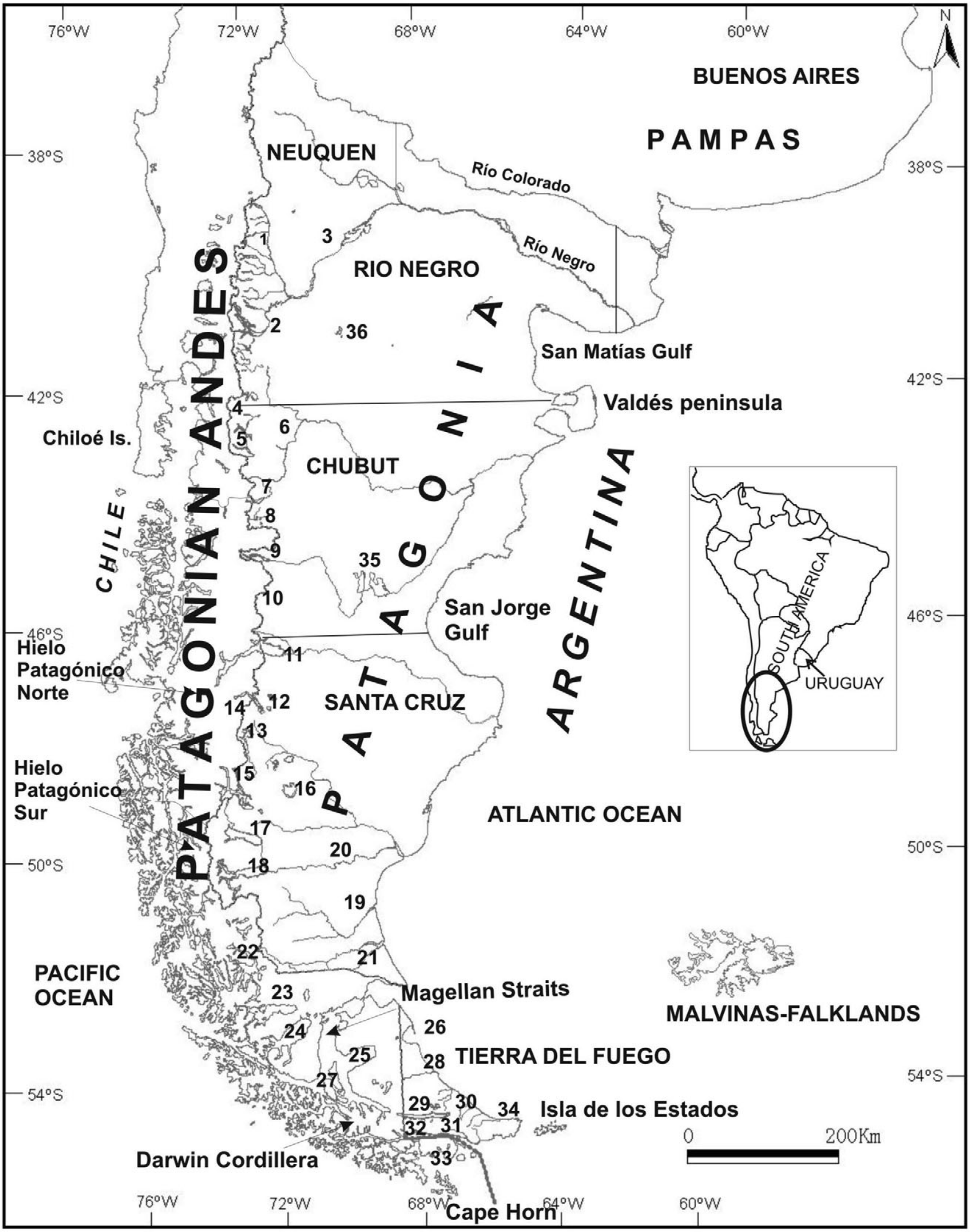
The eastern limits of the mountain ice sheet formed in northern Patagonia (between 39°30′S and 46°S) during each of the Patagonian Pleistocene glaciations have been drawn as an update of Coronato *et al*. (2004a, b). These contributions were adapted using new evidence from the analysis of digital terrain models (SRTM 90 m) and recent higher definition satellite imagery. For the spatial and chronological ordering of the glacial limits, the boundaries of the GPG (Mercer, 1976; 'Initioglacial' of Caldenius, 1932) have been used as main reference. This glaciation occurred at around 1 Ma, in the early Pleistocene (Meglioli, 1992; Ton-That *et al*., 1999; Singer *et al*., 2004a; Rabassa, 2008). Following Coronato *et al*. (2004a, b), ancient (mostly Pliocene and earliest Pleistocene) glaciations, preserved in between basalt lava flows, have been named Pre-GPG, whereas the Middle Pleistocene Glaciations have been termed Post-GPG I, II and III and, finally, the LGM in the late Pleistocene. Likewise, previous glaciostratigraphical schemes, defined for the Lago Nahuel Huapi area (41°S; Fig. 1, number 2) and for the Esquel valley (43°S; Fig. 1, number 5; Flint & Fidalgo, 1964, 1969) have provided a highly reliable mapping of the GPG moraines and other glacial drifts.

The occurrence of a regional drainage-deepening event of tectonic nature known as the 'canyon-cutting event' (Rabassa & Clapperton, 1990), close to the early Pleistocene–middle Pleistocene boundary, allowed the preservation of older glaciation sediments and landforms over the divides.

At least five major glaciations have been identified for the Pleistocene, some including more than one glacial episode. Not all five glacial events are clearly represented in each glacial valley sequence. As a result of their younger age and better preservation, the last glaciation moraines provide greater certainties concerning the local glaciostratigraphical scheme and the subsequent regional correlation.

NORTHERN PATAGONIA

Along the northernmost portion of the Patagonian Andes, in northern Neuquén Province, glaciation took place only from isolated mountain ice caps (including high volcanoes rising above the regional snowline), independently developed from the Patagonian Ice Sheet, which extended from 37°S to the southernmost end of the continent. All sequences presented here correspond to the northern portion of the Patagonian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Río Negro
RIO NEGRO
PATAGONIAN ANDES
PATAGONIA
San Matías Gulf
42°S
Valdés peninsula
Chiloé Is.
CHUBUT
CHILE
ARGENTINA
San Jorge Gulf
46°S
Hielo Patagónico Norte
SANTA CRUZ
Hielo Patagónico Sur
ATLANTIC OCEAN
50°S
PACIFIC OCEAN
Magellan Straits
MALVINAS-FALKLANDS
TIERRA DEL FUEGO
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Figure 1. List of localities cited in the text. As a result of the extension of the area and the scale used, it was sometimes necessary to merge several closer localities under one single number. 1, Río Malleo; 2, Lago Nahuel Huapi; 3, Río Limay; 4, Epuyén and Cholila valleys; 5, Esquel, El Maitén, Laguna Súnica and Río Corintos; 6, Río Chubut and Río Tecka; 7, Río Huemul valley (43°30′S, 71°10′W), Río Corcovado valley (43°45′S, 71°20′W), Lago General Vintter (43°55′S, 71°25′W) and Río Corcovado and Río Putrachoique valleys; 8, Río Pico (44°10′S, 71°20′W) and Río Apeleg (44°30′S, 71°20′W) valleys; 9, La Plata and Fontana lakes (45°S, 71°10′W), El Coyte (45°15′S, 71°15′W) and Río Mayo (45°30′S, 71°15′W); 10, Lago Blanco (45°55′S, 71°15′W); 11, Lago Buenos Aires–General Carrera (46°16′–46°56′S, 71°09′–72°50′W); 12, Pueyrredón-Posadas lakes (47°08′–47°30′S, 71°47′–72°33′W); 13, Belgrano and Burmeister lakes (47°47′–47°57′S, 72°04′–72°18′W); 14, Mt. San Lorenzo and Sangra Mountains; 15, San Martín-Tar lakes (48°55′–49°15′S, 71°54′–72°31′W); 16, Lago Cardiel; 17, Lago Viedma (49°24′–49°54′S, 70°46′–72°50′W) and Río Guanaco; 18, Lago Argentino (50°09′–50°28′S, 70°53′–72°08′W), Cerro del Fraile and Punta Banderas; 19, Río Coyle (50°49′–51°16′S, 70°56′–72°36′W); 20, Río Santa Cruz; 21, Río Gallegos and Tres de Enero site (51°49′S, 69°24′W); 22, Balmaceda and Pinto lakes and Seno Última Esperanza (Chile); 23, Seno Skyrring (52°08′–52°48′S, 71°07′–72°40′W) (Chile); 24, Seno Otway (52°03′–53°12′S, 70°11′–71°54′W) (Chile); 25, Bahía Inútil (Chile); 26, Bahía San Sebastián; 27, Isla Dawson and Whiteside Channel (Chile); 28, Río Grande and Punta Sinaí; 29, Lago Fagnano, Tolhuin and Lago Chepelnut; 30, San Pablo, Fuego and Ewan valleys; 31, Beagle Channel and Estancia Harberton; 32, Ushuaia and Carbajal valley; 33, Isla Navarino (Chile); 34, Península Mitre; 35, Musters and Colhue Huapi lakes; 36, Carrilaufquen Chica and Grande lakes.

Ice Sheet, a 3000-km-long ice field, the largest ice field in the Southern Hemisphere outside Antarctica. Coordinates roughly indicate the central position of the studied area.

THE RÍO MALLEO VALLEY (39°37′30″S, 71°17′W; FIG. 1, NUMBER 5)

This sequence was described by Rabassa *et al*. (1987, 1990) and Rabassa (2008). The Río Malleo valley shows different glacial drift units irregularly distributed along the valley. They have been ordered chronologically using geomorphological, palynological and palaeomagnetic criteria (for further details, see Rabassa, 2008).

HEADS OF THE RÍO LIMAY AND LAGO NAHUEL HUAPI (41°8′S, 71°8′W; FIG. 1, NUMBERS 2 AND 3)

A general overview of this glacial sequence is given in Rabassa (2008). The glacial stratigraphy defined for this region correlates with the glacial sequence of the Chilean Lake district (41°S; Porter, 1981). Rabassa & Evenson (1996) suggested that the Pichileufú Drift (the GPG Drift), the oldest unit, includes the products of at least three different glacial advances, perhaps corresponding to several glaciations, all preceding the fluvial canyon-cutting event. The El Cóndor Drift could be subdivided into two glaciogenic units, probably corresponding to the Post-GPG II and Post-GPG III glaciations (of pre-late Pleistocene age). These glaciations also occur at higher elevations than those of the LGM drift, a result of tectonic uplift and/or fluvial incision occurring between each glacial event, thus demonstrating their relatively old ages. The last glaciation is represented by the Nahuel Huapi Drift, with stadials I and II [probably two close advances during the Marine Isotope Stage (MIS) 2]. Late-glacial readvances have not been confirmed yet in this region by absolute chronologies.

THE PRE-ANDEAN VALLEY OF EL MAITÉN (42°10′S, 71°10′W; FIG. 1, NUMBER 5)

The establishment of a stratigraphical correlation for this area is difficult, as no absolute dates are available (for references, see Rabassa, 2008). The pre-Andean valley of El Maitén (Fig. 1, number 5) was occupied by several Pleistocene glaciations. Two ice lobes, the Epuyén and the Cholila valley lobes (Fig. 1, number 4; Fig. 3) flowed from the east and southeast, respectively. However, it is possible that, during the oldest glaciations, ice may have flowed from the northwest. Smaller transverse valleys allowed the oldest ice sheet (GPG) to reach its maximum extent at 70°40′W. Immediately towards the west, the Post-GPG I deposits are found occurring as entrenched sedimentary bodies at lower topographical levels. These younger hills today act as water divides, separating Pacific from Atlantic Ocean draining basins. The best-preserved moraines of the area are found between Lago Epuyén and Río Chubut (Fig. 1, numbers 4 and 6). They probably correspond to the Post-GPG II, Post-GPG III and the last glaciation advances.

VALLEY OF ESQUEL AND RÍO CORINTOS (43°S–71°W; FIG. 1, NUMBER 5)

These sequences are based on Martínez (2002) and the references cited therein. The present 16 de Octubre valley was the pathway regularly followed by successive ice advances from the southwest occupying the mountain passes of Esquel and Súnica. The east-

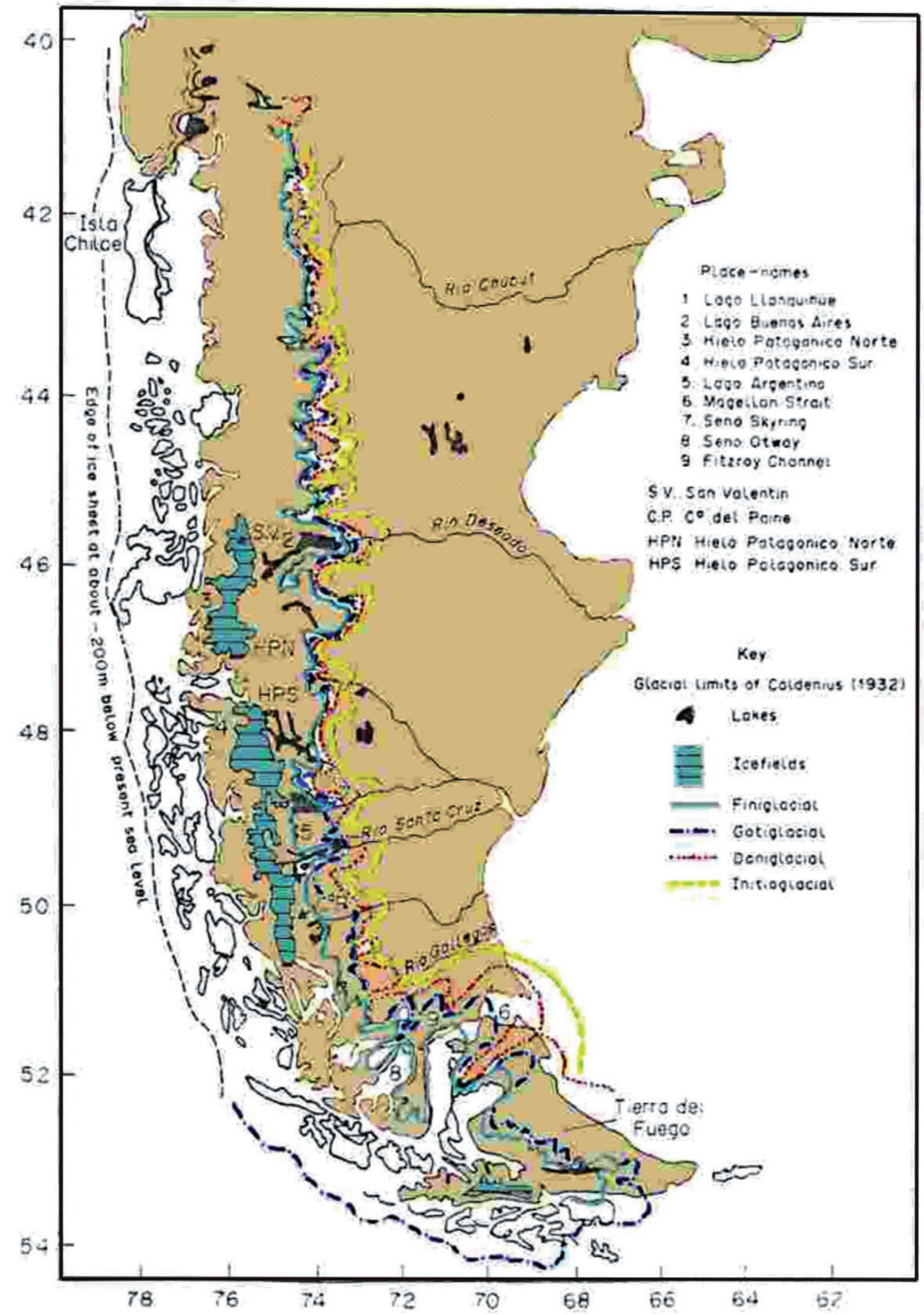


Figure 2. General glaciation map of Patagonia and Tierra del Fuego based on Caldenius (1932).

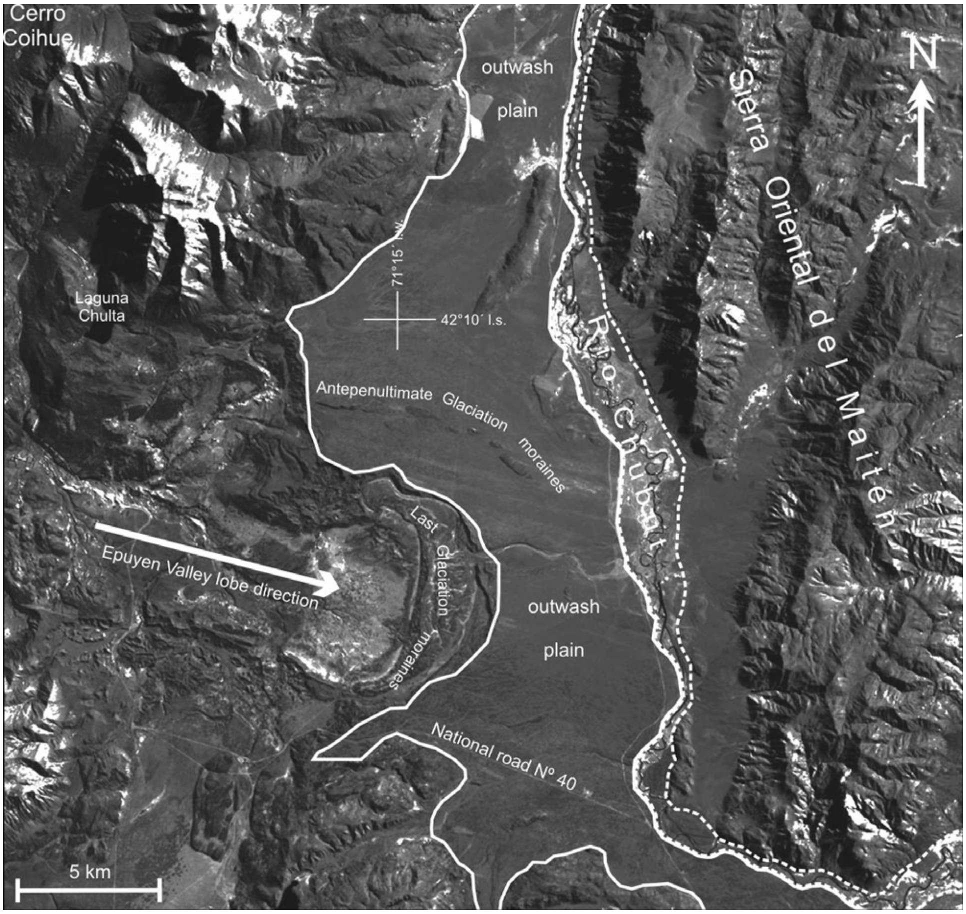


Figure 3. Middle Pleistocene and Last Glacial Maximum (LGM) moraines and related glaciofluvial deposits in the Epuyén valley, northern Patagonia (after Martínez *et al*., 2011).

ernmost moraines, which today occur as highly degraded landforms, reached their maximum extent at 70°49′W, in the Río Tecka valley (Fig. 1, number 6). These deposits do not correspond to the GPG mountain ice sheet. Instead, the ice sheet of that age is represented by other moraines further west, above 1000 m a.s.l. These moraines have been identified east of the Esquel Airport and along the mountainsides east and north of Laguna Súnica (Fig. 1, number 5). Thus, the innermost and topographically highest moraine systems should be correlated with the GPG, and the easternmost moraines, deeply entrenched in the valleys, probably correspond to the Post-GPG I advance. The Post-GPG II moraine is very well preserved closing the northernmost Esquel valley. The Post-GPG III moraines (penultimate glaciation) are represented by three belts that enclose Laguna Súnica, and by the moraines located west of Esquel Airport. Southwest of Laguna Súnica, a moraine, 2 km in length, and the remnants of a second, more distal moraine are found corresponding to the last glaciation. The Esquel valley is blocked on the east by an elongated moraine arc of the same age, today highly degraded by glaciofluvial and glaciolacustrine erosion. Between these last glaciation moraines and those beyond, there are important terraced glaciofluvial deposits reaching the Río Tecka valley. This stream and the Río Chubut (Fig. 1, number 6) acted as glaciofluvial drainage spillways towards the Atlantic Ocean, during at least the last three major glaciations. The moraines of the penultimate and the last glaciation dammed meltwaters during ice recession. These lakes were interconnected and occupied a large part of the Cordilleran environment until they ultimately drained towards the Pacific Ocean when the water level overtopped the surface of the ice bodies located towards the west.

THE RÍO HUEMUL VALLEY
(43°30′S, 71°10′W; FIG. 1, NUMBER 7)

This sequence was studied by Lapido, Beltramone & Haller (1989), Haller *et al*. (2003) and Martínez (2002), who investigated the glacial stratigraphy east of the town of Corcovado and west of the Río Tecka valley. They defined three glacial events for this area: (1) 'Caquel Drift', isolated deposits along the mountain slopes above 1000 m a.s.l.; (2) 'Tecka Drift', represented by two or more terminal moraines, located in the eastern margin of the Río Tecka; and (3) 'Mallín Grande Drift', equivalent to the last glaciation, represented by two, well-preserved, moraine arcs with their corresponding glaciofluvial plains extending eastwards, and adjacent glaciolacustrine deposits towards the west. Recent studies have suggested a GPG age for the 'Caquel Drift'.

THE RÍO CORCOVADO VALLEY (43°45′S, 71°20′W) AND LAGO GENERAL VINTTER (43°55′S, 71°25′W) (FIG. 1, NUMBER 7)

Lago General Vintter drains towards the Pacific Ocean through Río Corcovado. In Argentina, this stream wanders aimlessly between moraine arcs, before turning west at 43°30′S. A frontal moraine dams the lake and, together with a second moraine immediately to the east, represents the last glaciation (Haller, 1979; Martínez, 2002; Haller *et al*., 2003; Martínez *et al*., 2011). Two very well-preserved moraine arcs, equivalent to these units, have been deposited by a glacier advancing from the north along the Río Corcovado valley. Eastwards, highly eroded glacial deposits, corresponding to the older systems, are found. The two westernmost ones occur between the Río Corcovado and the Río Putrachoique valleys (Fig. 1, number 7). They probably represent the Post-GPG III, Post-GPG II and Post-GPG I events, respectively.

THE RÍO PICO VALLEY (44°10′S, 71°20′W; FIG. 1, NUMBER 8)

Four end moraine groups were distinguished at the Río Pico valley by Beraza & Vilas (1989). All units showed normal polarity magnetization and correspond to the Brunhes Palaeomagnetic Chron (younger than 0.78 Ma). The different drifts, termed I (outer), II, III and IV (inner), are thus middle and/or late Pleistocene in age. Lapido (2000) identified five drift units, two undifferentiated tills and several terraced glaciofluvial deposits. The inner 'Las Mulas Drift' is equivalent to the LGM and is represented by dissected marginal and frontal moraines and glaciofluvial deposits. The 'Tremenhau Drift' is a more external moraine arc, tentatively equivalent to the penultimate glaciation or Post-GPG III event. The 'Cherque Drift' occurs in an external position and comprises a complex glaciogenic unit that probably includes deposits of several glaciations. This unit may correlate with the antepenultimate glaciation or Post-GPG II event. 'Drift I' (Beraza & Vilas, 1989) includes another, even more external group of moraines, in a higher position, which are tentatively correlated with the Post-GPG I event. Finally, the 'Baguales Drift', of uncertain Pliocene–Pleistocene age, is represented by both moraine and glaciofluvial deposits that close the valley at higher elevations (1300–1000 m a.s.l.). This drift is tentatively correlated with the GPG, but it probably includes older deposits as well. Figure 4 shows the external limits of glaciations in the Río Pico valley.

THE RÍO APELEG VALLEY (44°30′S, 71°20′W; FIG. 1, NUMBER 8) AND THE LA PLATA AND FONTANA LAKES (45°S, 71°10′W; FIG. 1, NUMBER 9)

These sequences were studied by Ramos (1981), Ploszkiewicz (1987) and Lapido (2000). The moraines crossing this valley were deposited by a glacial lobe derived from the Río Frías valley when the ice divide was located further west. Most of the moraines corresponding to the Pleistocene glacial fronts are today found in Chile. It is still not possible to define a glaciostratigraphical scheme. The 'Río Moro Till' in the La Plata and Fontana lakes is represented by basal moraines to the north and south of the lakes, at over 1000 m a.s.l. (Ramos, 1981). These moraines were deposited by a mountain ice sheet whose frontal position was further east in the Post-GPG III or older advance limits. The last glacial advance confined the lakes between moraine deposits. Ramos (1981) showed that the last glaciation would be represented by the 'Fontana Till', deposited at Lago Fontana and on its southern margins. Figure 4 indicates the external limits of glaciations in the Río Apeleg valley.

THE EL COYTE (45°15′S, 71°15′W), HEADS OF THE RÍO MAYO (45°30′S, 71°15′W) AND LAGO BLANCO (45°55′S, 71°15′W) REGIONS (FIG. 1, NUMBERS 9 AND 10)

Three drift units indicating glacial stillstand positions occur in the westernmost portion of these valleys. These units may be correlated with the last glaciation ('La Elvira Drift'), with the penultimate glaciation or Post-GPG III event ('Río Mayo Drift') and with the pre-penultimate glaciation or Post-GPG II episode ('Ricardo Rojas Drift') (Beltramone, 1991; Dal Molin & González Díaz, 2002). In addition, two outermost, more eroded and less continuous glacial fronts have been identified, which usually emerge above the glaciofluvial deposits of the glaciations already mentioned. These probably correspond to the Post-GPG I and GPG events, respectively.

THE SOUTHERN PATAGONIAN PALAEO-ICE LOBES

In southern Patagonia, the piedmont areas were extensively glaciated by giant outlet glaciers coming

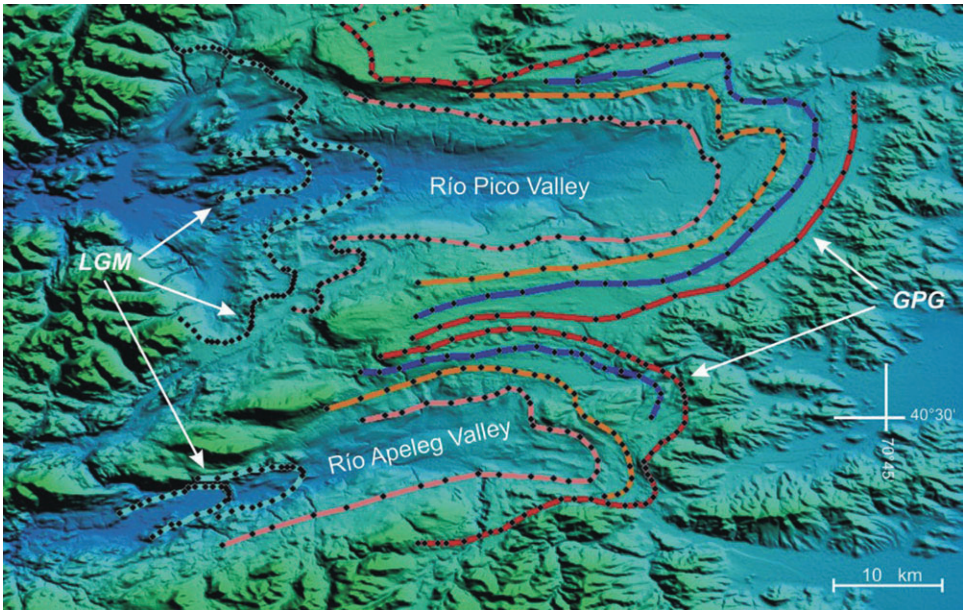


Figure 4. Glacial limits in the Pico and Apeleg valleys, northern Patagonia (after Martínez *et al*., 2011). GPG, Great Patagonian Glaciation; LGM, Last Glacial Maximum. Lines in between the GPG and LGM boundaries show the extent of three different glacial advances that occurred in the middle Pleistocene.

from the Patagonian Ice Sheet. South of Río Gallegos (Fig. 1, number 21), the ice extended even to the present Atlantic submarine shelf during GPG and other Middle Pleistocene Glaciations.

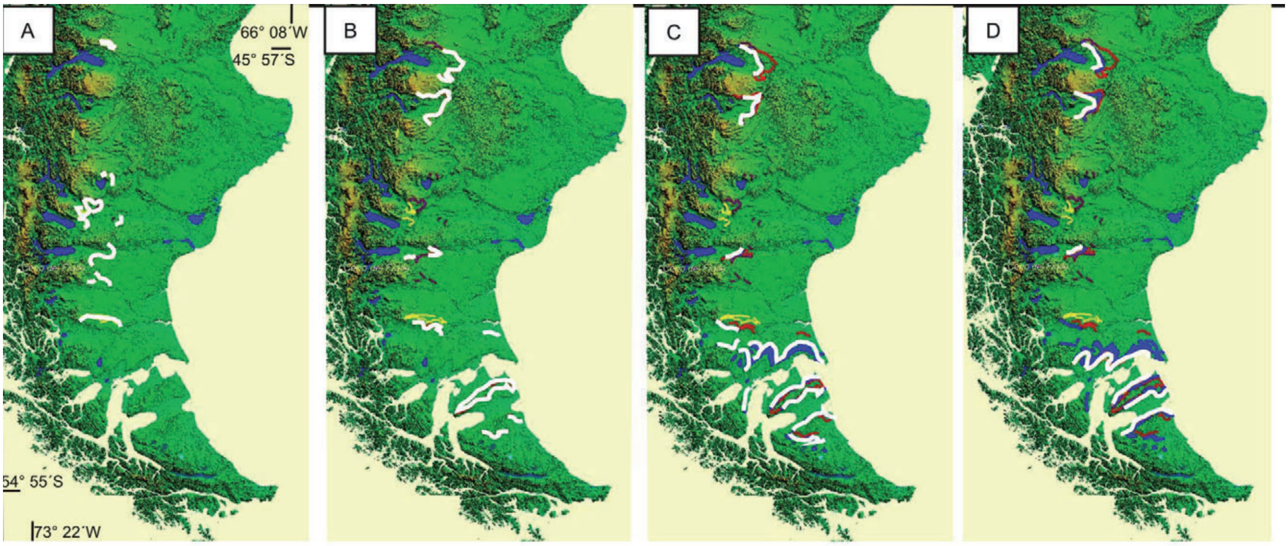
THE LAGO BUENOS AIRES–GENERAL CARRERA (ARGENTINA–CHILE) LOBE (46°16′–46°56′S, 71°09′–72°50′W; FIG. 1, NUMBER 11, FIG. 5)

Since Ton-That *et al*. (1999), in which the maximum age for GPG was indicated at 1.15 Ma, further research has been undertaken in the area. It has mainly been devoted to the establishment of the chronology of the glacial advances previously mapped by Caldenius (1932), Malagnino (1995) and others. Singer *et al*. (2004a) and Kaplan *et al*. (2004) described 19 moraine suites that relate to the frontal position of a piedmont lobe flowing from the palaeo-Northern Patagonian Ice Field (or Hielo Patagónico Norte; Fig. 1) between 1.2 Ma and 16 ka BP. The occurrences of lava flows interbedded with till or stratigraphically related to moraines have provided absolute ages for the glacial limits, based on $^{40}Ar/^{39}Ar$ (incremental heating technique) dating on basalts. Later, Kaplan *et al*. (2005) determined the age of two glacial advances using cosmogenic isotope measurements. These advances occurred during MIS 6 and within the period between MIS 18 and 8–10. The present chronostratigraphy of glacial deposits in the area includes the following moraines: Telken VII (1.016–1.168 Ma), Telken I–VI (0.76–1.016 Ma), Deseado I–III (?–760 ka), Moreno I–III (350?–109 ka), Fénix I–IV (16–25 ka; LGM) and Menucos [< 15.8 radiocarbon kiloyears before present (^{14}C ka BP)]. Turner *et al*. (2005) demonstrated a rapid glacier retreat at 15–16 calibrated kiloyears ago (cal. ka), followed by stability and a complete deglaciation phase at *c*. 12.8 cal. ka. Later, Douglass *et al*. (2006) refined the LGM and late-glacial chronology by means of cosmogenic isotope dating techniques. They found six glacial advances between 22.7 and 14.4 ka in phase with the Antarctic Cold Reversal (ACR) signal.

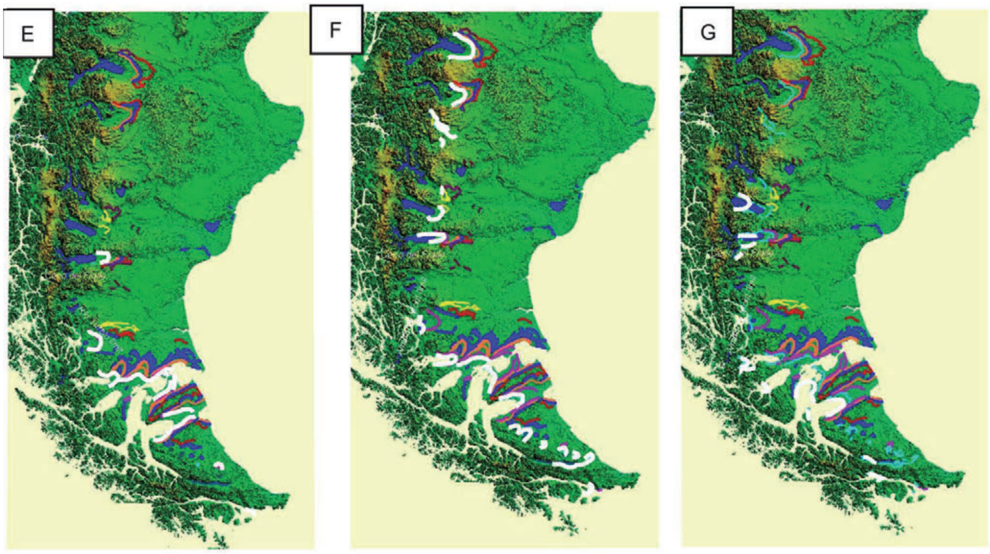
A Pre-GPG limit is presented here based on Malagnino (1995), who defined the ‘Chipanque moraines’ on the basis of geomorphology and stratigraphy, but without absolute ages, although he postulated a range of between 7 and 4.6 Ma or 3.5 and > 2.3 Ma.

THE PUEYRREDÓN–POSADAS LAKES LOBE (47°08′–47°30′S, 71°47′–72°33′W; FIG. 1, NUMBER 12; FIG. 5)

Hein *et al*. (2009) recently reported the detailed mapping of four glacial boundaries following those of Caldenius (1932), named ‘Gorra de Poivre’ (Initioglacial), ‘Cañadón Caracoles’ (Daniglacial), ‘Hatcher’ (Gotiglacial) and ‘Río Blanco’ (Finiglacial). The glacial chronology is mainly referred to the glacial model of Lago Buenos Aires proposed by Singer *et al*. (2004a) and Kaplan *et al*. (2004, 2005). More refined evidence was presented here for the Middle Pleistocene Glaciations. Thus, the Gotiglacial advance has been



Late Pliocene-early Pleistocene Middle Pleistocene (1Ma) Middle Pleistocene (<1>760ka) Middle Pleistocene (<760>315 ka)



Middle Pleistocene (<260>150 ka) Last Glacial Maximum (ca. 25 ka) Late Glacial (16-11 ka)

Figure 5. Pliocene to late-glacial glaciation limits of southern Patagonia and Tierra del Fuego. White lines indicate the extent of glacial advances in each indicated period of time. A, Pre-Great Patagonian Glaciation evidence; B, Great Patagonian Glaciation (GPG); C, Post-GPG I; D, Post-GPG II; E, Post-GPG III; F, Last Glacial Maximum; G, late glacial; in all cases, according to Coronato *et al*. (2004a) and Coronato & Rabassa (2011).

referred to *c*. 260 ka (i.e. MIS 8). The age of the Río Blanco glaciation was determined at *c*. 27–25 ka, which is similar to that of Lago Buenos Aires LGM moraines (Singer *et al*., 2004a).

THE BELGRANO AND BURMEISTER LAKE LOBES (47°47′–47°57′S, 72°04′–72°18′W; FIG. 1, NUMBER 13; FIG. 5)

Wenzens (2003) suggested that these lakes were part of the same glacial outlet flowing from Mt. San Lorenzo (3700 m a.s.l.; Fig. 1, number 14) and joining the palaeo-ice lobe of the Río Chico, which flowed from the Sangra Mountains (Fig. 1, number 14). The LGM moraines have been identified several kilometres east of the present heads of the lakes (Wenzens, 2005). Moraines closing the lakes were referred to late-glacial readvances.

THE SAN MARTÍN–TAR LAKES LOBE (48°55′–49°15′S, 71°54′–72°31′W; FIG. 1, NUMBER 15; FIG. 5)

Four glacial limits have previously been recognized in this area (Coronato *et al*., 2004a). Later, LGM moraines were defined surrounding Lago Tar and the southern coast of Lago San Martín (Wenzens, 2003, 2005). Radiocarbon dating on basal organic matter in a drainage channel between two moraine arcs indicated that the oldest late-glacial advance occurred before 13.1 ka BP and the youngest occurred prior to 9.3 ka BP (Wenzens, 1999). Late-glacial moraines have been mapped enclosing the two branches of Lago San Martín and both shores of the central lake branch. They were interpreted as representing a third late-glacial readvance at *c.* 10.5–9.5 ^{14}C ka BP (Wenzens, 2003). Further east, in the tableland region, several moraine arcs and spillway evidence have been mapped. These moraines are located on the tablelands. They have been interpreted as indicating glaciations of Miocene age (Wenzens, 2006), herein mapped as Pre-GPG events, and undetermined age moraines for those of middle topographic position. Moreover, northern Lago Cardiel (Fig. 1, number 16) ancient glacial limits and spillways were recognized by Wenzens (2006) as evidence of the eastern frontal position of very ancient (middle Miocene) piedmont glaciers. However, there is no general agreement about such a great eastwards expansion of the ice at such an early age.

THE LAGO VIEDMA LOBE AREA (49°24′–49°54′S, 70°46′–72°50′W; FIG. 1, NUMBER 17; FIG. 5)

A set of moraine arcs surrounding the head of the lake and the Río Guanaco valley (Fig. 1, number 17) was recognized by Wenzens (1999) as marking the ice position during the LGM. An extensive drumlin and megaflute field occurs between the LGM moraines and the lake heads (Rabassa *et al.*, in press).

Late-glacial ice limits have been identified along the coasts of Lago Viedma, the Cóndor and Guanaco valleys. Wenzens (1999, 2005) proposed that these glaciers advanced three times between 14 and 10 ^{14}C ka BP, the younger probably partially equivalent to the Younger Dryas (YD) stadial (12.9–11.7 cal. ka). Pre-GPG glacial evidence has been pointed out in Coronato *et al.* (2004a). East of the LGM limit, Pre-GPG relict moraines have been recognized by Wenzens (2000).

THE LAGO ARGENTINO LOBE (50°09′–50°28′S, 70°53′–72°08′W; FIG. 1, NUMBER 18; FIG. 5)

Several terminal moraines have been mapped by different authors, indicating the occurrence of at least nine separate glacial advances since the late Pliocene to the late glacial (Coronato *et al.*, 2004a; Rabassa, 2008). Singer *et al.* (2004b) studied the Cerro del Fraile (Fig. 1, number 18) sequence, where eight till units interbedded with lava flows are exposed. Piedmont glaciations of the tableland region occurred in the period 2.1–1.0 Ma (early Pleistocene), herein considered as Pre-GPG events. In the Cachorro creek glacial valley, a sequence of four frontal moraine suites was mapped by Lovecchio, Strelin & Astini (2008) and assigned to the Punta Banderas (Fig. 1, number 18) sequence on the basis of geomorphological characteristics.

THE RÍO COYLE VALLEY LOBE (50°49′–51°16′S, 70°56′–72°36′W; FIG. 1, NUMBER 19; FIG. 5)

Five glacial limits were recognized on the basis of geomorphology along the upstream valley (Coronato *et al.*, 2004a). Pre-GPG moraines were assumed to be equivalent to those at Lago Argentino (Strelin *et al.*, 1999), and both ancient moraine systems are located on the tablelands at *c.* 400 m a.s.l.

THE RÍO GALLEGOS VALLEY LOBE (51°27′–52°03′S, 70°37′–72°26′W; FIG. 1, NUMBER 21; FIG. 5)

The upper stream of the Río Gallegos valley flowed along the late and middle Pleistocene moraines, but the younger moraine arcs are located in the Balmaceda and Pinto lakes (Chile), close to the Última Esperanza sound (Fig. 1, number 22). The older glacial landscape has been mapped here by several authors (Coronato *et al.*, 2004a). Meglioli (1992), Ton-That *et al.* (1999) and Singer *et al.* (2004a) constrained the age of the GPG event, with a maximum age of 1.16 Ma (Singer *et al.*, 2004a) for this glaciation. Early Pleistocene drumlins, megaflutes and drumlinoid forms have been described (Ercolano *et al.*, (2004) in the ancient Río Gallegos valley resulting from one of the GPG advances. The dry climate of the region since the early Pleistocene has contributed to the excellent preservation of these glacial landforms.

Cosmogenic isotope measurements on boulders on top of the GPG moraines were performed by Kaplan *et al.* (2007). They found discrepancies between the cosmogenic ages of 106–124 ka and the well-dated tills interbedded with lava flows. As this also occurred in northern Tierra del Fuego moraines, these authors postulated that cosmogenic nuclide dating cannot be used as a reliable chronometer of glacial deposits older than the LGM in these areas (Kaplan *et al.*, 2005; Douglass *et al.*, 2006). They suggested that Quaternary geomorphological processes operated differently towards the south, mainly because of the wetter climate and proximity of the sea during interglacial times (Kaplan *et al.*, 2007). Two Post-GPG glacial limits have been mapped in the region, although no detailed chronological constraint is yet available for these deposits. According to E. Sagredo,

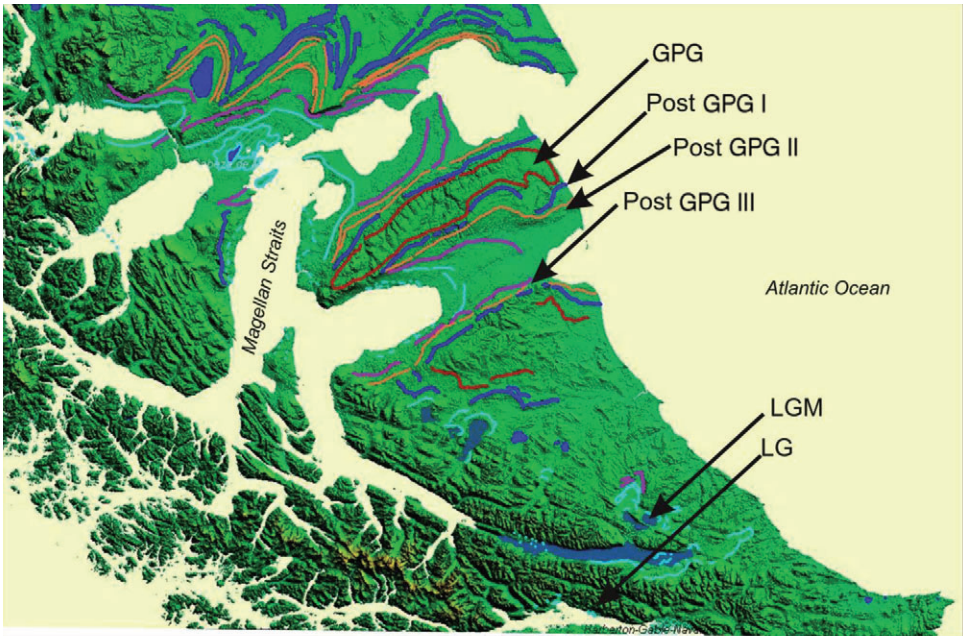


Figure 6. Map of greater detail, compared with Figure 5, of the glacial limits of Tierra del Fuego and the Magellan Straits area from Coronato & Rabassa (2011). GPG, Great Patagonian Glaciation; LGM, Last Glacial Maximum; LG, late glacial.

P. Moreno, R. Villa-Martínez & M. Kaplan, (pers. comm.; Institute of Ecology and Biodiversity, Department of Ecological Sciences, University of Chile, Santiago de Chile), a piedmont ice lobe covered the head of this valley during the LGM, after which the Balmaceda and Pinto lakes were formed. On the basis of geomorphology, stratigraphy and radiocarbon dating, these authors proposed that the LGM termination began shortly before 17.5 cal. ka BP, in phase with the Lago Buenos Aires sequence (Kaplan *et al*., 2004) and the Magellan Straits area (Figs 1, 5 and 6; McCulloch *et al*., 2005a, b). Deglaciation was interrupted by a stabilization phase, which ended at 16.3 cal. ka BP, as the Lago Buenos Aires area (Douglass *et al*., 2006) and the intermediate Lago Pinto complex were formed. A final advance was dated between 14.6 and 12.8 cal. ka BP in the Última Esperanza sound area, attributed to the ACR.

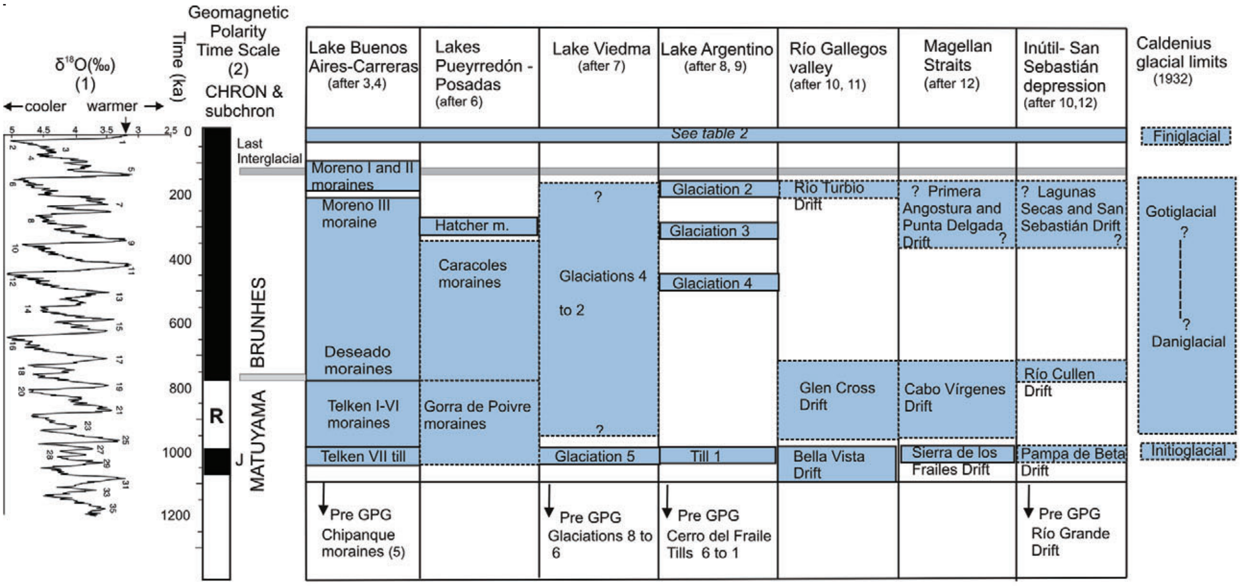
THE SENO SKYRRING LOBE (52°08′–52°48′S, 71°07′–72°40′W; FIG. 1, NUMBER 23; FIG. 5)

Four glacial advances have been recognized along this palaeo-ice lobe (Meglioli, 1992). The GPG was not recognized as a moraine system, but till remnants were observed in the higher hills. Three Middle Pleistocene Glaciations have also been identified. By contrast, Kilian *et al*. (2007) proposed a late-glacial/Holocene ice retreat. A non-dated LGM limit is coincident with the moraine arcs mapped as Post-GPG II and III by Meglioli (1992), but the moraine limit closing the present sound is coincident with Meglioli's LGM position. From this limit, the beginning of the ice retreat was identified between 18.3 and 17.5 cal. ka. Then, a more rapid glacier retreat occurred until around 15–14 cal. ka. A much slower retreat then took place from 14 to 11 cal. ka during both the ACR and the YD stadials. Late Holocene glacial advances have also been recognized from 1220 to 1910 AD. These authors postulate a differential behaviour, the Andean palaeo-mountain ice sheet being distinctly more climate sensitive here than in the Southern Patagonian Ice Field.

THE SENO OTWAY LOBE (52°03′–53°12′S, 70°11′–71°54′W; FIG. 1, NUMBER 24; FIG. 5)

The glacial limits of this palaeo-ice lobe follow those of Caldenius (1932) and Meglioli (1992) for the Middle Pleistocene Glaciations. The Quaternary chronostratigraphy of the Southern Patagonian glaciations is presented in Tables 1 and 2. Table 1 comprises all glaciations since the pre-Great Patagonian Glaciation advances to the pre-Last Glaciation. Table 2 describes the Last Glaciation in detail. They are termed as Post-GPG I, II and III (Coronato *et al*., 2004a). Kilian *et al*. (2007) recognized the same moraine limits as those occurring in the northern Skyring sound. The glaciological behaviour of the palaeo-glacier that

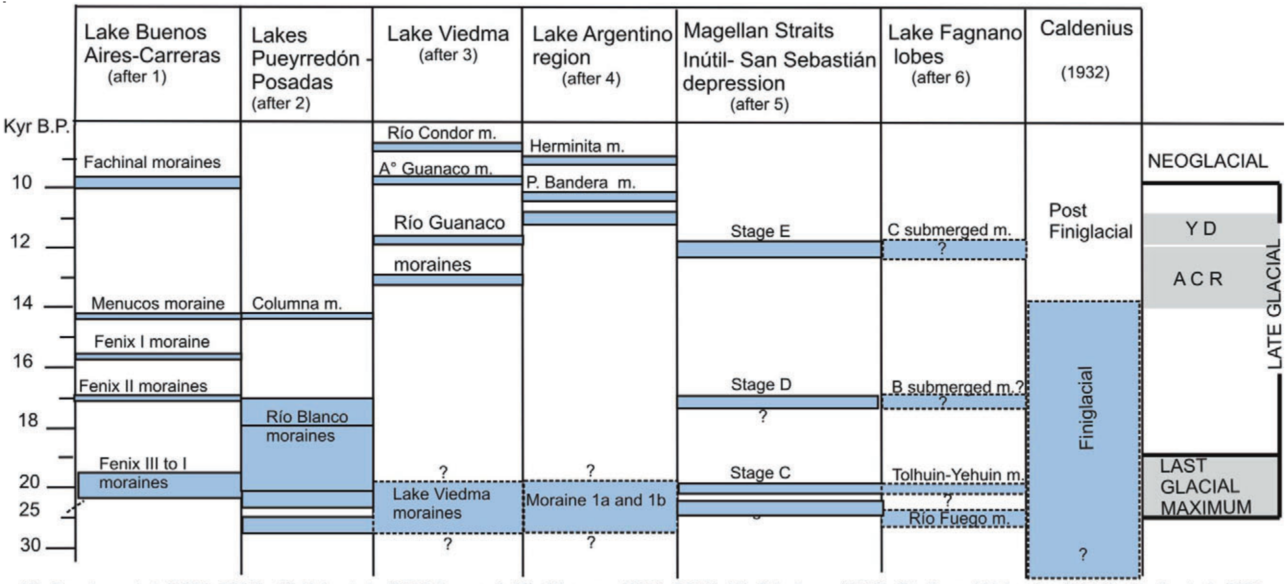
Table 1. Quaternary chronostratigraphy of the main east-flowing palaeo-glacier lobes from 46°S to 54°S



!1): Lisiecki and Reimo (2004);(2): (3): Singer et al (2004); (4): Kaplan et al 2005; (5): Malagnino, 1995; (6): Hein et al, 2009; (7): Wenzens, 2006 and previous papers; (8) Schellman (1998); (9): Singer et al., 2004b;(10): Meglioli, 1992; (11): Singer et al. (2004a); 12: Walther et al., 2007

The ages are based on uncalibrated radiocarbon dates and on cosmogenic isotope measurements providing minimum exposure ages on boulders. The broken lines and question marks indicate chronological uncertainties. GPG, Great Patagonian Glaciation. From Coronato & Rabassa (2011).

Table 2. Comparison of the chronostratigraphy of southern Patagonian glaciation during Marine Isotope Stage (MIS) 2 (Last Glacial Maximum, LGM) of the major palaeo-glacier lobes from 46°S to 54°S



(1): Douglass et al. (2005, 2006); (2):Hein et al., (2009, in press); (3): Wenzens (1999, 2003); (4): Schellman (1998), Strelin and Malagnino (2000); Strelin et al., 2008; Ackert et al. (2005); (5):McCulloch et al., (2005a); (6): Coronato et al., (2006, 2008a), Waldmann et al (In press).

The ages are based on uncalibrated radiocarbon dates and on cosmogenic isotope measurements providing minimum exposure ages on boulders. The broken lines and question marks indicate chronological uncertainties. GPG, Great Patagonian Glaciation. From Coronato & Rabassa (2011).

occupied this sound was interpreted to be the same as that of the Skyring and Magellan palaeo-glaciers.

THE MAGELLAN STRAITS LOBE (51°46′–53°34′S, 69°12′–70°32′W; FIGS 1, 5, 6)

The glacial history of the Magellan palaeo-glacier has been described and mapped from the GPG, followed by three Middle Pleistocene Glaciations (Post-GPG I–III; Coronato *et al*., 2004a), the LGM and three late-glacial advances (Clapperton *et al*., 1995; McCulloch *et al*., 2005a). Bockheim *et al*. (2009) have proposed that the GPG was, in fact, a multiple glacial advance. Sand-wedge casts developed on two till units in the Tres de Enero site (51°49′S, 69°24′W; Fig. 1, number 21), previously considered to be of Initioglacial age (Meglioli, 1992), reveal that these deposits would have been formed during different stadials or even in two different glaciations. The tundra environment allowed the development of sand wedges on the lower basal till unit; after erosive processes severed their upper portions, a new glacial advance deposited the upper basal till unit in which a new set of sand wedges was also formed. This indicates that at least three to four very cold climatic periods occurred close to the present Atlantic Ocean coast by 1 Ma ago or earlier, two in the form of true glacial advances and two as the development of harsh tundra environments. Till, erratic boulders and glaciofluvial deposits have been recognized 20 km offshore on the present Atlantic Ocean continental shelf and the present easternmost outlet of the Magellan Straits by oceanographic and seismic studies (see Rabassa, 2008). Pleistocene till and outwash deposits forming submerged tablelands gently sloping to the east have also been recognized. In addition, a southeast-trending submerged glacial valley, 125 km in length, has been identified as the ancient outwash channel, perhaps belonging to different glaciations. Thus, sometime in the Pleistocene, the Magellan palaeo-glacier was part of an extensive piedmont glacier that covered southernmost Patagonia and northern Tierra del Fuego (Fig. 1). During recessional phases, the main outwash channel terminated close to the southern Bahía San Sebastián (Fig. 1, number 26) palaeo-glacier. On the western side of the Magellan Straits, new detailed mapping focused on the LGM and late-glacial landforms and palaeo-glacier limits has been published by Bentley *et al*. (2005) and McCulloch *et al*. (2005a, b). Four glacial limits correspond to the LGM and its recession phases, but the outermost limit was referred to the last Middle Pleistocene Glaciation or Post-GPG III (Coronato *et al*., 2004a).

The LGM limits are coincident with those mapped by previous authors, but the chronology has been constrained. McCulloch *et al*. (2005a, b) proposed that the LGM limit occurred after 31.2 cal. ka BP and culminated at 25.2–23.1 cal. ka BP, but was followed by a less extensive advance before 22.4–20.3 cal. ka BP. A considerably less extensive stage culminated before 17.7–17.6 cal. ka BP. Subsequently, a rapid and widespread glacial retreat occurred. The last advance dammed glacial lakes and spanned 15.5–11.7 cal. ka BP, coinciding with the ACR. At the end of this phase, the lake drained catastrophically to the Pacific Ocean but, between the LGM limit and the previous one (Post-GPG III limit), a valley was formed. The present marine environment was fully installed during early Holocene times: *c*. 8.2–7.4 ^{14}C ka BP.

THE FUEGIAN PALAEO-ICE LOBES

Isla Grande de Tierra del Fuego (Figs 1, 6) is the main island of the Fuegian archipelago. Its separation from continental South America was a result of marine flooding of deep glacial troughs during the Holocene. Quaternary glaciations affected this island along the Magellan Straits, the Bahía Inútil–Bahía San Sebastián depression (Fig. 1, numbers 25 and 26), the Lago Fagnano (Fig. 1, number 29), the Carbajal valley (Fig. 1, number 32), the Beagle Channel (Fig. 1, number 31) and small tributary or hanging valleys. Five main glaciations have been mapped in the northern area, but only the last two have been recognized so far in the mountainous southern area. Gaps of information still exist north and south of the Río Grande region (Fig. 1, number 28) and along the eastern Atlantic coast.

THE BAHÍA INÚTIL–BAHÍA SAN SEBASTIÁN LOBE (FIG. 1, NUMBERS 25 AND 26; FIG. 6)

The classic glacial model was developed for this area by Caldenius (1932; Fig. 2), and later refined by Meglioli (1992). Submerged till, glaciofluvial deposits and erratic boulders have been recognized by seismic investigations and coring (Bahía San Sebastián; see Rabassa, 2008). This glacial evidence has been interpreted as the result of a huge piedmont glacier covering the area during the early Pleistocene. The easternmost till position was found 30 km offshore, whereas boulders occurred at 90 km. Preliminary studies of palaeomagnetism on well-exposed basal till along Punta Sinaí cliffs (Fig. 1, number 28) were performed by Walther *et al*. (2007), who proposed a normal, Brunhes-age polarity for this till, thus providing the first chronological data for the Post-GPG I moraines (Coronato *et al*., 2004b) in Tierra del Fuego, younger than 760 ka. On the basis of the stratigraphical position of paraglacial fans and raised marine beaches, Bujalesky, Coronato & Isla (2001) postulated that the Sierras de San Sebastián and Lagunas Secas glacial limits (Meglioli, 1992) should correspond to MIS 10 and 6, respectively.

An extensive erratic boulder field has been interpreted as rock avalanche supraglacial debris produced along the southern margin of the palaeo-glacier when it flowed nearby Cordillera Darwin, where this allochthonous lithology outcrops. Cosmogenic isotope dating of boulders of the Post-GPG I and Post-GPG II moraines indicates that these glacial erratics have had a much shorter exposure period than the assumed age of the landforms in which they are found (Kaplan *et al*., 2007; Evenson *et al*., 2009). Intensive weathering and complex geomorphological processes throughout the Pleistocene have been proposed to explain this discrepancy (Kaplan *et al*., 2007).

McCulloch *et al*. (2005a, b) studied the Bahía Inútil region, proposing the same glacial model as developed for the Magellan Straits during the LGM and late-glacial times. As the palaeo-glaciers covering these areas belong to the same outlet glacier, the glaciological behaviour is assumed to be under the same conditions. The first set of late-glacial moraines is marked by stillstand ice positions which built up three distinct boundaries (Bentley *et al*., 2005). The glacial lobe had retreated here into the Whiteside Channel (Fig. 1, number 27) sometime before *c*. 17.5–16.6 cal. ka BP (McCulloch *et al*., 2005a). A minimum age for a proglacial lake in the following stage, provided by a basal peat bog date in Isla Dawson (Fig. 1, number 27), refers to 10.3–10 ^{14}C ka BP, but the lake phase is thought to have persisted until 7.2 ^{14}C ka BP. These glacial stages demonstrate that the glacial behaviour was again controlled by the ACR before the complete retreat of the ice.

THE LAGO FAGNANO LOBE (54°09′–54°39′S, 66°49′–68°43′W; FIG. 1, NUMBER 29; FIG. 6)

Lago Fagnano is located along a transform plate boundary in central Tierra del Fuego. It was one of the main glacial axes along which ice flowed eastwards from the Darwin Cordillera mountain ice sheet (Figs 1, 6). The LGM and pre-LGM boundaries have been recognized in this region by previous authors (Coronato *et al*., 2004b). The LGM–late-glacial frontal positions have been identified along Lago Fagnano and San Pablo, Fuego and Ewan valleys (Fig. 1, number 30) by Coronato, Roig & Mir (2002), Coronato *et al*. (2008a, b, 2009) and Waldmann *et al*. (2010). The Post-GPG III limit is only present in the Río Fuego valley. Recent surveys have demonstrated that the Fagnano glacial outlet was fed by almost 50 alpine-type glaciers flowing from the northern and southern mountain ranges. Close to the ablation zone, it was joined laterally by alpine glaciers flowing from the southern mountains (Coronato *et al*., 2009). The most conspicuous moraines are developed at the head of the lakes: the Tolhuin moraines (Fig. 1, number 29). These features did not develop at the maximum extent of the LGM, but during the first readvance, as in the Bahía Inútil lobe (McCulloch *et al*., 2005a). An ancient proglacial lake was also reported in this area by Coronato *et al*. (2002). Beyond this proglacial environment, an outwash plain with kettles and lateral moraines encloses the valley. Frontal moraines are not well developed, perhaps because of a very low gradient of the ice at its terminus (Coronato *et al*., 2009). The late-glacial advances have been found in Lago Fagnano by seismic and coring activities. Waldmann *et al*. (2010) have recognized a series of five elongated crested topographic highs by seismic stratigraphy, and interpreted them as either a sequence of lateral moraines or as medial moraines formed by the junction of the Fagnano palaeo-glacier flowing from the west with other glaciers advancing from the southern mountains. A standstill position forming a proglacial lake, in which calving took place during the recession, was interpreted by Waldmann *et al*. (2008) from seismic stratigraphy. Towards the west, the terminal moraines and semicircular crested structures have been recognized by seismic studies and interpreted as the last glacial readvances or standstills before complete ice disintegration. Although the chronological evidence is sparse, the advancing phases of the Lago Fagnano palaeo-glacier were compared with the glacial stages in the Bahía Inútil lobe and also attributed to the ACR influence (Waldmann *et al*., 2010).

A glacial lobe flowed from the Fagnano palaeo-glacier towards the north and northeast, over the Fuego and Ewan valleys. Along the Río Fuego valley, four moraine arcs have been distinguished. A thermoluminescence age of 25.7 ka was obtained in the latero-frontal LGM moraine in the Río Fuego valley (Coronato *et al*., 2008c). The moraine was correlated with the Bahía Inútil lobe (McCulloch *et al*., 2005a).

Three moraine arcs have been recognized in the Río Ewan valley; the outermost two were interpreted as belonging to the LGM and the inner, surrounding Lago Chepelmut (Fig. 1, number 30), as a post-LGM moraine (Coronato *et al*., 2008b). A basal date of 9.2 ^{14}C ka BP in the second moraine arc (Coronato *et al*., 2008b) reveals that ice was very far from the area already during the early Holocene.

THE BEAGLE CHANNEL LOBE (54°50′S, 66°29′–68°33′W; FIG. 1, NUMBER 31; FIG. 6)

The LGM and pre-LGM boundaries (Post-GPG III; Coronato *et al*., 2004b) have been found along this valley. Antonione (2006) surveyed the Carbajal-

Harberton drumlin field in the Estancia Harberton area (Fig. 1, numbers 31 and 32) and distinguished drumlin types on the basis of their sedimentary composition as rock drumlins, basal till-cored drumlins and glaciofluvial and glaciolacustrine sedimentary-core drumlins. This author postulated that the drumlin field emplacement was conditioned by the joining of the palaeo-Beagle glacier with the tributary Carbajal glacier in the widest section of the tectonic trough (Antonione, 2006). Recently, Rabassa *et al.* (2008) identified the location of marine deposits at Isla Navarino (Fig. 1, number 33) on the southern coast of the Beagle Channel (Chile). Tree trunks and marine shells have been dated to 41.7 ^{14}C ka BP and > 46.1 ^{14}C ka BP. The dates clearly indicate that the marine environment in which they were deposited did not belong to the Holocene, thus suggesting a last interglacial age.

ENVIRONMENTAL CHANGES IN SOUTHERN SOUTH AMERICA DURING THE GLACIATIONS

The Patagonian glacial sequence provides a reasonable framework for understanding the environmental evolution of southernmost South America from the latest Miocene to the Pleistocene–Holocene boundary. Clapperton (1993), Heusser (2003), Rabassa *et al.* (2005) and Rabassa (2008) discussed the climatic and environmental changes in southern South America that followed the establishment and development of the late Cenozoic Patagonian glaciations. Firstly, global sea level changes partially exposed the Argentine submarine shelf, enhancing continental climatic conditions. Significant eustatic movements took place, with sea level decreasing by up to 100–140 m during full glacial episodes. The climatic continentality of the surrounding areas increased, with rising extreme temperatures, decreasing precipitation and a lack of sea-moderating effect as the coastline moved eastwards. This process occurred in both Pampa and Patagonia (Fig. 1), with almost a doubling in size of the continental areas and subsequent strong continentalization (Cavallotto, Violante & Hernández-Molina, 2011; Ponce *et al.*, 2011).

Sea surface temperatures were decreased by up to 4 °C in tropical areas during MIS 2, with a greater decrease towards the poles. This decrease in the mean sea surface temperature affected evaporation and the mobility of marine currents, with a consequent decrease in mean annual temperature in all continental areas. In northern Patagonia, temperatures would have been at least 5–6 °C lower than at present, and perhaps even lower further south (Clapperton, 1993). These conditions increased the influence of the Malvinas-Falkland current, which today reaches up to southern Brazil. Most probably, this current reached a much more northerly position during the glacial winters, and stayed there for longer portions of the year (Cavallotto *et al.*, 2011). As a consequence of the coastline mobility, the positions of the littoral marine currents, both the Brazil and Malvinas-Falkland currents, were affected. During the glacial epochs, their meeting front was displaced northwards, modifying the Pampean winter storm pattern, and probably diminishing the oceanic influence and increasing the water deficit during these periods. Moreover, the sea level decrease provoked a strong decrease in marine depth between the Patagonian coast and the Malvinas-Falkland archipelago (Fig. 1), forcing an eastward displacement of the Malvinas-Falkland current, with a further increase in continental climate intensity along the present littoral zones.

The climatic conditions during glacial episodes had an influence on the displacement of the oceanic anticyclonic centres in both the Pacific and Atlantic Oceans. The South Pacific anticyclonic centre was displaced northwards during the glacial periods, increasing the effect of the ‘Pampero’, cold dry winds which dominate the weather and aeolian sedimentation in the Pampas of eastern Argentina and Uruguay (Fig. 1, inset). The northward movement of this anticyclonic area determined that those regions previously free of the cold and dry ‘westerlies’ became affected by these winds. The increasing aeolian action led to the development of intensive deflation processes, with the genesis of hydro-aeolian depressions, salt lakes and endorheic basins, and also the dune field formation in northern Patagonia and western Buenos Aires Province (Fig. 1). This aeolian activity was also responsible for loess accumulation in the Pampean region and Uruguay, where the Pampean vegetation, although thinner than in interglacial times, was capable of retaining the fine sand–coarse silt fractions (Rabassa *et al.*, 2005). Deflation was strongly dominant during all glacial events, with the formation of aeolian features in areas that are wetter today. Climatic changes forced changes in plant cover, with large latitudinal displacements of the major ecosystems during glaciations. Tundra, which is restricted today in Patagonia to mountain summits above the tree line, developed all over southern Patagonia, and perhaps up to 42–44°S. Tundra conditions included permanent or transient frozen ground, at least around the ice margins, although its eastward expansion could have been larger. Tundra palaeoenvironments, inferred from palynological records of fossil peat at Lago Fagnano, were characterized by the absolute lack of arboreal (*Nothofagus* spp.) pollen. In late-glacial times, as the glaciers receded, this tundra environment was probably rapidly replaced by a park vegetation, with isolated *Nothofagus* spp. forest patches in a grassy steppe environment. These conditions are particularly evident in the Harberton peat-bog pollen profile (Heusser, 1989), where the recession of the 'Beagle Glacier' from its outermost LGM positions allowed the partial recovery of the Fuegian forest as early as 14.8 ^{14}C ka BP. At that moment, and for several hundred years, the forest started its slow but steady recovery, advancing from (still) theoretical refugia located on the present submarine shelf, or perhaps around Isla de los Estados (Fig. 1), as suggested by the pollen record (Ponce *et al*., 2011). However, at least twice, around 13 and 11 ^{14}C ka BP, the arboreal pollen content practically disappeared from the record, indicating the return to colder conditions, which perhaps forced a recession of the Fuegian forest towards its Pleistocene refugia. Towards 10.2 ^{14}C ka BP, the forest restarted its expansion, reaching present-day conditions in the first millenium of the Holocene, although the present conformation of the forest was achieved only towards *c*. 8 ^{14}C ka BP. These cold late-glacial episodes may be comparable in terms of both chronology and intensity with their Northern Hemisphere equivalents, the 'Oldest/Older Dryas' and 'Younger Dryas' events. Alternatively, a strong influence of the ACR episode has been proposed (Sugden *et al*., 2005). Nevertheless, the pollen record undoubtedly indicates that the second event was more intense and extreme than the previous one, but its environmental consequences on the forest are still unknown.

The Patagonian forest became isolated from other South American forest formations perhaps in the middle Miocene. On the Chilean side, as the ice reached the Pacific Ocean waters south of 44°S (south of Chiloé Island, Fig. 1), the forest was probably completely suppressed, perhaps with isolated refugia on small, remote islands or uncovered coastal peaks. On the eastern slopes, the forest was concealed in between the glacier front and/or the 0 °C annual isotherm and the shrubby steppe environments and 300-mm annual isohyeth, which would have bounded its eastern expansion. These ecosystems were severely damaged and the forest was disrupted into fragmented populations, in remote and restricted refugia, from 36°S southwards (Sérsic *et al*., 2011). In Tierra del Fuego, the forest was probably displaced towards the present submarine shelf, north of Península Mitre (Fig. 1, number 34) and Isla de los Estados (Ponce *et al*., 2011).

The Pampean grassy prairies were spatially reduced and pushed north and northeast during glacial events. Thus, the Patagonian steppe expanded northwards into the Pampean domain and, perhaps, even into Uruguay and northeastern Argentina, thus becoming an important factor in loess accumulation. The Patagonian equivalents of the Pampean prairies, which had developed since the early–middle Miocene, disappeared as well, being replaced by the northwards and eastwards expanding Monte and Steppe ecosystems (Rabassa *et al*., 2005).

These ecosystem changes were closely followed by a significant terrestrial faunal replacement, with the northward expansion of Patagonian faunas during colder events, reaching up to southern Brazil. Likewise, the Brazilian faunas invaded the Pampas and even northernmost Patagonia during interglacial periods. This has been shown for the late Pleistocene Pampean vertebrate fossil record (Tonni & Cione, 1995), probably during each major climatic cycle.

The Pleistocene–Holocene transition, the timing of the human occupation of Patagonia, was an epoch of high environmental instability. There was a varied environmental mosaic which, together with locations closer to the sea and under its influence, would have offered appropriate, although perhaps different, routes for human peopling. In those times, environments, and thus faunal resources, would have been equivalent in both Pampa and Patagonia. These faunas are characteristic of grassland environments or, at least, grassy steppes of cold, dry to semi-arid climates (Cione & Tonni, 1999). The changes leading to definitive Holocene environments took place only after 9 ^{14}C ka BP, towards a shrubby steppe, with the final disappearance of the Pleistocene faunas.

When the Holocene environments had finally been established, the glaciers were reduced to their present conditions, thus allowing for full occupation of most of the Patagonian lands, including the Andean piedmont and the Magellan Straits. Faunas changed from those of drier environments to others corresponding to higher relative moisture. The Brazilian faunas occupied the Pampas during the late Holocene, and the Patagonian faunas have been similar to the extant ones throughout the Holocene (Tonni & Cione, 1995).

FINAL REMARKS

During recent years, glacial geology and palaeoclimatic changes have been intensively investigated on the eastern flank of the Andes and in Tierra del Fuego. Much attention has been focused on the Pleistocene glaciations. The timing of glacier advances around the LGM and readvance phases during the late glacial has been improved as a result of the application of a combination of dating methods. In addition to improved geochronology, the geomorphological knowledge has been expanded, mainly by the application of digital terrain models as mapping tools. The latter offer much improved precision for regional mapping. Seismic, coring and stratigraphical analyses in sediments performed in glacial lakes and fjords are also contributing to the understanding of the late-glacial climate and glacier readvances of the main palaeo-glacier lobes. Different glaciological behaviour in the Patagonian Pleistocene ice sheets has been recognized through palaeo-ice modelling, and the northern and southern Patagonian (the Hielo Patagónico Norte and Hielo Patagónico Sur; Fig. 1) and the Cordillera Darwin (Fig. 1) ice fields have been described as the main sources of palaeo-glaciers. The timing and how and where they separated from each other are the focus of current research.

The colder stages, from MIS 32 to 2, are almost all represented by glacial morphology or palaeoenvironmental records; only MIS 4 (*c.* 80–50 ka BP) is less well understood or represented. No full evidence of this colder period has been found so far in most of the Patagonian glacial valleys. The scientific question most actively debated today is whether the ACR forced the main late-glacial cooling in southern Patagonia, whereas the YD event affected the northern Patagonian Andes instead. In addition, the shifting of the westerlies during the Pleistocene, as the key process for humidity–snow delivery and the increase in glacial accumulation areas, is one of the targets of the present palaeoenvironmental studies in the region.

The impact of glaciers was highly significant in the drainage network pattern and the location of the Cordilleran lakes. The basins of all present Andean lakes were formed by glacial action and covered by ice during the LGM. These basins may have already been developed during the middle Pleistocene glaciations, after the canyon-cutting event. These lakes were finally formed when the climate changed at the end of the LGM, as the ice receded. At least between 16 and 11 cal. ka BP, these lakes were in contact with the glaciers. The Cardiel (Fig. 1, number 16), Musters and Colhue Huapi (Fig. 1, number 35) and Carrilaufquen Chica and Grande (Fig. 1, number 36) lakes were instead never covered by glacier ice or in ice contact. Finally, as a consequence of the glacier retreat and the occurrence of thick frontal deposits, some of the lakes reversed their drainage towards the Pacific Ocean, but in most cases not before the YD event.

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REFERENCES

Antonione G. 2006. La genesi dei drumlin Tardo Pleistocenici nell'analisi geomorfologica di Estancia Harberton (Terra del Fuoco, Argentina). Degree Thesis, Facoltá di Scienze Matematiche, Fisiche e Naturali, Universitá degli Studio di Trieste, Italy.

Beltramone C. 1991. Estratigrafía glacial del valle de Río Mayo, Provincia de Chubut, Argentina. In: *Congreso Geológico Chileno*, ed. Santiago, Chile: Vol. 1. Resúmenes Expandidos, 58–61.

Bentley M, Sugden D, Hulton N, McCulloch R. 2005. The landforms and pattern of deglaciation in the Strait of Magellan and Bahía Inútil, southernmost South America. *Geografiska Annaler* **87A (2):** 313–334.

Beraza L, Vilas J. 1989. Paleomagnetism and relative age from Pleistocenic end moraines at Río Pico valley, Patagonia, Argentina. *International geological congress*. Washington, DC: International Geological Congress, 28, no. 1, 128–129.

Bockheim J, Coronato A, Ponce F, Ercolano B, Rabassa J. 2009. Relict sand wedges in southern Patagonia and their stratigraphic and paleoenvironmental significance. *Quaternary Science Reviews* **28:** 1188–1199.

Bujalesky G, Coronato A, Isla F. 2001. Ambientes glacifluviales y litorales Cuaternarios de la región del Río Chico, Tierra del Fuego, Argentina. *Revista de la Asociación Geológica Argentina* **56:** 73–90.

Caldenius C. 1932. Las Glaciaciones Cuaternarias en Patagonia y Tierra del Fuego. Ministerio de Agricultura de la Nación. *Dirección General de Minas y Geología* **95:** 1–148 Buenos Aires.

Cavallotto JL, Violante RA, Hernández-Molina FJ. 2011. Geological aspects and evolution of the Patagonian Continental Margin. *Biological Journal of the Linnean Society* **103:** 346–362.

Cione AL, Tonni EP. 1999. Biostratigraphy and chronological scale of uppermost Cenozoic in the Pampean area, Argentina. In: Tonni E, Cione AL, eds. *Quaternary vertebrate paleontology in South America, Quaternary of South America & Antarctic Peninsula, 12*. Rotterdam: A.A. Balkema Publishers, 23–51.

Clapperton C. 1993. Nature and environmental changes in South America at the Late Glacial Maximum. *Palaeogeography, Palaeoclimatology, Palaeoecology* **101:** 189–208.

Clapperton C, Sudgen D, Kaufman D, McCulloch R. 1995. The last glaciation in Central Magellan Strait, southernmost Chile. *Quaternary Research* **44:** 133–148.

Coronato A, Coronato F, Mazzoni E, Vázquez M. 2008a. Physical geography of Patagonia and Tierra del Fuego. In: Rabassa J, ed. *Late Cenozoic of Patagonia and Tierra del Fuego. Development in Quaternary Sciences*, Volume 11, 3. Amsterdam: Elsevier, 13–56.

Coronato A, Martínez O, Rabassa J. 2004a. Pleistocene glaciations in Argentine Patagonia, South America. In: Ehlers J, Gibbard PL, eds. *Quaternary glaciations – extent and chronology. Part III*. Amsterdam: Elsevier, 49–67.

Coronato A, Meglioli A, Rabassa J. 2004b. Glaciations in the Magellan Straits and Tierra del Fuego, southernmost South America. In: Ehlers J, Gibbard PL, eds. *Quaternary glaciations – extent and chronology, Part III*. Amsterdam: Elsevier, 45–48.

Coronato A, Ponce F, Rabassa J, Seppälä M. 2008b. Evidencias morfológicas del englazamiento del valle del río Ewan, Tierra del Fuego, Argentina. In: Zappettini E, Crosta S, González MA, Segal S, eds. *Actas del XVII Congreso Geológico Argentino, San Salvador de Jujuy*. Buenos Aires: Asociación Geológica Argentina, 1196–1197.

Coronato A, Ponce F, Seppälä M, Rabassa J. 2008c. Englazamiento del valle del río Fuego durante el Pleistoceno tardío, Tierra del Fuego, Argentina. In: Zappettini E, Crosta S, González MA, Segal S, eds. *Actas del XVII Congreso Geológico Argentino, San Salvador de Jujuy*. Buenos Aires: Asociación Geológica Argentina, 1194–1195.

Coronato A, Rabassa J. 2007a. Mid-Quaternary glaciations in the Southern Hemisphere. In: Elias S, ed. *Encyclopedia of quaternary science*, Vol. 2. Amsterdam: Elsevier, 1051–1056.

Coronato A, Rabassa J. 2007b. Late Quaternary glaciations in South America. In: Elias S, ed. *Encyclopedia of quaternary science*, Vol. 2. Amsterdam: Elsevier, 1101–1108.

Coronato A, Rabassa J. 2011. Pleistocene glaciations in southern Patagonia and Tierra del Fuego. In: Ehlers J, Gibbard P, eds. *Quaternary glaciations – extent and chronology, Part IV – a closer look*. Amsterdam: Elsevier.

Coronato A, Roig C, Mir X. 2002. Geoformas glaciarias de la región oriental del Lago Fagnano, Tierra del Fuego, Argentina. In: Cabaleri N, Cingolani C, Linares E, López de Luchi M, Ostera H, Panarello H, eds. *Actas del XV Congreso Geológico Argentino, El Calafete*. CD-ROM, Artículo 24. Buenos Aires: Asociación Geológica Argentina, 6.

Coronato A, Seppälä M, Ponce F, Rabassa J. 2009. Glacial geomorphology of the Pleistocene Lake Fagnano ice lobe, Tierra del Fuego, southern South America. *Geomorphology* **112:** 67–81.

Dal Molin CN, González Díaz EF. 2002. Geomorfología del área comprendida entre el Río Senguerr y el Lago Blanco, sudoeste de la Provincia del Chubut. In: Cabaleri N, Cingolani CA, Linares E, López de Luchi MG, Ostera HA, Panarello HO, eds. *Actas del XV Congreso Geológico Argentino, El Calafate*. CD-ROM, Artículo 284. El Calafate, 6.

Darwin C. 1842. On the distribution of the erratic boulders and on the contemporaneous unstratified deposits of South America. *Transactions of the Geological Society of London* **6:** 415–431.

Douglass D, Singer B, Kaplan M, Michelson D, Caffee M. 2006. Cosmogenic nuclide surface exposure dating on boulders on last-glacial and late glacial moraines and paleoclimatic implications. *Quaternary Geochronology* **1:** 43–58.

Ercolano B, Mazzoni E, Vázquez M, Rabassa J. 2004. Drumlins y formas drumlinoides del Pleistoceno Inferior en Patagonia Austral, Provincia de Santa Cruz. *Revista de la Asociación Geológica Argentina* **59:** 771–777 Buenos Aires.

Evenson E, Burkhart P, Goose J, Baker G, Jacofsky G, Meglioli A, Dalziel I, Krauss S, Alley R, Berti C. 2009. Enigmatic boulder trains, rock avalanches and the origin of 'Darwin Boulders', Tierra del Fuego. *GSA Today* **19:** 4–10.

Flint R, Fidalgo F. 1964. Glacial geology of the east flank of the Argentine Andes between latitude 39°10′S and latitude 41°20′S. *Geological Society of America Bulletin* **75:** 335–352.

Flint R, Fidalgo F. 1969. Glacial drift in the eastern Argentine Andes between latitude 41°10′S and latitude 43°10′S. *Geological Society of America Bulletin* **80:** 1043–1082.

Glasser N, Harrison S, Winchester V, Aniya M. 2004. Late Pleistocene and Holocene paleoclimate and glacier fluctuations in Patagonia. *Global and Planetary Change* **43:** 79–101.

Glasser N, Jansson C, Harrrinson S, Kleman J. 2008. The glacial geomorphology and Pleistocene history of South America between 38°S and 56°S. *Quaternary Science Reviews* **27:** 365–390.

Haller M. 1979. *Descripción Geológica de la Hoja 44 a-b, Trevelin, Provincia de Chubut*. Buenos Aires: Servicio Geológico Minero.

Haller M, Lech RR, Martínez OA, Meister CM, Page SM. 2003. *Hoja Geológica 4373IV/III, Trevelin, Provincia del Chubut*. Programa Nacional de Cartas Geológicas de la República Argentina, 1:250.000. Buenos Aires: Servicio Geológico Nacional.

Hein A, Hulton N, Dunai T, Scnabel C, Kaplan M, Naylor M, Sheng X. 2009. Middle Pleistocene glaciation in Patagonia dated by cosmogenic-nuclide measurements on outwash gravels. *Earth and Planetary Science Letters* **286:** 184–197.

Heusser C. 1989. Climate and chronology of Antarctica and adjacent South America over the past 30 000 yr. *Paleogeography, Paleoclimatology, Paleoecology* **76:** 31–37.

Heusser C. 2003. *Ice Age southern Andes*. Developments in Quaternary Science, 3. Amsterdam: Elsevier.

Kaplan M, Ackert R, Singer B, Douglass D, Kurz M. 2004. Cosmogenic nuclide chronology of millennial-scale glacial advances during the O-isotope stage 2 in Patagonia. *Geological Society of America Bulletin* **116:** 308–321.

Kaplan M, Coronato A, Hulton N, Rabassa J, Kubik P, Freeman S. 2007. Cosmogenic nuclide measurements in southernmost South America and implications for landscape change. *Geomorphology* **87:** 284–301.

Kaplan M, Douglass D, Singer B, Ackert R, Mc Caffee M. 2005. Cosmogenic nuclide chronology of pre-last glacial maximum moraines at Lago Buenos Aires, 46°S, Argentina. *Quaternary Research* **63:** 301–315.

Kilian R, Schneider C, Koch J, Fesq-martin M, Biester D, Casassa G, Arévalo M, Wendt G, Baeza O, Behrmann J. 2007. Paleoecological constraints on Late Glacial and Holocene ice retreat in the southern Andes (53°S). *Global and Planetary Change* **59:** 49–66.

Lapido O. 2000. *Carta Geológica de la República Argentina, Escala 1:250.000*. Gobernador Costa 4572-II/I. Edición Cartográfica Preliminar. Buenos Aires: Servicio Geológico Nacional.

Lapido O, Beltramone C, Haller M. 1989. Glacial deposits on the Patagonian Cordillera at latitude 43°30′ south. In: Rabassa J, ed. *Quaternary of South America and Antarctic Peninsula, 6*. Rotterdam: A.A. Balkema, 257–266.

Lovecchio J, Strelin J, Astini A. 2008. Cronología de las morenas del Cachorro, Lago Argentino, provincia de Santa Cruz. In: *Actas del XVII Congreso Geológico Argentino, San Salvador de Jujuy*. San Salvador de Jujuy: Congreso Geológico Argentino, 713–714.

Malagnino E. 1995. The discovery of the oldest extra-Andean glaciation in the lago Buenos Aires basin, Argentina. In: Rabassa J and Salemme M, eds. *Quaternary of South America and Antarctic Peninsula*. Rotterdam: A.A. Balkema Publishers, **9:** 69–83.

Martínez O. 2002. Geomorfología y geología de los depósitos glaciarios y periglaciarios de la región comprendida entre los 43° y 44° lat. Sur y 70°30′ y 72° long. Oeste, Chubut, República Argentina. Doctoral Thesis, Universidad Nacional de la Patagonia-San Juan Bosco, Comodoro Rivadavia and Esquel.

Martínez O, Coronato A, Rabassa J. 2011. Pleistocene glaciations in northern Patagonia, Argentina: an updated review. In: Ehlers J, Gibbard P, eds. *Quaternary glaciations – extent and chronology, Part IV – a closer look*. Amsterdam: Elsevier.

McCulloch R, Bentley M, Tipping M, Clapperton C. 2005b. Evidences for late glacial dammed-lakes in the Central Straits of Magellan, southern Chile. *Geografiska Annaler* **87A:** 335–362.

McCulloch R, Fogwill C, Sudgen M, Bentley M, Kubik P. 2005a. Chronology of the last glaciation in Central Strait of Magellan and Bahía Inútil. *Geografiska Annaler* **87A:** 289–312.

Meglioli A. 1992. Glacial geology of southernmost Patagonia, the Strait of Magellan and northern Tierra del Fuego. PhD Dissertation, Lehigh University, Bethlehem, PA.

Mercer J. 1976. Glacial history of southernmost South America. *Quaternary Research* **6:** 125–166.

Ploszkiewicz JV. 1987. *Descripción Geológica de la Hoja 47c, Apeleg, Provincia de Chubut*, Boletín N°204. Buenos Aires: Dirección Nacional de Minería y Geología.

Ponce JF, Rabassa J, Coronato A, Borromei AM. 2011. Paleographic evolution of the Atlantic coast of Pampa and Patagonia from the Last Glacial Maximum to the Middle Holocene. *Biological Journal of the Linnean Society* **103:** 363–379.

Porter SC. 1981. Pleistocene glaciation in the southern Lake District of Chile. *Quaternary Research* **16:** 263–292.

Rabassa J. 2008. Late Cenozoic glaciations in Patagonia and Tierra del Fuego. In: Rabassa J, ed. *Late Cenozoic of Patagonia and Tierra del Fuego, Developments in Quaternary Sciences*. Amsterdam: Elsevier, **11:** 151–204.

Rabassa J, Clapperton C. 1990. Quaternary glaciations of the southern Andes. *Quaternary Science Reviews* **9:** 153–174.

Rabassa J, Coronato A. 2009. Glaciations in Patagonia and Tierra del Fuego during the Ensenadan Stage/Age (Early Pleistocene–earliest Middle Pleistocene). *Quaternary International* **210:** 18–36.

Rabassa J, Coronato A, Ponce JF, Schlieder G, Martínez O. in press**.** Geoformas y depósitos glacigénicos en la Provincia del Neuquén. In: Leanza H, ed. *Relatorio de la Geología del Neuquén*. Neuquén: Congreso Geológico Argentino.

Rabassa J, Coronato A, Salemme M. 2005. Chronology of the Late Cenozoic Patagonian glaciations and their correlation with biostratigraphic units of the Pampean Region (Argentina). *Journal of South American Earth Sciences* **20:** 81–103.

Rabassa J, Evenson EB. 1996. Reinterpretación de la estratigrafía glaciaria de la región de San Carlos de Bariloche (Prov. de Río Negro, Argentina). In: *XIII Congreso Geológico Argentino y III Congreso de Exploración de Hidrocarburos,* Actas IV. Buenos Aires: Asociación Geológica Argentina, 237.

Rabassa J, Evenson EB, Clinch JM, Schlieder G, Zeitler P, Stephens G. 1990. Geología del Cuaternario del valle del río Malleo, Provincia del Neuquén. *Revista de la Asociación Geológica Argentina* **45:** 55–68 Buenos Aires.

Rabassa J, Evenson EB, Schlieder G, Clinch JM, Stephens G, Zeitler P. 1987. Edad Pre-Pleistoceno superior de la Glaciación El Cóndor, valle del río Malleo, Neuquén, Argentina. In: *X Congreso Geológico Argentino, San Miguel de Tucumán, 1987*, Actas III. San Miguel de Tucumán: Asociación Geológica Argentina, 261–263.

Rabassa J, Gordillo S, Ocampo C, Rivas Hurtado P. 2008. The southernmost evidence for an interglacial transgression (Sangamon?) in South America. First record of upraised Pleistocene marine deposits in Isla Navarino (Beagle Channel, southern Chile). *Geologica Acta* **6:** 251–258.

Ramos VA. 1981. Descripción geológica de la Hoja 47ab Lago Fontana, Prov. del Chubut. *Servicio Geológico Nacional, Boletín 183*. Buenos Aires: Servicio Geológico Nacional.

Sérsic AN, Cosacov A, Cocucci AA, Johnson LA, Pozner R, Avila LJ, Sites Jr JW, Morando M. 2011. Emerging phylogeographic patterns of plants and terrestrial vertebrates from Patagonia. *Biological Journal of the Linnean Society* **103:** 475–494.

Singer B, Ackert R, Guillou H. 2004a. ^{40}Ar/^{39}Ar and K–Ar chronology of Pleistocene glaciations in Patagonia. *Geological Society of America Bulletin* **116:** 434–450.

Singer B, Brown L, Rabassa J, Guillou H. 2004b. ^{40}Ar/^{39}Ar ages of Late Pliocene and Early Pleistocene geomagnetic and glacial events in southern Argentina. *AGU Geophysical Monograph 'Timescales of the Internal Geomagnetic Field'*, 175–190.

Strelin J, Re G, Keller R, Malagnino E. 1999. New evidence concerning the Plio-Pleistocene landscape evolution of southern Santa Cruz region. *Journal of South American Earth Sciences* **12:** 333–342.

Sugden D, Bentley M, Fogwill C, Hulton N, McCulloch D. 2005. Late-Glacial glacier events in southernmost South America: a blend of 'northern' and 'southern' hemispheric climatic signals? *Geografiska Annaler* **87A:** 273–288.

Tonni EP, Cione AL. 1995. Los mamíferos como indicadores de cambios climáticos en el Cuaternario de la Región Pampeana de la Argentina. In: Argollo J, Mourguiart P, eds. *Cambios Cuaternarios en América del Sur*. La Paz: ORSTOM Publicaciones, 319–326.

Ton-That T, Singer B, Mörner N, Rabassa J. 1999. Datación de lavas basálticas por ^{40}Ar/^{39}Ar y geología glacial de la región del Lago Buenos Aires. *Revista de la Asociación Geológica Argentina* **54:** 333–352.

Turner K, Fogwill R, McCulloch R, Sudgen D. 2005. Deglaciation of the eastern flank of the North Patagonian Icefield and associated continental scale lake diversions. *Geografiska Annaler* **87A:** 363–374.

Waldmann N, Ariztegui D, Anselmetti F, Austin J, Dunbar R, Moy C, Recasens C. 2008. Seismic stratigraphy of Lago Fagnano sediments (Tierra del Fuego, Argentina) – A potential archive of paleoclimatic change and tectonic activity since the Late Glacial. *Geologica Acta* **6:** 101–110.

Waldmann N, Ariztegui D, Anselmetti F, Coronato A, Austin J. 2010. Geophysical evidence of multiple glacier advances in Lago Fagnano (54°S, southernmost Patagonia) since the LGM. *Quaternary Science Reviews* **29:** 1888–1200.

Walther A, Rabassa J, Coronato A, Tassone A, Vilas JF. 2007. Paleomagnetic study of glacigenic sediments from Tierra del Fuego. In: *Geosur 2007, Abstract volume*, Santiago de Chile, Chile. p. 174.

Wenzens G. 1999. Fluctuations of outlet and valley glaciers in the southern Andes (Argentina) during the past 13 000 years. *Quaternary Research* **51:** 238–247.

Wenzens G. 2000. Pliocene piedmont glaciation in the Río Shehuen valley, southwest Patagonia, Argentina. *Arctic, Antarctic and Alpine Research* **32:** 46–54.

Wenzens G. 2003. Comment on: 'The Last Glacial Maximum and deglaciation in southern South America'. *Quaternary Science Reviews* **22:** 751–754.

Wenzens G. 2005. Glacier advances east of the southern Andes between the Last Glacial Maximum and 5000 BP compared with lake terraces of the endorrheic Lago Cardiel (49°S, Patagonia, Argentina). *Zeitschrift für Geomorphologie* **49:** 433–454.

Wenzens G. 2006. Terminal moraines, outwash plains, and lake-terraces in the vicinity of Lago Cardiel (49°S, Patagonia, Argentina) – evidence of Miocene Andean foreland glaciations. *Arctic, Antarctic and Alpine Research* **38:** 276–291.