

A Paleocene lowland macroflora from Patagonia reveals significantly greater richness than North American analogs

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ABSTRACT

Few South American macrofloras of Paleocene age are known, and this limits our knowledge of diversity and composition between the end-Cretaceous event and the Eocene appearance of high floral diversity. We report new, unbiased collections of 2516 compression specimens from the Paleocene Salamanca Formation (ca. 61.7 Ma) from two localities in the Palacio de los Loros exposures in southern Chubut, Patagonia, Argentina. Our samples reveal considerably greater richness than was previously known from the Paleocene of Patagonia, including 36 species of angiosperm leaves as well as angiosperm fruits, flowers, and seeds; ferns; and conifer leaves, cones, and seeds. The floras, which are from siltstone and sandstone channel-fills deposited on low-relief floodplain landscapes in a humid, warm temperate climate, are climatically and paleoenvironmentally comparable to many quantitatively collected Paleocene floras from the Western Interior of North America. Adjusted for sample size, there are >50% more species at each Palacio de los Loros quarry than in any comparable U.S. Paleocene sample. These results indicate more vibrant terrestrial ecosystems in Patagonian than in North American floodplain environments ~4 m.y. after the end-Cretaceous extinction, and they push back the time line 10 m.y. for the evolution of high floral diversity in South America. The cause of the disparity is unknown but could involve reduced impact effects because of greater distance from the Chicxulub site, higher latest Cretaceous diversity, or faster recovery or immigration rates.

Keywords: Paleocene, Salamanca Formation, plant diversity, Patagonia, South America.

INTRODUCTION

Paleocene macrofloras provide fundamental data regarding ecosystem diversity after the end-Cretaceous extinction (e.g., Wolfe and Upchurch, 1986; Johnson and Ellis, 2002; Barclay et al., 2003; Wilf et al., 2006) and before the major biotic transitions that accompanied global warming across the Paleocene-Eocene boundary (e.g., Wing and Harrington, 2001; Jaramillo, 2002). However, there are virtually no records of confirmed Paleocene macrofloras from South America (Burnham and Johnson, 2004; Wing et al., 2004), which harbored elevated plant diversity in both Patagonia and the Neotropics during the Eocene (Berry, 1938; Wilf et al., 2005; Jaramillo et al., 2006). Today, South America has notably high plant diversity in most of its vegetational zones (e.g., Phillips and Miller, 2002).

In southern South America, the few floras reported as Paleocene in the literature have either been redated as Eocene (Wilf et al., 2005; Yabe et al., 2006) or have no reliable geochronology. Most floras of possible Paleocene age are known only from small collections that lack stratigraphic context or reliable information about floral diversity. A relatively

well understood example is the Salamanca Formation flora, from central Patagonia (Fig. 1), which is mostly known from palynological and fossil wood studies (Romero, 1968; Archangelsky, 1973; Archangelsky and Romero, 1974; Petriella and Archangelsky, 1975; Archangelsky and Zamalao, 1986; Brea et al., 2005; Matheos et al., 2005). Compression floras from the Salamanca Formation have only been studied by Berry (1937) from a small collection, including 24 figured specimens and 11 species, that has never been revised.

Here, we report the first quantitative estimates of plant megafossil diversity for the Paleocene of southern South America, using large, unbiased collections of the Salamanca Formation compression flora. We review the stratigraphy and age of the flora, analyze floral richness, contrast the results with comparable Paleocene floras from similar absolute latitudes of the Western Interior of North America, and place these results in the context of early Cenozoic floral diversification in South America.

GEOLOGICAL SETTING AND AGE

The new collections come from two localities in the Palacio de los Loros ("Parrot Palace") exposures of the Salamanca Formation. These

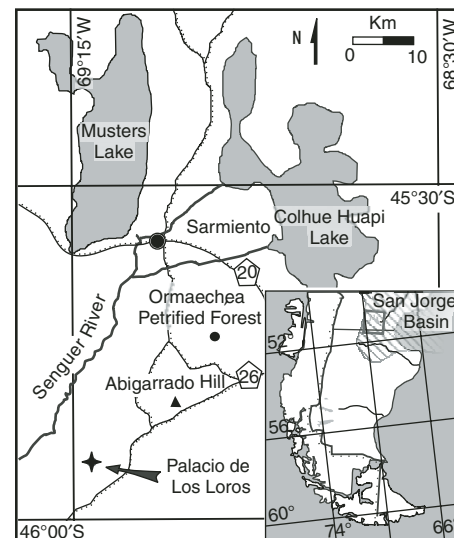


Figure 1. Regional map of the San Jorge Basin and modern location of the fossiliferous Palacio de los Loros outcrops (arrow) in the west-central basin (see also Appendix DR1 [see text footnote 1]). Inset: 62 Ma positions (using Ocean Drilling Stratigraphic Network [2004] online plate reconstruction service, with modern coastlines); box shows study area.

crop out in the western San Jorge Basin, 36 km south of Sarmiento in southern Chubut Province, Argentina (Fig. 1).

In the local section at Palacio de los Loros (GSA Data Repository Appendix DR1¹), the Salamanca Formation, which is extensively exposed in an old valley of the Senguer River, lies unconformably upon the Late Cretaceous Bajo Barrial Formation of the Chubut Group and conformably beneath the continental,

¹GSA Data Repository item 2007233, Appendix DR1 (section of the Salamanca Formation at Palacio de los Loros locality), Appendix DR2 (distinguishing features of angiosperm leaf morphotypes from Palacio de los Loros), and Appendix DR3 (relative abundance of dicot leaf morphotypes for rarefaction analysis), is available online at www.geosociety.org/pubs/ft2007.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

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middle and late Paleocene Río Chico Formation. The bulk of the Salamanca Formation is a transgressive marine package, corresponding to the middle and lower Salamanca, but the uppermost Salamanca in the western part of the basin contains mudstone and fine-grained sandstone beds that represent channels and oxbow fills from a meandering, low-relief fluvial environment. The mudstone and some of the sandstone beds contain well-preserved plant compression fossils throughout the exposure area. The two sites reported here, PL1, a channel siltstone, and PL2, a channel siltstone topped by mudstone fill at approximately the same stratigraphic level as PL1, had the best preservation of plant remains.

The Salamanca Formation is generally assigned to the Danian stage, based on foraminifera and ostracoda from the northern and eastern parts of the basin (Méndez, 1966; Bertels, 1975).

Specifically, the foraminifera species present, including *Globanomalina (Turborotalia) compressa* and *Globoconusa daubjergensis*, reliably indicate an upper Danian age (zone P1c) for the marine Salamanca (following Olsson et al., 1999). There are three less reliable but consistent radiometric ages, all from whole-rock K-Ar analyses. First, a tuff reported as being from the uppermost Salamanca Formation, 70 km north-east of Palacio de los Loros, rendered an age of 62.6 ± 5.0 Ma (Andreis, 1977; adjusted using Dalrymple, 1979). Second, two basalt units at or just under the base of the formation yielded ages of 64.0 ± 0.8 Ma and 62.8 ± 0.8 (Marshall et al., 1981). Marshall et al. (1981, 1997) used these ages and paleomagnetic data to assign the overlying Banco Negro Inferior (a massive, black, tabular bed conventionally used to identify the Salamanca–Río Chico contact throughout the basin) at several localities to polarity

subchron C26r. We also sampled a tuff horizon immediately below the Banco Negro Superior (Feruglio, 1949), 41.5 m above correlative plant-bearing levels, for $^{40}\text{Ar}/^{39}\text{Ar}$ analyses. The sanidines we retrieved were clearly altered, and the resulting isochron age of 57.80 ± 6.00 Ma has little interpretive value.

Based on this evidence and the lack of significant hiatuses observed between the relevant units, the Palacio de los Loros megaflores, which locally overlie the marine Salamanca and underlie the Banco Negro Inferior, can be well constrained to an age near the Danian-Selandian boundary. This is equivalent to the magnetic polarity chron 26–27 boundary at 61.7 ± 0.2 Ma (Gradstein et al., 2004). However, a more precise age assignment for the Palacio de los Loros floras requires additional work, with particular attention to western strata of the San Jorge Basin.

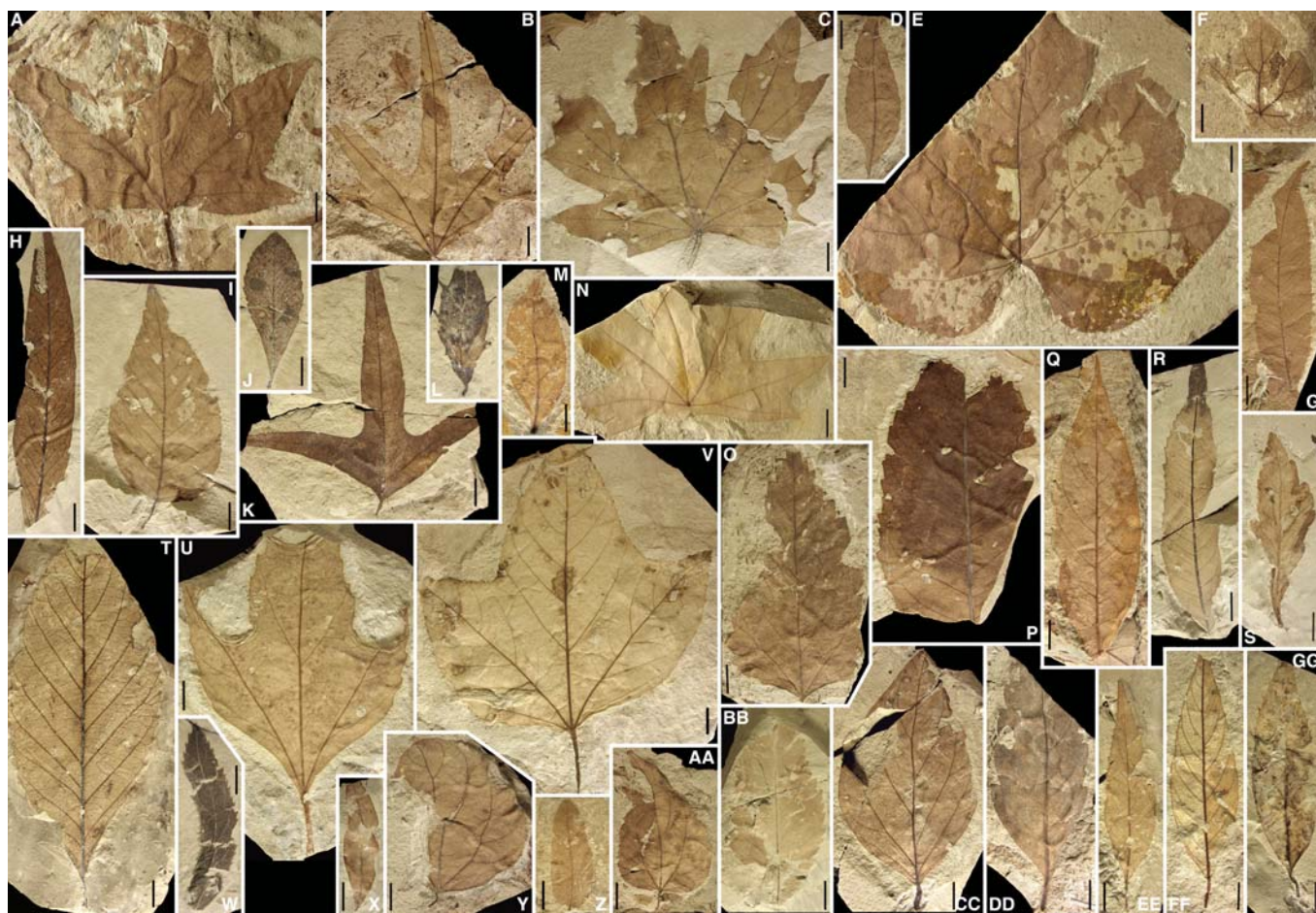


Figure 2. The 33 dicot leaf species found at Palacio de los Loros (see also Appendix DR2 [text footnote 1]). A: Morphotype SA035 (specimen MPEF-Pb-2031 [Museo Paleontológico Egidio Feruglio]). B: “*Sterculia*” *acuminataloba* (MPEF-Pb-2027). C: SA019 (MPEF-Pb-2029). D: SA044 (MPEF-Pb-2037). E: *Paranymphea aristolochiaformis* (MPEF-Pb-2032). F: SA040 (MPEF-Pb-2033). G: SA052 (MPEF-Pb-2045). H: SA016 (MPEF-Pb-2028). I: *Dryophyllum australis* (MPEF-Pb-2022). J: “*Myrica*” *premira* (MPEF-Pb-2042). K: SA058 (MPEF-Pb-2050). L: SA057 (MPEF-Pb-2049). M: *Laurophyllum chubutensis* (MPEF-Pb-2039). N: SA055 (MPEF-Pb-2047). O: SA008 (MPEF-Pb-2024). P: SA054 (MPEF-Pb-2046). Q: SA056 (MPEF-Pb-2048). R: SA020 (MPEF-Pb-2030). S: SA059 (MPEF-Pb-2051). T: SA002 (MPEF-Pb-2021). U: SA047 (MPEF-Pb-2040). V: *Cissites patagonica* (MPEF-Pb-2025). W: SA051 (MPEF-Pb-2044). X: SA050 (MPEF-Pb-2043). Y: SA060 (MPEF-Pb-2052). Z: SA045 (MPEF-Pb-2038). AA: *Banaraphyllum ovatum* (MPEF-Pb-2041). BB: SA043 (MPEF-Pb-2036). CC: *Laurophyllum piatnitzkyi* (MPEF-Pb-2026). DD: *Fagophyllum duseni* (MPEF-Pb-2035). EE: SA005 (MPEF-Pb-2023). FF: SA041 (MPEF-Pb-2034). GG: *Akania* sp. (MPEF-Pb-2020). Scale bar = 1 cm.

SALAMANCA FLORA AND PALEOCENE PLANT DIVERSITY

Fossil plants at Palacio de los Loros were discovered by A. Piatnitzky (Feruglio, 1949), who collected the 24 type specimens (Berry, 1937) from an unknown stratigraphic level. Prospecting in this area, we discovered the PL1 and PL2 sites and sampled them using standard bench-quarrying techniques (e.g., Barclay et al., 2003). All identifiable material, including 1119 specimens from PL1 and 1397 from PL2, was prepared and deposited at the Museo Paleontológico Egidio Feruglio (MPEF), Trelew, Argentina. The 2417 leaf specimens were segregated into discrete morphotypes using distinct leaf architectural features (Johnson et al., 1989; Ash et al., 1999; Fig. 2; Appendix DR2 [see text footnote 1]) to allow for paleoecological and paleoclimatic analyses.

From these morphotypes, we estimate the presence of 36 angiosperm leaf species, including 33 dicots (Fig. 2; Appendix DR2) and three monocots. Recognizable angiosperm groups include: a large-leaved *Nothofagus* (Southern Beech, Fig. 2D); Menispermaceae (moonseed family, Fig. 2Y); *Akania* (an Australian rain-forest endemic also known from early Eocene Patagonia; Romero and Hickey, 1976; Fig. 2GG); a variable species of Lauraceae (laurel family, Fig. 2CC); at least one species of Urticaceae (nettle family, Fig. 2W); legume leaflets that represent one of the oldest records of the family (Fabaceae, Fig. 2Z); at least one species of Sapindaceae (litchie family, Figs. 2G and 2BB); palmately lobed Malvaceae of the “*Sterculia*” type (Figs. 2B and 2K); and Rosaceae (Fig. 2O). Well-preserved angiosperm flowers, fruits, and seeds are also present. Also, the flora contain conifers, including Araucariaceae cone scales and Podocarpaceae leaves and cones, and at least two fern species including *Lygodium*. These are the first occurrences of reproductive and foliar organs of gymnosperms and the first fern foliage found in the Salamanca Formation, corroborating data from wood and palynomorphs (Archangelsky, 1973; Romero, 1968; Matheos et al., 2005). The recognizable elements, especially *Nothofagus*, *Akania*, and the conifer groups, indicate a Gondwanan affinity for the flora.

Using standard techniques of leaf-margin (updated in Wilf, 1997, their equations 2 and 4) and leaf-area (Wilf et al., 1998, p. 204) analyses from the 33 dicot leaves at both Palacio de los Loros outcrops combined (Appendix DR2, see footnote 1), we estimated a mean annual temperature of 14.1 ± 2.6 °C (57.6% of species toothed) and mean annual precipitation of at least 115 cm (+50/–35 cm), consistent with the lack of Andean rain shadow at this time.

The paleoclimate estimates are supported by the presence of diverse thermophilic groups, such as palm organs, which are found throughout the basin (Romero, 1968; Archangelsky, 1973), and alligatorids from the eastern basin, which require a

minimum winter isotherm of 10 °C (Bona, 2005). Podocarps nearly exclusively inhabit high-rainfall environments (e.g., Brodribb and Hill, 1999), and *Akania* today only survives in eastern Australian tropical and subtropical rain forest. Growth-ring studies of petrified wood also suggest a frost-free environment (Brea et al., 2005).

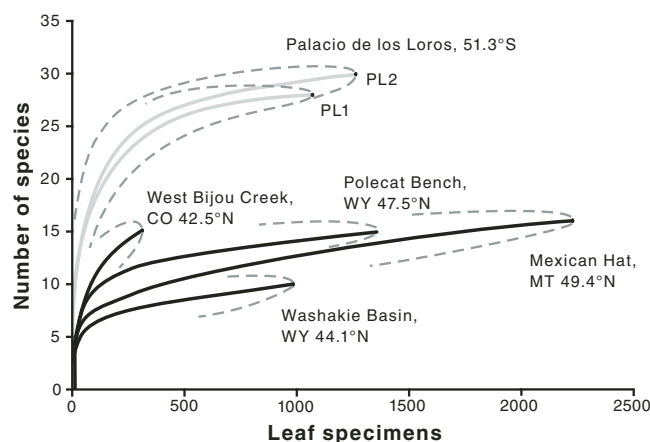
Alpha diversity of dicot leaves was adjusted for sample size using rarefaction (Fig. 3; Appendix DR3) and compared with well-sampled Paleocene floras that represent the maximum Paleocene alpha diversity conventionally known (see below) from hundreds of sites in the Western Interior of North America (e.g., Wing et al., 1995; Wilf, 2000; Barclay et al., 2003). These samples come from similar paleolatitudes and paleotemperatures and from comparable low-relief, floodplain paleoenvironments (e.g., Wing et al., 1995); they all were collected using similar, unbiased methods. Our results (Fig. 3) show that diversity at both PL1 and PL2 is more than 50% higher than comparable U.S. floras. We note that a suite of diverse Paleocene floras, including the Castle Rock flora, has been discovered in the Denver Basin of Colorado, proximal to the elevated Laramide Front Range (Johnson and Ellis, 2002; Ellis et al., 2003; Johnson et al., 2003). However, these floras clearly are not analogs for Palacio de los Loros because they represent premontane, high-rainfall environments, whereas the samples in Figure 3 come from basin centers or other low-relief settings. The foliar physiognomy of the Castle Rock flora indicates higher temperatures by 8 °C and twice the annual rainfall of the Palacio de los Loros floras, indicating benign conditions associated with very high biodiversity today.

Eocene floras from Patagonia are known for high diversity far exceeding the Paleocene Sala-

manca floras (Berry, 1938; Wilf et al., 2005). Although observed here at a much coarser temporal scale, this pattern is consistent with Paleocene-Eocene diversification seen in Neotropical palynofloras (Jaramillo, 2002; Jaramillo et al., 2006) and in Northern Hemisphere macrofloras and palynofloras (e.g., Wing and Harrington, 2001). The species composition of the Palacio de los Loros floras is dissimilar to that of the extremely diverse Laguna del Hunco flora, from early Eocene (51.9 Ma) tuffaceous lake beds in northwest Chubut Province (Wilf et al., 2005), although there is taxonomic overlap at the generic and familial level (Appendix DR3; Wilf et al., 2005). Therefore, a number of turnover events occurred between the Paleocene and early Eocene that remain to be documented; globally increasing temperatures during the early Eocene would have facilitated immigration and evolutionary diversification that increased floral diversity in Patagonia, as seen in other areas of the Americas (Wilf, 2000; Wing and Harrington, 2001; Jaramillo, 2002; Jaramillo et al., 2006).

The elevated richness of Patagonian Paleocene floras adds a new dimension to the history of South American biodiversity. Shortly after the end-Cretaceous event, Patagonia already harbored considerably richer Paleocene plant communities than comparable environments in the Western Interior of North America. This high baseline presumably anchored the evolution of the floral diversity seen 10 m.y. later at Laguna del Hunco, apparently mirrored in diverse Eocene Neotropical palynofloras (Jaramillo et al., 2006). The cause of the Paleocene diversity pattern is not known but may be related to greater distance from the Chicxulub impact, differences in Cretaceous plant diversity, and/or higher immigration or speciation rates.

Figure 3. Rarefied richness of dicot leaf species, with selected 95% confidence intervals (Tipper, 1979) and paleolatitudes (using Ocean Drilling Stratigraphic Network [2004] online plate reconstruction service) at Palacio de los Loros (localities PL1 and PL2; Appendix DR3 [see text footnote 1]) and representative and identically collected Paleocene floras from single localities in the Western Interior of North America. The West Bijou Creek sample is from Denver Museum of Nature and Science loc. 2379, in the D1 unit (ca. 65.5 Ma), eastern Denver Basin (Barclay et al., 2003). The 64.4 Ma Mexican Hat sample is from Smithsonian National Museum of Natural History (USNM) loc. 42090, from the Lebo Member of the Fort Union Formation, Powder River Basin, south-eastern Montana (Wilf et al., 2006). The Polecat Bench sample is the 57.5 Ma Lur'd Leaves site (USNM loc. 42042; Wilf et al., 2006) from the Fort Union Formation, Bighorn Basin, Wyoming. The ca. 56.5 Ma Washakie Basin, Wyoming, sample is USNM loc. 41270 (Wilf, 2000) from the uppermost Fort Union Formation. For West Bijou Creek and the Washakie Basin, which each had multiple published localities, we selected the most diverse localities for this analysis.



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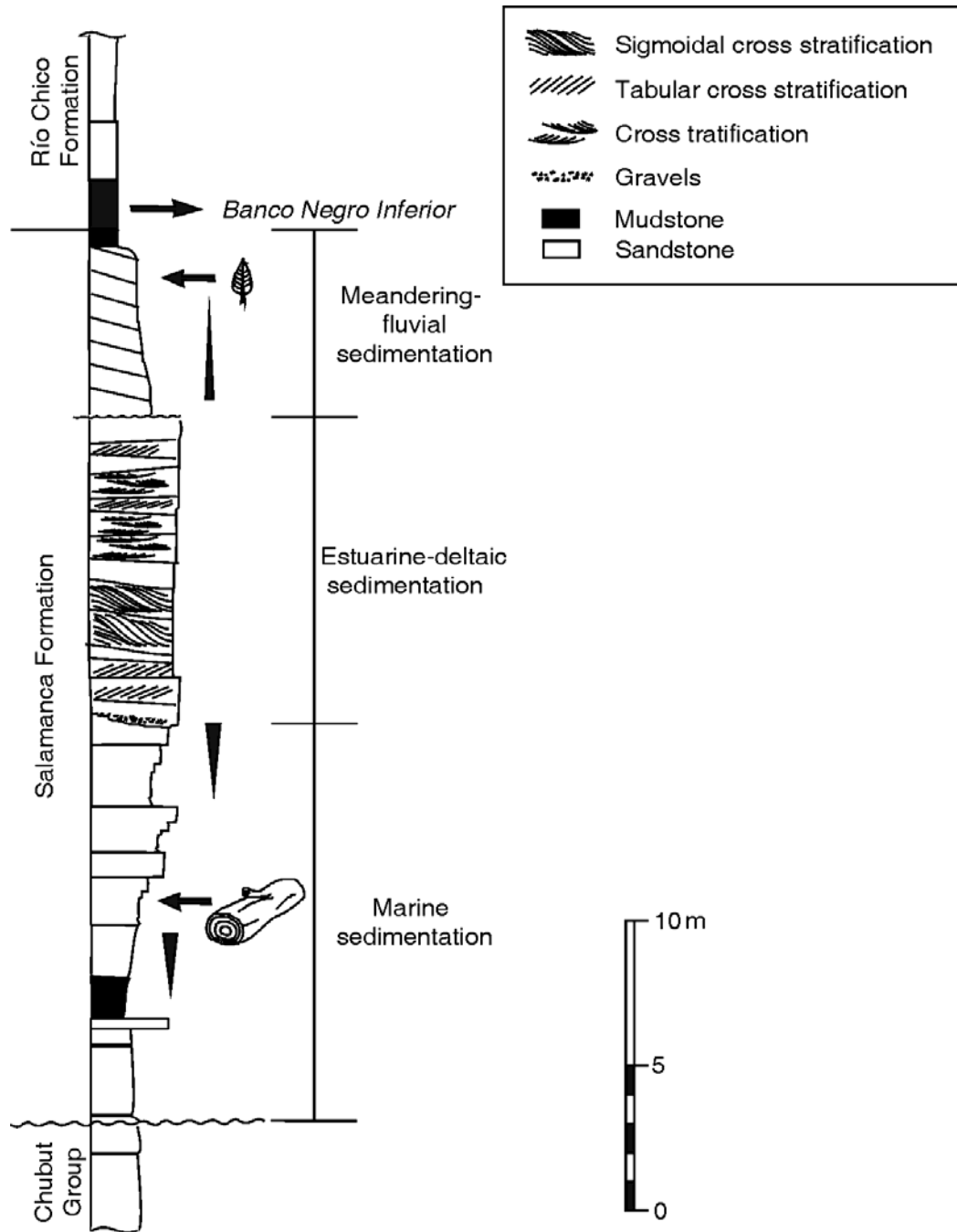
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Data Repository DR1

Section of the Salamanca Formation at *Palacio de los Loros* locality



The section at Palacio de los Loros shows an unconformity surface over the Late Cretaceous Bajo Barrial Formation (Chubut Group). The Salamanca Formation

begins with 7 m of sandstones, fining upward, that represent transgressive marine sedimentation. The section continues with large cycles of regularly sorted, medium to coarse yellow sands with sigmoidal cross beds, interpreted as deltaic, tidally influenced sedimentation (Martinez, 1992; Matheos et al., 2001); these beds preserve large, petrified, transported tree trunks. The uppermost Salamanca Formation contains mudstones and poorly sorted, fine grey sandstones on top of an erosive base, with infilled concave lenses and large lateral accretion sets. These rocks represent a meandering fluvial environment of low energy, with high sinuosity channels. The Palacio de los Loros section is topped by a massive, black, tabular 1.6 m mudstone bed with pedogenic features, root marks, slickensides and high bioturbation. This unit is named *Banco Negro Inferior* ("Lower Black Bank"; Feruglio, 1949), and in the eastern portion of the basin it contains significant mammal fossils representing the Peligran South American land-mammal age (Bonaparte et al., 1993; Flynn and Swisher, 1995). Locality PL1 is at S 45.91341° W 69.21355°; locality PL2 is at S 45.91167° W 69.21394° (WGS84 datum).

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Data Repository DR2

Distinguishing features of angios

perm leaf morphotypes from Palacio de los Loros (Fig. 2; Table DR3).

Repository number*	Figure	Morphotype	Description	Margin	Mean size class (range) #
MPEF-Pb-2020	2GG	SA 001 <i>Akania</i> sp.	Blade ovate; primary veins pinnate; secondary veins semicraspedodromous; teeth simple, curved, spinose; basal portion of blade untoothed; fimbrial vein present.	Serrate	Microphyll (Microphyll-Notophyll)
MPEF-Pb-2021	2T	SA 002	Blade elliptic to weakly ovate; base acute, or decurrent; primary vein strong with straight course; secondary veins congested basally; agrophic veins absent; tertiary angle increasing basally.	Serrate	Notophyll (Microphyll-Mesophyll)
MPEF-Pb-2022	2I	SA 004 <i>Dryophyllum australis</i>	Blade ovate; primary veins pinnate; secondary veins numerous, uniform in angles and spacing, different angles in each side of primary; tertiary veins regularly alternate percurrent, with obtuse angle to primary; teeth compound; texture membranaceous.	Dentate	Notophyll (Microphyll-Mesophyll)
MPEF-Pb-2023	2EE	SA 005	Blade narrow ovate; primary veins pinnate; secondary veins semicraspedodromous, increasing spacing toward base; intersecondary veins weak; teeth small, glandular, 3 per cm.	Dentate	Microphyll (Nanophyll-Notophyll)
MPEF-Pb-2024	2O	SA 008	Blade ovate, base decurrent; primary veins pinnate; secondary veins craspedodromous; compound agrophic veins present; teeth compound, with deep sinuses.	Dentate	Microphyll (Nanophyll-Notophyll)
MPEF-Pb-2025	2V	SA 009 <i>Cissites patagonicum</i>	Blade trilobate or ovate; primary veins basal acrodromous; secondary veins regularly spaced, numerous, craspedodromous, straight, not ramified; agrophic veins present; petiole long; teeth small, compound, with glandular apices.	Serrate	Mesophyll (Nanophyll-Macrophyll)
MPEF-Pb-2026	2CC	SA 010 <i>Laurophyllum piatnitzkyi</i>	Blade elliptic or ovate; primary veins pinnate; secondary veins brochidodromous; tertiary veins regular polygonal reticulate; ultimate venation looped; resin dots present.	Entire	Notophyll (Nanophyll-Macrophyll)
MPEF-Pb-2027	2B	SA 014 "Sterculia" <i>acuminataloba</i>	Blade palmately 4-5 lobed; lobes simple, large, with straight apex; primary veins actinodromous, rarely palinactinodromous, not branched; secondary veins brochidodromous; intramarginal vein conspicuous; areolation well developed.	Entire	Notophyll (Nanophyll-Mesophyll)
MPEF-Pb-2028	2H	SA 016	Blade elliptic lanceolate; primary veins pinnate; secondary veins densely spaced, weak brochidodromous or festooned brochidodromous; leaf rank 2r.	Entire	Microphyll (Nanophyll-Microphyll)
MPEF-Pb-2029	2C	SA 019	Blade palmately lobate; lobes compound with convex apex; base cordate; primary veins actinodromous; secondary veins regularly curved; tertiary veins percurrent, course convex, chevroned towards base; areolation well developed.	Entire	Notophyll (Notophyll-Macrophyll)
MPEF-Pb-2030	2R	SA 020	Blade ovate; primary veins pinnate; secondary veins decurrent, forking far from margin to vascularize two teeth; intersecondaries weak, with more acute angle than the secondaries; teeth large, retroflexed on basal flank, with rounded apices.	Serrate	Microphyll (Nanophyll-Mesophyll)
MPEF-Pb-2031	2A	SA 035	Blade palmately 3-5 lobate; base wide, cordate or rounded; primary veins strong; areolation strong, well developed; teeth homogeneous spaced, triangular, with simple apices.	Serrate	Notophyll (Notophyll-Mesophyll)
MPEF-Pb-2032	2E	SA 039 <i>Paranymphea aristolochiaformis</i>	Blade palmately lobate, lobes short, wide; base lobate; primary veins 7; basal veins 9; secondary veins festooned-brochidodromous; tertiary veins percurrent, opposite; areolation well developed.	Entire	Microphyll (Notophyll-Mesophyll)
MPEF-Pb-2033	2F	SA 040	Blade lobate, insertion eccentric peltate; primary veins 5, branching, in zig-zag; secondary veins brochidodromous; tertiary veins weak, opposite percurrent; margin with small crenations.	Entire	Notophyll (Notophyll-Mesophyll)
MPEF-Pb-2034	2FF	SA 041	Blade somewhat ovate; margin wavy; primary veins pinnate; secondary veins weak brochidodromous; tertiary veins very weak, opposite percurrent, densely spaced, perpendicular to primary; texture membranaceous.	Entire	Notophyll (Notophyll-Mesophyll)
MPEF-Pb-2035	2DD	SA 042 <i>Fagophyllum duseni</i>	Blade elliptic; primary veins craspedodromous; secondary veins regularly spaced, not branched, reaching the teeth medially; teeth large, convex-convex.	Serrate	Microphyll (Notophyll-Microphyll)
MPEF-Pb-2036	2BB	SA 043	Blade ovate or elliptic; primary veins pinnate; secondary veins forking, uniform; areolation well developed; teeth strong, simple, flexuous/flexuous, regularly spaced and sized, sinuses acute.	Dentate	Microphyll (Nanophyll-Microphyll)
MPEF-Pb-2037	2D	SA 044	Blade ovate; primary veins pinnate; secondary veins numerous, curved in course, non ramified, craspedodromous; teeth distinctly asymmetrical, glandular.	Serrate	Microphyll (Notophyll-Microphyll)

MPEF-Pb-2038	2Z	SA 045	Blade ovate; petiole pulvinate; base wide, rounded; apex convex; primary veins pinnate; secondary veins weak brochidodromous; intersecondaries weak.	Entire	Microphyll (Nanophyll-Microphyll)
MPEF-Pb-2039	2M	SA 046 <i>Laurophyllum chubutensis</i>	Blade narrow elliptic; primary veins pinnate; secondary veins sinuous, branched, reticulodromous; tertiary veins random reticulate; marginal ultimate venation fimbrial; low rank.	Entire	Microphyll (Notophyll-Microphyll)
MPEF-Pb-2040	2U	SA 047	Blade trilobate; primary veins strong, basal acrodromous; secondary veins scarce, craspedodromous; strong fimbrial vein present; teeth spinose, curved, regularly spaced.	Serrate	Notophyll (Nanophyll-Mesophyll)
MPEF-Pb-2041	2AA	SA 048 <i>Banaraphyllum ovatum</i>	Blade ovate; base rounded, truncate or concave-convex; primary veins basal actinodromous; secondary veins craspedodromous; basal veins 5.	Crenate	Notophyll (Nanophyll-Mesophyll)
MPEF-Pb-2042	2J	SA 049 <i>"Myrica" premira</i>	Blade obovate or elliptic; base decurrent; primary veins pinnate; secondary veins numerous, irregular in course and spacing, semicraspedodromous or festooned semicraspedodromous; low rank; teeth simple.	Crenate or dentate	Microphyll (Nanophyll-Microphyll)
MPEF-Pb-2043	2X	SA 050	Blade slightly ovate; primary veins pinnate; secondary veins reticulodromous, numerous; tertiary veins parallel to secondaries, admedially ramified; four order venation dichotomizing; rank 3r.	Entire	Microphyll (Microphyll-Notophyll)
MPEF-Pb-2044	2W	SA 051	Blade elliptic or narrow ovate; primary veins pinnate; secondary veins semicraspedodromous; tertiary veins opposite percurrent; marginal ultimate venation in fimbrial vein; teeth in two order, strong, triangular, spherulate.	Serrate	Microphyll (Nanophyll-Microphyll)
MPEF-Pb-2045	2G	SA 052	Blade oblong; apex acuminate; primary veins pinnate; secondary veins craspedodromous, subopposite, spacing decreasing toward the base; teeth simple.	Serrate	Microphyll
MPEF-Pb-2046	2P	SA 054	Blade ovate, symmetric; primary veins pinnate; secondary veins semicraspedodromous; intersecondaries strong; tertiary veins strong, random reticulate, uniform in angle; teeth compound, triangular, with two distinct orders.	Dentate	Notophyll (Notophyll-Mesophyll)
MPEF-Pb-2047	2N	SA 055	Blade palmately lobate, insertion peltate eccentric; primary veins basal actinodromous, 5 basal veins; secondary veins brochidodromous; tertiary veins irregular percurrent, weak.	Entire	Mesophyll
MPEF-Pb-2048	2Q	SA 056	Blade elliptic, apex acuminate; primary veins pinnate; secondary veins brochidodromous, regularly spaced; tertiary veins reticulate; rank 3; areolation well developed; fimbrial vein present.	Entire	Microphyll (Notophyll-Microphyll)
MPEF-Pb-2049	2L	SA 057	Blade elliptic; primary veins pinnate; secondaries veins semicraspedodromous; marginal ultimate venation in fimbrial vein; FEVs associated with resin dots; teeth large, narrow, curved, irregularly spaced.	Dentate	Microphyll
MPEF-Pb-2050	2K	SA 058	Blade trilobate; lobes long, narrow; primary veins pinnate, secondary veins brochidodromous; tertiary veins strong, irregular percurrent.	Entire	Notophyll (Notophyll-Mesophyll)
MPEF-Pb-2051	2S	SA 059	Blade elliptic; primary veins pinnate; secondary veins weak, branching, decurrent near base, festooned semicraspedodromous; fimbrial vein present; rank 2r; teeth compound.	Dentate	Microphyll
MPEF-Pb-2052	2Y	SA 060	Blade asymmetrical, ovate; apex rounded, mucronate; primary veins basal acrodromous; secondary veins brochidodromous, curved; basal veins strong, simple agrophic; areolation well developed.	Entire	Notophyll

*MPEF-Pb, *Museo Paleontológico Egidio Feruglio* Paleobotany Collection, Trelew, Chubut, Argentina.

#Size class using the Raunkiaer-Webb system of leaf-area classification (Webb, 1959).

Webb, L. J., 1959, A physiognomic classification of Australian rain forests: *Journal of Ecology*, v. 47, p. 551-570.

Data Repository DR3

Relative abundance of dicot leaf morphotypes* for rarefaction analysis (Figure 3).

Palacio de los Loros, Chubut, Argentina

Morphotype	Affinity	Specimens	
		PL1	PL2
<i>Akania</i> sp.	Akaniaceae	3	12
SA 002	unknown	14	13
<i>Dryophyllum australis</i>	Nothofagaceae	69	19
SA 005	unknown	11	10
SA 008	Rosaceae	53	9
<i>Cissites patagonicum</i>	?Vitaceae	207	256
<i>Laurophyllum piatnitzkyi</i>	Lauraceae	208	175
" <i>Sterculia</i> " <i>acuminataloba</i>	Malvaceae	94	66
SA 016	unknown	3	26
SA 019	?Cochlospermaceae	63	22
SA 020	unknown	3	125
SA 035	unknown	13	25
<i>Paranymphaea aristolochiaformis</i>	unknown	8	0
SA 040	unknown	4	1
SA 041	unknown	8	42
<i>Fagophyllum duseni</i>	unknown	24	11
SA 043	Sapindaceae	0	58
SA 044	unknown	62	14
SA 045	Fabaceae	4	0
<i>Laurophyllum chubutensis</i>	Lauraceae	56	8
SA 047	unknown	18	38
<i>Banaraphyllum ovatum</i>	?Flacourtiaceae	99	8
" <i>Myrica</i> " <i>premira</i>	?Myricaceae	15	272
SA 050	unknown	0	8
SA 051	Urticaceae	2	5
SA 052	Sapindaceae	1	0
SA 054	unknown	0	9
SA 055	unknown	0	1
SA 056	unknown	4	4
SA 057	unknown	0	1
SA 058	Malvaceae	3	8
SA 059	unknown	0	1
SA 060	Menispermaceae	2	0

*Morphotypes that appear to be herbaceous are conventionally excluded (as for one morphotype from PL not analyzed in this paper) from paleoclimate analyses using leaf physiognomy and from rarefaction analysis of diversity (e.g., Wilf, 2000; Barclay et al., 2003).