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Paleogene flora of the Sloggett Formation, Tierra del Fuego, Argentina

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Abstract. In the southeastern corner of the Isla Grande of Tierra del Fuego, southernmost Argentina, small outcrops representing Late Eocene-Early Oligocene sedimentation in fluvial environments, are referred to the Sloggett Formation. This unit crops out along the shores of Bahía Sloggett, where it is represented by carbonaceous mudstones, sandstones and conglomerates. A new paleofloristic collection of this site, originally reported by Andersson at the beginning of the 20th, was collected and analyzed, revealing the presence of gymnosperm and angiosperm leaves. Conifers are represented by probable Podocarpaceae and the presence of Araucariaceae is confirmed by leaves with preserved anatomy. Angiosperms, although fragmentary, have been grouped in morphotypes, which are referred to the Nothofagaceae, Myrtaceae and Lauraceae. The Sloggett paleoflora is similar in composition to other contemporary floras, described from southern South America and that originated in temperate to cold-temperate and humid forest.

Resumen. FLORA PALEÓGENA DE LA FORMACIÓN SLOGGETT, TIERRA DEL FUEGO, ARGENTINA. En el extremo sureste de la Isla Grande de Tierra del Fuego los reducidos afloramientos depositados en un ambiente fluvial durante el Eoceno Tardío-Oligoceno Temprano son conocidos como Formación Sloggett. Dicha unidad aflora a lo largo de la costa de Bahía Sloggett, donde se encuentra representada por pelitas carbonosas, areniscas y conglomerados. Una nueva colección paleoflorística de este sitio, originalmente reportado por Andersson a principios del siglo XX, fue colectada y analizada, reconociendo la presencia de hojas de gimnospermas y angiospermas. Las coníferas están representadas por probables Podocarpaceae junto a hojas con anatomía preservada que indican la presencia de Araucariaceae. Las angiospermas, aunque fragmentarias, han podido ser agrupadas en morfotipos que pueden ser relacionados con Nothofagaceae, Myrtaceae, y Lauraceae. La paleoflora de la Formación Sloggett se asemeja en composición a otras paleofloras contemporáneas de bosques húmedos templados a templados fríos, y que han sido descriptas para dicha región austral.

Key words. Fossil leaves. Angiosperm. Gymnosperm. Paleogene. Tierra del Fuego. Argentina.

Palabras clave. Hojas fósiles. Angiosperma. Gimnosperma. Paleógeno. Tierra del Fuego. Argentina.

Introduction

Paleogene fossil plants are well documented from Patagonia by numerous studies from the last century. Near the Paleocene-Eocene boundary, rich subtropical floras from both Río Pichileufú and Laguna del Hunco in Río Negro, Argentina were described (Berry, 1938; Wilf *et al.*, 2003). Several deposits bearing fossil leaves that characterize neotropical and mixed floras without *Nothofagus* Blume (Troncoso and Romero, 1998) from the lower Eocene of Argentina and Chile have also been studied (see Berry 1922, 1928; Troncoso, 1992, Troncoso *et al.*, 2002)). The Middle Eocene Río Turbio Formation, a mixed paleoflora with *Nothofagus* from Argentina, was described by Berry (1937), Frenguelli (1941) and Hünicken (1967). Finally, the Late Eocene-Early Oligocene subantarctic floras from the Ñirihuau Formation in Río Negro, Argentina (Fiori, 1931, 1938, 1939-40) and Loreto Formation in Punta Arenas, Chile (Dusén, 1899) were studied.

However, most of these floras are in need of revision due to the fact that the same specimens have been treated under different views according to the different authors. Nowadays, with the manual of leaf architecture (Ash *et al.*, 1999), these subjectivity can be avoided, thus unifying the concepts. Additionally, fossil floras from the region of Tierra de Fuego are poorly known.

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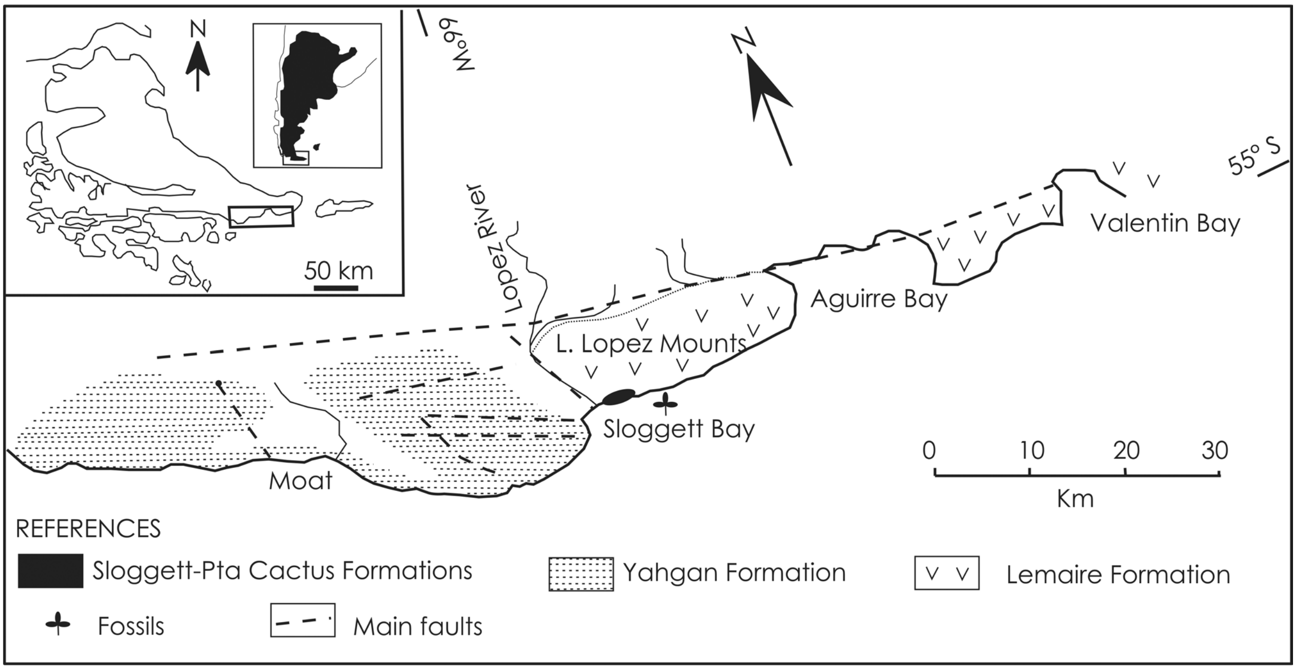


Figure 1. Location map. Taken from Olivero *et al*. 1998 / *mapa de ubicación. Tomado de Olivero* et al. *1998.*

At Isla Grande de Tierra del Fuego the Paleogene continental sediments are scarce compared to the extensive marine deposits. Small outcrops of Paleogene sediments occur along the southeastern shores of the island, and are referred to the Punta Cactus (125 m thick) and Sloggett (95 m thick) Formations (Caminos *et al*, 1981; Zanettini and Zappettini, 1988). The Sloggett Formation (figure 1) was divided into two members (Gris and Bayo Members) bearing palynological and megafloristic assemblages (Olivero *et al*, 1998). These authors proposed that this unit represents the evolution of a mixed-load anastomosing fluvial system developed in a humid and heavily vegetated environment. The lower Gris Member represents dominantly floodplain deposits with restricted ponds, swamps and crevasse channels while the upper Bayo Member represents the main channel belt with associated crevasse splay deposits (Olivero *et al*, 1998). The abrupt superposition of the Bayo Member onto the Gris Member may suggest an avulsion episode (figure 2).

The palynological assemblages described from the Sloggett Formation, are mostly dominated by Podocarpaceae (*Podocarpidites* spp., *Phylocladidites mawsonii* Cookson 1947, *Lygistepollenites florinii* (Cookson and Pike) Stover and Evans 1973, Nothofagaceae (*Nothofagidites* spp.) and Proteaceae (*Proteacidites* spp., *"Triorites" minor*), as well as gymnosperms and ferns. Based on the presence of these species Olivero *et al*. (1998) suggested a Late Eocene-Early Oligocene age for the unit.

Continental coal sediments outcrops along the San Pablo River, several tens of kilometers from the NNW (Estancia La Correntina), have been recently described and correlated with the Sloggett Formation based on lithology and palynological assemblages (Rosello, *et al*., 2004).

Andersson (1907) originally mentioned the presence of fossil plants in these rocks but unfortunately his collection was lost when his vessel, the Antarctic, sunk in the Weddell Sea. The aims of this paper are to document for the first time a new flora assemblage from the Sloggett Formation and to compare it with previously described Paleogene fossil plants from Patagonia.

Material and methods

The macrofloral material has been collected from dark massive mudstones (AF4 of Olivero *et al*., 1998) belonging to the lower section or the Gris Member, and from thin muddy levels associated with heterolithic sandstone-mudstone couples (AF3 of Olivero *et al*., 1998) at the top of Bayo Member of the Sloggett Formation (figure 2). The fossiliferous locality is located at 54º59'30"S, 66º18'04"W.

The studied material is permanently stored in the Paleobotanical Collection of the Museo Argentino de Ciencias Naturales (BAPb).

Plant fossils studied are preserved as impressions and compressions and the studied angiosperms ra-

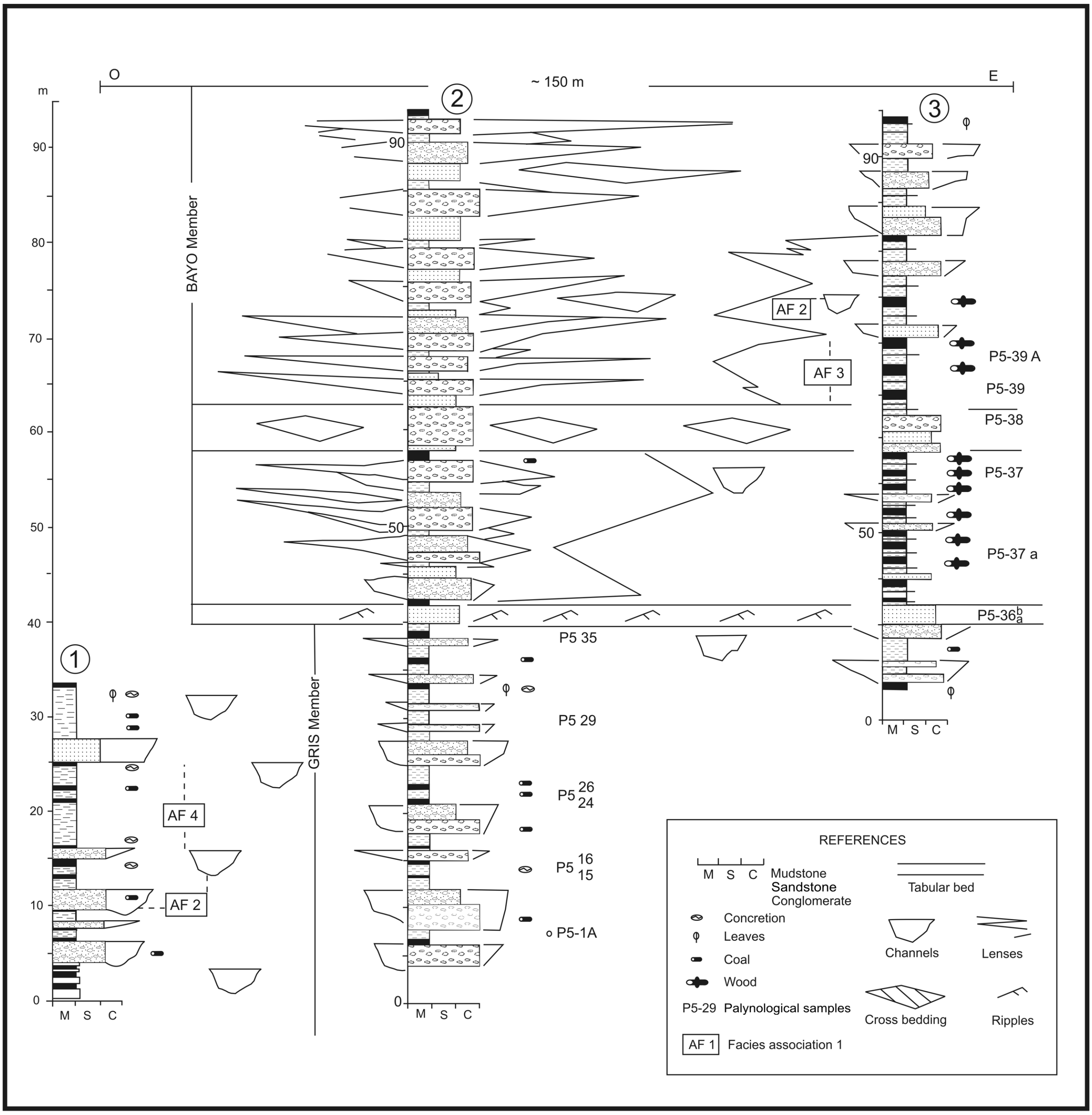


Figure 2. Stratigraphic columns of the Gris and Bayo Members of the Sloggett Formation. Taken from Olivero *et al*. 1998/ *Perfiles columnares de los Miembros Gris y Bayo de la Formación Sloggett. Tomado de Olivero* et al. *1998*.

rely preserve the third venation order. A more precise analysis of the leaf venation was made by tracing the venation on a PC screen of photographs taken with a Nikon Coolpix 4500 camera.

To avoid systematic assignments, an informal system of foliar morphotypes for angiosperm diversity which is based on distinctive vegetative morphological patterns was adopted. The morphotypes have been described following the terminology used in the manual of leaf architecture (Ash *et al*., 1999) and Dilcher (1974). Measurements are given as the mean followed by the range in parentheses.

Comparisons are made with coeval assemblages from Patagonia. Although the presence of Eocene-Oligocene leaves was mentioned for Antarctica (Dusén, 1908; Case, 1988; Dutra, 2001, 2004; Torres, 2001), detailed descriptions are still unavailable.

Systematic paleontology

MORPHOTYPE 1
Figures 3.1 and 4.1

Description. Partial lamina length 33 mm. Lamina width 16 mm, microphyllous. Apex partially complete, convex to somewhat attenuated in shape and acute (57º). Base not preserved. Margin toothed. Teeth small and simple, approximately 5 teeth per cm regularly spaced (2 mm). Dominating serration type concave on the apical side, convex to straight on the basal side. Sinuses rounded.

Pinnate primary venation. Midvein 0.48 mm width. Straight in course. Semicraspedodromous secondary venation. Secondaries opposite to subopposite diverge at moderate acute angle to primary vein (57º, 47º-72º). Secondary veins curved to moderately curved in course, can branch and anastomose with supradjacent secondaries before reaching margin. Alternate percurrent tertiary venation, sinuous in course. Tertiary veins angles on the exmedial-lower-side and the admedial-upper-side of the secondary veins are acute. Random reticulate fourth venation. Ultimate marginal venation looped. Higher venation order not clearly preserved. Tooth seems to be served by secondary or tertiary ramifications.

Studied specimen. BAPb 14862 (single and incomplete specimen with well preserved venation).

Discussion. This morphotype can be compared to *Styrax glandulifera* Berry. This species is an 11 cm long leaf where the tertiary veins, contrary to the alternate percurrent pattern observed in this morphotype, form an open mesh (Berry, 1938; p. 124, Plate 46, figure 5). On the other hand, the specimens described by Hünicken (1967; p. 218, plate XIII, figs. 7-8) as *S. glandulifera* is the most similar to our morphotype. The smaller specimen is 8 cm long, the teeth are regularly spaced and the tertiary veins show a more alternate percurrent pattern in the middle region of the leaf, being more polygonal to apex. Other species that can be compared to the morphotype here described is *Fagara serrata* Berry (Berry, 1938; p. 81, Plate 23, figs. 3-4) which is characterized by an oblong leaf shape, well marked camptodrome arcs and irregularly spaced teeth. Although the venation is very similar to our morphotype, the lamina is bigger and teeth are more spaced in the species described by Berry.

MORPHOTYPE 2
Figures 3.2 and 4.2

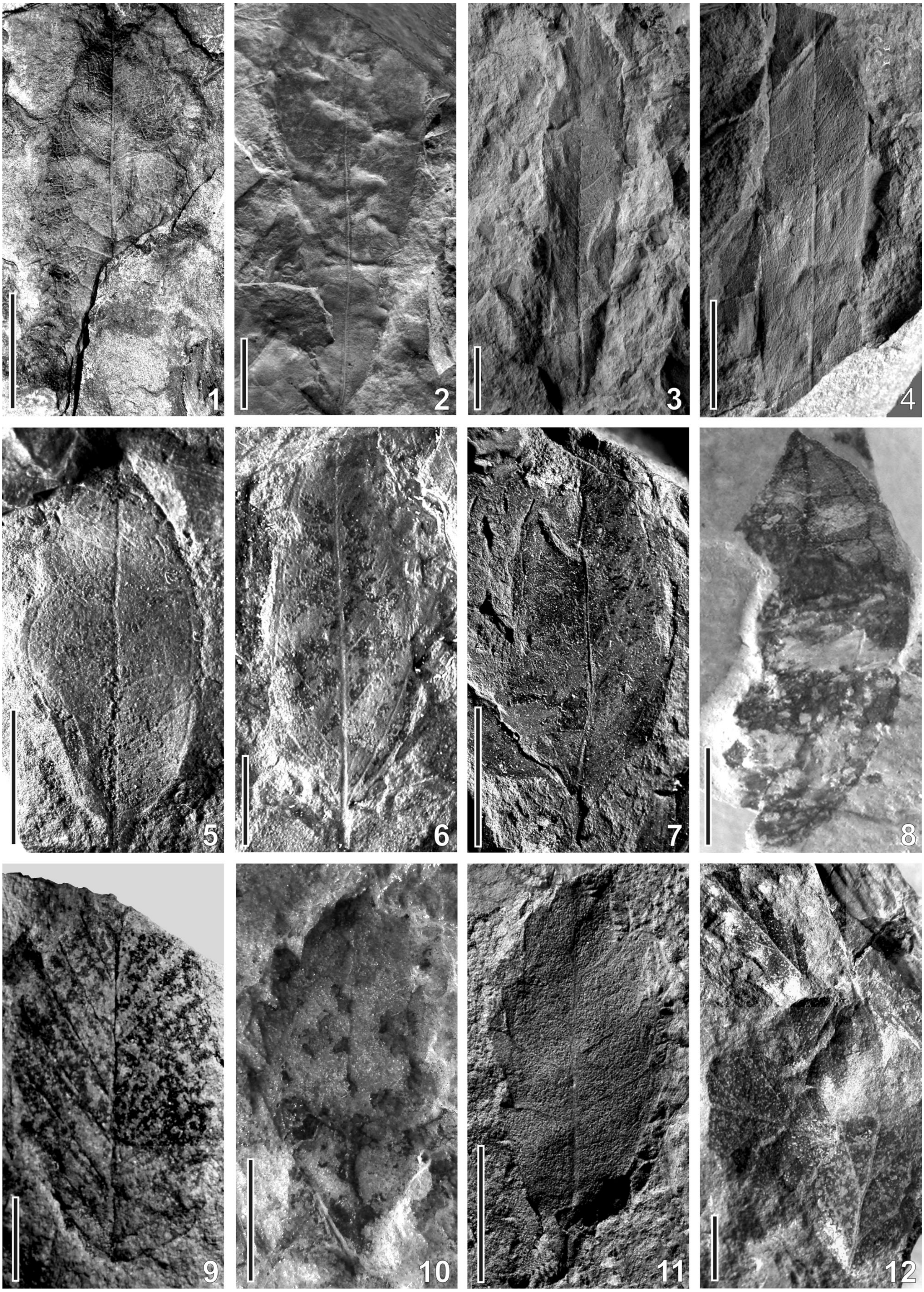
Description. Partial lamina length 55 mm. Lamina width 22.6 mm. Obovate or elliptic in shape, microphyllous. Apex not preserved. Basal angle 43º, acute. Base cuneate, somewhat decurrent in shape. Petiole marginal. Margin toothed. Teeth small, simple or compound (second order). Approximately 5 teeth per cm regularly spaced. Dominating serration type concave on the apical side, retroflexed on basal side. Sinuses flat, somewhat rounded. Space between the teeth of first order 3.9 mm and between the teeth of first and second order 1.6 mm.

Pinnate primary venation. Average primary vein width 0.26 mm. Straight in course. Craspedodromous secondary venation. Secondaries opposite to subopposite at moderate acute angle (56º, 46º-62º), straight but sinuous in course. Higher order venation not clearly preserved. Primary tooth seems to be served by a secondary vein.

Studied specimen. BAPb 14861 (single and incomplete specimen with poorly preserved venation).

Discussion. This morphotype can be compared to *Myrica premira* Berry (Berry, 1937; p. 38; Plate V, figs. 3-4 and Hünicken, 1967; p 161; Plate I, figs. 9-11) which shares with our specimen an acuminate base and margins with small serrate teeth. The venation, although craspedodromous with subparallel secondaries, is not exactly the same because in *M. premira* also exist intermediate camptodromous veins that are not observable in the specimen studied. Another species from the same genera can be compared as well. *Myrica mira* Berry (Berry, 1925; p. 196, Plate IX, fig. 4 and 1938; p. 64; Plate 14; figs. 8, 9) is represented by leaves of variable size, widest below the middle with a narrowly cuneate base like the observed in the morphotype. Also, there are teeth separated by flat sinuses, roundly excavated and, as they are observed in our specimen, occasionally extra and subordinate teeth exist that result in a closer spacing. The secondary veins are straight and diverge from the midrib at angles of 45º (the majority at angles of 60º) and like in *M. premira*, exist one or two camptodromous secondaries between adjacent craspedodromous ones. The morphotype here described is very similar to these two species as far as the cuneate base, the craspedodromous secondary venation and the small teeth. The only difference is the camptodromous secondary veins between the craspedodromous ones, but this

Figure 3. 1, Morphotype 1 / *Morfotipo 1*, BAPb 14862; **2,** Morphotype 2 / *Morfotipo 2*, BAPb 14861; **3-4,** Morphotype 3/ *Morfotipo 3*; **3,** General view of the leaf / *vista general de la hoja*, BAPb 14860; **4,** Detail of the venation pattern / *detalle del patrón de venación* BAPb 14859; **5,** Morphotype 4/ *Morfotipo 4*, BAPb 14866; **6,** Morphotype 5/ *Morfotipo 5*, BAPb 14870; **7,** Morphotype 5 / *Morfotipo 5*, BAPb 14868; **8,** Morphotype 6 / *Morfotipo 6*, BAPb 14871; **9,** Morphotype 7 / *Morfotipo 7*, BAPb 14872; **10,** Morphotype 8 / *Morfotipo 8*, General view of the leaf/ *Vista general de la hoja*, BAPb 14875; **11,** General view of the leaf and venation pattern / *Vista general de la hoja y patrón de venación*, BAPb 14873; **12,** Morphotype 9/ *Morfotipo 9*, BAPb 14879. Scale bar (figures 1-4) / *escala gráfica (figuras 1-4)* = 10 mm, Scale bar (figures 5-7, 9-12) / *Escala gráfica (figuras 5-7, 9-12)* = 5 mm. Scale bar (figure 8) / *Escala gráfica (figura 8)* = 2.5 mm.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could be due to the preservation of our material in which a good observation of the craspedodromous secondary veins is already difficult.

Finally, there can be found similarities with *Allophyllus graciliformis* Berry (Berry, 1938; p. 97; Plate 30; figs. 6-9; Hünicken, 1967; p., 192; Plate V; fig. 31-6) in the cuneate base, subparallel, thin craspedodromous secondary veins and margins with small and sharp teeth. The teeth of this species are defined as couchant-serrate that is, with the points somewhat outward recurved instead of direct upward. These type of teeth cannot be determinate in our specimen because the poor preservation of the material.

MORPHOTYPE 3
Figures 3.3-4 and 4.3-4

Description. Partial lamina length 68 mm. Lamina width 14.4 mm. Lamina symmetrical and elliptic to somewhat obovate in shape, microphyllous. Apex not preserved, probably attenuated or somewhat convex. Base acute (35º), convex to cuneate in shape. Petiole not visible in available specimens. Margin entire.

Pinnate primary venation. Average primary vein width 0.6 mm. Straight in course, slightly curved at the apex. Camptodromous brochidodromous secondary venation. Secondaries opposite to alternate at moderate acute angle (48º, 30º-73º), straight in course. Before reaching margin they curved and anastomose with supradjacent secondaries. Percurrent tertiary venation, sinuous in course. Random reticulate fourth venation order. Ultimate marginal venation looped. Higher venation order not clearly preserved.

Studied specimens. Two incomplete specimens. BAPb 14859 (well preserved venation) and BAPb 14860 (moderately well preserved venation).

Discussion. This morphotype is very similar to the specimens that Hünicken described as *Nectandra prolifica* Berry (Berry, 1938; p.111, Plate 42, figs, 1-7). Berry defined this species based on leaves of 6 to 15 cm long and 1.1 to 4 cm maximum width, variables in shape, ranging from narrowly to broadly lanceolate, widest midway between the tip and the base or slightly above or below and acuminate base. Margins entire, midvein prominent, somewhat curved and secondaries openly spaced, sweepingly curving, ascending and camptodrome. All these characters are observable in our morphotype as well. The more notorious difference is that the tertiary veins are oriented at near right angles to the midvein in the species described by Berry whereas in our morphotype are oriented more obliquely. Nevertheless, in the specimens that Hünicken described as *N. prolifica*, the tertiary veins seem to be more obliquely oriented like in the morphotype here described (1966; p. 179, Plate III, figs. 1-3; Plate IV, figs. 4-7; Plate XII, fig. 10). Although the predominant venation pattern of this genera is defined as low angled, broadly spaced secondaries with geniculated courses that curves sharply distally near the leaf margin and with an intercostal scalariform venation (that is tertiaries oriented at near right angles to midvein), there are exceptions (*i.e. Nectandra whitei* (Woodson) C.K. Allen, 1945) that have a percurrent intercostal venation, that is tertiary veins oriented obliquely to midvein (Klucking, 1987). Therefore the morphotype 3 can be considered like pertaining to *Nectandra* Roland. ex Rottb.

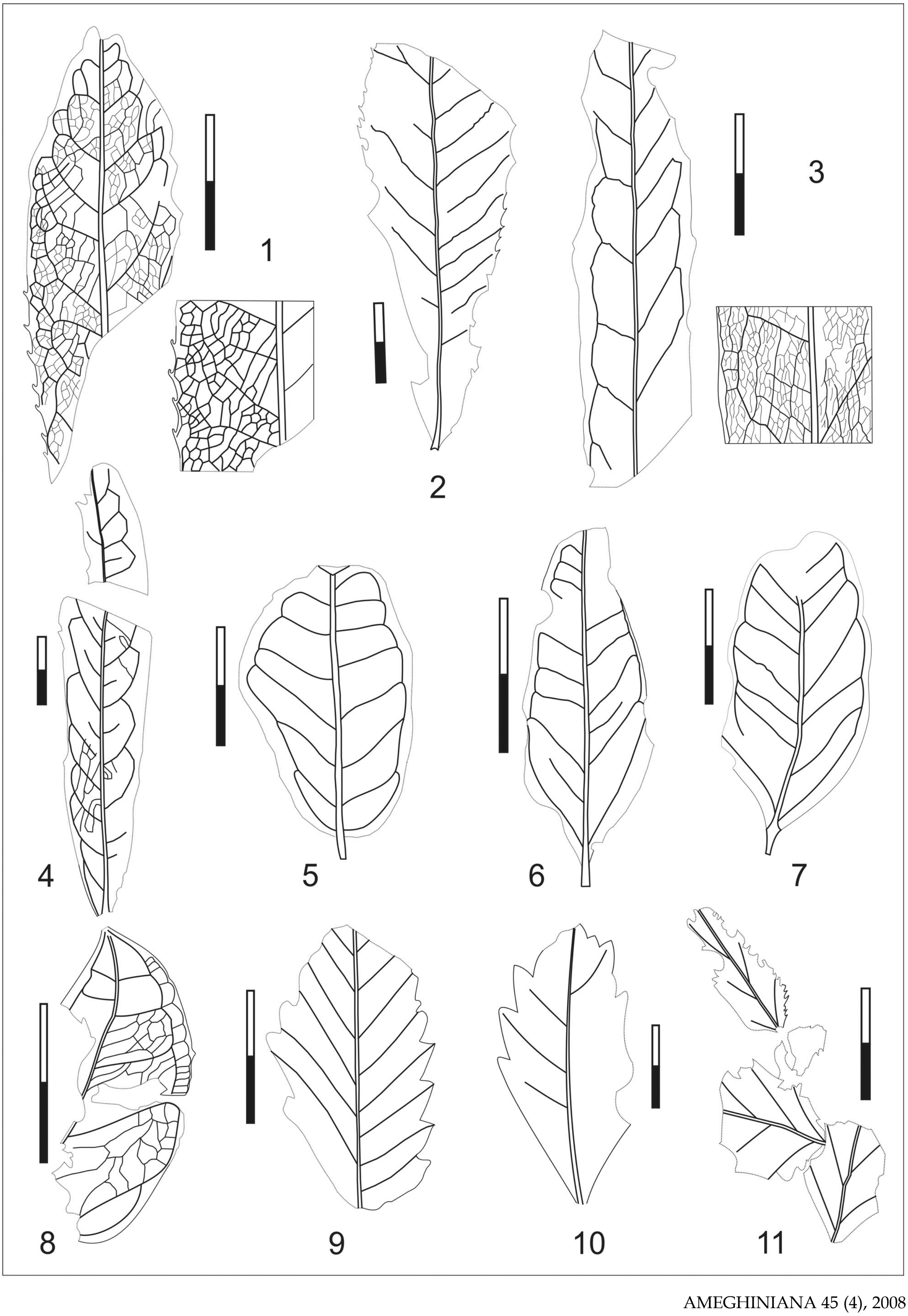
MORPHOTYPE 4
Figures 3.5 and 4.5

Description. Lamina length 12-31.3 mm. Lamina width 6-19.5 mm. Lamina symmetrical, oval to elliptical in shape, nanophyllous. Apex not preserved. Basal angle acute (83º, 76º-91º). Base convex to rounded in shape. Petiole marginal. Margin entire.

Pinnate primary venation. Midvein straight in course, 0.37 mm average width. Camptodromous brochidodromous secondary venation. At least seven pairs of secondary veins opposite to subopposite diverge at wide acute angle to primary veins (69º, 47º-86º). Secondaries relatively thin; almost subparalell and straight in course can branch and anastomose with supradjacent before reaching margin. Intersecondary veins similar to secondaries in thickness. Intramarginal vein at 0.6 (0.4-1.2) mm from the leaf margin. Higher venation order is not clearly distinctive.

Studied specimens. BAPb 14863a, BAPb 14863b (partially complete specimens with reserved venation. BAPb 14864 (incomplete leaf with preserved venation); BAPb 14865 (incomplete leaf with poorly preserved venation); BAPb 14866 (incomplete leaf with preserved venation); BAPb 14867 (incomplete leaf with preserved venation); BAPb 14868 (incomplete leaf with poorly preserved venation).

Figure 4. Drawings of the diferent morphotypes / *dibujos de los diferentes morfotipos*; **1,** Morphotype 1 / *Morfotipo 1*; General view of the leaf and detail of the venation pattern/ *Vista general de la hoja y detalle del patrón de venación, BAPb 14862*; **2,** Morphotype 2/ *Morfotipo 2*, BAPb 14861; **3-4,** Morphotype 3/ *Morfotipo 3*; **3,** General view of the leaf/ *Vista general de la hoja, BAPb 14860*; **4,** Detail of the venation pattern/ *Detalle del patrón de venación*, BAPb 14859; **5,** Morphotype 4/ *Morfotipo 4*, BAPb 14866; **6-7,** Morphotype 5/ *Morfotipo5*; **6,** BAPb 14870; **7,** BAPb 14868; **8,** Morphotype 6/ *Morfotipo 6*, BAPb 14871; **9,** Morphotype 7/ *Morfotipo 7*, BAPb 14872; **10-11,** Morphotype 8/ *Morfotipo 8*; **10,** General view of the leaf/ *Vista general de la hoja*, BAPb 14875; **11,** Detail of the venation pattern/ *Detalle del patrón de venación*, BAPb 14873; 12, Morphotype 9/ *Morfotipo 9*, BAPb 14879. Scale bar (figures 1-4, 12)/ *Escala gráfica (figuras 1-4, 12)* = 10 mm, Scale bar (figures 5-7, 9-10, 12) / *Escala gráfica (figures 5-7, 9-10)* = 5 mm. Scale bar (figures 8, 11)/ *Escala gráfica (figuras 8, 11)* = 2.5 mm.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Discussion. This morphotype presents characters like the tendency to develop an intramarginal vein and intersecondaries that allow us to compare with the Myrtaceae. According to Klucking (1988), the typical Myrtaceae venation pattern is one acrododromal secondary venation which is often referred to as intramarginal veins. These acrododromals are generally connected to the midvein by pinnate veins of secondary strength; some of these do not join the acrododromal vein and so look more like intersecondary ones.

Our morphotype can be compared to *Eugenia comparabilis* Hollich, 1924 (Fiori, 1939-40; p. 105, table V, figs. 1-3a) which is characterized by an elliptical to somewhat oval lamina, and a slightly rounded base. The midvein is straight and the secondary veins are numerous, almost parallel, straight in course curving abruptly near the margin and form a very wide divergence angle to midvein (74º-82º). The size is the only character our morphotype does not share (*E. comparabilis* is microphyllous whereas the specimens included in the morphotype are nanophyllous). *Myrcia bagualensis* Dusén (Hünicken, 1995; p. 214, Table E, figs. 10-17, 19, 20) is another species that can be compared by its small leaf, ovate to somewhat elliptical shape, rounded to wide cuneate base, straight midvein and secondary veins which emerge at wide angles (60º-65º to 80º-85º) from the midvein. Secondaries are joined near the margin to an acrododromal vein and tertiary veins form an irregular mesh. One microphyllous specimen, bigger than the rest, but that shares the same characteristics, is included provisionally in this morphotype (BAPb 14863a, BAPb 14863b). *Myrcia nitens* Engelhardt (Berry, 1928; p. 23; Plate 3; figs. 1-9) is identical to *M. bagualensis* but bigger in size. According to Berry (1928) the species described by Dusén (1899) come from over 11º farther south where, because of the possibility of more severe climate conditions, the leaves were normally smaller. Therefore its is possible that both names represents single botanical species with different sizes, every gradation.

MORPHOTYPE 5
Figures 3.6-7 and 4.6-7

Description. Partial lamina length 8.7-23.2 mm. Lamina width 3.6-8.8 mm. Symmetrical, somewhat elliptical in shape, nanophyllous. Apex not preserved. Base convex to somewhat decurrent, basal angle average acute (72º, 68º-81º). Petiole marginal. Margin entire.

Pinnate primary venation. Midvein 0.2 mm average width, straight in course. Camptodromous brochidodromous secondary venation, secondaries moderate and straight in course can branch and anastomose with supradjacent before reaching margin. At least 9 pairs of secondary veins diverge at wide acute angle (47º, 30º-73º) to primary vein. Lowermost pair more acute than those of above. Intersecondary veins similar to secondaries in thickness. Intramarginal vein at 0.6 (0.4-1.2) mm from the leaf margin. Preservation makes difficult the observation of the tertiary venation. Higher venation order is not observed.

Studied specimens. three specimens partially complete. BAPb 14868 (leaf without apex with preserved venation); BAPb 14869 (leaf without apex with preserved venation); BAPb 14870 (leaf without apex and partially complete base with preserved venation).

Discussion. The characters of this morphotype are very similar to those of morphotype 4, so we relate this morphotype to Myrtaceae as well. In morphotype 5, like in morphotype 4, it is possible to observe similarities in venation and leaf shape. Both morphotypes are characterized by an intramarginal (or acrododromal) vein, by the presence of intersecondaries and by an elliptical lamina shape. The most distinguishable character between morphotypes is a more acute inferior pair of secondary veins, and a more convex and decurrent base shape. These characters allow us to relate this morphotype with *Eugenia rioturbioensis* Hünicken (Hünicken, 1967; p. 212; Plate XII, fig. 6) because its more convex and decurrent base. *Eugenia rioturbioensis* was described as a medium sized leaf with an oval to lanceolate lamina, and a midvein straight with numerous secondaries that emerge in a wide angle to primary vein (70º). The secondary veins are alternate and straight and near the margin are joined to a thin acrododromal vein.

Temporarily included in this morphotype is one leptophyllous specimen that shares most of the characters described above except the lamina size (BAPb 14869).

MORPHOTYPE 6
Figures 3.8 and 4.8

Description. Partial lamina length 9.9 mm. Lamina width 4.6 mm. Leaf appears to be asymmetrical, nanophyllous and elliptical to oval in shape. Base partially preserved, seems to be rounded to convex in shape. Apex acute (78º) and convex. Petiole not preserved. Margin entire.

Pinnate primary venation. Midvein 0.16 mm average width, curved in course. Camptodromous brochidodromous secondary venation. Secondary veins opposite to alternate diverge in wide acute angle (74º, 58º-91º) to primary vein. The secondary veins can branch and anastomose with supradjacent veins before reaching margin. Tertiaries seem to be admedially ramified. Ultimate marginal venation forms loops and eyelets. The preservation of the material avoids the observation of a higher order venation.

Studied specimen. BAPb 14871 (single and incomplete specimen).

Discussion. The venation pattern is represented by a pinnate middle vein and acrododromous secondaries that are interpreted intramarginal veins. These facts, together with the ultimate marginal venation, are characters that allow us to compare with the Myrtaceae (Kuckling, 1988). Like the last two morphotypes described above, this one is characterized by the same venation pattern. The main difference is the asymmetrical lamina shape. Berry describes one species belonging to the Myrtaceae that has an asymmetrical leaf. *Myrcia deltoidea forma inequilateralis* Berry (Berry, 1938; p. 118, Plate 43, fig. 2) is defined by small leaves (about 3.25 cm in length by 1.2 cm in width), falcate in shape and markedly inequilateral throughout, with a rounded base and apex, a midvein stout and curved and secondaries straight, parallel, with acrodromous marginals. Although our specimen is smaller with a convex apex and a greater angle of divergence of the secondaries, it seems to be the only fossil species comparable to the Myrtaceae because its asymmetrical leaf shape.

Other species that can be compared is *Caesalpinia prebahamensis* Berry, described for the Miocene of Cuba (Berry 1939; p.115, Plate XV, figs. 4-5). *Caesalpinia prebahamensis* is defined as small leaflets (17.5 mm in length and 7.5 mm in width), entire, inequilateral and elliptical in outline; with a midvein stout and prominent that is usually curved and secondaries abruptly curved brochidodromous. In spite of the poorly description, the illustrations provided by Berry are very similar to the morphotype here described.

Morphotype 7
Figures 3.9 and 4.9

Description. Partial lamina length 21.2 mm. Lamina width 12.5 mm, nanophyllous. Lamina symmetrical, obovate to somewhat elliptical in shape. Apex not preserved. Base obtuse (70º, 57º-80º), cuneate to convex in shape. Petiole absent. Margin serrate. Teeth simple (3 teeth per cm), spacing in regular way. Average angle defined by the tooth apex is acute (81º, 78º-87º). Dominant serrate type is convex apical as basally. Sinuses angular. Space between teeth 3 (2.75-3.16) mm.

Pinnate primary venation. Midvein 0.51 mm wide, straight in course. Craspedodromous secondary venation. Relatively thin secondary veins, curved to almost straight in course, arising opposite to subopposite at moderate acute angle (44º, 30º-61º) to primary vein. Slightly more acute on one side of the lamina. Preservation avoids the observation of higher venation order. Teeth apparently fed by secondaries veins.

Studied specimen. BAPb 14872 (single and incomplete specimen with well preserved venation).

Discussion. The serrate margin along with the craspedodromous venation, are characters that allow a close comparison to the Nothofagaceae. Several species were described for the Tertiary of Patagonia belonging to the genus *Nothofagus* Blume (see Berry, 1937, 1938; Dusén, 1899; Fiori, 1938, 1939-40 and Hünicken, 1967).

Leaves of Nothofagaceae may be characterized as pinnate, with secondary veins typically straight and craspedodromous, entering the teeth centrally. The intercostal venation is formed by veins that are well differentiated from the secondaries, closely spaced, approximately at right angles to the secondaries and a fourth order venation well organized (Wolfe, 1973, Romero and Dibbern 1985). According to Romero and Dibbern (1985) and Gandolfo and Romero (1992) leaves of living *Nothofagus* have great variation. They can have entire, serrate or crenate margins, simple or compound teeth of various types, an usually low number of secondaries and outer and lower secondary veins. Unfortunately essential characters that allow the differentiation of species such as tooth venation, the preservation of our material avoids a good observation of these features. Therefore, a close assignment seems unreliable.

Morphotype 8
Figures 3.10-11 and 4.10-11

Description. Partial lamina length 15.1 mm. Lamina width 7.3 mm, nanophyllous. Lamina symmetrical, obovate in shape. Apex not preserved. Basal angle acute (65.6º), cuneate in shape. Petiole missing.
Margin toothed. Teeth simple, spaced in a regular way. Average angle defined by the acute apex (42º; 24º-59º). Dominating serration type between straight and concave on the apical side and convex to straight on the basal side. Sinuses angular. Space between teeth 3 (2-3.6) mm.

Pinnate primary venation. Midvein 0.25mm average width, straight in course. Craspedodromous secondary venation. Secondary veins subopposite to opposite arise at moderate acute angle (56º, 35º-67º) to primary vein. Secondaries seem to be moderate to relatively thin and nearly straight in course. Higher venation orders are not clearly preserved. Primary teeth seem to be served by secondary veins.

Studied specimens. BAPb 14873 (fragmentary leaf with preserved venation); BAPb 14874 (leaf incomplete, venation not observed); BAPb 14875 (fragmentary leaf, venation not observed).

Discussion. In spite of this morphotype is represented by fragmentary leaves lacking well preserved venation, the serrate margin type along with the cuneate base shape are very similar to those observed in the species belonging to *Myrica* Linné. Several species were described as *Myrica mira* (Berry, 1925; p. 196, Plate IX, fig. 4 and 1938; p. 64; Plate 14; figs. 8-9), *Myrica premira* (Berry,1937; p. 38; Plate V, figs. 3-4 and Hünicken, 1967; p. 161; Plate I, figs. 9-11), *Myrica hunzikeri* Hünicken (Hünicken, 1967; p. 162; Plate XV, fig. 1), *Myrica nordenskjöldidus* Dusén (Dusén, 1908; p. 10; Plate II, fig. 5) and *Myrica* sp. (Fiori, 1938; p. 63, Table I, fig. 31) from Patagonia. They are characterized by a cuneate or acuminate base very similar to that observed in the morphotype and by margins with serrate teeth. Among these species, the one described and illustrated by Fiori (*op. cit.*) is the most similar in size, shape and the presence of prominent, less acute teeth. The rest of the species seem not to share size or lamina shape. All are defined as microphyllous and elliptical or lanceolate in outline (except in *M. hunzikeri* which is more oval) whereas our morphotype is nanophyllous and seems to be more obovate.

Also, morphotype 8 can be related to the Nothofagaceae and Sapindaceae. Among the Sapindaceae, the genus *Allophylus* Berry, shares the craspedodromous venation, the thin, subparallel and hardly curved secondary veins but the leaf shape is not the same (in *Allophylus* is ovate) and the teeth are described as couchant-serrate, that is, with the points somewhat outward recurved (see Berry, 1938 and Hünicken, 1967).

Morphotype 9
Figures 3.12 and 4.11

Description. Partial lamina length 11.7 mm. Lamina width 8.5 mm, nanophyllous. Lamina symmetrical, obovate to elliptical in shape. Apex and base not preserved.

Margin toothed. Teeth apparently simple, regularly spaced. Apex teeth angle acute (65º; 58º-74º). Serration type between straight to concave on the apical side and convex to straight on the basal side. Sinuses angular. Average space between teeth 2.9 (2 to 3.6) mm.

Pinnate primary venation. Midvein 0.27 mm average width, straight in course. Craspedodromous secondary venation. Secondary veins arise subopposite to opposite at narrow acute angle (30º, 20º-42º) to primary vein. Secondaries moderate to relatively thin, somewhat straight in course. Higher venation order is not clearly preserved. Primary tooth seems to be served by secondary veins.

Studied specimens. BAPb 14876, BAPb 14877, BAPb 14878 and BAPb 14879 (several fragmentary specimens correspond to leaves with poorly preserved venation).

Discussion. Although this morphotype is represented by several fragmentary specimens very abundant in the collection, in which the margin preservation is rare to be observed, the craspedodromous venation along with the straight and parallel secondary along with the serrated margin allow us to suggest a relationship with the Nothofagaceae. However a more precise assignment is unreliable because the preservation of the material described.

Morphotype 10
Figures 5.1-2 and 6.1-2

Description. Lanceolate and elongate leaves with parallel margins. The most complete fragment is 24.5 mm long and 2 mm wide. Venation runs parallel to the leaf margins and, in some cases, it is possible to differentiate one more prominent vein on the middle part of the leaves.

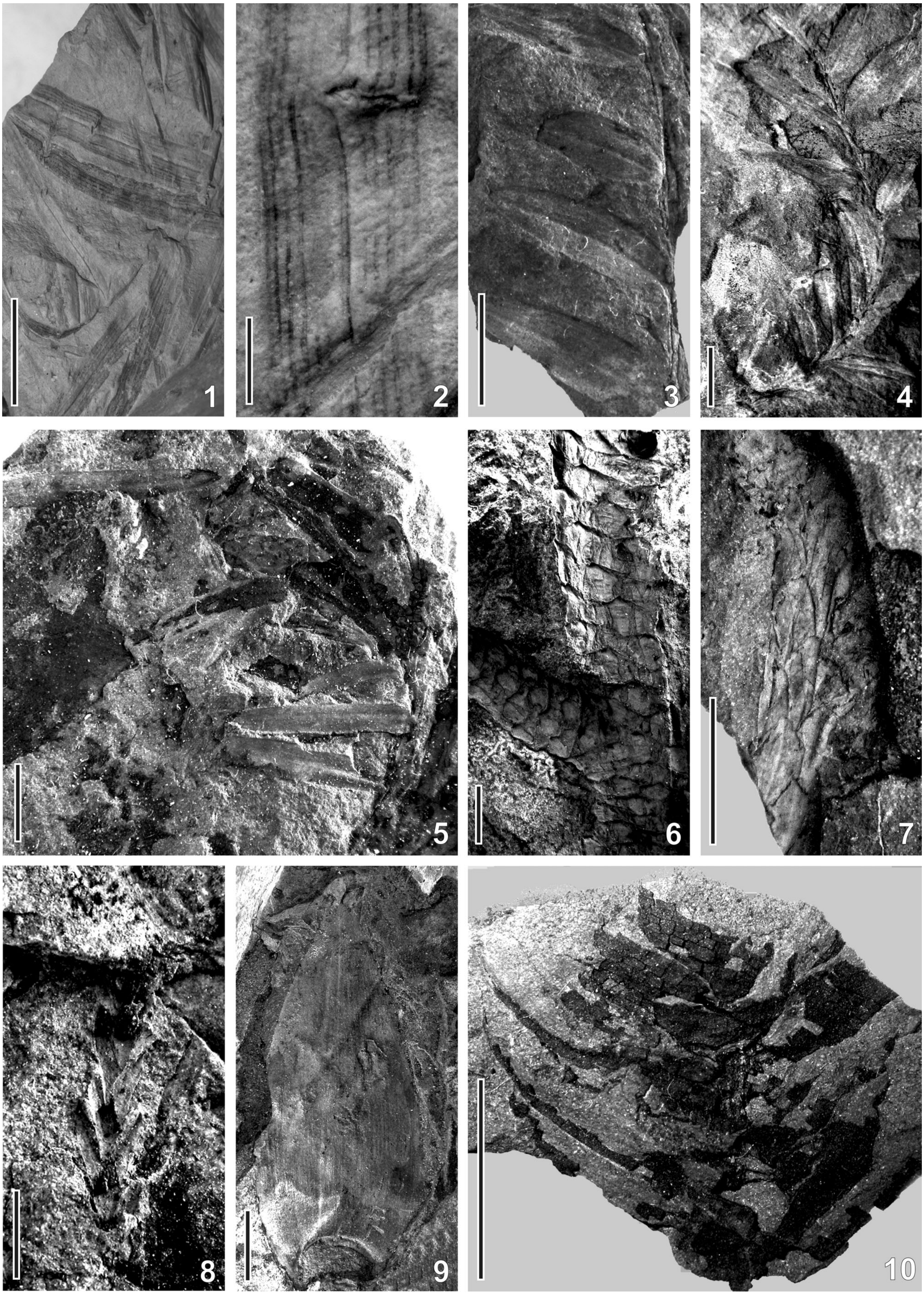
Studied specimens. BAPb 14880; BAPb 14881 (several specimens with well preservation).

Discussion. This morphotype corresponds most likely to a monocotyledonous plant. Several remains of this group have been described, like the genus *Poacites* Schlotheim, indicating the presence of these plants already in the Eocene of Patagonia (Berry, 1937, 1938; Fiori, 1938).

Morphotype 11
Figures 5.3-4 and 6.3-4

Description. Several axes of 37.9 (18.2-50.5) mm long and 0.5 mm wide that support leaves uninervate, not

Figure 5. 1-2, Morphotype 10 / *Morfotipo 10*; **1,** General view of the leaves / *vista general de las hojas*, BAPb 14881; **2,** Detail of the venation pattern/ *Detalle del patrón de venación*, BAPb 14881; **3-4,** Morphotype 11 / *Morfotipo 11*, BAPb 14882 and BAPb 14884; 5, Morphotype 12 / *Morfotipo 12*, BAPb 14885; **6,** Morphotype 13 / *Morfotipo 13*, BAPb 14887; **7,** Morphotype 14 / *Morfotipo 14*, BAPb 14889; **8,** Morphotype 15 / *Morfotipo 15*, BAPb 14891; **9-10,** *Araucaria pararaucana* sp nov.; **9,** Complete leaf / *Hoja completa*, BAPb 13542; 10, Imbricate leaves in tight helix / *Hojas imbricadas en espiral apretada*, BAPb 13541. Scale bar (figures 9-10) / *Escala gráfica (figuras 9-10)* = 10mm, Scale bar (figures 1, 3-7) / *Escala gráfica (figuras 1, 3-7)* = 5 mm, Scale bar (figure 8) / *Escala gráfica (figura 8)* = 2.5 mm, Scale bar (figure 2) / *Escala gráfica (figura 2)* = 1 mm.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imbricate, flattened bifacially and petiolated. Leaves of 8.9 (7.68-11) mm long and 2.6 (1.7-4.3) mm wide, with a prominent midvein. Leaves emerge opposite to subopposite at acute angles from the axes (49º, 23º-65º) and appear to have a twist at the leaf base.

Studied specimens. BAPb 14882, BAPb 14883, BAPb 14884.

Discussion. This morphotype seems to have a twist at the leaf base as is observed in the Podocarpaceae genera *Retrophyllum*, *Afrocarpus* and *Nageia*. These three genera created by Page (1988) that until recently were sections of a single genus *Nageia* (formerly *Decussocarpus*, de Laubenfels 1987), are characterized by leaves usually subopposite or opposite and leaf bases twisted in a characteristic fashion. In *Retrophyllum* the petioles twist through approximately 90º and both petioles of the pair of opposite leaves do so in an anticlockwise direction (heterofacially flattened shoots) (Hill and Pole, 1992). In *Nageia* and *Afrocarpus* the petioles of the pair of opposite leaves twist in opposite directions (homofacially flattened shoots). Along with this, the leaves in *Retrophyllum* and in *Afrocarpus* have a prominent and very robust midvein, whereas leaves of *Nageia* species lack a central midvein but have many fine, parallel lengthwise veins that converge towards the apex (Hill and Pole, 1992).

The twisted bases and the prominent midvein observed in our morphotype are characters that define these genera of Podocarpaceae. However, it is not possible to place them into a particular genus due to absence of cuticle.

MORPHOTYPE 12
Figures 5.5 and 6.5

Description. Axis of 25.9 mm long and 1.6 mm wide bearing leaves of 12.5 mm in length and 2.5 mm wide. Apex not preserved. Leaves inserted by the whole base without petiole, lanceolate in shape and not imbricate. Leaves emerge in obtuse angle (103º, 100º-106º) to the axis. It is possible to observe a slight depression on the leaf surface. Leaf scars were seen on the axis.

Studied specimens. BAPb 14885, BAPb 14886.

Discussion. This morphotype can be assigned to coniferous leaf type II defined by de Laubenfels (1953). This type, like our morphotype, is characterized by lanceolate and bifacially flattened leaves. The attachment to stem may be as wide as (like as in the specimen here described), or narrower than the leaf. As a consequence of the existence of a single vascular bundle it is possible to observe a ridge or, in the case of this morphotype, a slight depression on the leaf surface. This kind of leaf is present in all families of conifers at some period of ontogeny and that is why we could not make a proper assignment of it to a particular family without preserved cuticle. Despite of that, it is quite probable that our leaves belong to the Podocarpaceae or Araucariaceae because those are the coniferous families recognized in this paleoflora.

MORPHOTYPE 13
Figures 5.6 and 6.6

Description. Branched axes bearing spirally arranged leaves, overlapped and appressed. Axes of 31.4 mm long and 6 mm wide. Leaves rhomboidal in shape with a free portion of 3.3 mm long and 1.7 mm wide. Prominent keel on the abaxial surface. Texture coriaceous.

Studied specimens. BAPb 14887a; BAPb 14887b and BAPb 14888.

Discussion. According to de Laubenfels (1953) morphotypes 13 and 14 have leaves type III that are essentially reduced leaves, where the free portion of the leaf may be smaller than the decurrently one and, in most cases, are closely appressed to the stem. This type of leaves appear on mature plants of Taxodiaceae, Cupressaceae and Podocarpaceae and on seedlings they occur in *Araucaria* section *Araucaria*. The scales of most genera are quite similar, being triangular, thick and sharply keeled on the back. Variations in the external morphology of scale leaves include the proportion of the leaf free from the stem, the length of the free portion in comparison with the width and the angle that the free portion makes with the stem. Therefore, the absence of more detailed characters preserved in our specimens avoids a closer comparison.

MORPHOTYPE 14
Figures 5.7 and 6.7

Description. Axes that bear leaves imbricate spirally arranged and appressed. Main axis of 77.1 mm long and 9.7 mm wide, secondary axis of 54.3 mm in length and 5.4 mm wide. Length of the free portion of the leaf 3.3 mm in average on the main axis and 2.4 mm in length on the secondary one. Leaves triangular in shape, with a central keel on the abaxial surface. The texture is thick and coriaceous.

Studied specimen. BAPb 14889.

Discussion. See discussion of morphotype 13.

MORPHOTYPE 15
Figures 5.8 and 6.8

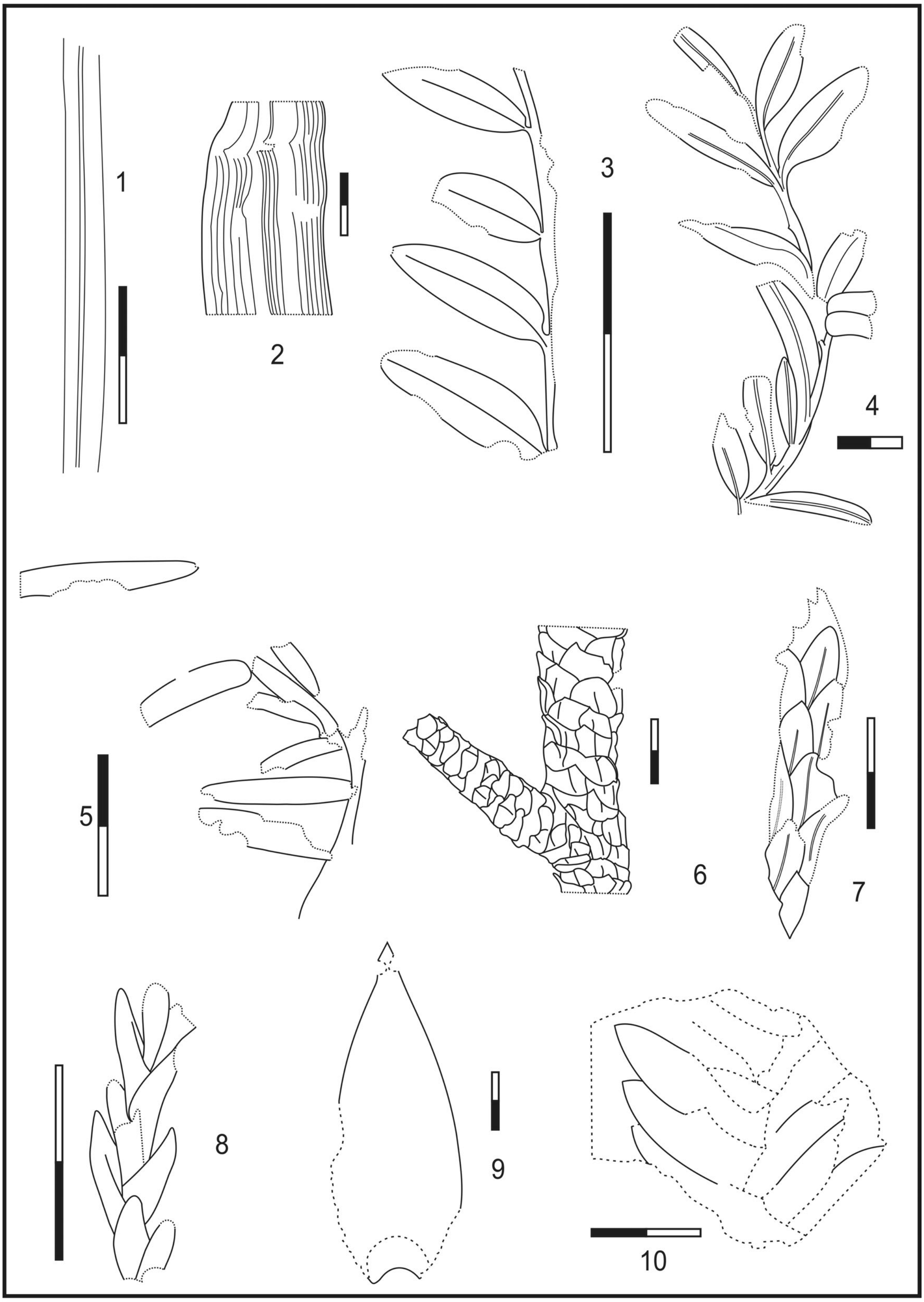

Figure 6. Drawings of the diferent morphotypes / *dibujos de los diferentes morfotipos*; **1-2,** Morphotype 10 / *Morfotipo 10*; 1, General view of the leaves / *vista general de las hojas*, BAPb 14881; **2,** Detail of the venation pattern / *detalle del patrón de venación*, BAPb 14881; **3-4,** Morphotype 11 / *Morfotipo 11*, BAPb 14882 and BAPb 14884; **5,** Morphotype 12 / *Morfotipo 12*, BAPb 14885; **6,** Morphotype 13 / *Morfotipo 13*, BAPb 14887; **7,** Morphotype 14 / *Morfotipo 14*, BAPb 14889; **8,** Morphotype 15 / Morfotipo 15, BAPb 14891; **9-10,** *Araucaria pararaucana* sp nov.; **9,** Complete leaf / *hoja completa*, BAPb 13542; **10,** Imbricate leaves in tight helix / *hojas imbricadas en espiral apretada*, BAPb 13541. Scale bar (figures 9-10)/ *Escala gráfica (figuras 9-10)* = 10 mm, Scale bar (figures 1, 3-7)/ *Escala gráfica (figuras 1, 3-7)* = 5 mm, Scale bar (figure 8)/ *Escala gráfica (figura 8)* = 2.5 mm, Scale bar (figure 2)/ *Escala gráfica (figura 2)* = 1 mm.

Description. Several remains of unbranched axes of 27 mm long and 1.7 mm wide. Axes bears spirally arranged and imbricate leaves. Free portion of the leaves: 2.5 mm long and 0.7 mm wide. Leaves elongated and narrow in shape, with a furrow that may indicate the possible existence of a keel.

Studied specimens. BAPb 14890 and BAPb 14891.

Discussion. The leaves of this morphotype can be included also into the Laubenfels type III and related to *Dacrycarpus* Endlicher which are long, narrow and closely appressed to the branch. The scale leaves in this genus are confined to essentially non-vegetative branches (de Laubenfels, 1953).

Araucaria pararaucana Panti *et al*. 2007
Figures 5.9-10 and 6.9-10

Leaves imbricate, ovate-lanceolate and anatomically preserved, were recently described by Panti *et al*. (2007) from this stratigraphic unit and assigned to the new species *A. pararaucana*. They are amphistomatic, with stomata arranged in parallel and discontinuous rows, mostly oriented parallel to the leaf margin (but oblique and horizontal oriented stomata occur). Epidermal cells are rectangular to quadrangular between stomata rows and irregular around stomata, with their outlines slightly sinuous.

Discussion

This macrofossil new plant association from Tierra del Fuego is characterized by the small size of its leaves with 75% being nanophyllous (25-225 mm^2) and the remaining 25% not greater than microphyllous (225-2,025 mm^2). In addition to this more than a third of the described morphotypes toothed margins. According to the paleofloristic types recognized by Troncoso and Romero (1998), the Sloggett Formation flora, like those studied at the Loreto and Ñirihuau formations, would be considered as subantarctic. This type of flora is dominated by the Fagaceae and Myrtaceae in association with families of southern lineage and is characterized by scarce leaves of 10 cm in length and 25-30% of leaves with entire margin. From the Eocene-Oligocene boundary and Oligocene, the steep reduction of the temperatures and annual precipitations, is consistent with the development of the subantarctic paleoflora (Hinojosa, 2005).

Climate in the late Eocene to early Miocene in Antarctica and Patagonia changed in three major steps: (i) the Late Eocene (34.5-36.5 Ma), when relatively warm conditions prevailed, but glacier formation was initiated; (ii) the Late Eocene-Early Oligocene (28.5-34.5 Ma), characterized by the transition from relatively warmer to cooler conditions coinciding with glacial intensification and sea-level fall; and (iii) the Late Oligocene-Early Miocene (22-28.5 Ma), when large-scale glaciations began to dominate Antarctica (Wilson *et al*., 1998). Accordingly the temperature curve of Zachos *et al.* (2001) shows a stepwise climatic deterioration during the Middle and Late Eocene from the thermal optimum at the end of the Paleocene or beginning of the Eocene until the first Cenozoic Antarctic glaciations in the basal Oligocene (the Oi-1 stable-isotope event (33.3 Ma) *e.g*., Zachos *et al*., 2001).

These climatic trends are reflected in the diversity of the Paleogene floras of southern Patagonia. The composition of the Early Eocene Río Pichileufú and Laguna del Hunco floras (Wilf *et al*., 2003) agrees with the development of a climatic optimum. In these units the species diversity was high with more than 102 species recollected (Wilf *et al*., 2003). In the Middle to early Late Eocene Río Turbio Formation (Malumián y Caramés, 1997) the diversity reached only about 60 species (Arguijo and Romero, 1981) representing a possible climatic deterioration. The Late Eocene-Early Oligocene Sloggett Formation, Ñirihuau and Loreto Formation floras, show a further diversity reduction (less than 40 species described) which would represent the steepest reduction of the temperatures observed, with values that oscillate between 14.5° (±3.0º) and 15.3 (±3.0º)°C, and that corresponds to the minimums of all the Cenozoic (Hinojosa, 2005).

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