



# Neoselachians and Chimaeriformes (Chondrichthyes) from the latest Cretaceous–Paleogene of Sierra Baguales, southernmost Chile. Chronostratigraphic, paleobiogeographic and paleoenvironmental implications



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## ABSTRACT

This paper discusses a well-represented fossil record of cartilaginous fishes (Chondrichthyes) from southern South America. The recovered samples allow the recognition of three assemblages with chronostratigraphic and paleogeographic value: i) typical Maastrichtian sharks and rays with affinities to eastern Pacific fauna, including the taxa *Ischyrrhiza chilensis*, *Serratolamna serrata*, *Centrophoroides* sp. associated to *Carcharias* sp., and *Dasyatidae* indet.; ii) a scarce reworked assemblage of Paleocene–Early Eocene age including the taxa *Otodus obliquus* and *Megascyliorhinus cooperi*; iii) a rich assemblage with reworked taxa of Early to Middle Eocene age, together with autochthonous deposited Middle to Late Eocene taxa with close affinities to paleoichthyofaunas recovered from the North Atlantic, represented by *Carcharias 'hopei'*, *Odontaspis winkleri*, *Carcharoides catticus*, *Macrorhizodus praecursor*, *Carcharocles auriculatus*, *Striatolamia* sp., *Striatolamia macrota*, *Hexanchus agassizi*, *Notorhynchus* sp., *Myliobatis* sp., *Abdounia* sp., *Pristiophorus* sp., *Squatina* sp., cf. *Rhizoprionodon* sp., *Ischyodus* sp., and one new species, *Jaekelotodus bagualensis* sp. nov. The studied samples include for the first time taxa with well established chronostratigraphic resolutions as well as taphonomic information that help clarifying the age of the fossil-bearing units. In addition, they provide relevant information about the evolution of the Magallanes (=Austral) Basin from the Upper Cretaceous to the Paleogene, suggesting a probable connection with the Quiriquina Basin of south-central Chile during the latest Cretaceous. Finally, the studied assemblages indicate a latitudinal pattern of distribution that provides valuable data on the environmental evolution and temperature of southern South America during the Paleogene.

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## 1. Introduction

The Weddellian Biogeographic Province (WBP) as defined by Zinsmeister (1979) is a vast region that extends from northern Antarctica to New Zealand, Australia, and southern South America, including a common distribution of marine faunas with ecological affinities, temporally ranging from the Upper Cretaceous until the Late Eocene. Cartilaginous fishes within the WBP include several

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Upper Cretaceous sharks and chimaeroid fishes from Antarctica (Cione and Medina, 1987; Grande and Eastman, 1986; Richter and Ward, 1990; Kriwet et al., 2006; Martin and Crame, 2006; Otero et al., 2013; Stahl and Chatterjee, 1999, 2003). Cartilaginous fishes are also well represented in the Maastrichtian of central Chile (Philippi, 1887; Suárez et al., 2003; Suárez and Cappetta, 2004; Suárez and Otero, 2009), the Maastrichtian of Argentina (Arratia and Cione, 1996; Bogan and Agnolin, 2010), and to date, are represented only by endemic Chimaeriformes in the Campanian–Danian of New Zealand (Consoli, 2006). The Paleogene record of cartilaginous fishes in the WBP includes scarce finds from Paleocene beds of New Zealand (Consoli, 2008; Mannering and Hiller, 2005), while richer assemblages are known from the Eocene of Antarctica (Welton and Zinsmeister, 1980; Ward and Grande, 1991; Kriwet and Gaździcki, 2003; Kriwet, 2005), and the Late Eocene of southernmost South America (Otero et al., 2012b).

The present paper discusses a rich diversity of cartilaginous fishes from southwestern Patagonia, southernmost Chile. The identified taxa and their interpreted provenance indicate at least three different chronostratigraphic ranges and paleobiogeographic affinities represented in the study area: i) Maastrichtian taxa with close affinities to previous southeast Pacific records, ii) scarce, typical Tethyan Paleocene to Early Eocene taxa, iii) a rich, Middle to Late Eocene diversity with affinities to North Atlantic contemporary assemblages. The Paleocene–Early Eocene assemblage shows clear evidence of reworking, being hosted in younger beds of Middle to Late Eocene age. On the other hand, the Upper Cretaceous assemblage does not include any distinctive Cenozoic taxon (at least based in the recovered material), suggesting that the reworking affected exclusively Paleogene levels. Additionally, there is an absence of taxa typical of the Oligocene and the overlying beds are comprised of continental facies indicating a marine regression after the Eocene. The paleobiographic, paleoenvironmental and chronostratigraphic significance of this record is discussed here.

## 2. Locality and geologic setting

Sierra Baguales (S50°48'S; W72°31') is located more than 1900 km south of Santiago, and about 40 km northeast of the Torres del Paine National Park (Fig. 1). Access is very difficult and becomes impossible during the cold season (May–October) due the extreme weather conditions. The section studied in Sierra Baguales is characterized by beds cropping out as N–S trending strips and dipping approximately 30°E. The rocks in the studied section are referred to the following units (from base to top):

**Dorotea Formation (Katz, 1963)** — Sandstones variable in color from green, gray, yellowish, brown and reddish, commonly with lenticular conglomerates and intercalations of clay levels. Calcareous levels and concretionary nodules are present in the upper levels hosting a rich fossil diversity with abundant invertebrates (Katz, 1963) and scarce vertebrates (Otero and Suárez, 2009). The thickness of the unit is variable, reaching ca. 350 m in the southern part, while in the middle part of the N–S outcrops it reaches 1000 m at Cerro Cazador, fading toward the north and re-appearing in Sierra Baguales as a thinner section of several tens of meters. The age of this unit was assigned to the late Campanian–Maastrichtian based on marine invertebrates (Pérez and Reyes, 1978), although, additional evidence based on microfossils (Martinez-Pardo, 1965) as well radioisotopic dates (Hervé et al., 2004) supports an upper Maastrichtian age. The material recovered from this unit includes the taxa *Carcharias* sp., *Ischyrhiza chilensis*, *Serratolamna serrata*, *Centrophoroides* sp. and *Dasyatidae* indet.

**Río Baguales Formation (Cecioni, 1957)** — This unit consists of 750 m of marine sediments with clay-rich limestones and sandy conglomerates near the top. Its type locality was indicated as “the

left shore of the river, in the beginning of the way, crossing the bridge over the Baguales River that leads to the Las Flores shelter” (Cecioni, in Hoffstetter et al., 1957: p. 309). This author indicated that the Río Baguales Formation overlies the Cancha Carrera Formation, while in turn, the latter unit is conformably overlain by the continental Las Flores Formation (Cecioni, 1957), which is equivalent to the Río Leona Formation exposed in Argentina (sensu Malumián and Caramés, 1997). The ambiguous original type locality of the Río Baguales Formation indicated by Cecioni (1957), was subsequently refined by Hoffstetter et al. (1957) who provided geographic coordinates (S50°57'; W72°22'), showing that these outcrops are placed about 25 km east-southeast of the locality studied in this paper. In the latter area, the Río Baguales Formation was tentatively assigned to the Late Oligocene (Chattian) based on stratigraphic correlations (Le Roux et al., 2010). The absence of more precise geochronological data at the time and based on its tentative correlation with the Centinela/Río Turbio Formations in Argentina, with which it has many invertebrates in common. However, a subsequent SHRIMP date on detrital zircons from near the base of their measured section indicated a maximum age of  $40.48 \pm 0.37$  Ma (Le Roux, 2012; Bostelmann et al., 2012), confirming at least a latest Lutetian to Bartonian age. The studied section could possibly be correlated with the Loreto Formation of the Brunswick Peninsula, which is lithostratigraphically and paleoenvironmentally similar and has been dated with U/Pb detrital zircons at  $36.48 \pm 0.47$ – $36.73 \pm 0.5$  Ma (Otero et al., 2012b). In Argentina, the Río Baguales Formation may also partially correlate with the Río Turbio Formation (Feruglio, 1938) and especially with the Man Aike Formation (Furque and Camacho, 1972). The latter is coincident in lithology with the most of the outcrops here referred to the Río Baguales Formation and was dated as late Middle Eocene based on its marine micropaleontological content (Malumián, 1990; Malumián and Náñez, 2011; Concheyro, 1991; Camacho et al., 2000), and fossil invertebrates and  $^{87}\text{Sr}/^{86}\text{Sr}$  dating (Casadio et al., 2009), although Pérez Panera (2013) suggested an Early to Middle Eocene age for the subsurface deposits of this formation. The section exposed in Chile includes taxa which are typically Paleocene and Early Eocene, but most of these vertebrate remains are fragmentary, without a single find of articulated portions. They are always scattered and the recovered fragments show a relatively good size selection, which strongly suggests that they were reworked from older beds and subsequently incorporated into the younger deposits. This explains why part of the fauna studied here is older than the host units assigned to a maximum lower Bartonian age based on a radioisotopic date of  $40.48 \pm 0.37$  Ma. The contact with the Dorotea Formation, which lies a few tens of meters below the dated sandstone, is therefore clearly an erosional unconformity (paraconformity).

The depositional environment of the Río Baguales Formation was interpreted as a north- to northwestward prograding estuary (Le Roux et al., 2010), which changed from river- and wave-dominated to tide-dominated at different stages in its development.

The material recovered from the Río Baguales Formation includes the taxa *Otodus obliquus*, *Megascyliorhinus cooperi*, *Carcharias 'hopei'*, *Odontaspis winkleri*, *Carcharoides caticus*, *Macrorhizodus praecursor*, *Carcharocles auriculatus*, *Striatolamia* sp., *Striatolamia macrota*, *Hexanchus agassizi*, *Notorhynchus* sp., *Myliobatis* sp., *Abdounia* sp., *Pristiophorus* sp., *Squatina* sp., cf. *Rhizoprionodon* sp., *Ischyodus* sp., *Callorhynchidae* indet., as well as the new species *Jaekelotodus bagualensis* sp. nov.

**Las Flores Formation (Cecioni, 1957)** — This unit comprises continental, clayey sediments with abundant fossil content of leaf prints, intercalated with continental sandstones. It was defined in the Las Flores Creek, on the lower slopes of the Cerro Ciudadela,

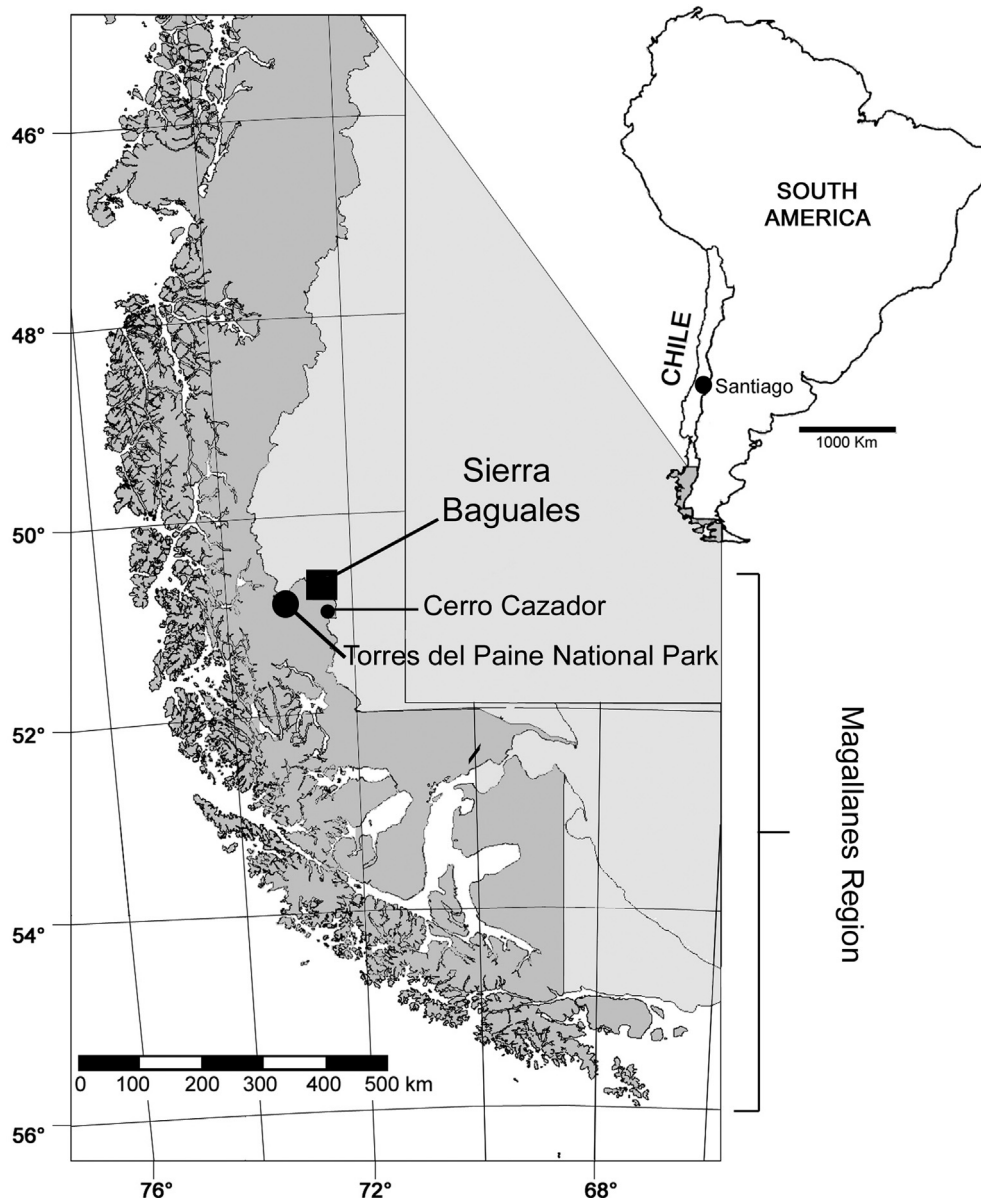


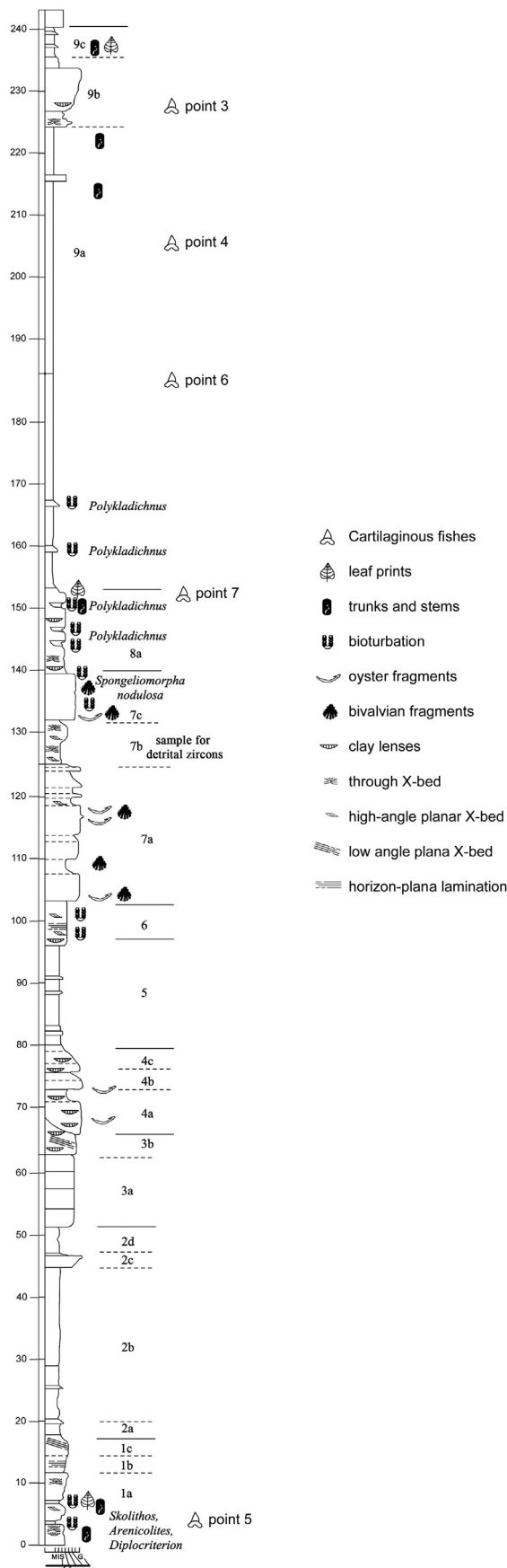
Fig. 1. Map of the study area in the Magallanes Region, southernmost Chile, indicating the locality of Sierra Baguales where the analyzed samples were collected.

which is located in the southern part of the Sierra Baguales (72°18'W; 50°55'S). It overlies the Río Baguales Formation through an apparent concordant contact, while its upper contact is not clear but is covered by volcanic rocks exposed at Cerro Ciudadela (Hoffstetter et al., 1957). Its observed thickness is ca. 160 m. Based on the abundant content of *Nothofagus* spp., the unit was correlated with the El Salto Formation on the Brunswick Peninsula, which is assigned to the Oligocene. Further correlations allow identify these strata exposed in the Sierra Baguales as equivalent to those from the continental Río Leona Formation in Argentina (Malumián and Caramés, 1997), which is assigned by these authors to the latest Eocene–lower Oligocene based on stratigraphic correlations as well as palynomorphs.

### 3. Material and methods

Approximately one thousand five hundred remains of sharks were initially collected from the studied section. Most of these

samples are fragmentary non-diagnostic teeth or have been transported, thus losing any contextual information. On the other hand, glacio-fluvial erosion forming cliffs in the western part of the study area exposed good stratigraphic sections of each unit, while cryogenic fractures and eolian erosion caused the disaggregation of previously consolidated sandstones that included the studied materials. The fossil cartilaginous fishes are represented by dental parts, and less frequently, fragmentary vertebrae, spines and coprolites. It was necessary to establish several criteria for collecting in trying to obtain better stratigraphic results, because most of the fossils have been reworked and scattered by natural transport processes. These were as follows: First, evidently, the finding of *in situ* remains, in order to identify the host strata of each assemblage. Second, in the absence of these, attempts to find unusual concentrations of cartilaginous fish remains, which fortunately were frequent in the area. Third, after finding concentrated materials, these were evaluated with regard to their preservation. The intact presence of delicate lateral cusplets, well-preserved enamel and



**Table 1**  
Points of collection of the studied materials.

Point	Geodetic coordinates (WGS84)	Lithostratigraphic unit	Typical fossil representatives
1	50°44'6.50"S; 72°26'57.4"W	Las Flores Formation	Wood and leaf prints
2	50°44'24.00"S; 72°27'34.1"W	Las Flores Formation	Wood and leaf prints
3	50°44'10.6"S; 72°28'10.9"W	Las Flores Formation	Wood and leaf prints
4	50°43'59.9"S; 72°28'26.0"W	Río Baguales Formation	Cartilaginous fishes
5	50°44'16.5"S; 72°28'56.2"W	Dorotea Formation	Cartilaginous fishes
6	50°43'42"S; 72°28'19.0"W	Río Baguales Formation	Cartilaginous fishes
7	50°44'05.5"S; 72°28'32.2"W	Río Baguales Formation	Cartilaginous fishes

generally good condition of the teeth were considered as indicative of relatively little transportation (Cook, 1995); thus, their stratigraphic provenance should be very close to the discovery site. Reference points were taken in the overlying continental beds with a very rich diversity of leaf imprints and fossil wood, but a total absence of shark teeth, these being indicated as points 1 and 2 (Fig. 2). Point 3 is characterized by having mixed samples including silicified wood and shark teeth. Points 4–7 were selected to meet the criteria explained above, and comprise the collection sites of the studied samples according to the previously described methodology (Table 1). Finally, identifications based on isolated elements that usually lead to dubious taxonomical interpretations were avoided by collecting a large number of samples, later submitted to selection based on common characters that could give a more reliable identification of each taxon, especially in the case of odontaspids where isolated teeth of different taxa can be easily confused.

The stratigraphic position of each point is detailed in Fig. 2 (after Le Roux et al., 2010).

#### 4. Systematic Paleontology

Class Chondrichthyes Huxley, 1880

Subclass Elasmobranchii Bonaparte, 1838

Subcohort Neoselachii Compagno, 1977

Order Lamniformes Berg, 1958

Family Odontaspidae Müller and Henle, 1839

Genus *Carcharias* Rafinesque, 1810

*Type species* — *Carcharias taurus* Rafinesque, 1810. Recent.

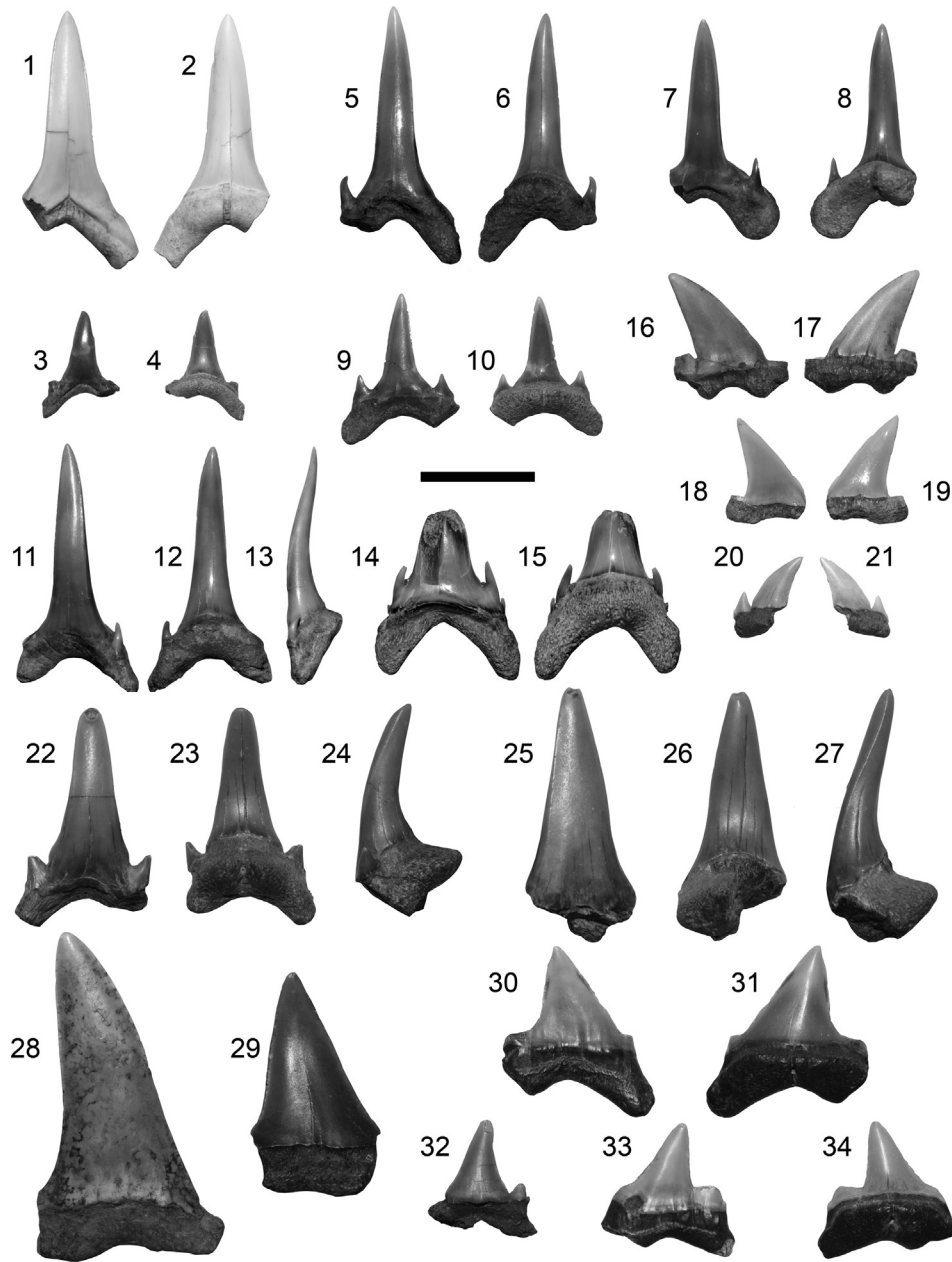
*Carcharias* sp.

Fig. 3: 1–4

**Material** — SGO.PV.6645: Five selected teeth. SGO.PV.6645b: Two hundred and seventy-six additional samples with poor preservation. Point 5 (Table 1). Dorotea Formation, upper levels, Maastrichtian. SGO.PV.6525d: One hundred and forty-seven teeth. Point 6. Río Baguales Formation, upper levels, Middle to Late Eocene.

**Description** — SGO.PV.6645: Medium-sized teeth not larger than 3 cm, with sharp crown having smooth enamel in both labial and lingual surfaces; the cutting edge is complete and reaches the base of the crown; one single lateral cusplet on each side, absent in most

**Fig. 2.** Stratigraphic column of the studied section (after Le Roux et al., 2010), indicating the position of the sampling points with cartilaginous fishes.



**Fig. 3.** *Carcharias* sp., selected anterior teeth (SGO.PV.6645). Dorotea Formation, Maastrichtian. 1, 3, labial view; 2, 4, lingual view. *Carcharias 'hopei'* (Agassiz), selected teeth (SGO.PV.6525). 5, 7, 9, labial view; 6, 8, 10, lingual view. *O. winkleri* Leriche (SGO.PV.6526). 11, 14, labial view; 13, profile view; 12, 15, lingual view. *Carcharoides catticus* (Philippi), upper lateral tooth (SGO.PV.6512a). 16, labial view; 17, lingual view. Upper lateral teeth (SGO.PV.6512b). 18, 20, labial view; 19, 21, lingual view. *J. bagualensis* sp. nov., anterior tooth (holotype, SGO.PV.6528). 22, labial view; 23, lingual view; 24, profile view. Anterior tooth (referred, SGO.PV.6528b). 25, labial view; 26, lingual view; 27, profile view. *Macrorhizodus praecursor* (Leriche), two upper lateral teeth (SGO.PV.6529). 28, 29, lingual view. Lateral tooth (SGO.PV.6530). 30, labial view; 31, lingual view. Anterior tooth (SGO.PV.6530b). 32, labial view. posterior lateral tooth (SGO.PV.6530b). 33, labial view; 34, lingual view. Río Baguales Formation, Middle to Late Eocene. Scale bar equals 10 mm.

of the recovered samples; separated, slender root branches with medial groove and deep depression between them; moderate lingual bulk. SGO.PV.6525d: It displays the same morphologies, but are characterized by a larger size in most cases, reaching less than 5 cm.

**Remarks** — The samples recovered from the lower levels of the studied section, belonging to the upper levels of the Dorotea Formation, are characterized by having a white to gray color, very different from the darker tones of the samples recovered from younger strata in Sierra Baguales. The genus *Carcharias* is not a good index of age due to its cosmopolitan distribution and large chronostratigraphic biochron; nevertheless, other directly associated

taxa (particularly sclerorhynchids) with good chronostratigraphic resolution allow these samples to be assigned to the Maastrichtian. The recovered material is hard to compare with other taxa due its fragmentary preservation lacking the lateral cusplets in most cases.

**Type species** — *Synodontaspis hopei* (Agassiz, 1843). Eocene of England, France, Belgium and Morocco.

*Carcharias 'hopei'* (Agassiz)

Fig. 3: 5–10

**Material** — SGO.PV.6525: Three anterior teeth and one lateral tooth. Point 3. SGO.PV.6525b: Thirteen selected teeth. Point 6.

SGO.PV.6525c: One hundred and twenty-three teeth with poor preservation. Point 6. Río Baguales Formation, upper levels, Middle to Late Eocene.

**Description** — Anterior teeth with high and slender cusp, slightly sigmoidal in profile, having soft enamel in both faces and some folds at the base of the crown, especially on the lingual face; the labial face is flat while the lingual face is convex. The cutting edge fades out near the base of the crown; the latter extends over the root on the labial face, having a partial overhang; lateral cusplets are in contact with the crown but do not share the cutting edge; root branches are separated, having an inverted 'V'-shape, a medial bulk, and a moderately projected bulk on the lingual face; all teeth are characterized by having a unique lateral cusplet on each side, being very sharp in anterior teeth, while in posterior positions this becomes thicker, acquiring a triangular shape; posterior teeth have shorter and broader triangular crowns with a complete cutting edge that is continuous through the lateral cusplets, these being in contact with the crown.

**Remarks** — Several odontaspids have been regarded as junior synonyms of *Carcharias hopei* (Ward, 1988). Additionally, Cappetta and Nolf (2005) considered that the 'hopei' species is still not clearly described. With this in mind, our determination aims to recognize SGO.PV.6525 as a singular representative of the genus *Carcharias*, consistent with the anterior and lateral teeth referred to *C. hopei* by Ward (1988) and to those referred to *Carcharias* sp. by Cappetta and Nolf (2005). We prefer to keep the species name but consider it to be tentative, because of the doubts expressed by the mentioned authors. The studied samples can be part of a single taxon, probably the unique *Carcharias* species recognized to date in the Paleogene of the Magallanes Basin (=Austral Basin: Biddle et al., 1986; Olivero and Malumián, 1999). Identical teeth have been recovered from Priabonian beds of the Loreto Formation, in Punta Arenas, southernmost Chile (Otero et al., 2012b). The genus *Carcharias* has a cosmopolitan distribution from the Campanian to Recent (Kent, 1994; Cione et al., 2007; Bogan and Agnolin, 2010). The species *C. hopei* is known from the Early Eocene of England, and the Eocene of the French–Belgian Basin and Morocco (Cappetta, 1987). Ward (1988) also indicates its occurrence in the Late Paleocene of England, the Paleocene and the Middle Eocene of Belgium and the Eocene of Maryland.

#### Genus *Odontaspis* Agassiz, 1838

**Type species** — *Squalus ferox* Risso, 1910. Leriche, 1905. Paleocene–Eocene, cosmopolitan.

#### *Odontaspis winkleri* Leriche, 1905

Fig. 3: 11–15

**Material** — SGO.PV.6526: Two anterior teeth. Point 7. SGO.PV.6526b: Twenty-nine teeth with different preservation. Point 6. Río Baguales Formation, middle levels, Middle to Late Eocene.

**Description** — High and slender crown with moderate sigmoidal profile. As typical for the genus, the cutting edge does not reach the base; the labial face of the crown is flat near the top, becoming slightly convex at the base; a pair of lateral cusplets are present on each side of the crown, being sharp and recurved to the crown; roots are typical for odontaspids with separate branches and a medial groove.

**Remarks** — This species has been reported from the Paleocene and Early Eocene of England (Ward, 1980), the Early–Middle Eocene of Belgium (Leriche, 1951), the Eocene of the eastern United States (Cappetta, 1987), the Eocene of Australia (Kemp, 1991), and the Eocene of Seymour Island, Antarctica (Long, 1992; Kriwet, 2005) indicating that this species reached a cosmopolitan distribution during the Paleogene.

#### Genus *Carcharoides* Ameghino, 1901

**Type species** — *Carcharoides caticus* (Philippi, 1846). 'Tertiary' of Europe.

#### *Carcharoides caticus* (Philippi, 1846)

Fig. 3: 16–21

**Material** — SGO.PV.6527: Three incomplete upper lateral teeth. Point 6. SGO.PV.6527b: Two lateral teeth. Point 7. Sierra Baguales, northern Magallanes. Río Baguales Formation, middle and upper levels, Middle to Late Eocene.

**Description** — Teeth with high, triangular crown recurved backwards; lingual face slightly convex and labial face flat, with some folds at the base; two lateral cusplets generally present, the most prominent having a broad, triangular shape, while the secondary is much reduced and sharp; roots are flattened, with a medial groove. Anterior teeth are typically odontaspid-like, with a high and slender crown, having two lateral cusplets, but comparatively broader and less sigmoidal in profile than in the genus *Odontaspis*.

**Remarks** — The first regional record of teeth belonging to this taxon was reported by Otero et al. (2012b), although its presence in Priabonian beds was disputed on because previous records of the species were restricted to the Oligocene–Miocene. The finding of identical teeth in Sierra Baguales suggests that this taxon could be part of the contemporary chondrichthyan diversity that inhabited the area during the deposition of the beds, contrary to other taxa that are represented by reworked samples with older chronostratigraphic resolution. It is possible that the chronostratigraphic occurrences of *C. caticus* could be extended to the Middle Eocene based on the records from Sierra Baguales.

#### Genus *Jaekelotodus* Menner, 1928

**Type species** — *Hypotodus trigonalis* Jaekel, 1895. Lower Oligocene, Europe.

#### *Jaekelotodus bagualensis* sp. nov.

Fig. 3: 22–27

**Holotype** — SGO.PV.6528: One nearly complete anterior tooth. Point 6. Río Baguales Formation, upper levels, Middle to Late Eocene.

**Paratypes** — SGO.PV.6528b: Three additional incomplete teeth. SGO.PV.6528c. Four incomplete teeth. Point 7. SGO.PV.6528d. Two incomplete teeth. Point 6. Río Baguales Formation, upper levels, Middle to Late Eocene.

**Etymology** — After the type locality, Sierra Baguales, southernmost Chile.

**Differential diagnosis** — Following Cappetta (1987), same as for genus; large teeth with wide, bulky and thick crowns, soft enamel, triangular cusplet in anterior teeth, labial face flat and overhanging the root, lingual face cambered, cutting edge extended into the cusplets. *J. bagualensis* can be distinguished among other species of the genus by having a much thicker root and more pronounced lingual bulk. Also, the presence of a single, massive, triangular cusplet on each side of the crown is clearly different from the more slender crown with a sharper and more reduced pair of cusplets on each side observed in the species *Jaekelotodus trigonalis* (Jaekel, 1895); also, it differs from *Jaekelotodus robustus* (Leriche, 1921) by having more massive crowns and larger cusplets; on the other hand, *Jaekelotodus heinzlini* (Casier, 1967) and *Jaekelotodus londonensis* Zhelezko (1994) are characterized by small and sharp cusplets, more reduced than those of the Chilean material. Similar cusplets to those of *J. bagualensis* sp. nov. are present in the species *Jaekelotodus heersensis* (Hermann, 1972), but the crowns are comparatively slender and the roots are not as massive.

**Description** — Rare odontaspid with crowns, cusplets and roots being massive; the crown is broadly triangular and high, with

soft enamel on both faces, having cracks, and being sigmoidal in profile; The lingual face is very convex, while the labial face is only slightly convex; cutting edges become weak near the base, but extends into the cusplets; the cutting edge is complete and extends through the lateral cusplets; these latter are massive, with a triangular shape, and have continuous contact with the enamel on the labial face, while in the lingual face they appear separated; the roots are massive, with a large bulk in the lingual portion and short but separated branches having a well-marked medial groove.

**Remarks** — The genus *Jaekelotodus* is known from the Thanetian and Early Eocene of Belgium, and the Late Eocene–Early Oligocene of Russia and the Paris Basin (Cappetta, 1987). The studied material is the first record from the Southern Hemisphere.

Family Lamnidae Müller and Henle, 1838

Genus *Macrorhizodus* Glikman, 1964

**Type species** — *Isurus praecursor* Leriche, 1905. Middle Eocene, Belgium.

*Macrorhizodus praecursor* (Leriche, 1905).

Fig. 3: 28–34

**Material** — SGO.PV.6529: Two lateral teeth. Point 6. SGO.PV.6529b: Three lateral teeth. Point 7. SGO.PV.6530: One anterior tooth, one lateral tooth. Point 3. Río Baguales Formation, middle levels, Middle to Late Eocene.

**Description** — Lateral teeth with high, slender and triangular crown that becomes broader toward the base, being labio-lingually compressed; flat labial face with soft enamel and smooth folds near the root; lingual face is convex with some cracks in the enamel; root is slightly massive, basally flattened.

**Remarks** — Teeth referred to this species were reported in the WBP, particularly the Middle to Late Eocene of the La Meseta Formation on Seymour Island in Antarctica (Cione and Reguero, 1994) and in the Priabonian of the Loreto Formation, in southernmost Chile (Otero et al., 2012b). Tethyan records include Eocene deposits in Belgium, Syria, Egypt, Nigeria, Togo, Guinea Bissau and England (Cappetta, 1987). It was also reported from the Middle–Late Eocene of Chesapeake Bay, U.S. (Kent, 1994).

Family Otodontidae Glikman, 1964

Genus *Otodus* Agassiz 1843

**Type species** — *Otodus obliquus* Agassiz, 1843. Ypresian of England.

*Otodus obliquus* Agassiz, 1843

Fig. 4: 1, 2

**Material** — SGO.PV.6531. One incomplete tooth. Point 4. Río Baguales Formation, upper levels, Middle to Late Eocene.

**Description** — Large and massive tooth preserving the basal portion of the crown, both cusplets and the complete root; the preserved part of the crown shows that this was massive, with a 'D' shape in cross-section, having a flat labial face and convex lingual face; presence of a large apron on the lingual face, between the crown and the root; crown with complete cutting edges without serration; the lingual face displays the typical otodontid apron between the crown and the root; lateral cusplets are quite damaged, although it is possible to observe that these are rounded and low; root is massive, with well separated, thick branches and one large foramina.

**Remarks** — *O. obliquus* was frequently reported in the Thanetian–Ypresian of Europe, North America and southern Africa (Cappetta, 1987), the latter being a unique occurrence south of the equator. The Chilean material is the first high-latitude record from the Southern Hemisphere.

Genus *Carcharocles* Jordan and Hannibal, 1923

*Carcharocles auriculatus* (de Blainville, 1818)

Fig. 4: 3–8

**Type species** — *C. auriculatus* de Blainville, 1818. Middle Eocene of Belgium.

**Material** — SGO.PV.6532. Two incomplete teeth. Point 3 and 6. SGO.PV.6533. One fragmentary tooth preserving one lateral cusplet. Point 4. Río Baguales Formation, upper levels, Middle to Late Eocene.

**Description** — Large teeth with massive, triangular and high crown, slightly lanceolate, being 'D' shaped in cross-section; labial face is flat, while lingual face is convex; complete cutting edges with slightly irregular serrations (only well preserved in one specimen) that become more regular near the top; massive root with thick, separated branches and shallow notch in-between them; large foramina in the labial portion of the root; presence of the typical otodontid apron between the crown and the root on the lingual face; presence of one large lateral cusplet on each side, based on the contour preserved in one of the samples.

**Remarks** — *C. auriculatus* can be distinguished from other Paleogene species of the genus by several features: a lanceolate crown different from the broader crown of *Carcharocles angustidens* (Agassiz, 1843); the irregular serrations of *C. auriculatus* are different from the fine and regular serrations that characterize *Carcharocles sokolovi* (Jaekel, 1895). Finally, *Carcharocles aksuaticus* (Agassiz, 1843) probably represents the earlier morphotype by having cutting edges with incipient basal serrations that become more marked near the top of the crown, differing from the complete cutting edges in *C. auriculatus*. The latter species has been reported from the Middle Eocene of Europe and the late Early Eocene of the eastern coast of the United States (Cappetta, 1987; Kent, 1994).

Family Cretoxyrhinidae Glikman, 1958

Genus *Serratolamna* Landemaine, 1991

**Type species** — *Otodus serratus* Agassiz, 1843. Maastrichtian of Netherlands.

*Serratolamna serrata* (Agassiz, 1843)

Fig. 4: 9–16

**Material** — SGO.PV.6641: Two anterior teeth; two lateral teeth. SGO.PV.6641b: Eight incomplete lateral teeth. Point 5. Dorotea Formation, upper levels, Maastrichtian.

**Description** — Medium-sized teeth having a compressed, blade-like, triangular crown with complete cutting edges, slightly convex on both labial and lingual faces; lateral teeth with crowns recurved backwards; crown with soft enamel; some teeth with two anterior lateral cusplets and two or three posterior cusplets; cusplets with triangular shape, convex faces and complete cutting edges; crown overhangs the root on the labial face; root depressed, rectangular in shape, with separate branches.

**Remarks** — *S. serrata* has been reported from the Campanian of France (Vullo, 2005), the Campanian and Maastrichtian of Mexico (Kirkland and Aguillón-Martínez, 2002), and the Maastrichtian of Jamaica (Underwood and Mitchell, 2000), Argentina (Bogan and Agnolin, 2010), Venezuela (Carrillo et al., 2008), North Africa (Landemaine, 1991) and the Netherlands (Agassiz, 1843).

Family Mitsukurinidae Jordan, 1898

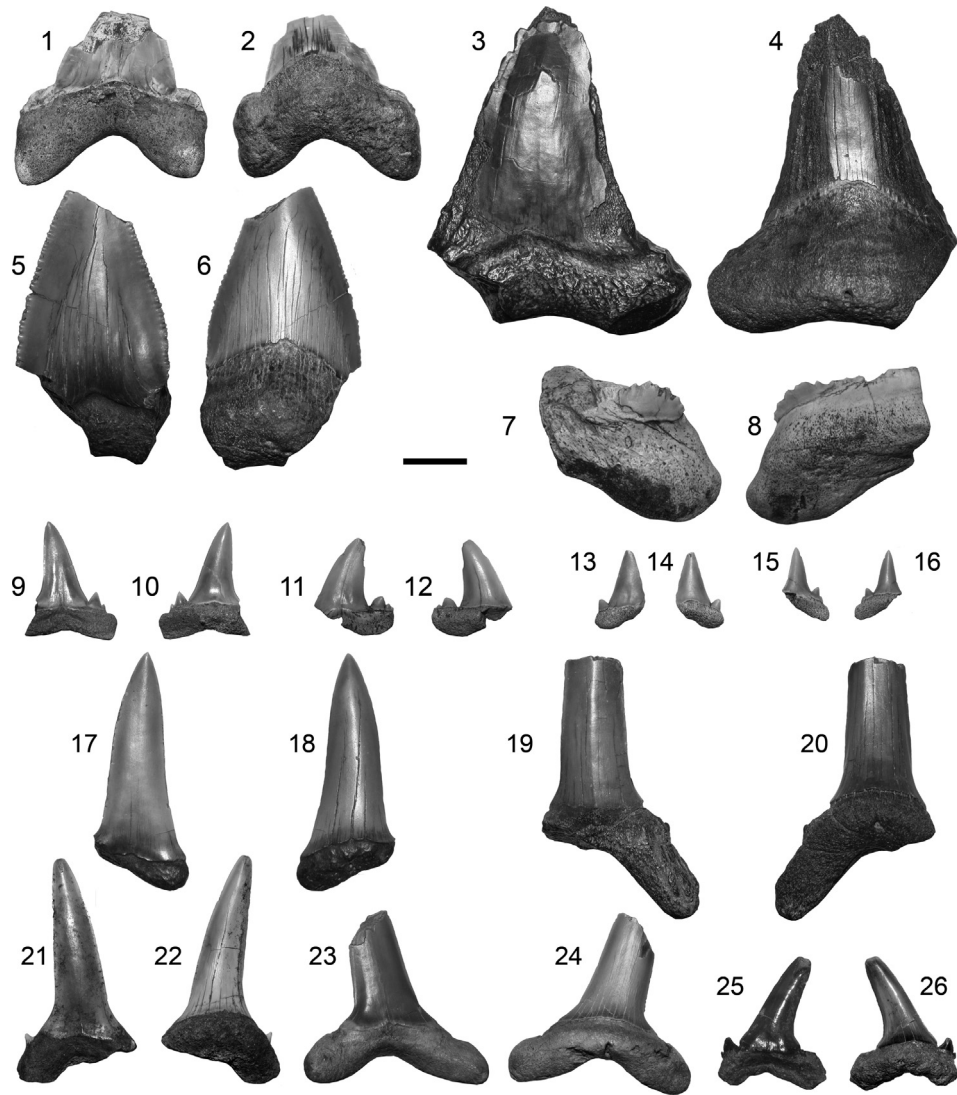
Genus *Striatolamia* Glikman, 1964

**Type species** — *Otodus macrotus* Agassiz, 1843. Eocene of the Paris Basin, France.

*Striatolamia* sp.

Fig. 4: 17, 18

**Material** — SGO.PV.6534: Two large teeth. Point 6. SGO.PV.6534b: Ten incomplete teeth. Point 3. SGO.PV.6534c:



**Fig. 4.** *Otodus obliquus* Agassiz, isolated lateral tooth (SGO.PV.6531). 1, labial view; 2, lingual view. *Carcharocles auriculatus* (de Blainville), upper anterior teeth (SGO.PV.6532). 3, 5, labial view; 4, 6, lingual view. Isolated fragment of tooth preserving its lateral cusplet (SGO.PV.6533). 7, labial view; 8, lingual view. Río Baguales Formation, Middle to Late Eocene. *Serratolamna serrata* (Agassiz), twelve lateral teeth (SGO.PV.6641). 9, 11, 13, 15, labial view; 10, 12, 14, 16, lingual view. Dorotea Formation, Maastrichtian. *Striatolamia* sp., anterior lateral tooth (SGO.PV.6534). 17, labial view, 18, lingual view. *Striatolamia macrota* (Agassiz), assorted anterior and lateral teeth (SGO.PV.6535a–f). 19, 21, 23, 25, labial view; 20, 22, 24, 26, lingual view. Río Baguales Formation, Middle to Late Eocene. Scale bar equals 10 mm.

Thirty-seven additional samples with poor preservation. Point 6. Río Baguales Formation, middle and upper levels, Middle to Late Eocene.

**Description** — Very large teeth having a broad and high crown, with very soft striations over the enamel and showing several rifts over this on both faces; lateral cusplets are not preserved; root branches well-separated and slender, with the presence of a medial groove and poor development of the lingual bulk.

**Remarks** — The studied samples are coincident in general shape and size with some large teeth of *Striatolamia macrota* (Agassiz, 1843), although SGO.PV.6524 have very soft striations over the enamel on both faces of the crown, contrary to the well-marked striations in the latter species. Regarding their size and morphologic affinities, the studied samples are here considered as a taxon closer to *S. macrota* (actually, almost identical but with softer striations) than to *Carcharias* spp.

**Type species** — *Otodus macrotus* Agassiz, 1843. Eocene of the Paris Basin, France.

#### *Striatolamia macrota* (Agassiz, 1843)

Fig. 4: 19–26

**Material** — SGO.PV.6535a: One anterior tooth; two lateral teeth. SGO.PV.6535b: Two lateral teeth, one anterior tooth. Point 6. SGO.PV.6535c: Twenty-five selected teeth. Point 6. SGO.PV.6535d: Forty-seven teeth with different grades of preservation. Point 7. SGO.PV.6535e: Fifteen teeth. Point 3. SGO.PV.6535f: Two-hundred-and-one crowns. Point 6. Río Baguales Formation, upper levels, Middle to Late Eocene.

**Description** — High and slender crown, slightly sigmoidal in profile, having soft cutting edges that fade out near the base. The anterior teeth are typically odontaspidd, having well-marked striations that extend from the base and fade close to the top of the crown over the lingual face. Lateral cusplets are triangular, small and recurved to the crown. The root has separate branches that are gracile in anterior teeth and become thicker in lateral positions. Lateral teeth have broader crowns, with soft striations on



the lingual face. The cusplets are broad and short, but maintaining a triangular shape.

**Remarks** — Regionally, the species *S. macrota* was reported from Priabonian beds of the Loreto Formation in southern Magallanes (Otero et al., 2012b) and in the Middle Eocene of the Río Turbio Formation, near Puerto Natales (Sallaberry et al., 2010). It has been reported from the Early Paleocene–Late Eocene of the ex-U.S.S.R., North America, and the north and west of Africa (Cappetta, 1987). It is also known from the Eocene of Seymour Island (Long, 1992; Kriwet, 2005) and Mount Discovery, Antarctica (Long and Stillwell, 2000). Cappetta (1987) indicates that during its stratigraphic history, among other features, the lateral cusplets of lateral teeth of this species underwent a marked widening, becoming broad, short and rounded (pectinated aspect). They also display a fading of the striations on the lingual face, these becoming shorter, fading or even disappearing altogether. On contrary, the samples recovered from Sierra Baguales have sharp, triangular cusplets that suggest affinities to older representatives of this taxon. Affinities to other mitsukurinids such *Scapanorhynchus* are prevented due the presence of pectinated cusplets which are typical of *S. macrota* (Cappetta, 1987).

Order Hexanchiformes de Buen, 1926

Suborder Hexanchoidei Garman, 1913

Family Hexanchidae Gray, 1851

Genus *Hexanchus* Rafinesque, 1810

**Type species** — *Hexanchus agassizi* Cappetta, 1976. Ypresian of England, Eocene of New Jersey, and the Oligocene of Australia and the ex-U.S.S.R.

*Hexanchus agassizi* Cappetta, 1976

Fig. 5: 1–6

**Material** — SGO.PV.6540. Three teeth. Point 4. SGO.PV.6540b. Eleven teeth. Point 6. SGO.PV.6540c. Two teeth. Point 7. Río Baguales Formation, middle and upper levels, Middle to Late Eocene.

**Description** — Upper lateral teeth (Fig. 3.1, 2) with acrocone, the anterior cutting edge having a serrated base; two accessory cusplets in the posterior margin; lower lateral teeth with similar acrocone being serrated at the base of the anterior cutting edge; acrocone smaller than those of the upper teeth; ten or more accessory cusplets on the posterior margin of lateral teeth. All teeth are compressed in a linguo-labial sense.

**Remarks** — This species was recorded in the Ypresian of England, the Eocene of New Jersey and Australia, and the Lower Oligocene of the ex-USSR (Cappetta, 1987).

Genus *Notorhynchus* Ayres, 1855

**Type species** — *Notorhynchus maculatus* Ayres, 1855. Recent.

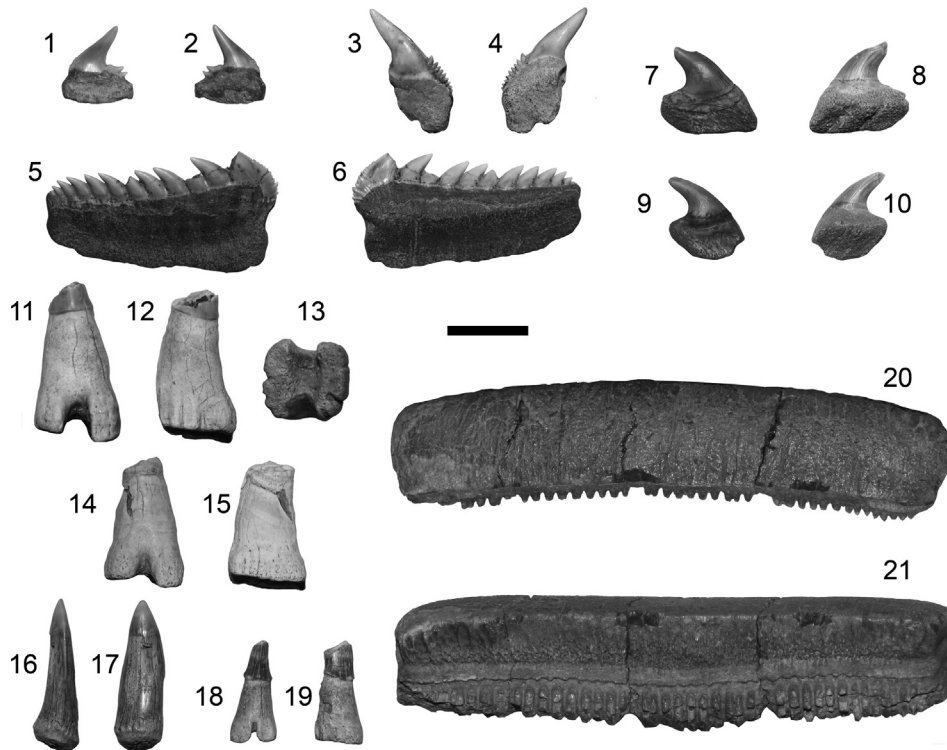
*Notorhynchus* sp.

Fig. 5: 7–10

**Material** — SGO.PV.6541. Two teeth. Point 6. Río Baguales Formation, upper levels, Middle to Late Eocene.

**Description** — The two specimens are anterior teeth, characterized by an acrocone without accessory cusplets; the acrocone is strongly recurved backwards, while its cutting edges are soft; thick root with two grooves.

**Remarks** — This genus is known since the Cretaceous to the Recent, having been reported from the late Aptian of Europe, the Eocene of England, and the Oligocene–Miocene of Europe, North America and Australia (Cappetta, 1987), while extant species have a widespread distribution that does not reach high latitudes (Compagno, 1984). Very similar teeth from beds of the Loreto



**Fig. 5.** *Hexanchus agassizi* Cappetta, upper anterior tooth (SGO.PV.6540). 1, 3, labial view, 2, 4, lingual view. Lower lateral teeth. 5, labial view; 6, lingual view. *Notorhynchus* sp., two isolated teeth (SGO.PV.6541). 7, 9, labial view; 8, 10, lingual view. Río Baguales Formation, Middle to Late Eocene. *I. chilensis* (Philippi), fifteen rostral teeth (SGO.PV.6640). 11, 14, peduncle and fragment of the crown in axial view; 13, basal view; 12, 15, dorsal view; 16, crown in axial view; 17, crown in dorsal view; 18, almost complete rostral tooth lacking the tip of the crown, in axial view; 19, dorsal view. Dorotea Formation, Maastrichtian. *Myliobatis* sp. Isolated median tooth (SGO.PV.6544). 20, occlusal view; 21, posterior view. Río Baguales Formation, Middle to Late Eocene. Scale bar equals 10 mm.

Formation in southern Magallanes were referred to Hexanchidae indet. by Otero et al. (2012b).

Superorder Bathomorphi Cappetta, 1980b

Order Rajiformes Berg, 1940

Family Sclerorhynchidae Cappetta, 1974

Genus *Ischyrrhiza* Leidy, 1856

*Type species* — *Ischyrrhiza antiqua* Leidy, 1856. Late Cretaceous of North Carolina.

*Ischyrrhiza chilensis* (Philippi, 1887)

Fig. 5: 11–19

*Material* — SGO.PV.6640. One incomplete rostral tooth, two peduncles, and one isolated crown. SGO.PV.6640b. Eleven fragmentary rostral teeth. Point 5. Dorotea Formation, upper levels, Maastrichtian.

*Description* — Rostral teeth having a cap larger than the peduncle, reaching a size less than 4 cm; the cap is robust, with striated enamel, with soft cutting edges that fade to the peduncle; the latter has a broad groove that splits the base; the surface of the peduncle bears strong striations.

*Remarks* — *I. chilensis* is a common taxon in marine beds of upper Maastrichtian age in central Chile (Suárez and Cappetta, 2004), and can be considered a good index fossil for the Maastrichtian. Its presence in southernmost Chile extends its previous paleobiogeographic distribution ca. 1500 km to the south, while it also confirms the presence of Maastrichtian beds in western Sierra Baguales. Part of the specimens were obtained *in situ*, discarding evident reworking.

Order Myliobatiformes Compagno, 1973

Family Myliobatidae Bonaparte, 1838

Genus *Myliobatis* Cuvier, 1817

*Type species* — *Raja aquila* Linnaeus, 1758. Recent.

*Myliobatis* sp.

Fig. 5: 20, 21

*Material* — SGO.PV.6544. Large median tooth. SGO.PV. 6544b. Lateral tooth. Point 6. SGO.PV.6544c. 10 fragmentary teeth. SGO.PV.6544d. Fragments of spines. Point 7. Río Baguales Formation, middle and upper levels, Middle to Late Eocene.

*Description* — SGO.PV.6544 is the best preserved tooth from Sierra Baguales. It is broader than it is long, with a slightly hexagonal contour; crown flat and quite convex, being displaced anteriorly with respect to the root; in basal view, the root shows multiple parallel grooves disposed in an antero-posterior direction.

*Remarks* — The genus *Myliobatis* is known since the Early Paleocene to Recent, with a cosmopolitan distribution (Cappetta, 1987). Regionally, this genus was previously reported from Priabonian beds of the Loreto Formation in southern Magallanes (Otero et al., 2012b).

Family Dasyatidae Jordan, 1888

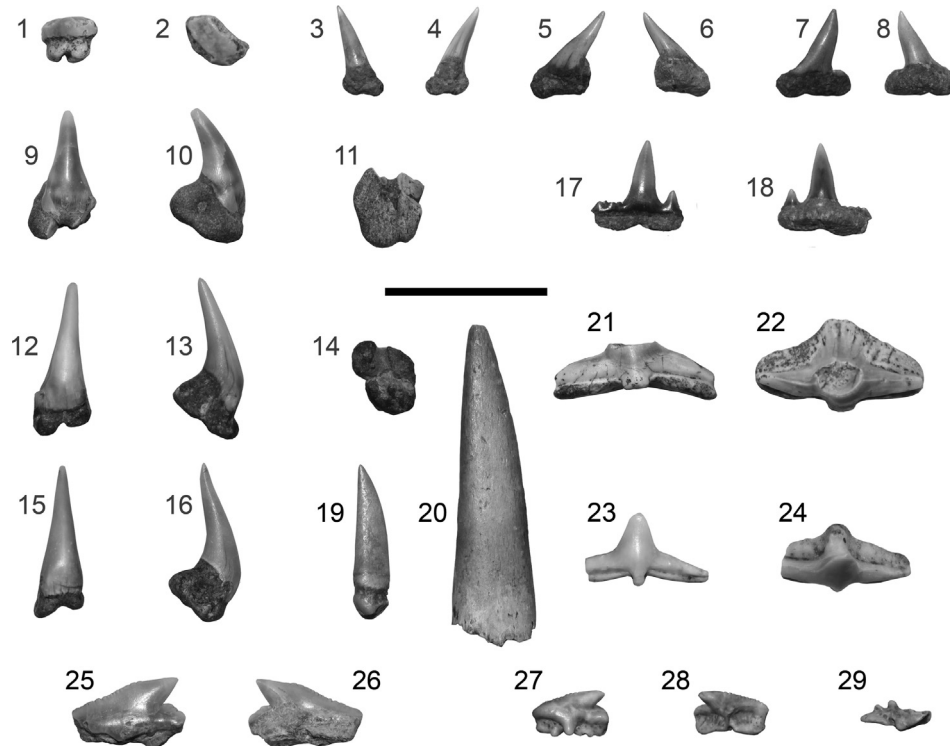
Dasyatidae indet.

Fig. 6: 1, 2

*Material* — SGO.PV.6644. One tooth. Point 5. Dorotea Formation, upper levels, Maastrichtian.

*Description* — small tooth having a crown with thick enamel, slightly hexagonal in contour; bilobed root, being slightly constricted under the crown; several foramina vertically extended along the sides of the root.

*Remarks* — The material is similar to the genus *Hypolophodon* Cappetta, 1980b, but it is also similar to teeth present in the genus



**Fig. 6.** Dasyatidae indet., one isolated tooth (SGO.PV.6644). 1, lateral view; 2, occlusal view. Dorotea Formation, Maastrichtian. cf. *Rhizoprionodon* sp., three teeth (SGO.PV.6538). 3, 5, 7, labial view; 4, 6, 8, lingual view. Río Baguales Formation, Middle to Late Eocene. *Megascyliorhinus cooperi* Cappetta and Ward, assorted teeth (SGO.PV.6539). 9, 12, 15, labial view; 10, 13, 16, profile view; 14, basal view. Río Baguales Formation, lower levels, Middle to Late Eocene. *Abdounia* sp., one isolated anterior tooth (SGO.PV.6536). 17, labial view; 18, lingual view. *Pristiophorus* sp., two rostral spines (SGO.PV.6545). 19, 20, dorsal view. *Squatina* sp., two teeth (SGO.PV.6543). 21, 23, labial view; 22, 24, occlusal view. Río Baguales Formation, Middle to Late Eocene. *Centrophoroides* sp., two isolated lateral teeth (SGO.PV.6643). 25, 27, labial view; 26, 28, lingual view; 29, basal view. Dorotea Formation, Maastrichtian. Scale bar equals 10 mm.

*Pseudohypolophus* Cappetta and Case, 1975. The first has been reported from the Eocene of Europe (Cappetta, 1987) and Egypt (Murray et al., 2010). Additionally, very similar teeth are frequent in late Maastrichtian beds of central Chile, probably being a closely related taxon to SGO.PV.6644, which were previously identified as an indeterminate dasytid (Suárez et al., 2003). In addition, Cione et al. (2012) described a new species, *H. patagoniensis*, from the ? latest Cretaceous–Early Paleocene of Chubut, Argentina. The association of the studied sample with abundant teeth of *I. chilensis* supports its Maastrichtian age. Histological cuts were not prepared since this is the only tooth recovered so far, reason why no generic identification is provided for the moment.

Order Carcharhiniformes Compagno, 1973

Family Carcharhinidae Jordan and Evermann, 1896

Genus *Rhizoprionodon* Whitley, 1929

Type species — *Carcharias* (*Scoliodon*) *crenidens* Klunzinger, 1880. Recent.

cf. *Rhizoprionodon* sp.

Fig. 6: 3–8

Material — SGO.PV.6538. Three teeth. Point 6. Río Baguales Formation, upper levels, Middle to Late Eocene.

Description — Small teeth with slender and sharp crown recurved backwards, with continuous, soft cutting edges; lingual face shows soft parallel crackings; teeth with one distal cusplet, with rounded shape and complete cutting edge; root elongated in antero-posterior sense, with a medial groove on the lingual face.

Remarks — The very high crown of all the recovered specimens differs from the known species of the genus, therefore it is only tentatively referred to this genus here. The lack of complete teeth does not allow a more specific determination.

Family Scyliorhinidae Gill, 1862

Genus *Megascyliorhinus* Cappetta and Ward, 1977

Type species — *Megascyliorhinus cooperi* Cappetta and Ward, 1977. Ypresian of England.

*Megascyliorhinus cooperi* Cappetta and Ward, 1977

Fig. 6: 9–16

Materials — SGO.PV.6539. Five teeth. Point 4. Río Baguales Formation, upper levels, Middle to Late Eocene.

Description — Medium-sized teeth (up to 1 cm) with mesio-distally compressed crowns, having a slender shape with continuous cutting edges that fade to the base. The lingual and labial faces bear striations only near the base with the lingual ones being longer, while the labial striations are only restricted to the contact with the root. The root is massive and separated into two lobes by a deep median groove. Its lingual surface has a projection with a flattened base. In addition, the root has two or three postero-lateral foramina.

Remarks — *M. cooperi* was reported from the Ypresian (Early Eocene) of England (Cappetta, 1987). Materials referred to the same taxon were also reported from the Early to Middle Oligocene of New Zealand and the Late Miocene of New Zealand and Australia (Keyes, 1984), although this undoubtedly represents a different species. The present find is the first occurrence of the species *M. cooperi* in South America. Regionally, the genus was previously recorded in the Miocene of Argentina (Cione, 1986; Cione et al., 2008) and Chile (Suárez et al., 2006).

Genus *Abdounia* Cappetta, 1980a

*Abdounia* sp.

Fig. 6: 17, 18

Type species — *Eugaleus beaugei* Arambourg, 1952. Ypresian of Morocco.

Materials — SGO.PV.6536: Anterior tooth. Point 6. SGO.PV.6537: Anterior tooth. Point 7. Río Baguales Formation, upper levels, Middle to Late Eocene.

Description — SGO.PV.6536. Small tooth with high crown, having flat labial face and convex lingual face; asymmetrical number of lateral cusplets, having one main triangular cusplet along its distal edge, while the other has three; smooth enamel with continuous cutting edge in the lateral cusplets; typical carcharhinid root with medial groove and flat, rectangular branches. SGO.PV.6537 differs from the other sample in having a thicker and more massive crown, with triangular lateral cusplets.

Remarks — The genus is known from the Early to Late Eocene of Europe, North America, North and West Africa (Cappetta, 1987) and from the Early Eocene of India (Rana et al., 2004). Regionally, it was recorded in Priabonian beds of the Loreto Formation (Hoffstetter et al., 1957), about 280 km SE of the studied locality (Otero et al., 2012b). Specimen SGO.PV.6537 is very similar to the anterior teeth referred to *Abdounia enniskilleni* (White, 1956) by Case and Borodin (2000; fig. 40), although the isolated teeth does not allow any specific determination.

Order Pristiophoriformes Berg, 1958

Family Pristiophoridae Bleeker, 1859

Genus *Pristiophorus* Müller and Henle, 1837

Type species — *Pristis cirratus* Latham, 1794. Recent.

*Pristiophorus* sp.

Fig. 6: 19, 20

Materials — SGO.PV.6545. One rostral tooth. SGO.PV.6545b. One rostral tooth. SGO.PV.6545c. One rostral tooth. SGO.PV.6545, point 6; SGO.PV.6545b, point 4; SGO.PV.6545c, point 3. Río Baguales Formation, upper levels, Middle to Late Eocene.

Description — The best preserved rostral teeth comprise one complete tooth and a crown; crowns are high, slender and flattened, with coarse cutting edges (maybe due to erosion); the enamel is poorly preserved.

Remarks — This genus has a widespread chronostratigraphic and paleogeographic distribution, being recorded since the Santonian to Recent (Cappetta, 1987) in all continents, including Antarctica (Long, 1992).

Order Squatiniformes de Buen, 1926

Family Squatinidae Bonaparte, 1838

Genus *Squatina* Duméril, 1806

*Squatina* sp.

Fig. 6: 21–24

Type species — *Squalus squatina* Linnaeus, 1758. Recent.

Materials — SGO.PV.6543. Two teeth. Point 6. Río Baguales Formation, upper levels, Middle to Late Eocene.

Description — Teeth broader than high, with crown being medially slender and having flanks extended over the mesial and distal edges. The cutting edges are continuous over the whole crown. The enamel in the labial face bears a ventral apron that overhangs the root. The root possess a triangular outline in basal view, having a lingual platform which also has a projection of the crown in occlusal view, while in basal view, this bears several nutritious foramina.

Remarks — The genus *Squatina* has been previously recorded in the Eocene of the Southern Hemisphere (Long, 1992; Welton and Zinsmeister, 1980). It is a cosmopolitan taxon that is well represented during all the Cenozoic (Cappetta, 1987).

Order Squaliformes Goodrich, 1909

Family Squalidae Bonaparte, 1834

Genus *Centrophoroides* Davis, 1887

*Type species* — *Centrophoroides latidens* Davis, 1887. Late Santonian of Lebanon.

*Centrophoroides* sp.

Fig. 6: 25–29

*Materials* — SGO.PV.6643a, b. Two teeth. Point 5. Dorotea Formation, upper levels, Maastrichtian.

*Description* — Small teeth broader than high, with short crowns recurved distally with complete cutting edges along the cusp and also along the distal margin of the crown. The mesial portion of the cutting edge bears irregular serrations. The labial face has an apron that extends ventrally to the root, while in the lingual face there is a projection of the crown (uvula, sensu Cappetta, 1987). The root has a rhomboidal basal outline, being narrower than the crown and having several nutritious foramina.

*Remarks* — The presence of this genus in Sierra Baguales was previously reported by Otero and Suárez (2009), based on a relatively large tooth that could might belong to another taxon (i.e., *Squalus*), although such large teeth have been observed in early Maastrichtian beds of central Chile were *Centrophoroides* is an abundant taxon, while *Squalus* remains unreported (RAO, pers. obs.). The presence of serrated cutting edges in the mesial portion of the crown was regarded by Cappetta (1987) as distinctive of *Centrophoroides*, and since this feature is present in both specimens, we prefer to maintain the larger sample in *Centrophoroides* until other additional materials could shed light on different taxonomic affinities.

Superorder Holocephali Bonaparte, 1832

Order Chimaeriformes Obruchev, 1953

Family Callorhynchidae Garman, 1901

Genus *Ischyodus* Egerton, 1843

*Ischyodus* sp.

Fig. 7: 1–3

*Type species* — *Ischyodus dolloi* Leriche, 1902. Paleocene, Belgium.

*Materials* — SGO.PV.6542. Two incomplete mandibular plates. Point 6. Río Baguales Formation, upper levels, Middle to Late Eocene.

*Description* — The larger specimen is an incomplete left mandibular lacking the anterior and symphyseal portions. The medial tritor is large, hypermineralized, and bears an anterior embayment. In symphyseal view, a descending lamina is present, which is incomplete but was probably present along most of the symphysis. The posterior portion is absent. The second specimen is a small left mandibular with similar features, but preserves most of the posterior portion of the plate.

*Comments* — The anterior embayment of the medial tritor is similar to that observed in the genus *Callorhynchus*, although the presence of a descending lamina in symphyseal view is a typical feature of the genera *Edaphodon* and *Ischyodus*. In addition, the hypermineralized tritor allows the studied materials to be distinguished from the genus *Edaphodon* which has poorly mineralized tritors. The incompleteness of the specimens does not allow closer taxonomic affiliations to be established. Regionally, the genus *Ischyodus* was previously reported in the Eocene of Antarctica (Ward and Grande, 1991) and in the Priabonian of southernmost Chile (Otero et al., 2012b).

Callorhynchidae indet.

Fig. 7: 4–13

*Materials* — SGO.PV.6543a, b. Two indeterminate dental plates. Point 6. Río Baguales Formation, upper levels, Middle to Late Eocene.

*Description* — Dental plates (tentatively mandibulars) larger than broad, with a narrower end interpreted as the anterior portion; occlusal surface comprised of a large and unique tritor with coarse punctations; basal surface flat.

*Remarks* — Despite the fragmentary nature of both materials, these show a large and unique tritor disposed over all the occlusal surface of the preserved plates. This morphology is not known among any Mesozoic or Cenozoic Chimaeriformes, while similar conditions are only observed in Carboniferous forms such as the genera *Sandalodus* and *Deltoptychius* (Stahl, 1999: figs. 77H, 96K). The very large chronostratigraphic gap between the latter and the material studied here is difficult to explain. A more plausible explanation is that the morphologies observed in the studied samples are an artifact of erosion, since the tritor pad is comprised of very hard, hypermineralized tissue, while the basal portion of the plate is composed of trabecular dentine (Stahl, 1999) that can be separated from the tritor and subsequently lost without revealing any crack mark or evidence of fragmentation. If this is the case, the tentatively isolated tritors belong to large plates, while the nature of the occlusal surface having coarse punctuation is similar to that observed in the specimen SGO.PV.6542 referred to *Ischyodus* sp., thus, suggesting that these might belong to large indeterminate callorhynchids.

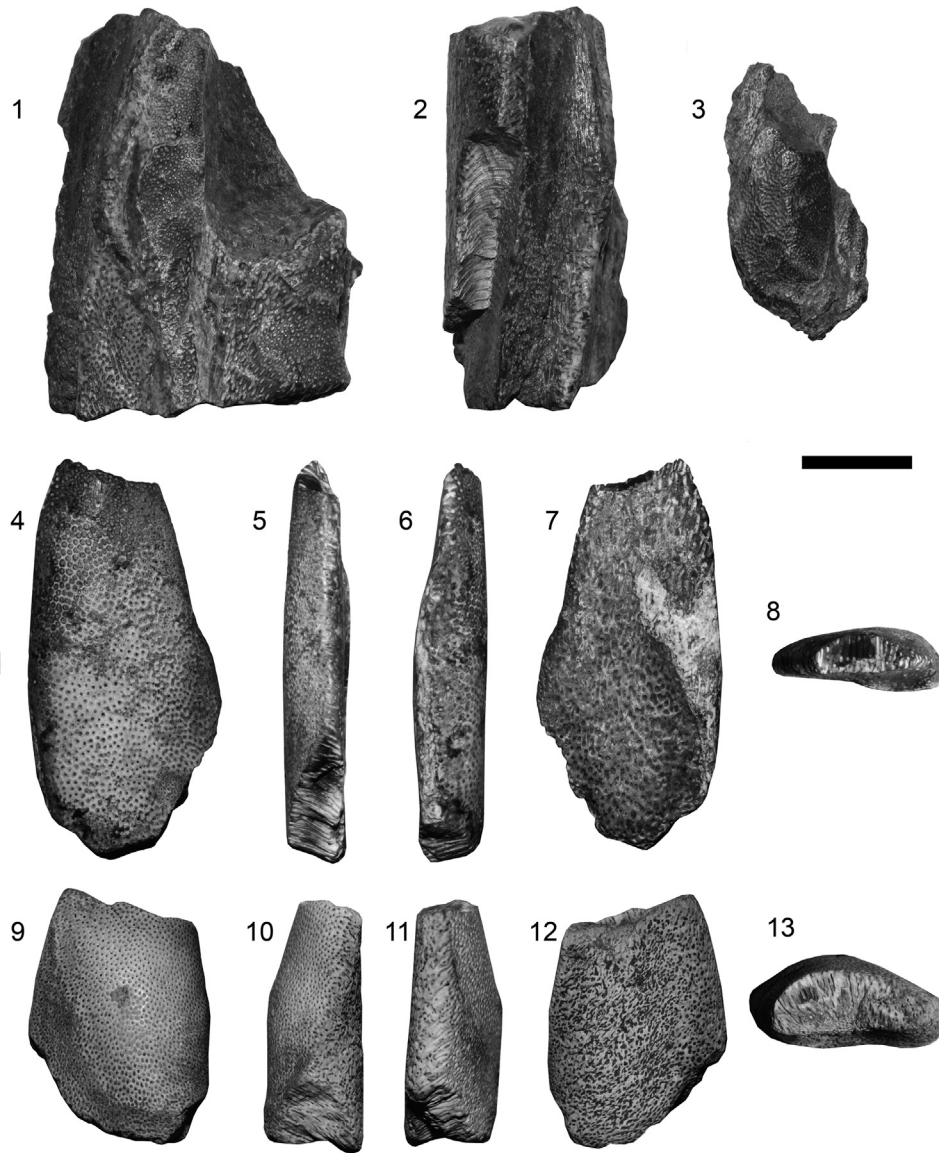
## 5. Discussion

### 5.1. Relative age

The studied assemblage can be divided into three main groups based on the chronostratigraphic range of each taxon (Table 2). The group collected at Point 5 includes three Late Cretaceous taxa not known to have survived the K/P boundary, and particularly, the common presence of *I. chilensis*, *S. serrata* as well as an indeterminate dasyatid which is common in the Quiriquina Formation, strongly suggests a Maastrichtian age based on their previous records in South America. A second group recovered at Point 4 includes two taxa: *O. obliquus* and *M. cooperi*, stratigraphically distributed between the Paleocene and Early Eocene. Finally, the largest group includes the materials recovered at points 3, 6 and 7, which indicate a general Eocene age, while the presence of well preserved and scarcely reworked samples of *C. auriculatus* suggests that these are autochthonous faunal elements within the fossil bearing beds, and in consequence, these strata should not be younger than the Middle to Late Eocene.

### 5.2. U/Pb dating

A sample for radiometric dating of detrital zircons was collected from the level 7b of the measured section in Fig. 2, which lies stratigraphically below the sections where most of the shark teeth were recovered, with the sole exception of the levels at point 5 (Maastrichtian). The U–Pb–Th ages determined during this investigation were obtained using SHRIMP I, II and RG at the Research School of Earth Sciences, Australian National University, Canberra. The measurement techniques employed followed those of Williams (1998). FC1 was used as the standard throughout, and the data were processed using the SQUID Excel Macro of Ludwig (2001). Sixty grains were analyzed, in each case with four-scan data. The Geological Time Scale (as used throughout the text) is that of Gradstein et al. (2008). The obtained results indicate a peak of 16 grains between 40 and 41 Ma, with minor peaks of 10 grains between 41 and 42 Ma and 6 grains between 39 and 40 Ma, i.e. around the Lutetian/Bartonian limit (40.4 Ma). As the sections with shark teeth are stratigraphically above this unit, a Bartonian to



**Fig. 7.** *Ischyodus* sp., two mandibular plates (SGO.PV.6542), 1,3, occlusal view; 2, symphyseal view. Callorhynchidae indet., indeterminate plate (SGO.PV.6543a), 4, occlusal view; 5, indeterminate profile view; 6, opposite profile view; 7, basal view; 8, anterior view. Callorhynchidae indet., indeterminate plate (SGO.PV.6543b), 9, occlusal view; 10, indeterminate profile view; 11, opposite profile view; 12, basal view; 13, anterior view. Río Baguales Formation, Middle to Late Eocene. Scale bar equals 10 mm.

possibly Priabonian age can be inferred, which is independently supported by the fossils analyzed here.

### 5.3. Paleobiogeography

The presence of *Carcharias* sp., *Centrophoroides* sp., *I. chilensis*, as well as an indeterminate dasyatid are common elements in the uppermost Cretaceous of the southeastern Pacific (i.e., the Quiriquina Basin sensu Spalletti and Franzese, 2007). These taxa are frequent in beds exposed in central Chile, ranging from the early to late Maastrichtian (Muñoz-Ramírez et al., 2007; Suárez and Otero, 2009; Suárez et al., 2003). Their relative abundance in Magallanes is coincident with the records in central Chile with *Carcharias* sp. being the most abundant taxon followed by frequent rostral spines of *I. chilensis*, while *Centrophoroides* and Dasyatidae indet. are scarcer. On the other hand, contemporary records in the southwestern Atlantic include *S. serrata*, *Squalicorax pristodontus*, *Cretalamna appendiculata*, *Carcharias* sp., *Odontaspis* sp. and cf.

*Pseudohypolophus mcultyi* (Bogan and Agnolin, 2010), which to date are not known from the Quiriquina Basin. Based on this, the distribution of *Serratolamna* is here verified as widespread throughout the Atlantic, although it seems to be latitudinally restricted since no records are known from Antarctica. The distribution of all these taxa indicates a stronger influence of the Pacific fauna on the Magallanes Basin compared to those of the Atlantic, suggesting the existence of a relatively direct connection with the Quiriquina Basin in central Chile, as previously suggested by Cecioni (1970) and Le Roux (2012). The younger beds overlying point 5 studied here are consist of mudstones with leaf imprints and sandstones with shallow-water mollusks and scarce dinosaur remains (RAO, pers. obs.), indicating proximity to the coast and a local regression of the sea level after the deposition of the beds harboring Maastrichtian chondrichthyans, while the upper strata of the studied succession include a rich assemblage with taxa typical of the North Atlantic, consistent with the general model of the Magallanes Basin opening into the Atlantic since the Early

**Table 2**  
Chronostratigraphic distribution of the most informative taxa recovered at Sierra Baguales. Gray bars indicate the known stratigraphic range of each taxon.

Taxon	Upper Cretaceous		Paleocene		Eocene			Oligocene		Sampling points						
	Campanian	Maastrichtian	Danian	Selandian	Thanetian	Ypresian	Lutetian	Bartonian	Priabonian	Rupelian	Chattian	3	4	5	6	7
<i>Centrophoroides</i> sp.																x
<i>Serratolamna serrata</i> (Agassiz)																x
Dasyatidae indet.																x
<i>Ischyrhiza chilensis</i> (Philippi)																x
<i>Otodus obliquus</i> Agassiz																x
<i>Megascyliorhinus cooperi</i> Cappetta and Ward																x
<i>Striatolamia</i> sp.																x x
<i>Jaekelotodus bagualensis</i> sp. nov.																x x x
<i>Carcharocles auriculatus</i> (de Blainville)																x x x
<i>Striatolamia macrotia</i> (Agassiz)																x x x
<i>Abdounia</i> sp.																x
<i>Carcharias 'hopei'</i> (Agassiz)																x x
<i>Carcharoides caticus</i>																x x
<i>Macrorhizodus praecursor</i> (Leriche)																x x x
<i>Odontaspis winkleri</i> Leriche																x x
<i>Hexanchus agassizi</i> Cappetta																x x x
<i>Ischyodus</i> sp.																x
<i>Myliobatis</i> sp.																x x
cf. <i>Rhizoprionodon</i> sp.																x
<i>Carcharias</i> sp.																x x
<i>Notorhynchus</i> sp.																x
<i>Pristiophorus</i> sp.																x x
<i>Squatina</i> sp.																x

Cretaceous (Spalletti and Franzese, 2007). The new evidence suggests the existence of a continental corridor with a N–S trend that commenced during the Maastrichtian, which separated the waters of the Pacific (=Quiriquina Basin-related) from those of the Magallanes Basin.

#### 5.4. Paleoenvironment

During the Paleocene, the Magallanes Basin was a shallow sea surrounded by land masses in its western and eastern part (Spalletti and Franzese, 2007; Le Roux et al., 2010). The Paleogene chondrichthyans studied here show close relationships with Atlantic assemblages (especially during the Middle Eocene), which is consistent with the absence of circumpolar currents before the opening of the Drake Passage and the Tasmanian Gulf, restricting their surrounding sea conditions to shallow shelf waters (Huber and Nof, 2006; Lawver and Gahagan, 2003). In addition, the presence of abundant remains of indeterminate turtles and crocodyli-forms at Sierra Baguales (Otero et al., 2012a) in strata of at least Middle to Late Eocene age, together with their total absence from Priabonian beds of the Loreto Formation (nearly 280 km farther south) are consistent with the probable constraining of the group to lower latitudes starting in the Middle Eocene (Markwick, 1998), related to a drastic and sudden fall of the sea temperature associated with the deepening of the Drake Passage, nearly 40 Ma ago (Lawver and Gahagan, 2003; Scher and Martin, 2006; Case et al., 2007; Le Roux, 2012). Another alternative is that the presence of fragmentary remains of crocodiles and turtles could be explained by reworking from older strata to be incorporated subsequently as bioclasts in younger levels, which is consistent with the total absence of articulated remains in the studied area, the presence of reworked materials of chondrichthyans (here studied), and with the climate conditions before the Middle Eocene.

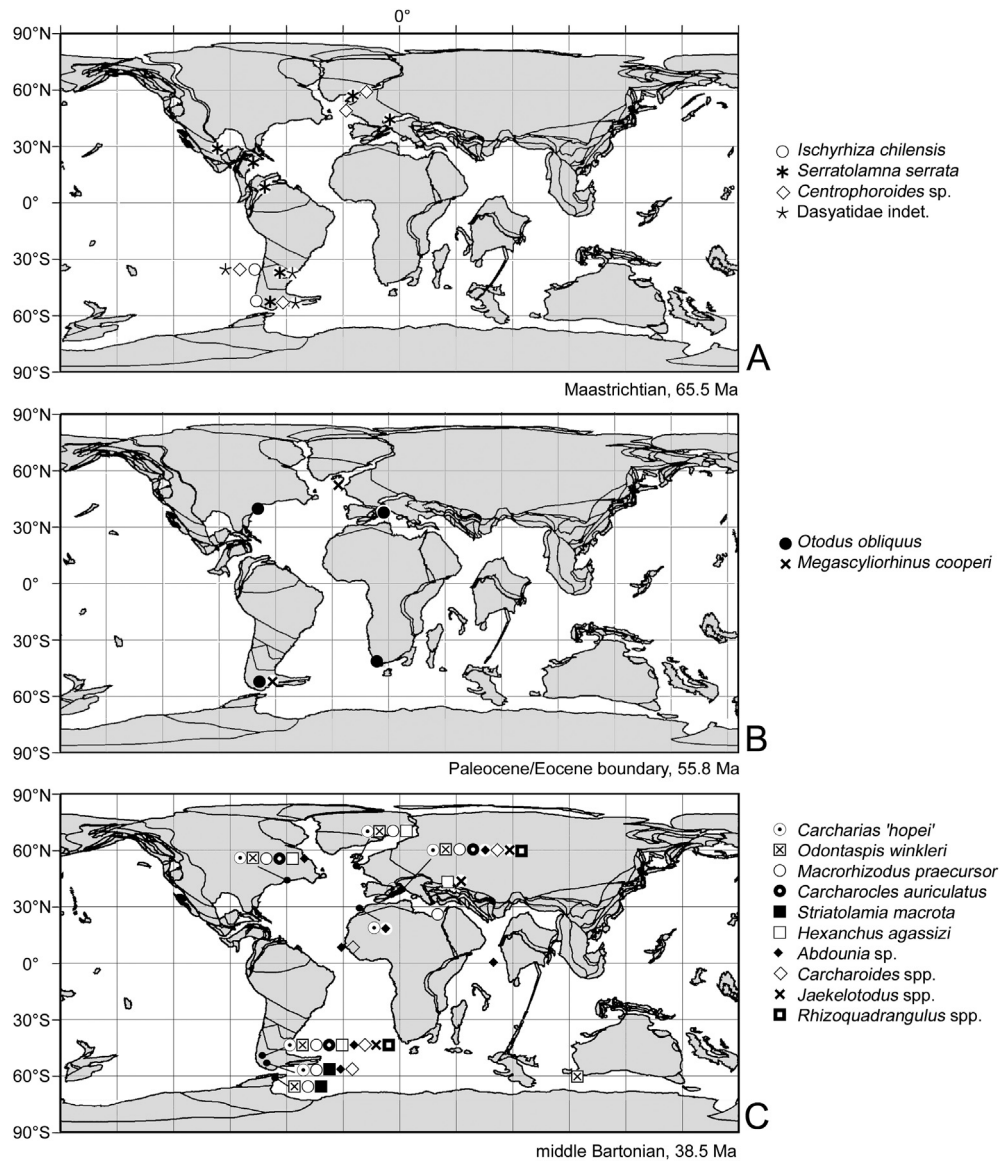
The presence of the genus *Megascyliorhinus* in Sierra Baguales is consistent with warm temperate waters (Cione et al., 2008). This is also supported by the presence of large-sized taxa of Early to Middle Eocene age (e.g., *C. auriculatus*, and *Striatolamia* sp.),

indicating the existence of a temperature gradient between the Early Eocene and the Late Eocene. This could represent one of the last relicts of warm temperate waters in the northern part of the Magallanes Basin before the cooling into cold-temperate waters recorded in the Priabonian of the Loreto Formation (Otero et al., 2012b) and the Late Eocene of Seymour Island, in Antarctica (Cione et al., 2007).

#### 5.5. Latitudinal distribution patterns of the studied fauna

In the case of southeastern South America, during the Upper Cretaceous warm temperate waters dominated latitudes near 45° to 60°S, such conditions reaching lower latitudes in the southeastern Pacific (near 30°S), while cool temperate waters were restricted to polar regions (de Souza Carvalho et al., 2010). The Maastrichtian assemblage studied here is consistent with this model (Fig. 8A), supporting similar oceanic conditions within southernmost South America and the southeastern Pacific (de Souza Carvalho et al., 2010: fig. 2). Also, the presence of the genus *Ischyrhiza* supports a latitudinal distribution in southwestern South America between 30° and 60°S, as is the case in the Northern Hemisphere with the closely related species *Ischyrhiza mira* recorded mainly from the Campanian–Maastrichtian of the United States (Cappetta, 1987). The distribution of *S. serrata* during the Maastrichtian suggests that this taxon inhabited tropical to warm waters, reaching a broad latitudinal distribution within the Atlantic, although this remains unknown in the Pacific to date.

The poor Paleocene diversity recovered from Sierra Baguales is not sufficiently informative, although the identified taxa seem to reach a higher latitudinal distribution within the Southern Hemisphere in comparison to the Northern Hemisphere. Nevertheless, they still remain constrained to latitudes below 60°S. On the other hand, the Early to Middle Eocene assemblage is coincident with well-documented finds especially recognized between 45° and 60°S, with the presence of mixed chondrichthyan fauna of cold-temperate and tropical waters, which is consistent with the



**Fig. 8.** Plate tectonic maps during the Maastrichtian, the Paleocene/Eocene boundary and the middle Bartonian, indicating the known occurrences of some of the taxa studied here. Taxa with a broad chronostratigraphic distribution were selected in order to analyze the biogeographic relationships between the assemblage from southernmost Chile and the rest of the world. Plate tectonic maps were obtained through the free online software of ODSN Plate Tectonic Reconstruction Service, University of Bremen, Germany (<http://www.odsn.de/odsn/services/paleomap/paleomap.html>).

observed reworking of older taxa and their subsequent mixing with younger taxa.

### 5.6. Associated vertebrates

The Maastrichtian assemblage contains scarce and indeterminate reptile teeth (discarded as belonging to plesiosaurs or mosasauroids), and abundant but fragmentary bone remains of reptiles and dinosaurs. Paleocene taxa are scarce and only isolated, indeterminate bone fragments were recovered, with no evidence of other vertebrates. Finally, the Eocene assemblage is associated with relatively abundant bone remains of crocodiles and fragments of turtle carapaces (Otero et al., 2012a) and rare bird bones (Sallaberry et al., 2010), labrid and other indeterminate osteichthyan fishes, scarce vertebrae of archeocete whales (Otero and Suárez, 2008), as well as scarce land mammals (E. Bostelmann, pers. comm. 2012).

## 6. Conclusions

A rich assemblage of fossil cartilaginous fishes from southern South America is discussed here. Although they are mostly comprised by reworked material, these represent one of the most complete faunal successions of the group known at any single locality in the Southern Hemisphere, being only comparable with the records from Seymour Island in Antarctica. The recovered material allows recognizing a Maastrichtian assemblage consisting of the taxa *Carcharias* sp., *I. chilensis*, *S. serrata*, *Centrophoroides* sp. and *Dasyatidae* indet., which indicate closer relationships with similar Pacific faunas than contemporaries from the Atlantic. A second group is comprised of the taxa *O. obliquus* and *M. cooperi* which indicate a Paleocene–Early Eocene age. The latter occurs together with a diverse assemblage of Middle to Late Eocene age comprised of *Carcharias 'hopei'*, *O. winkleri*, *Carcharoides caticus*, *Macrorhizodus praecursor*, *C. auriculatus*, *Striatolamia* sp., *Striatolamia*

*macrota*, *Hexanchus agassizi*, *Notorhynchus* sp., *Myliobatis* sp., *Abdounia* sp., *Pristiophorus* sp., *Squatina* sp., cf. *Rhizoprionodon* sp., *Ischyodus* sp. and *Callorhynchidae* indet., as well as one new species *J. bagualensis* sp. nov. The recovered Paleocene–Early Eocene fauna indicates that reworking affected older beds, the fossils of which now occur mixed with younger assemblages in Late Eocene beds, which is consistent with the radioisotopic date obtained. Most of these taxa are typical of the Atlantic and indicate an Early to Middle Eocene age for their original host beds.

The studied assemblage and their taphonomic conditions indicate a Maastrichtian to Late Eocene age interval for the strata exposed in the western part of Sierra Baguales. The overlying beds with fossilized tree trunks and leaf imprints could consequently represent an Oligocene floral assemblage consistent with younger continental strata exposed along the eastern margin of the locality, which are stratigraphically higher up including typical Miocene mammals (Bostelmann et al., 2013).

The paleogeographic distribution of the studied materials shows that during the Maastrichtian, constraining conditions probably existed for taxa of warm-temperate waters to inhabit high latitudes (over 60°), although proper tropical taxa (e.g., *S. serrata*) could reach latitudes near 60°. The scarce Paleocene records studied here are not informative enough in this sense, but their paleodistribution does not contradict this previous pattern. The recovered Late Eocene assemblage confirms the latitudinal distribution pattern for taxa of cold-temperate waters, while typical Paleocene–Middle Eocene taxa are more typical of tropical conditions (e.g., *C. auriculatus*). The cold-temperate water assemblage of chondrichthyans previously recognized in Priabonian beds of the Loreto Formation (about 280 km south of the studied locality), as well as the exclusive presence of crocodyliforms in Middle Eocene beds of the same basin exposed at lower latitudes, suggest the existence of a local south-to-north diminishing gradient of sea temperature during the Eocene, and finally becoming even more evident after major tectonic events such the deepening of the Drake Passage and the opening of the Tasmanian Gulf.

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