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LATE PALEOCENE TO MIDDLE EOCENE CALCAREOUS NANNOFOSSIL ASSEMBLAGES FROM PENÍNSULA MITRE, SOUTHEASTERN AUSTRAL BASIN, ARGENTINA

ASOCIACIONES DE NANOFÓSILES CALCÁREOS DEL PALEOCENO TARDÍO AL EOCENO MEDIO DE PENÍNSULA MITRE, SUDESTE DE LA CUENCA AUSTRAL, ARGENTINA

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Running Header: BEDOYA *ET AL*.: PALEOGENE CALCAREOUS NANNOFOSSILS FROM SE AUSTRAL BASIN.

Short Description: The Río Claro Group and the Río Bueno Formation biostratigraphy based on calcareous nannofossils, Southeast Isla Grande de Tierra del Fuego, Austral Basin, Argentina.

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Abstract. On the Fueguian Atlantic coast and in the southern Andean fold and thrust belt, the Paleogene is partially represented by numerous turbiditic deposits. Between Río Bueno and Cabo Leticia in Península Mitre, the Paleocene-Eocene is represented by the Río Claro Group (Cabo Leticia, La Barca, Punta Noguera, and Cerro Ruperto formations) and the Río Bueno Formation; which together constitute a ~1050 m thickness succession. Calcareous nannofossil assemblages recovered from 95 samples were analyzed to determine their relative ages. The Cabo Leticia Formation was barren in nannofossils. The upper LB2 Member of La Barca Formation contained *Rhomboaster cuspis* and *Fasciculithus richardii*, frequent in the Paleocene/Eocene boundary (Subzones NP9a/NP9b). Nannofossils recovered from Punta Noguera Formation indicate an early Eocene age (biozones NP9b–NP10), with *Fasciculithus tympaniformis*, *Rhomboaster cuspis*, and abundant *Toweius* spp. The Cerro Ruperto Formation provided one productive sample, with specimens of *Reticulofenestra* spp. and *Toweius* spp., which indicates an early Eocene age for the formation (biozones NP12–NP13). The Río Bueno Formation yields calcareous nannofossil assemblages characterized by *Chiasmolithus eograndis*, *Chiasmolithus expansus*, *Toweius* spp. and *Reticulofenestra* spp. which indicate a late early Eocene to middle Eocene age (biozones NP14–NP16). Although the calcareous nannofossil record is discontinuous due to preservational biases in the Río Claro Group, our data allow a better age constraint for the investigated formations and to correlate these units with other surface and subsurface units in the Austral Basin.

Keywords. Paleogene. Austral Basin. Calcareous nannofossils. Early Eocene. Tierra del Fuego.

Resumen. ASOCIACIONES DE NANOFÓSILES CALCÁREOS DEL PALEOCENO TARDÍO AL EOCENO MEDIO DE PENÍNSULA MITRE, SUDESTE DE LA

CUENCA AUSTRAL, ARGENTINA. En la costa atlántica fueguina y en la faja plegada y corrida de los Andes Fueguinos, el Paleógeno está representado parcialmente por numerosos sistemas turbidíticos. Entre el Río Bueno y el Cabo Leticia en Península Mitre, el Paleoceno-Eoceno está integrado por la Formación Río Bueno y al Grupo Río Claro (formaciones Cabo Leticia, La Barca, Punta Noguera y Cerro Ruperto) que alcanzan ~1050 m de espesor. En este trabajo se analizan los ensambles de nanofósiles calcáreos de 95 muestras a fin de precisar sus edades relativas. La Formación Cabo Leticia resultó estéril en nanofósiles. El miembro superior de la Formación La Barca, LB2, contiene ejemplares de *Rhomboaster cuspis* y *Fasciculithus richardii*, frecuentes en el límite Paleoceno/Eoceno (Subzonas NP9a–NP9b). Los nanofósiles recuperados en la Formación Punta Noguera indican una edad Eoceno temprano (subzonas NP9b–NP10), con *Fasciculithus tympaniformis*, *Rhomboaster cuspis* y abundantes *Toweius* spp. La Formación Cerro Ruperto proporcionó una muestra fértil, con ejemplares de *Reticulofenestra* spp. y *Toweius* spp., asignables al Eoceno temprano (biozonas NP12–NP13). La Formación Río Bueno, proveyó *Chiasmolithus eograndis*, *Chiasmolithus expansus* *Toweius* spp. y *Reticulofenestra* spp. Asignables al Eoceno temprano tardío - Eoceno medio (biozonas NP14–NP15).

Aunque el registro de nanofósiles calcáreos es discontinuo debido a las facies sedimentarias del Grupo Río Claro, nuestros datos permiten una mejor restricción de la edad de las formaciones investigadas y correlacionarlas con otras unidades aflorantes y del subsuelo en la Cuenca Austral.

Palabras clave. Paleógeno. Cuenca Austral. Nanofósiles calcáreos. Eoceno Temprano. Tierra del Fuego.

THE SOUTHERNMOST PORTION of the South American Andean Cordillera ends in the Fuegian Andes. Here, the Fuegian Thrust-Fold Belt includes foreland basin successions from the Upper Cretaceous to the Miocene (Olivero *et al.*, 2002, 2003; Torres Carbonell *et al.*, 2011; Torres Carbonell & Olivero, 2019). This work focuses on the stratigraphic record along the Atlantic shore of Península Mitre, SE Tierra del Fuego (Fig. 1.1), where a complex marine sedimentary succession from the Upper Cretaceous–Danian (Policarpo Formation) to the Paleogene (Río Claro Group and Río Bueno Formation) are exposed (Fig. 1.2).

The integrated stratigraphy of Paleogene rocks in the study area was based on dinocysts, foraminifera, and calcareous nannofossil assemblages. Accordingly, an upper Paleocene to middle Eocene age was assigned to formations now included in the Río Claro Group and middle Eocene for the Río Bueno Formation (Olivero *et al.*, 2002; Malumián & Jannou, 2010; Bedoya Agudelo, 2019).

Detailed calcareous nannofossil biostratigraphic studies have been done in subsurface successions of the northern Isla Grande de Tierra del Fuego and southeast Santa Cruz Province (*e.g.*, Mostajo, 1991; Pérez Panera 2009, 2013; Thissen & Pérez Panera, 2021). These studies prove the usefulness of calcareous nannofossils for relative age determination, and intrabasinal correlation in the Austral Basin. Despite the excellent exposures of Paleogene units at the southern Isla Grande de Tierra del Fuego, their calcareous nannofossil record remain relatively unknown (*e.g.*, Pérez Panera *et al.*, 2017; Bedoya Agudelo *et al.*, 2018; Bedoya Agudelo, 2019). Here we present new field data and interpretations, which allow better constraints on the depositional age of the Río Claro Group and Río Bueno Formation and the timing of some important tectonic events in this part of the Austral Basin (*e.g.*,correlation between angular unconformities).

Based on the calcareous nannofossils assemblages and their stratigraphic relationship, this paper aims to 1) revise the relative ages of the different formations that integrate the Río Claro Group and the Río Bueno Formation; and 2) to correlate these units with the subsurface units. It should be noted that in some formations, the nannofossil are scarce due to the turbidite facies that conform to the Río Claro Group. Moreover, the outcrops in this remote area are restricted to the coastal cliffs and inland river valleys of difficult access, limiting sampling to discontinuous stratigraphic columns. However, we were able to cover the fine-grained siliciclastic and calcareous facies present in each formation leading to an improved biostratigraphic framework.

Institutional abbreviations. CADIC-CONICET, Centro Austral de Investigaciones Científicas Ushuaia–Consejo Nacional de Investigaciones Científicas y Tecnológicas, Ushuaia, Argentina.

GEOLOGICAL SETTING

The Paleogene of Península Mitre is represented by a set of formations (Fig. 2) exposed along the Fuegian Atlantic coast, between the Río Bueno area and the Cabo Irigoyen (Fig. 1.2) (Olivero *et al.*, 2002, 2003, 2007; Olivero & Malumián, 2008). Part of the Paleogene succession, grouped into the Río Claro Group and the Río Bueno Formation represent a regressive megasequence, starting with turbidite deposits towards the base and prograding into shallower facies (Olivero & Malumián, 2008). The stratigraphic framework of the studied area is briefly described, based on the generalized section shown in Figure 3.1.

Figure 1.

Río Claro Group

In the studied area, the Río Claro Group comprises the Cabo Leticia, La Barca, Punta Noguera, and Cerro Ruperto formations (Olivero & Malumián, 2008).

Cabo Leticia Formation. The oldest unit of the Group,crops out in its type locality (Cabo Leticia) at the core of an asymmetrical anticline, where it reaches 150 m of thickness (Olivero *et al.*, 2002) and at Río Malengüena (Torres Carbonell *et al.*, 2011). The Cabo Leticia Formation is composed of breccias, conglomerates with abundant fragments of poorly preserved oyster shells, and tuffaceous sandstones interpreted as gravity flows, deposited in a fan delta environment (Olivero *et al.*, 2002). The base of the formation is not exposed and the top is transitional with the La Barca Formation (Olivero *et al.*, 2002).

Figure 2.

La Barca Formation. The type area of the La Barca Formation is located between the Cabo Leticia and playa La Barca, where it reaches a minimum thickness of 220 m (Olivero *et al.*, 2002). The Formation includes two members, the LB1 member (Fig. 3.1–3.3), with a minimum exposed thickness of 120 m, and the LB2 member (Fig. 3.2), approximately 100 m thick (Olivero *et al.*, 2002). In the Río Malengüena area, the formation crops out to the north and south of Punta Ainol, where it is deformed by an anticline-syncline pair.

To the south, the top of this unity is in tectonic contact with the Leticia Formation (middle–upper Eocene) through a reverse fault. To the north, the La Barca Formation is unconformably covered by the Leticia Formation (Torres Carbonell *et al.*, 2011).

The La Barca Formation is characterized by interbedded tuffaceous sandstones and carbonaceous siltstones (member LB1) and by black to dark gray mudstones with levels of ellipsoidal concretions that reach up to 2.5 m in their long axis (member LB2). These facies are interpreted as anoxic marine deposits (Olivero & Malumián, 2008; Torres Carbonell *et al.*, 2009). The presence of agglutinated foraminifera such as

Spiroplectammina spectabilis and endemic species such as *Buliminella isabelleana procera* and *Antarcticella* sp., allowed assigning a late Paleocene age (Malumián & Jannou, 2010). Recent evidence based on calcareous nannofossils (Bedoya Agudelo *et al.*, 2018) and dinocyst assemblages (Quattrocchio, 2021) also record lower Eocene horizons.

Punta Noguera Formation. The type section of the Punta Noguera Formation is exposed at the core of a syncline fold in the Punta Noguera area, with a minimum thickness of 380 m (Fig. 3.1) (Olivero *et al.*, 2002). To the west, at Punta Ainol and at the Río Malengüena area, the strata of this unit are overturned (Torres Carbonell *et al.*, 2011).

This formation is characterized by rhythmically stratified massive glauconitic sandstones, dark mudstones, and fine conglomerates, interpreted as turbidites (Olivero & Malumián, 2008) deposited at the foot of fan-deltas (Olivero *et al.*, 2002). The thickest sand-rich turbidite beds bear abundant fragments of molluscan shells (Fig. 3.1). At Punta Ainol, the formation is composed of fine sandstones with high content of volcaniclastic material, interspersed with levels of sandstones with heterolithic stratification (Torres Carbonell *et al.*, 2009). These sediments contain ostracods, radiolaria, and agglutinated foraminifera of the genera *Rzehakina*, *Criborotalia*, *Elphidium* (Malumián & Jannou, 2010), and the species *Chiloguembelina wilcoxesis*, constraining the age to the early Eocene (Malumián *et al.*, 2009; Torres Carbonell *et al.*, 2009). At Punta Ainol, the base and top of this unit are covered, whilst at Punta Noguera, the top is unconformably covered by the Río Bueno Formation (Furque & Camacho, 1949; Olivero *et al.*, 2002).

Figure 3.

Cerro Ruperto Formation. The type section of the Cerro Ruperto Formation crops out between Punta Cuchillo and Cerro Ruperto, with a minimum, exposed thickness of 200 m (Olivero *et al.*, 2002). The Cerro Ruperto Formation comprises glauconite-rich sandstones and siltstones, deposited in a restricted marine environment (Olivero & Malumián, 2008). It contains abundant solitary corals, gastropods, bivalves, radiolaria, and well-preserved dinocysts, like *Deflandrea dartmooria* from the early Eocene (Olivero *et al.*, 2002). The base is not exposed and the top is unconformably covered by the Río Bueno Formation (Olivero *et al.*, 2002).

Río Bueno Formation

The Río Bueno Formation (Furque & Camacho, 1949; Olivero *et al.*, 2002) is formed by two members, RB1 and RB2, which crop out in different localities. RB1 is exposed at Punta Noguera (the type section), Cerro Las Vacas, the northern coast of the Laguna Río Bueno, and Meseta de Orozco, with a minimum thickness of 30–40 m. The member RB2 crops out at the intertidal zone near Puesto Río Bueno, with a similar thickness. The Río Bueno Formation is composed of calcareous rocks with two lithological associations; RB1, formed by bioclastic limestones (mainly grainstones), and RB2 formed by an alternation of limestones, bioturbated marls, and micrites, all deposited in a shallow platform environment (Olivero *et al.*, 2002; Torres Carbonell, 2010). These sediments contain abundant fossils constrained to the lower middle Eocene, such as fragments of bivalves, gastropods, solitary corals, bryozoans, and calcareous algae, as well as radiolaria, ostracods and benthic and planktonic foraminifera (*Planorotalitesaustraliformis* and *Subbotina linaperta*) (Olivero *et al.*, 2002). The base of the formation covers in angular unconformity several units of different ages, from the Maastrichtian to the Paleocene, and to the lower Eocene such as the Policarpo, Cabo Leticia, La Barca, Punta Noguera and Cerro Ruperto formations, while the top is not exposed.

Previous structural and stratigraphic work in the area labelled this unconformity as U3, and related it to significant exhumation related to a stage of Paleocene–early Eocene thrusting and folding in this part of the thrust-fold belt (Olivero *et al.*, 2002; Torres Carbonell *et al.*, 2011; 2020). Deposition of the Río Bueno Formation atop this unconformity indicates that it forms part of a wedge-top depocenter within the foreleand basin system (Torres Carbonell & Olivero, 2019). Our new data regarding the age of the Río Bueno Formation gives a better constraint of the youngest age of this deformation stage and initiation of the wedge-top depocenter.

The analyzed samples in this study comprise both members of the Río Bueno Formation. Because the RB1 and RB2 members are not in contact, their stratigraphic relationships are uncertain. Olivero *et al.* (2002) tentatively assumed that member RB2 overlies the member RB1; however, as the microfossil content is not conclusive, the opposite alternative is also possible.

MATERIALS AND METHODS

Materials

A total of 95 samples collected in several field seasons by EBO, PTC and CG, were processed and analyzed for calcareous nannofossils. These were collected in several localities (Fig. 1.2) of Península Mitre: Río Leticia, Laguna Río Bueno, Punta Noguera, Cerro Ruperto, Río Malengüena, Punta Ainol, and Punta Cuchillo. They represent partial sections totalizing 1050 m thick-composite sections and are compiled on a single composite stratigraphic section (Fig. 3).

The recovered material and nannofossil fertile slides are stored in the Micropaleontological Collection Repository of CADIC–CONICET, under the acronym

CADIC MIC- (Cadic Micropaleontología) (Tab. 1). Barren samples keep the field code under which they were collected.

Table 1.

Methods

The samples were prepared following the smear slide standard technique (Bown and Young, 1998). Nannofossils were observed using a polarized light Leica DM750 microscope under 1000x magnification. Semiquantitative analysis was performed, and counts of 300 specimens were made along random longitudinal transects in the slides. In samples with low abundance, the total nannofossils observed in 10 longitudinal transects were counted. Relative species abundances were estimated as follows: VA= very abundant (>10 specimens/field of view); A = abundant (1–9 specimens/field of view); C = common (1 specimen/2–10 fields of view) F = few (1 specimen/11–50 fields of view); R = rare (1 specimen/ > 50 fields of view); B = barren. The preservation was estimated by examining the qualitative degree of dissolution and/or recrystallization: good (G), for specimens with little or no evidence of dissolution and/or overgrowth; moderate (M), for specimens with little or some dissolution and/or overgrowth, but that are still identifiable; and poor (P), for specimens with considerable dissolution and/or recrystallization.

Taxonomic concepts for species follow Perch-Nielsen (1985), Bown (2005, 2016) and the online Nannotax Catalog (Young *et al.*, 2022). The standard zonation scheme of Martini (1971) for the Cenozoic was used as a reference.

RESULTS

Recovered nannofossil assemblages in the Río Claro Group and Río Bueno Formation show highly variable preservation and abundance. All calcareous nannofossil species recovered in the studied formations are summarized in Figure 4. Most representative species are illustrated in Figures 5 and 6.

Figure 4.

Cabo Leticia Formation

Two samples from the Cabo Leticia Formation, one from Cabo Leticia locality and the other from the Río Malengüena, were barren in calcareous nannofossils.

La Barca Formation

In the analyzed samples from the LB1 and LB2 members of the La Barca Formation in Cabo Leticia, calcareous nannofossils were not recorded. Only a single specimen of *Hornibrookina australis* in sample 372-21 of the member LB2 was recognized. In samples from the Río Malengüena, mainly composed of black mudstones, calcareous nannofossils were also not recognized (Fig. 3.3).

Figures 5 and 6.

From the Punta Ainol section, 16 samples of the LB2 member were fertile (Fig. 3.2). The abundance was low to moderate throughout the section. The preservation is mostly poor, and species richness is low to moderate.

In the lower part of the profile (samples CADIC MIC-01 to CADIC MIC-08), assemblages show low abundance and poor to moderate preservation. They are characterized by small placoliths like *Toweius occultatus*, *Toweius eminens*, and *Toweius rotundus*, with few to rare *Chiasmolithus biden*s, *Coccolithus pelagicu*s, and *Fasciculithus involutus*. Other late Paleogene important species recovered in this lower part are *Fasciculithus alanii*, *Fasciculithus mitreus*, *Fasciculithus richardii*, and *Fasciculithus tympaniformis,* see Suplementary Online Information (**SOI**).

In the upper part (samples CADIC MIC-09 to CADIC MIC-16), assemblages have poor preservation. However, these assemblages have high species richness and show an increase in the relative abundance of the genus *Toweius*, and *Chiasmolithus bidens* and *Coccolithus pelagicus*.

In the lower sample of this part (CADIC MIC-09) (see SOI) the species richness is higher compared to the other samples, and some events close to the Paleocene/Eocene boundary were identified, like the Last Occurrence (**LO**) of *F. alanii* and LO of *F. richardii*, and the First Occurrence (**FO**) of *C. solitus*, *Discoaster* cf. *araneu*s and *R. cuspis.*

In addition, specimens of the genus *Heliolithus* (*H. kleinpellii* and *H. cantabriae*) and *Watznaueria* sp., observed both, in the lower and the upper part of the profile are considered as reworked taxa.

Punta Noguera Formation

At its type section, the recovered calcareous nannofossils exhibit poor preservation, low abundance, and medium to high species richness. Some samples were barren. Species richness decreases towards the upper levels, whereas abundance slightly increases.

Assemblages are characterized by high relative abundance of *Chiasmolithus bidens, Coccolithus pelagicus*, *Toweius callosus,* and *Toweius occultatus*. The presence of *Chiasmolithus solitus*, *Chiasmolithus eograndis*, *Cyclicarcolithus parvus*, *Fasciculitus tympaniformis*, *Fasciculithus involutus*, *Fasciculithus* cf. *sidereus, Hornibrookina australis,* cf. *Rhomboaster cuspis*, and the LOs of *Prinsius bisulcus* and *Prinsius martini* (see SOI) indicate an early Eocene age.

Cerro Ruperto Formation

In the studied section of the Cerro Ruperto Formation, only one sample yields calcareous nannofossils (sample CADIC MIC-170; see SOI). This assemblage has moderate preservation and moderate abundance and species richness. It is characterized by *Blackites creber*, *Chiasmolithus* spp., *Coccolithus formosus*, *Coccolithus* spp., *Coronocyclus bramlettei*, *Ellipsolithus bollii*, *Helicosphaera* sp., *Neoccocolithes dubius*, *Pontosphaera pectinata*, *Pontosphaera pulchra*, *Reticulofenestra* spp., *Toweius* spp., and *Umbilicosphaera* sp. In this sample *Reticulofenestra dictyoda* and small specimens of *Reticulofenestra* spp. are the most abundant taxa, followed by *Chiasmolithus solitus*, *Coccolithus pelagicus*, *R. lockeri*, and unidentified species of the genus *Toweius* and *Umbilicosphaera* (see SOI). The presence of *Coccolithus formosus*, *Neococcolithes dubius*, and the high relative abundance of *Reticulofenestra* spp. and *Toweius* spp., indicates an early Eocene age for this assemblage.

Río Bueno Formation

The 16 investigated samples of the Río Bueno Formation covered the two members of this formation. For the lower RB1 Member, 11 samples (Figs. 3.1, SOI) were taken from different sections in the intertidal area of the Punta Noguera type section. For the RB2 member, five samples (Figs. 3.1, SOI) were taken from different points near the Puesto Río Bueno and the Río Leticia (Fig. 1.2).

In member RB1, nannofossil assemblages display few abundance, and moderate preservation and species richness. The assemblage is characterized by *Coccolithus pelagicus*, *Toweius callosus*, and *Toweius* spp. reworking from the earliest Eocene is recognized by the presence of *Ellipsolithus bolli*, *Hornibrookina arca, Neochiastozygus junctus* and *Toweius occultatus*. However, some common species from the middle Eocene as *Chiasmolithus grandis*, *Chiasmolithus expansus*, *Neococcolithes minutus*,and *Reticulofenestra wadeae* could be identified (see SOI).

In the RB2 member there is a decrease in nannofossil abundance, together with a poor preservation. Only one sample (CADIC MIC-174) contains calcareous nannofossils. The assemblage is dominated by *Coccolithus pelagicus*, followed by

Toweius callosus. Rare taxa include *H. arca*, *N. junctus*, *P. pulchra*, *Reticulofenestra* spp., *S. moriformis*, *Toweius* spp., and *Z. bijugatus* (see SOI).

DISCUSSION

The Río Claro Group and Río Bueno Formation correspond to lower Paleogene turbidite deposits (Olivero & Malumián, 2008), thus microfossil recovery is patchy and biased by siliciclastic dilution. However, calcareous nannofossil results from the investigated sections allow a better age constraint for these successions and correlation with subsurface units (Fig. 7).

At the lower part of the Río Claro Group, the Cabo Leticia Formation is barren in calcareous nannofossils. However, an late Paleocene age is considered herein, following Olivero *et al.* (2002) based on stratigraphic relationships with the overlying La Barca Formation (upper Paleocene-lower Eocene) (Bedoya Agudelo *et al.*, 2018).

The La Barca Formation comprises the upper Paleocene- lower Eocene based on the FOs of *Discoaster* cf. *araneus* and *Rhomboaster cuspis*, and the LOs of *F. alanii* and *Fasciculithus richardii* group (*F. richardii*, *F. mitreus*, sensu Agnini *et al.*, 2014). These events were recorded on samples of the member LB2 in the Punta Ainol area and constrain the assemblage to the NP9a/NP9b subzones (s. Agnini *et al.*, 2007) (Bedoya Agudelo *et al.*, 2018). This subzonal boundary indicates the Paleocene/Eocene boundary (56 Ma, Speijer *et al.*, 2020). The presence of the genus *Rhomboaster* in the sample CADIC MIC-09 and *Fasciculithus tympaniformis* in samples CADIC MIC-09 to CADIC MIC-16 representing NP9b–NP10 biozones of Martini (1971), would indicate a lower Eocene age for the upper part of the LB2 Member.

Analyzed samples of the LB1 Member, (La Barca Formation) in this study were barren, possibly due to the lithology, characterized by volcaniclastic sandstones (Olivero *et al.*, 2002). According to Malumián and Caramés (2002), the LB1 Member would correspond to facies accumulated in low oxygen due to high paleoproductivity and organic matter accumulation, which could explain the absence of calcareous microfossils (nannofossils and planktic foraminifera) due to high concentration of carbon dioxide and calcium carbonate dissolution.

Figure 7.

The La Barca Formation was originally assigned to the upper Paleocene due to the presence of *Bulimina karpatica* Szczechura (Malumián & Caramés, 2002), *Palaeocystodinium golzowense* Alberti, and *Glaphyrocysta* sp. in the LB1 Member at Cabo Leticia (Olivero *et al.*, 2002). This age was also assigned to the LB2 Member (Malumián & Caramés, 2002; Olivero *et al.*, 2002; Torres Carbonell *et al.*, 2009). Later on, the LB2 Member at Punta Ainol was assigned to the upper Paleocene–lower Eocene, based on calcareous nannofossils and dinocysts assemblages (Bedoya Agudelo *et al.*, 2018; Quattrochio, 2021).

The late Paleocene and Paleocene/Eocene boundary seems to be absent in subsurface units in the southeastern Santa Cruz Province and northern of Tierra del Fuego Island (Pérez Panera, 2009, 2013; Thissen & Pérez Panera, 2021). Therefore, Punta Ainol is a reference section for this boundary in the Austral Basin.

In the Punta Noguera Formation, recovered calcareous nannofossil assemblages are characterized by the presence of *Fasciculithus tympaniformis*, *Fasciculithus involutus*, *Fasciculithus* cf. *sidereus*, and *Rhomboaster cuspis.* The genus *Fasciculithus* has its LO in the NP10 Biozone of Martini (1971) and *Rhomboaster cuspis* is restricted to the upper NP9 Biozone and lower NP10 Biozone (Raffi *et al.*, 2005; Agnini *et al.*, 2007; Agnini *et al.*, 2014). As there are no evident changes in the calcareous nannofossil assemblages throughout the whole investigated section, we propose an early Eocene age (early Ypresian-NP10 Biozone) for the Punta Noguera Formation. This age is consistent with the interpreted age of the underlying La Barca Formation, which indicate the upper Paleocene–lower Eocene.

Most common calcareous nannofossil species in the recovered assemblages are *Chiasmolithus bidens*, *Chiasmolithus solitus*, *Fasciculithus tympaniformis*, *Prinsius martini*, *Prinsius bisulcus*, *Toweius callosus*, *Toweius eminens*, and *Toweius pertusus.* This assemblage bears similarities with the Lower Uribe Formation from the subsurface of Tierra del Fuego (Mostajo, 1991; Thissen & Pérez Panera, 2021) and the Lower Magallanes Formation from the subsurface of Santa Cruz province (Pérez Panera, 2013) (Figure 7). It can be also correlated with the nannofossil assemblages from the lower part of the Punta Torcida Formation (Pérez Panera *et al.*, 2017; Bedoya Agudelo, 2019).

Regarding the age interpreted by other microfossils, Olivero *et al.* (2002) found a dinocysts association composed of *Apectodinium homomorphum*, *Deflandrea robusta*, and *Palaeocystodinium* sp., suggesting an age close to the Paleocene/Eocene boundary. The foraminifera *Alabamina creta* Finlay *Charltonina acutimarginata* Finlay, and the genera *Cribrorotalia* and *Elphidium*, are typical of post-Paleocene shallow waters and close to the Paleocene/Eocene boundary (Olivero *et al.*, 2002), together with *Chiloguembelina wilcoxensis* (Cushman and Ponton), a planktic species of chronostratigraphic value in southern latitudes (Malumián *et al.*, 2009), allowed to assign an early Eocene age. These ages agree with the calcareous nannofossil interpretations.

In the Cerro Ruperto Formation, calcareous nannofossil assemblages are characterized by the presence of abundant *Reticulofenestra dictyoda*, *R. lockeri*, *R. minuta*, and *Reticulofenestra* spp., together with *Toweius callosus* and *Toweius* spp. The occurrence of the genus *Reticulofenestra* at high latitudes is recognized from Biozone NP11 (Schneider *et al.*, 2011; Shepherd & Kulhanek, 2016). The *Toweius* -

Reticulofenestra turnover is an important event of the early Eocene, recorded in high and low latitudes around biozones NP12 and NP13 (Martini, 1971; Agnini *et al.*, 2006; Shamrock & Watkins, 2012; Shepherd and Kulhanek, 2016).

Considering the presence of both *Reticulofenestra* and *Toweius* characteristic of the NP12–NP13 biozones, in the productive sample from the Cerro Ruperto Formation, we propose a lower Eocene age for the formation, and it is consistent with the interpreted age of the underlying Punta Noguera Formation (lower Eocene). The most distinctive species of the Cerro Ruperto Formation are *C. solitus*, *P. pulchra*, *R. dictyoda*, and *R. minuta*, which allow partial correlation with the subsurface Lower Uribe Formation from Tierra del Fuego and the subsurface Lower Magallanes Formation from Santa Cruz province (Mostajo, 1991; Pérez Panera, 2009, 2013) (Fig. 7). This assemblage also can be correlated to the nannofossil assemblage and events recorded at Punta Torcida Formation (Pérez Panera *et al.*, 2017; Bedoya Agudelo, 2019).

Based on the dinocysts *Deflandrea dartmooria* (Williams), the abundant radiolaria *Nodosoria longicasta* d'Orb., and the presence of the foraminifera *Spiroplectamina spectabilis* (Grzybowski), an early Eocene age was assigned for the microfauna of the lower part of the Cerro Ruperto Formation (Olivero *et al.*, 2002), which is in agreement with the calcareous nannofossils age reported here.

The reduced samples with nannofossils in the Cerro Ruperto Formation can be related to unfavorable conditions for its fossilization, as well as the deposition in a restricted marine environment (Olivero *et al.*, 2002), massive sandstone facies, and the high abundance of radiolaria which indicates deepening of the basin (Malumián & Jannou, 2010).

In the Río Bueno Formation, calcareous nannofossil assemblages are represented by *C. expansus*, *C. eograndis*, *C. solitus*, *N. minutus*, and *R. wadeae*. *Reticulofenestra wadeae*, is common in NP14 to NP16 biozones, and *C. expansus,* present in the uppermost productive sample, is common in Biozone NP15 (see SOI). The presence of *Toweius callosus*, *T. occultatus*, and *Chiasmolithus eograndis*, species that are common in the NP14 biozone but also have their last occurrences in that biozone (Shamrock & Watkins, 2012; Shepherd & Kulhanek, 2016), are the most biostratigraphically important components in the Río Bueno assemblages. According to this, the RB1 Member of the Río Bueno Formation correlates with NP14–NP15 biozones (the upper part of the early Eocene to the early middle Eocene).

Chiasmolithus bidens, *Ellipsolithus* sp., *H. arca*, and *N. junctus* were also observed, and are frequently found in the early Eocene (NP10–NP11 biozones), and are considered as reworked material. The limestone deposition of the Río Bueno Formation in Tierra del Fuego occurs after an erosive period, which largely explains the presence of reworked species (Malumián, 1999).

The assemblage from the Río Bueno Formation bears similarities with the upper member of the Punta Torcida Formation (Bedoya Agudelo, 2019), the subsurface Lower Uribe Formation from Tierra del Fuego (Mostajo, 1991), and the Lower Magallanes Formation of Santa Cruz province (Pérez Panera, 2013), and the Agua Fresca (Chile), Río Turbio and Man Aike (Santa Cruz) surface formations (Thissen & Pérez Panera, 2021).

Based on the presence of *Subbotina patagonica*, *Planorotalites australiformis* (Jenkins) and *Subbotina linaperta* (Finlay), a lower middle Eocene age was interpreted for this unit by Olivero *et al.*, (2002) and Malumián and Jannou (2010).

Although the Río Bueno Formation assemblages contain reworked taxa from the lowermost Eocene deposits, the age of the formation could not be older than the upper part of the lower Eocene because the Río Bueno Formation lays on an angular unconformity cutting several lower Eocene units (Cerro Ruperto and Punta Noguera formations), which were folded before the development of the unconformity (Olivero *et al.*, 2002; Torres Carbonell *et al.*, 2011). It is important to note that abundant specimens of *Reticulofenestra* were not found being part of the nannofossil assemblages of member RB1, taking into account that nannofossil assemblages of the underlying lower Eocene formation (Cerro Ruperto) contain *Reticulofenestra*.

Our new data constrains the oldest age of the U3 unconformity to the early Eocene (late Ypresian) since it separates the NP12–NP13 Cerro Ruperto Formation from the NP14–NP15 Río Bueno Formation. This indicates that the significant deformation and erosion of the thrust-fold belt that led to the development of this important angular unconformity has the youngest age within the early Eocene (Ypresian). This data precludes a correlation between U3 and U4 (Fig. 2), which has an age between ca. 46 and 43 Ma and separates the Punta Torcida Formation from the Leticia Formation (Olivero *et al.*, 2020). U4 is also a more regional unconformity, with occurrence beyond the thrust-fold belt, indicating exhumation caused not only by local development of structures, as may be the case of U3 (Torres Carbonell & Olivero, 2019). In addition, our data indicate that the initiation of wedge-top deposition in the Austral Basin (with the deposits of the Río Bueno Formation) indicates the late Ypresian age.

Conclusions

In summary, the assemblages recorded in the Río Claro Group and the Río Bueno Formation indicate a late Paleocene-middle Eocene age, correlable to NP9 to NP15 biozones,~56 to 43 Ma (Speijer *et al*., 2020).

These assemblages allow correlations of these formations with others from drilled sediments previously studied in other sectors of the Austral Basin, like from S-SE of Santa Cruz province and the north-central Tierra del Fuego subsurface, which include broadly NP10 and NP12 to NP15 biozones.

Although analyzed samples from Cabo Leticia Formation are barren of calcareous nannofossils, it is most probable that this formation represents a late Paleocene sedimentation due to its stratigraphic position.

The LB2 Member of the La Barca Formation at Punta Ainol indicates an upper Paleocene–lower Eocene, equivalent to the NP9a/NP9b subzones, defined by the presence of *Fasciculithus alanii*, *Fasciculithus richardii* and *Rhomboaster cuspis*. In other sectors of the basin, the late Paleocene and the earliest Eocene are represented by hiatuses, making the La Barca Formation in the Punta Ainol area a reference section for this interval in the Austral Basin.

The Punta Noguera Formation is confirmed to be lower Eocene (early Ypresian, NP10 Biozone), due to the presence of *Fasciculithus tympaniformis*, *Fasciculithus involutus* and the absence of *Reticulofenestra* spp.

The calcareous nannofossils assemblage found in the Cerro Ruperto Formation is composed of *C. solitus*, C*occolithus* cf. *crassus*, *C. latus*, *E. formosa*, *N. dubius*, *R. dictyoda*, *R. lockeri*, *R. minuta*, and *T. callosus*, allow us to assign an early Eocene age, equivalent to biozones NP12–NP13.

In the Río Bueno Formation, the recorded assemblage is mostly reworked; however, some species such as *C. expansus*, *N. minutus*, and *R. wadeae* allow assigning an age not younger than the middle Eocene, equivalent to NP14–NP15 biozones. The U3 unconformity below the Río Bueno Formation thus represents the lower Eocene (upper Ypresian) and marks the onset of the wedge-top depocenter in the foreland basin during that age.

This age also precludes the correlation of U3 with the younger and more regional U4 unconformity.

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Figure captions

Figure 1. 1, Location map and geological sketch of southeastern Tierra del Fuego. The main stratigraphic units of the Southern Andes are shown. **2,** Geological map of the Río Bueno area and location of the Río Claro Group and Río Bueno Formation sections.

Figure 2, Chronostratigraphic chart and correlation of Paleogene formations within the different parts of the Austral Basin and coeval structural stages. Modified from Torres Carbonell & Olivero (2019). Ages sources: **1,** Flores *et al.* (1973); Malumián (1990); Masiuk *et al.* (1990); **2,** Malumián (1990, 2002); **3,** Olivero and Malumián (2008); Torres Carbonell *et al.* (2009); **4,** Biddle *et al.* (1986); Sánchez *et al.* (2010); **5,** Marenssi *et al.* (2002); Romans *et al.* (2011). **UC,** Upper Cretaceous; **U1,** Unconformity 1; **U3,** Unconformity 3; **U4,** Unconformity 4.

Figure 3. 1, Composite profile including partial sections from different locations of the Río Claro Group and Río Bueno Formation**.** After Olivero *et al.* (2002); **2,** LB2 member of the La Barca Formation stratigraphic profile at the Punta Ainol area; **3,** LB1 member of the La Barca Formation stratigraphic profile at the Río Malengüena area. Modified from Bedoya Agudelo *et al.* (2018).

Figure 4, Stratigraphic distribution summary of calcareous nannofossils from the Río Claro Group and the Río Bueno Formation, Tierra del Fuego, Austral basin.

Figure 5, Selected calcareous nannofossils recovered from the Río Claro Group and the Río Bueno Formation; **1,** *Blackites* sp.; **2,** *Blackites spinosus*; **3,** *Braarudosphaera bigelowii*; **4,** *Chiasmolithus bidens*; **5,** *Chiasmolithus grandis*; **6,** *Chiasmolithus nitidus*; **7,** *Chiasmolithus solitus*; **8,** *Coccolithus formosus*; **9,** *Coccolithus latus*; **10,** *Coccolithus pelagicus*; **11,** *Cyclicargolithus floridanus*; **12,** *Ellipsolithus bollii*; **13,** *Ericsonia staerkeri*; **14,** *Fasciculithus involutus*; **15,** *Fasciculithus richardii*; **16,** *Fasciculithus tympaniformis*; **17,** *Hornibrookina arca***; 18,** *Hornibrookina australis*; **19,** *Markalius inversus*; **20,** *Neochiastozygus concinnus*. Cerro Ruperto Formation (1,4,8,9,10,11,12); La Barca Formation (14, 15, 16, 17,18, 19, 20); Punta Noguera (6,3); Río Bueno (2,5,7,13). Scale bar equals 5 µm.

Figure 6, Selected calcareous nannofossils recovered from the Río Claro Group and the Río Bueno Formation; **1,** *Neochiastozygus junctus*; **2,** *Neococcolithes dubius*; **3,** *Neococcolithes minutus*; **4,** *Pontosphaera exilis*; **5,** *Pontosphaera pectinata*; **6,** *Pontosphaera pulchra*; **7,** *Prinsius bisulcus*; **8,** *Rhomboaster cuspis*; **9,** *Toweius callosus*; **10,** *Toweius eminens*; **11,** *Toweius occultatus*; **12,** *Toweius tovae*; **13,** *Reticulofenestra dictyoda*; **14,** *Reticulofenestra lockeri*; **15,** *Reticulofenestra minuta*; **16,** *Reticulofenestra wadeae*. Cerro Ruperto Formation (5,6,13,14,15); La Barca Formation (7,8,10,11,12); Punta Noguera (1); Río Bueno (2,3,4,9,16). Scale bar equals 5 µm.

Figure 7, Calcareous nannofossil assemblages recognized in surface and subsurface of Paleogene lithostratigraphic units in the Austral Basin, their correspondence with the biozones of Martini (1971) and considering the ages they represent. Correlation with other known microfossil assemblages (foraminifera and/or dinocyst). References: **1,** Bedoya Agudelo *et al.* (2018); **2,** Bedoya Agudelo (2019); **3.** This work; **4,** Mostajo

(1991); **5,** Thissen and Pérez Panera (2021); **6,** Pérez Panera (2009); **7,** Pérez Panera (2013); **8,** Olivero *et al.* (2002); **9,** Malumián *et al.* (2009); **10,** Torres Carbonell *et al.* (2009)**; 11,** Malumián and Jannou (2010); **12,** Quattrocchio (2021).

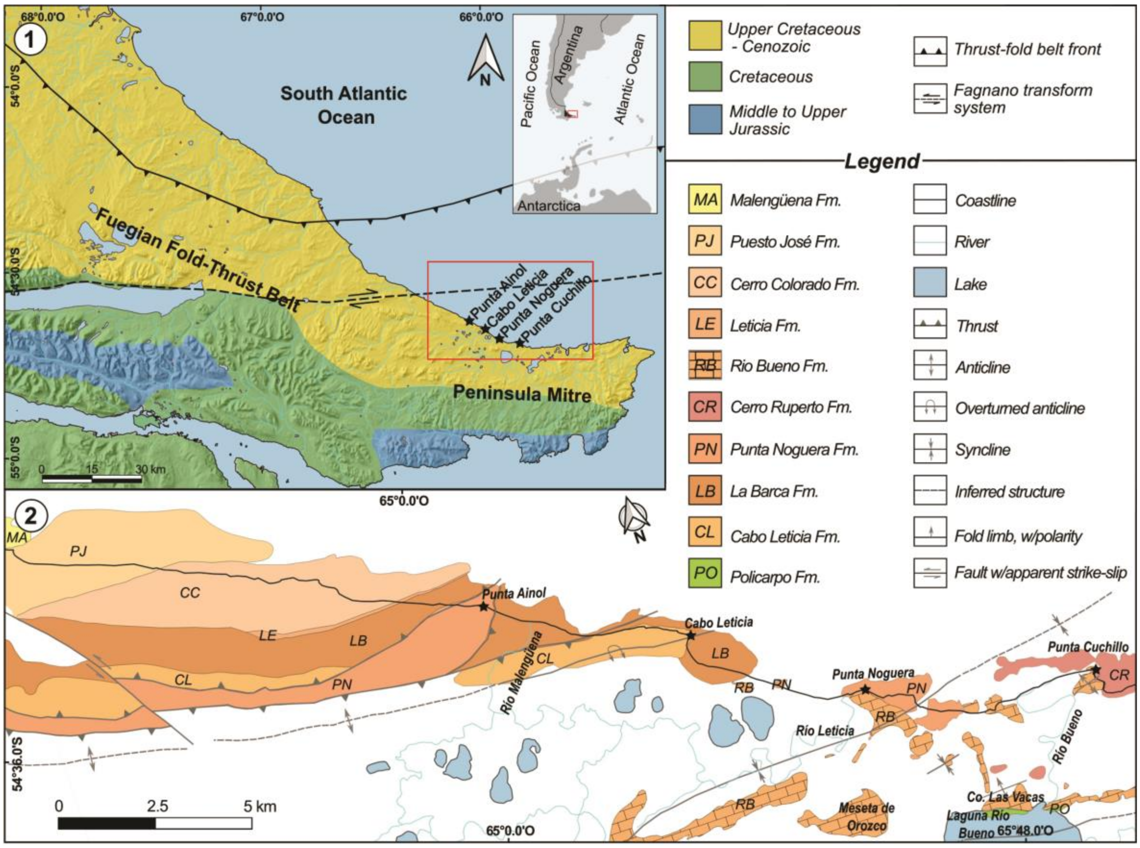

Figure 1.

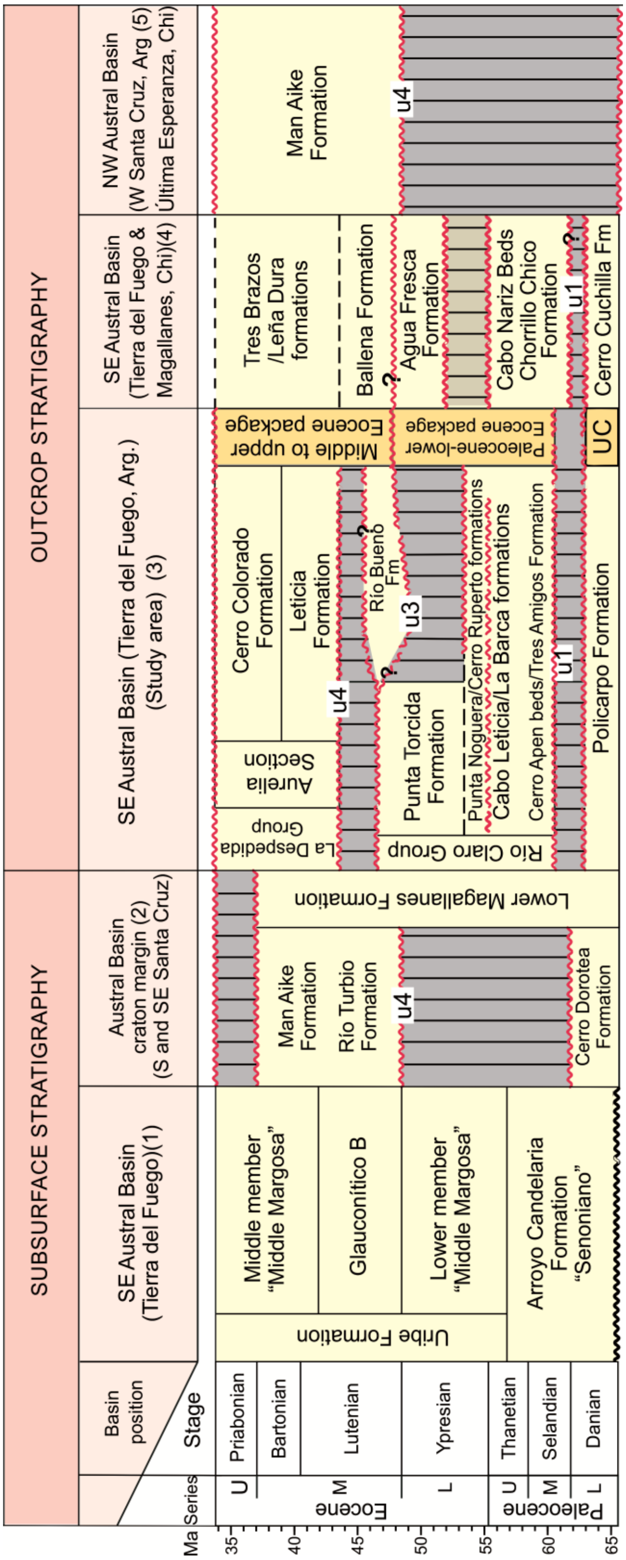
SUBSURFACE STRATIGRAPHY
OUTCROP STRATIGRAPHY
Ma
Series
Stage
Basin position
SE Austral Basin (Tierra del Fuego)(1)
Austral Basin craton margin (2) (S and SE Santa Cruz)
SE Austral Basin (Tierra del Fuego, Arg.) (Study area) (3)
SE Austral Basin (Tierra del Fuego & Magallanes, Chi)(4)
NW Austral Basin (W Santa Cruz, Arg (5) Última Esperanza, Chi)
35
40
45
50
55
60
65
Eocene
Paleocene
U
M
L
Priabonian
Bartonian
Lutenian
Ypresian
Thanetian
Selandian
Danian
Uribe Formation
Middle member "Middle Margosa"
Glauconítico B
Lower member "Middle Margosa"
Arroyo Candelaria Formation "Senoniano"
Man Aike Formation
Río Turbio Formation
Cerro Dorotea Formation
Lower Magallanes Formation
La Despedida Group
Aurelia Section
Cerro Colorado Formation
Leticia Formation
Río Bueno Fm
Punta Torcida Formation
Punta Noguera/Cerro Ruperto formations
Cabo Leticia/La Barca formations
Cerro Apen beds/Tres Amigos Formation
Río Claro Group
Policarpo Formation
Middle to upper Eocene package
Paleocene-lower Eocene package
UC
Tres Brazos /Leña Dura formations
Ballena Formation
Agua Fresca Formation
Cabo Nariz Beds Chorrillo Chico Formation
Cerro Cuchilla Fm
u1
u3
u4
?

Figure 2.

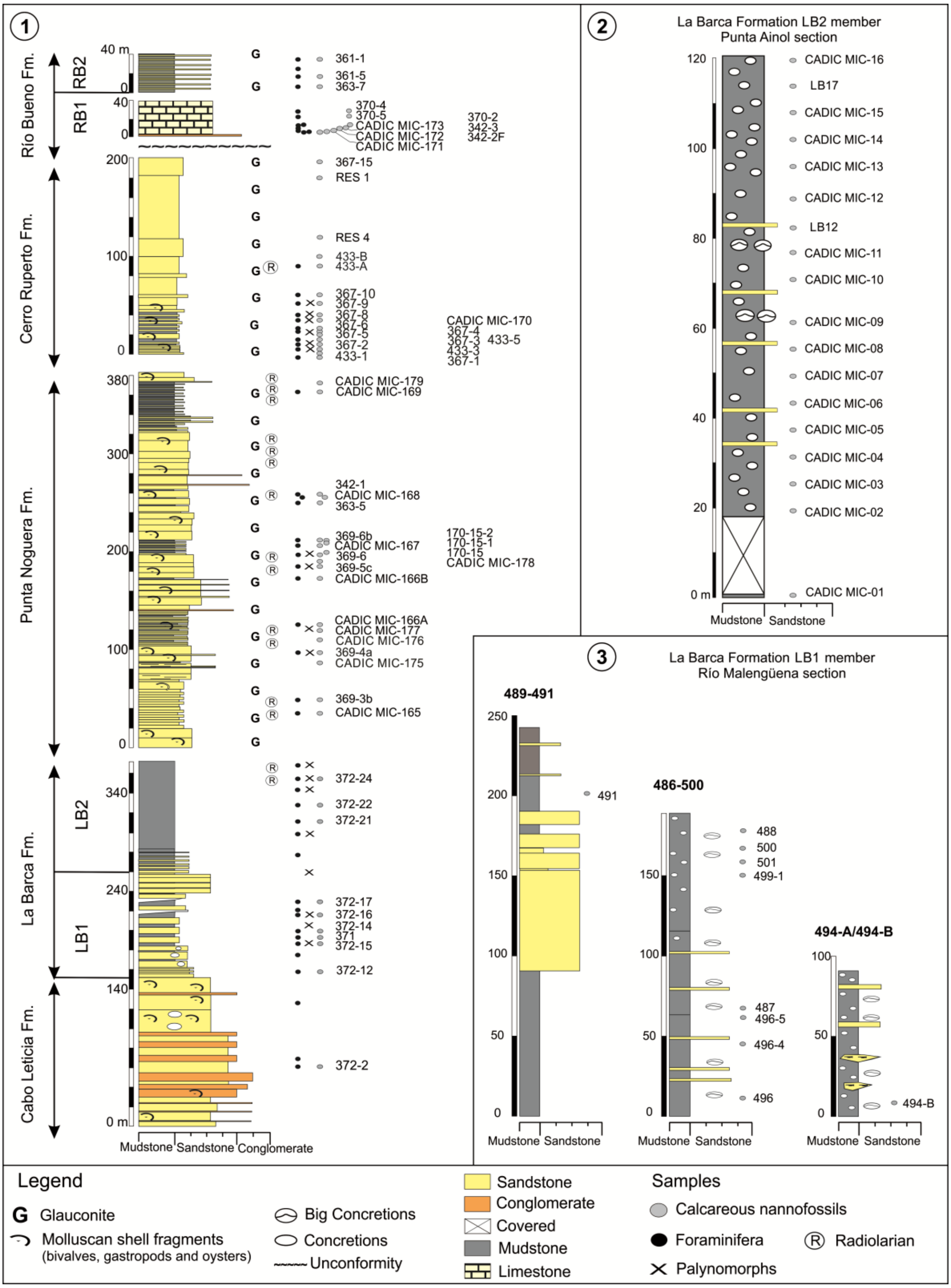
1
Río Bueno Fm.
RB2
RB1
Cerro Ruperto Fm.
Punta Noguera Fm.
La Barca Fm.
LB2
LB1
Cabo Leticia Fm.
Mudstone Sandstone Conglomerate
361-1
361-5
363-7
370-4
370-5
CADIC MIC-173
CADIC MIC-172
CADIC MIC-171
370-2
342-3
342-2F
367-15
RES 1
RES 4
433-B
433-A
367-10
367-9
367-8
367-6
367-5
367-2
433-1
CADIC MIC-170
367-4
367-3
433-3
367-1
433-5
CADIC MIC-179
CADIC MIC-169
342-1
CADIC MIC-168
363-5
369-6b
CADIC MIC-167
369-6
369-5c
CADIC MIC-166B
170-15-2
170-15-1
170-15
CADIC MIC-178
CADIC MIC-166A
CADIC MIC-177
CADIC MIC-176
369-4a
CADIC MIC-175
369-3b
CADIC MIC-165
372-24
372-22
372-21
372-17
372-16
372-14
371
372-15
372-12
372-2
2
La Barca Formation LB2 member
Punta Ainol section
CADIC MIC-16
LB17
CADIC MIC-15
CADIC MIC-14
CADIC MIC-13
CADIC MIC-12
LB12
CADIC MIC-11
CADIC MIC-10
CADIC MIC-09
CADIC MIC-08
CADIC MIC-07
CADIC MIC-06
CADIC MIC-05
CADIC MIC-04
CADIC MIC-03
CADIC MIC-02
CADIC MIC-01
Mudstone Sandstone
3
La Barca Formation LB1 member
Río Malengüena section
489-491
491
486-500
488
500
501
499-1
487
496-5
496-4
496
494-A/494-B
494-B
Legend
G Glauconite
Molluscan shell fragments (bivalves, gastropods and oysters)
Big Concretions
Concretions
Unconformity
Sandstone
Conglomerate
Covered
Mudstone
Limestone
Samples
Calcareous nannofossils
Foraminifera
Radiolarian
Palynomorphs

Figure 3.

Taxa / Formation	La Barca	Punta Noguera	Cerro Ruperto	Río Bueno
Blackites sp.		*		
Blackites cf. *creber*			*	
Braarudosphaera bigelowii	*	*		*
Chiasmolithus bidens	*	*		*
Chiasmolitus eograndis	*	*		*
Chiasmolitus expansus				*
Chiasmolitus modestus			*	
Chiasmolitus nitidus	*	*		
Chiasmolithus solitus	*	*	*	*
Coccolithus formosus			*	
Coccolithus latus			*	
Coccolithus pelagicus	*	*	*	*
Coccolithus cf. *crasus*			*	
Coronocyclus bramlettei			*	
Cyclicargolithus luminis				*
Cyclicargolithus parvus		*		
Dictyococcites productus			*	
Discoaster cf. *araneus*	*			
Ellipsolithus bollii			*	*
Ericsonia staerkeri				*
Ericsonia subpertusa	*	*		
Fasciculithus cf. *alanii*	*			
Fasciculithus involutus	*	*		
Fasciculithus cf. *mitreus*	*			
Fasciculithus richardii	*			
Fasciculithus cf. *sidereus*		*		
Fasciculithus tympaniformis	*	*		
Helicosphaera lophota		*		
Helicosphaera spp.	*	*	*	*
Helodiscolithus solidus	*			
Hornibrookina arca	*			*
Hornibrookina australis	*	*		
Lanternithus duocavus		*		
Lanternithus simplex	*			
Lanternithus unicavus		*		
Markalius inversus		*		*
Neochiastozygus concinnus	*			
Neochiastozygus junctus	*	*		*
Neococcolithes dubius		*	*	*
Neococcolithes minutus				*
Neococcolithes protenus	*			
Pontosphaera duocava				*
Pontosphaera exilis	*			*
Pontosphaera pectinata			*	
Pontosphaera plana				*
Pontosphaera pulchra		*	*	*
Pontosphaera versa				*
Prinsius bisulcus	*	*		
Prinsius martini		*		
Reticulofenestra dictyoda			*	
Reticulofenestra lockeri			*	
Reticulofenestra minuta			*	
Reticulofenestra producta			*	
Reticulofenestra spp.			*	*
Reticulofenestra wadeae				*
Rhomboaster cuspis	*			
Sphenolithus moriformis	*			*
Sphenolithus spp.	*		*	*
Thoracosphaera spp.	*	*		
Toweius callosus		*	*	*
Toweius eminens	*	*		
Toweius gammation				*
Toweius occultatus	*	*	*	*
Toweius pertusus	*			
Toweius rotundus	*			
Toweius serotinus	*			
Toweius spp.	*	*	*	*
Toweius tovae	*			
Umbilicosphaera spp.	*			*
Zygrhablithus bijugatus	*	*		*

Figure 4.

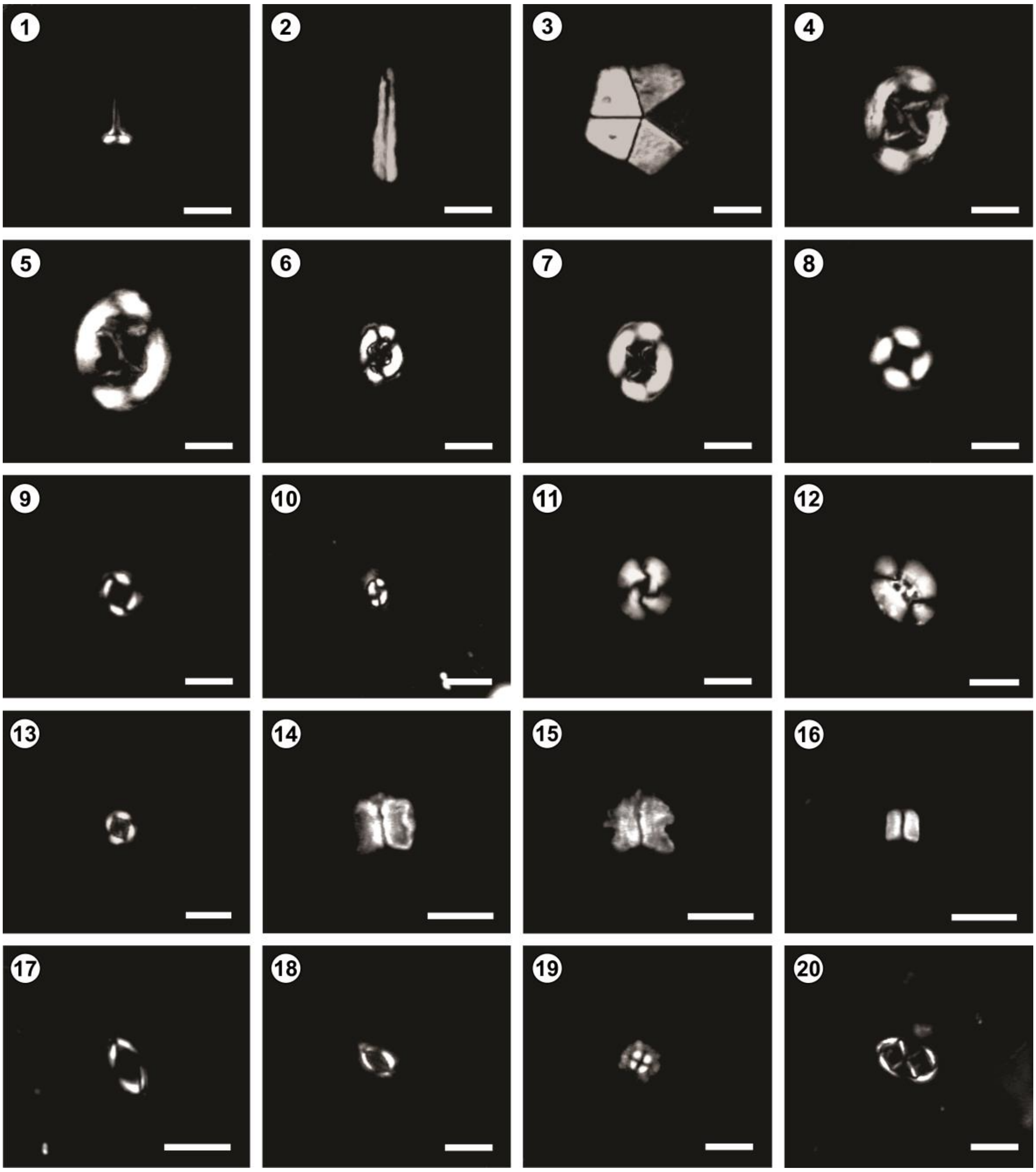

Figure 5.

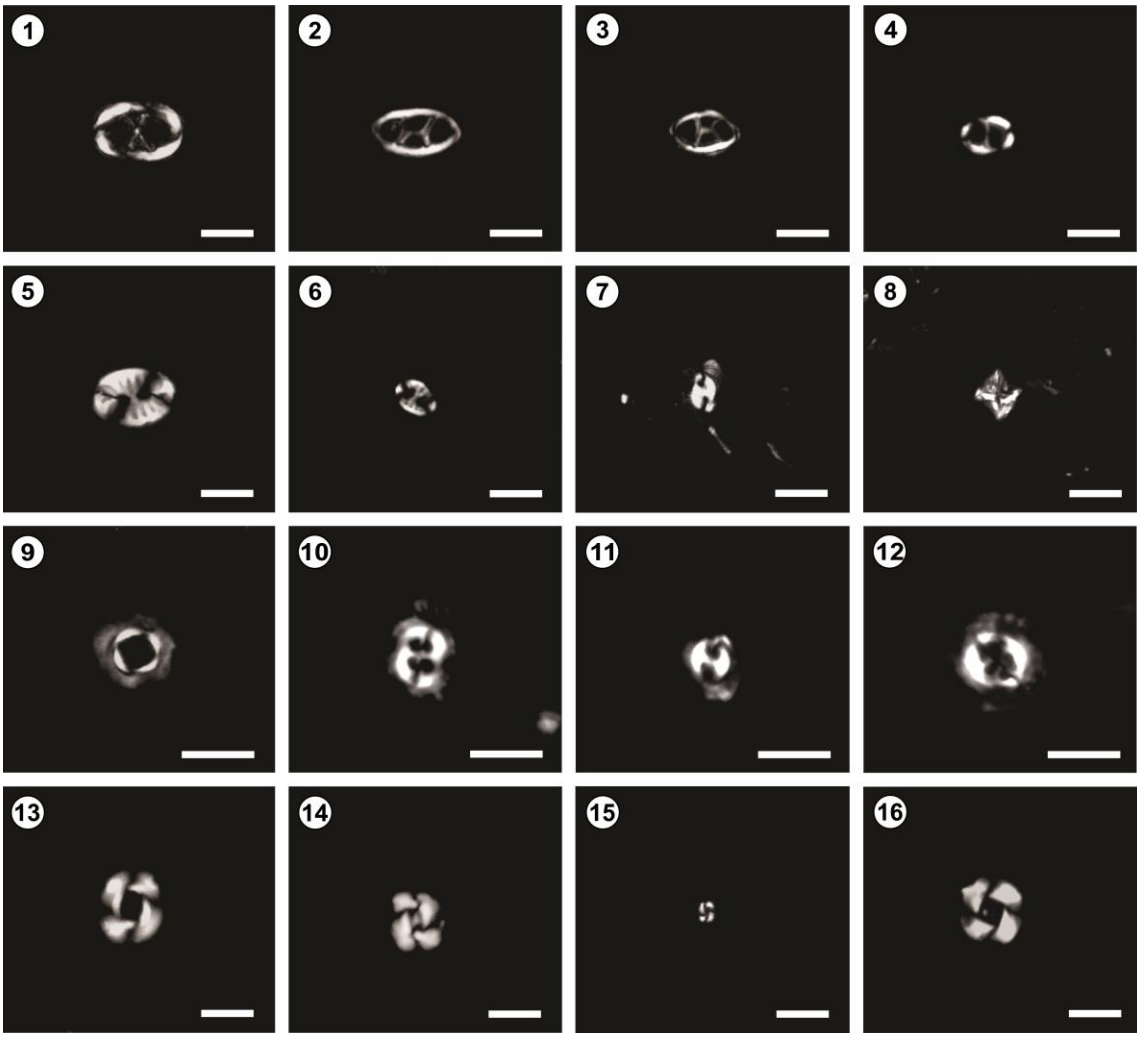

Figure 6.

Formation	Member	Age	Calcareous Nannofossil Zone (Martini, 1971)	Calcareous Nannofossil assemblage outcrop (1,2,3)	Calcareous Nannofossil assemblage subsurface		Microfossil assemblage outcrop (8,9,10,11,12)	
					SE Austral basin Tierra del Fuego (4,5)	Austral basin Santa Cruz (6 7)	Foraminifera	Dinocysts
Río Bueno	RB1	early Eocene middle Eocene	NP14-NP15	*Chiasmolithus grandis* *Chiasmolithus solitus* *Chiasmolithus expansus* *Reticulofenestra wadeae* *Neococcolithes minutus*	*B. bigelowii* *C. consuetus* *C.expansus* *N. dubius* *Z. bijugatus*	*C.modestus* *C. solitus* *P. multipora* *P. pulchra* *R. daviessi* *R. dictyoda* *R. minuta* *R. scripssae*	*Planorotalites australiformis* *Subbotina linaperta* *Subbotina patagonica*	
	RB2			*Reticulofenestra* spp. *Toweius callosus* *Zygrhablithus bijugatus*				
Cerro Ruperto		early Eocene	NP12-NP13	*Coccolithus formosus* *Neococcolithes dubius* *Reticulofenestra dictyoda* *Toweius callosus*	*C. bidens* *C. consuetus* *C. solitus* *C. pelagicus* *E. distichus* *P. multipora* *P. pulchra* *T. gammation* *Z. bijugatus*		*Spiroplectamina spectabilis*	*Deflandrea dartmoria* *Deflandrea antarctica*
Punta Noguera		early Eocene	NP9b-NP10	*Chiasmolithus bidens* *Chiasmolithus solitus* *Hornibrookina australis* *Fasciculithus involutus* *Fasciculithus tympaniformis* *Prinsius martini* *Rhomboaster cuspis* *Toweius eminens* *Toweius pertusus*		*C. bidens* *Fasciculithus tympaniformis* *P. martini* *T. callosus* *T. eminens* *T. pertusus*	*Chiloguembelina wilcoxenis* *Chiloguembelina noguerensis* *Rzehakina* *Cribrotalia* *Elphidium*	*Apectodinium homomorphum* *Deflandrea robusta* *Palaeocystiodinium* cf. *golzowense*
La Barca	LB1	late Paleocene - early Eocene	NP9a-NP9b	——			*Bulimina karpatica* *Stensioeina beccariformis* *Spiroplectamina spectabilis* *Bulimina isabelleana procera* *Anctarticella* sp.	*Palaeocystiodinium golzowense* *Glaphyrocysta*
	LB2			*Chiasmolithus bidens* *Discoaster* cf. *araneus* *Ericsonia subpertusa* *Hornibrookina australis* *Fasciculithus alanii* *Fasciculithus mitreus* *Fasciculithus richardii* *Fasciculithus tympaniformis* *Prinsius bisulcus* *Rhomboaster cuspis* *Toweius serotinus*				*Apectodinium homomorphum* *Cleistosphaeridium diversispinosum* *Enneadocysta dictyostila* *Impagidinium crassimuratum* *Samlandia septata*
Cabo Leticia		late Paleoc.	——	——			——	——

Figure 7.

TABLE 1. Sampling summary of the Río Claro Group and the Río Bueno Formation

Formation	Samples with profile associated	Isolated samples	Fertile samples	Barren samples	Sample Code Repository (Barren samples without code)	Total samples analyzed
Cabo Leticia	1	1	__	2	__	2
La Barca	38	0	22	16	CADIC MIC-01 to 16	38
Punta Noguera	21	0	10	11	CADIC-MIC 165 to 169; CADIC MIC-175 to 179	21
Cerro Ruperto	17	0	1	17	CADIC-MIC 170	18
Río Bueno	11	5	4	12	CADIC-MIC 171 to 174	16