



Paleontology and sedimentology of Middle Eocene rocks in Lago Argentino area, Santa Cruz Province, Argentina

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Abstract. Sedimentological and paleontological study of the Man Aike Formation at the Estancia 25 de Mayo, SW of Santa Cruz Province, Argentina, represents the evolution of an incised valley from fluvial to marine environment during the late middle Eocene. At the base of the unit there is an unconformity that corresponds to fluvial channels which cut down into the underlying Maastrichtian sandstones of the Calafate Formation. The fauna of invertebrates (mostly molluscs) illustrated herein was collected from shell beds interpreted as tidal ravinement surfaces. The fauna includes terebratulid brachiopods, bivalves of the families Malletiidae, Mytilidae, Pinnidae, Ostreidae, Pectinidae, Carditidae, Crassatellidae, Lahillidae, Mactridae, Veneridae, and Hiatellidae, and gastropods of the families Trochidae and Calyptraeidae, and a member of Archaeogastropoda of uncertain affinities. The similarities of this fauna with that recorded in the Upper Member of the Río Turbio Formation, together with ⁸⁷Sr/⁸⁶Sr ages, suggest a late Middle Eocene age for the Man Aike Formation.

Resumen. PALEONTOLOGÍA Y SEDIMENTOLOGÍA DE LAS ROCAS DEL EOCENO MEDIO EXPUESTAS EN EL ÁREA DE LAGO ARGENTINO, PROVINCIA DE SANTA CRUZ, ARGENTINA. Los estudios sedimentológicos y paleontológicos realizados en rocas asignadas a la Formación Man Aike, expuestas en la estancia 25 de Mayo, al sur de Calafate, provincia de Santa Cruz, Argentina, sugieren que esta unidad representa la evolución de un valle inciso desde ambientes fluviales a marinos durante el Eoceno medio tardío. En la base de la sucesión se registra una discordancia que corresponde a canales fluviales que cortan a las areniscas mastrichtianas de la Formación Calafate. La fauna de invertebrados (mayormente moluscos) ilustrada en este trabajo fue coleccionada de capas de conchillas que se interpretan como parte de diferentes superficies de *ravinement* mareal. La fauna incluye braquiópodos terebratulídeos, bivalvos de las familias Malletiidae, Mytilidae, Pinnidae, Ostreidae, Pectinidae, Carditidae, Crassatellidae, Lahillidae, Mactridae, Veneridae e Hiatellidae y gasterópodos de las familias Trochidae y Calyptraeidae y un miembro de Archaeogastropoda con afinidades inciertas. Las similitudes de esta fauna con aquellas registradas en el Miembro Superior de la Formación Río Turbio, junto con dataciones ⁸⁷Sr/⁸⁶Sr, sugieren para la Formación Man Aike una edad eocena media tardía.

Key words. Eocene. Incised valley. Bivalves. Gastropods. Brachiopods. Patagonia.

Palabras clave. Eoceno. Valle inciso. Bivalvos. Gastrópodos. Braquiópodos. Patagonia.

Introduction

Climate change during the Paleogene had long-lasting effects on the distribution of faunas and floras in the Southern Hemisphere. In Patagonia, these ef-

fects were accompanied by those caused by tectonic and volcanic processes related to subduction along the western margin of South America. At the same time, relative sea level changes along the Atlantic margin were responsible for major transgressions. Within this general picture, the Paleogene rocks from Patagonia – both the marine and the continental ones – offer an excellent opportunity to understand the relationships between the terrestrial and marine ecosystems in the continent.

An adequate understanding of the impact that the paleoenvironmental and oceanographic changes had on the marine ecosystems of the southern tip of South America during the Eocene requires improvement of the available stratigraphic and paleontological knowledge on successions of this age in Patagonia.

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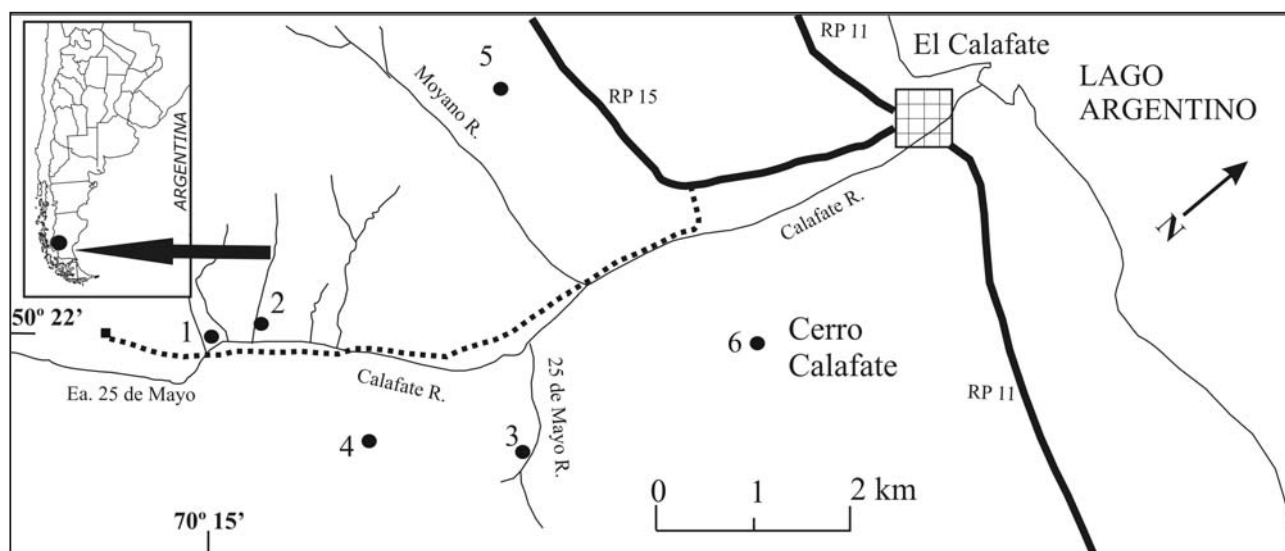


Figure 1. Map showing the localities mentioned in the text / *mapa de ubicación de las localidades mencionadas en el texto.*

Although Eocene rocks and faunas have been known to occur in southern South America ever since the beginning of the XX Century (see Griffin, 1991; Malumián, 1993), their study has been recently renewed (Camacho *et al.*, 2000; 2001). These rocks are patchily exposed in south-western Santa Cruz Province (Man Aike and Río Turbio formations) and along the Atlantic coast of Tierra del Fuego (La Despedida Group and equivalent strata).

The Man Aike Formation (Furque, 1973) was recorded from outcrops and drillings performed in the Austral Basin by oil companies (Malumián, 1999). Contributions based on micropaleontological data (Malumián, 1990; Carrizo *et al.*, 1990; Concheyro, 1991; Malumián and Caramés, 1997), established a middle Eocene age to the Man Aike Formation and are the foundation of the stratigraphic framework currently accepted. Camacho *et al.* (1998) correlated this unit with part of the Río Turbio Formation and inferred that it was separated by unconformities from the underlying Maastrichtian Calafate Formation and overlying Oligocene Río Leona Formation.

Originally, the Man Aike Formation was only recognized along the Río Leona valley and considered Maastrichtian in age (Furque, 1973). Later on, Macellari *et al.* (1989) pointed out that south of El Calafate there were exposed calcareous sandstones with a fauna of molluscs including *Venericardia* sp. in the uppermost beds of the Calafate Formation. He suggested a possible correlation of these beds with the Man Aike Formation. Marensi *et al.* (2002) confirmed the exposures of this unit south of El Calafate and commented on its stratigraphic relationships with under- and overlying rocks.

The aim of this contribution is to describe in detail the Eocene rocks exposed in the area of Lago Argentino and their fossil content, as well as to interpret the paleoenvironments and discuss their age and correlations.

Materials and methods

The study area lies within Estancia 25 de Mayo, south of the town of El Calafate in southwestern Santa Cruz (figure 1), and along the Calafate River valley.

Six stratigraphic sections were measured at Estancia 25 de Mayo using a Leica vector IV laser range-finder. Geometry of the beds, bounding surfaces, lithology, texture, sedimentary structures and fossil content of the rocks were recorded (figure 2). Fossils are housed at the Departamento de Ciencias Naturales, Universidad Nacional de La Pampa (GHUNLPam), Argentina.

$^{87}\text{Sr}/^{86}\text{Sr}$ ratio in biogenic carbonate was measured in eight small pieces (table 1) from one shell of "*Ostrea*" *groeberi* Feruglio, 1937, collected from locality 1, on the left bank of the Arroyo Calafate ($50^{\circ} 22' \text{ S}$; $72^{\circ} 15' \text{ W}$). The analyses were performed by the Radiogenic Isotopes Laboratory in the Department of Geological Sciences of the Ohio State University. Before of this, the sample was examined by petrographic microscope to determinate the state of textural preservation.

All chemical preparations were carried out with the general analytical procedures for Sr isolation, isotope dilution and mass spectrometry separation described in Foland and Allen (1991).

Table 1. $^{87}\text{Sr}/^{86}\text{Sr}$ ratio and calculated age. Each entry on the table is a separate small piece and represents a separate dissolution. Those indicated by the asterisk (*) were dissolved using acetic acid while the others were dissolved in dilute HCl / valores de $^{87}\text{Sr}/^{86}\text{Sr}$ y edades calculadas. Cada fila en la tabla corresponde a una muestra y representa una disolución independiente. Las marcadas con un (*) son las que fueron disueltas usando ácido acético, mientras que las otras lo fueron con HCl.

Sample	Sr (ppm) ^a	$^{87}\text{Sr}/^{86}\text{Sr}$ ^b	N	$^{87}\text{Sr}/^{86}\text{Sr}_{\text{rcc}}$	Limiting ages (Ma) ^d	Age (Ma) ^e
MA1	448	0.707673	7	0.707679	72.89-73.11	73
MA2 (*)	330	0.707770	9	0.707776	34.67-35.65 43.51-48.43	35.12 46.37 or 45.29
MA3		0.707744	8	0.707750	36.34-37.96 40.21-42.86 48.51-50.45	37.08 41.96 49.59
MA4		0.707736	89	0.707742	37.03-42.06 49.24-51.04	37.84 or 41.29 50.21
MA5 (*)-		0.707722	7	0.707728	38.42-40.88 50.43-52.39	51.36
MA6 (*)		0.707718	7	0.707724	39.12-40.42 50.79-55.40	51.74 or 54.82
MA7	258	0.707645	13	0.707651	73.81-74.14	73.96
MA8	186	0.707638	7	0.707644	74.05-74.42	74.22

$^{87}\text{Sr}/^{86}\text{Sr}$ determinations were made using dynamic multicollection of all Sr isotopes on a Finnigan MAT 261A thermal ionization mass spectrometer as outlined by Foland and Allen (1991). Measured values of $^{87}\text{Sr}/^{86}\text{Sr}$ were normalized assuming normal Sr with $^{86}\text{Sr}/^{88}\text{Sr} = 0.119400$. Data are presented on Table 1, where each entry represents a separate dissolution of the sample piece and a complete analysis. The reference value of $^{87}\text{Sr}/^{86}\text{Sr}$ for the SRM987 is 0.710242 ± 0.000010 (one sigma external reproducibility).

The $^{87}\text{Sr}/^{86}\text{Sr}$ values of the sample were converted to numerical ages using the SIS (Strontium Isotope Stratigraphy) Version 3:10/99 of the Look-Up Table of McArthur *et al.* (2001). The reference value $^{87}\text{Sr}/^{86}\text{Sr}$ used ($=0.710242$) was corrected to make the data concordant with SRM987 of 0.710248 used in the construction of this Look-Up Table. The time scale used for the Cenozoic is that of Berggren *et al.* (1995).

Stratigraphic relationships

The base of the Man Aike Formation was recorded at six localities. Localities 1 and 2 are on the left bank of the Calafate creek, locality 3 is on the left bank of the 25 de Mayo creek near its headwaters, locality 4 is on the right bank of the Calafate creek, locality 5 is on Cordon Moyano, and locality 6 is at the top of Cerro Calafate.

At all six localities the basal sediments overlie Maastrichtian rocks carrying a diverse fauna of marine invertebrates that includes *Pacitrigonia patagoni-*

ca (Feruglio, 1937). At different localities the Man Aike Formation overlies different stratigraphic levels of the Cretaceous Calafate Formation. Thus, at localities 4 and 6 the erosion surface cuts down sandstones and conglomerates of the middle to upper part of the Calafate Formation. On the other hand, at localities 1, 2, 3 and 5, the base of the Man Aike Formation overlies the uppermost brown sandstones and mudstones of the Calafate Formation.

The stratigraphic relationships described by Marensi *et al.* (2002) for localities 1, 4 and 3 suggest that the Man Aike Formation fills a wide valley incised into the Calafate Formation (figures 3 and 4.1). The presence of a thick, non-fossiliferous basal conglomerate at localities 4 and 6 - where the deepest or most upstream part of the valley would lie - supports this hypothesis. The Man Aike Formation is unconformably overlain by the Río Leona Formation (Oligocene). The contact is visible at locality 1, where the maximum thickness of the Eocene succession was recorded (100 m).

Sedimentology

Facies association 1

This facies association includes fine conglomerates and coarse sandstones. It is an upward fining succession four meter thick. The base is strongly erosive over yellowish green sandstones and occasional greenish grey conglomerates of the Calafate Forma-

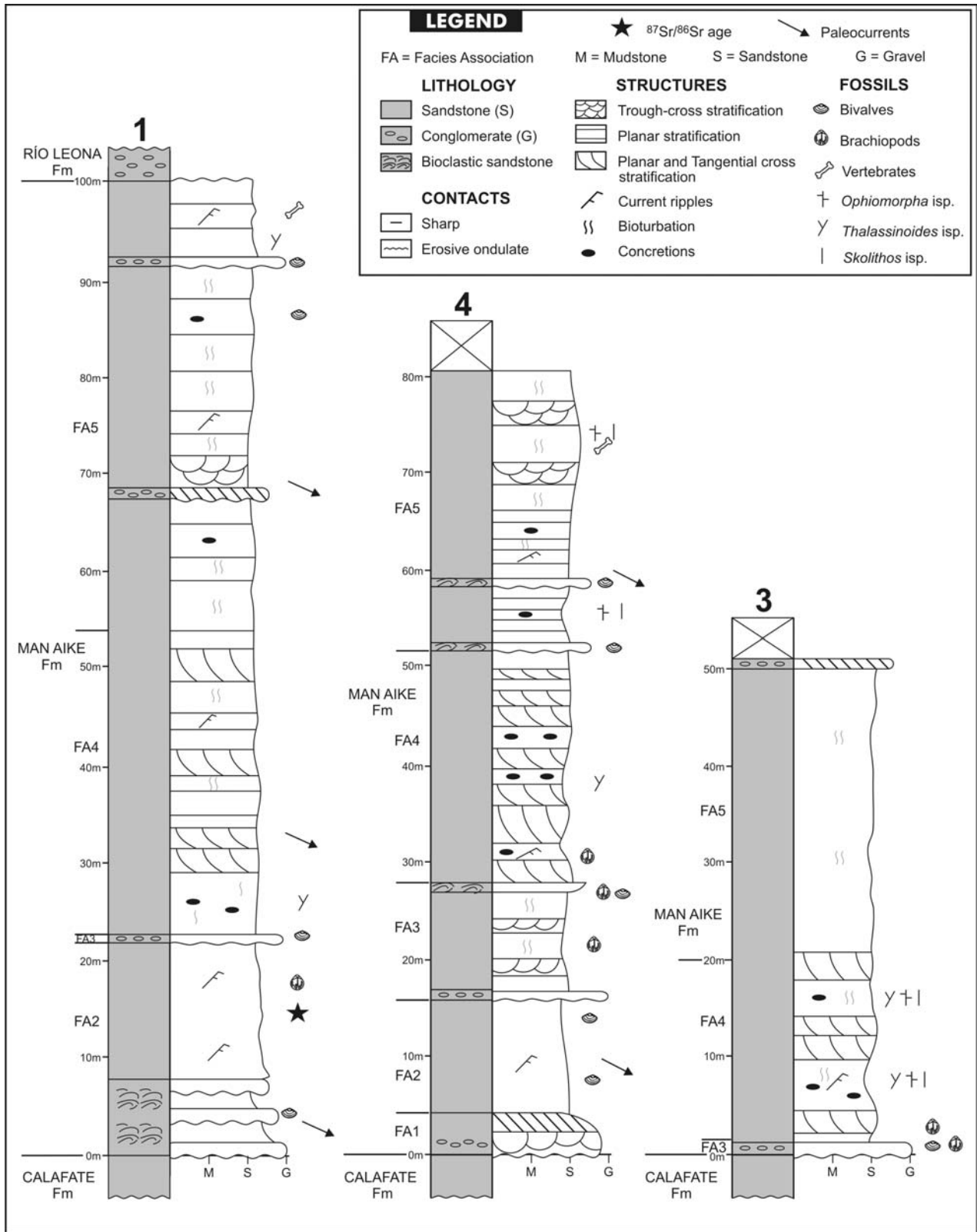


Figure 2. Stratigraphic sections of localities 1, 3, and 4 / secciones estratigráficas correspondientes a las localidades 1, 3 y 4.

tion. The general geometry of the deposits is lenticular (channel axis oriented Az 120°-300°), with lenses up to 1.2 m thick. At locality 4 conglomerates and sandstones fill the basal part of a small - 150 m wide AMEGHINIANA 46 (1), 2009

- channel with its axis oriented in a NE direction. At Cerro Calafate (locality 6) the same conglomerates are laterally more continuous. The yellowish brown conglomerates grade upward to coarse sandstones.

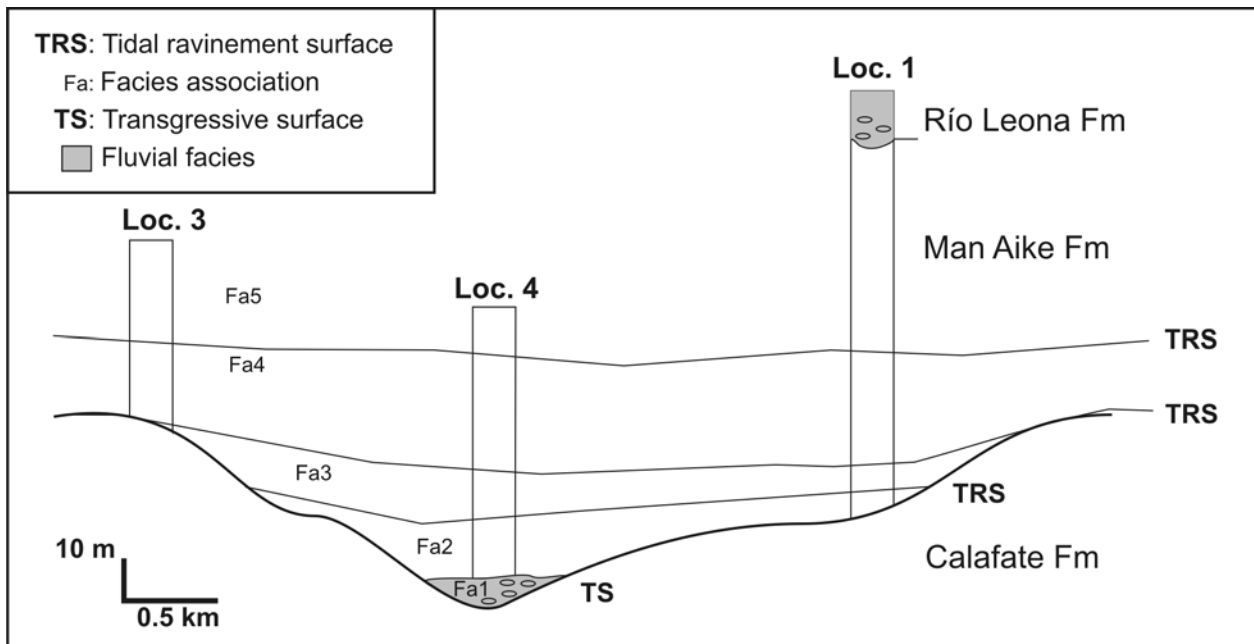


Figure 3. Stratigraphic correlation of the localities 1, 3, and 4 / correlación estratigráfica de las localidades 1, 3 y 4.

The conglomerates are clast-supported with a sandy matrix. Clasts are rounded to well rounded, with a maximum axis of 15 cm. Sorting is moderate to good and the clasts correspond to volcanic rocks, quartz, metamorphic rocks and sandstones similar to those of the underlying unit. The beds, 15 and 20 cm thick, are massive or with trough cross-stratification, medium scale planar cross-stratification, or with clast imbrications. There are matrix-supported conglomerates with a sandy matrix and intercalations of tuffaceous sandstones with carbonized plant material. The sandstones are massive or exhibit small scale trough cross-stratification. The only organic remains collected are pieces of wood.

Interpretation: Fluvial channels

The erosive base, lenticular geometry of the beds, coarse-grained lithology and the tractive structures allow interpreting this facies association as the infill of channels. These basal conglomerates without marine fossils or bioturbation could be the infill of fluvial channels running along the deepest part of an incised valley. This is clearly evidenced at localities 4 and 6 (figure 4.2). The sedimentary structures suggest the migration of gravel – and to a lesser degree sand – bars towards the Southeast. There are no flood-plains deposits preserved, therefore suggesting an irregular channel pattern and a braided fluvial system.

Facies association 2

It erosionally overlies facies association 1 and is composed predominantly of medium to fine sandstones, occasionally mudstones, with medium to small scale trough cross-stratification (sets about 10-25 cm thick and 45-80 cm wide and paleocurrent directions towards Az 110°). They also exhibit current ripple lamination. The lenticular beds show decreasing thickness from 25 to 10 cm. The fauna is composed mainly of disarticulate specimens of “*Ostrea groeberi*”, which are also frequently broken and uncommonly bryozoans (figure 4.3). Recorded trace fossils are *Thalassinoides* isp. and *Ophiomorpha* isp.

At localities 1, 2, 4 and 6 this facies association includes a basal section of fine to very fine shelly conglomerates and coarse sandstones with abundant and very fragmented invertebrate remains, among which gastropods and small oysters were identified. These shelly beds are densely packed and the bioclasts are abraded.

Interpretation: Upper estuarine channels and sandy tidal flats

The erosive base, lenticular geometry and current structures in the coarser deposits suggest the presence of channels and sand-bar migration. The transported fauna suggests a connection with favourable environments for the development of marine fauna;

thus this facies is interpreted as representing the infill of tidal channels.

The sandstones with current structures and bioturbation record the migration of medium scale sand waves and ripples in marine-influenced settings. Dominance of trace fossils assigned to *Thalassinoides* and *Ophiomorpha* suggests an impoverished *Skolithos* and *Cruziana* ichnofacies representing moderate energy conditions. The low diversity may be attributed to variable salinity and/or energy conditions. Taphonomic features of the recorded fossils suggest that these are parautochthonous and that the bearing beds were connected to areas of normal salinity.

The erosional surface that separates these deposits from those of facies association 1 could be a flooding surface, as the change from a gravely interwoven fluvial channel system to a sandy estuarine one could imply the beginning of the transgression.

Facies association 3

It overlies facies association 2 in a clear erosional contact and begins with a fine conglomerate or sabulitic sandstone with occasional sparse clasts of volcanic rocks up to 10 cm in diameter (figure 4.4). This bed is overlain by medium sandstones that may preserve traces of small scale trough cross-stratification and grade into fine-grained, massive and bioturbated sandstones. The sandstones contain abundant articulated brachiopods (*Bouchardia conspicua* Feruglio, 1937), bivalves (*Venericardia (V.) carrerensis* Griffin, 1991), echinoderms and bryozoans, which lie in life position towards the top of the unit.

At the top of this facies association is an 80 cm thick bed that begins with a medium-grained sandstone with abundant fragments of invertebrates covered by a shelly bed of disarticulated bivalves and brachiopods. Its clasts reach a gravel size of 5-7 cm in diameter, in a sandy matrix. This bed is reddish and at locality 3 it lies at an evident angle with the basal unconformity. This surface slopes gently to the Southeast following the regional structure while the contact between the Man Aike and Calafate formations slopes to the West (both are apparent directions).

Interpretation: Sandy complex at the estuary mouth.

The sandstones with current structures represent the migration of small scale bed-forms. The abundant bioturbation, which partly obliterates the primary structures, and the invertebrate fauna suggest normal salinity and a water-depth equivalent to at least the shoreface.

The high degree of bioturbation probably reflects a slow accumulation rate in deeper or protected conditions within the estuary mouth system.

The lower erosional surface may correspond to the base of tidal channels and thus would represent a tidal ravinement surface.

Facies association 4

This facies association overlies the topmost shelly bed of facies association 3 or – at locality 3 – it lies over a surface that cuts across beds of the underlying facies association.

Most of this association is composed of fine to medium grained sandstones, with medium to large scale planar cross-stratification with tangential foreset laminae. Occasionally it shows trough cross-stratification at a smaller scale. Bioturbation is abundant and is recorded mainly by *Planolites* isp., *Thalassinoides* isp. and *Ophiomorpha* isp (figure 4.5). Concretional, massive, coarse sandstones lying above cross-stratified sets are strongly bioturbated by *Skolithos* isp.

Interpretation: Subtidal channels and sandy bars.

The coarse laterally continuous shelly deposits at the base of this facies evidence maximum re-working surfaces, with winnowing of the smaller particles and concentration of coarse gravel and fossils. These could be part of a tidal ravinement surface. The upward coarsening tendency and the great lateral extension favour the former interpretation.

The sandstones with abundant current structures suggest migration of bedforms of different scales ranging from small ripples to small dunes and megaripples. The trace fossils (*Skolithos* ichnofacies) suggest high energy conditions. The fauna suggests normal salinity conditions. The water-depth is interpreted as equivalent to the middle shoreface (subtidal) – in which fields of megaripples developed. These fields were flanked by sandy flats with small ripples developed in areas of lower energy.

The physical structures are assigned to bedforms developed in tide-dominated plains and channels. This may have been caused by a high rate of sea level rise or because of a geographic environment favourable for amplification of tidal range (e.g. coastline constriction) and wave attenuation.

Facies association 5

This facies association includes fine to medium – occasionally coarse - grained sandstones, light green-

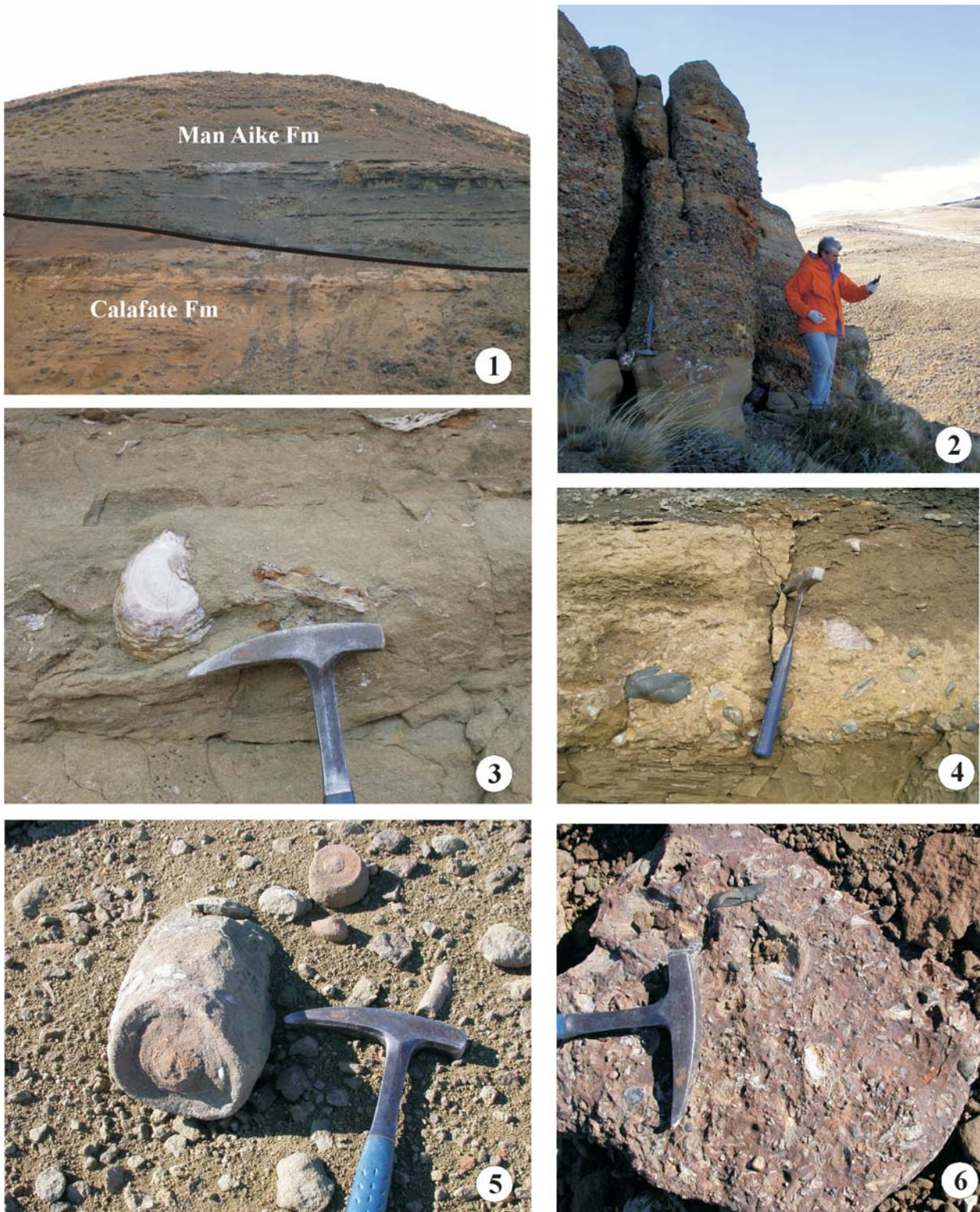


Figure 4.1. The Man Aike Formation (Eocene) overlies brown sandstones and mudstones of the uppermost beds of the Calafate Formation (Upper Cretaceous) at locality 3 / *la Formación Man Aike (Eoceno) cubre a las areniscas y pelitas castañas de la parte superior de la Formación Calafate (Cretácico Superior)*; 2, conglomerates and coarse sandstones of the facies association 1 at locality 6 / *conglomerados y areniscas gruesas correspondientes a la asociación de facies 1 en la localidad 6*; 3, disarticulate specimens of “*Ostrea*” *groeberi* in facies association 2 / *ejemplares desarticulados de “Ostrea” groeberi en la asociación de facies 2*; 4, conglomerate or sabulitic sandstone with occasional sparse clasts of up to 10 cm in diameter at the base of the facies association 3 / *conglomerado o arenisca sabulítica con clastos dispersos de más de 10 cm de diámetro en la base de la asociación de facies 3*; 5, strongly bioturbated sandstone of the facies association 4 / *arenisca muy bioturbada en la asociación de facies 4*; 6, thin conglomeratic-shelly bed at the bottom in the facies association 5 / *capa de conglomerado con abundantes restos de conchillas en la asociación de facies 5*.

ish with sparse whitish (carbonatic) beds towards the top of the section, and thin conglomeratic/shelly beds similar to those of facies association 4. Contact with the underlying facies association is given by a thin conglomeratic-shelly bed (figure 4.6) similar to those of the underlying facies but including sandy beds up to 50 cm thick with trough cross stratification alternating with thinner ones of fine grained to occasionally massive or wavy-rippled muddy sandstones. However, most of this facies association is still dominated by sandstones similar to the previous ones, with medium scale mainly trough and occasionally planar cross-lamination. Bioturbation is abundant and diverse, dominated by *Thalassinoides* isp., *Ophiomorpha* isp. and *Skolithos* isp.

The fossils collected in the massive sandstones, near the top of the section, are teeth of teleost fish and sharks, ray dental plates and bone fragments probably belonging to turtles (M. de la Fuente, personal communication). In the whitish carbonate beds there are monospecific bivalve concentrations (*Panopea* sp.).

Interpretation: Open marine (lower to middle shoreface)

The laterally continuous coarse deposit is a re-working surface, with winnowing of fine particles and concentration of gravels and fossils. This suggests another ravinement surface, probably of tidal origin.

The fauna - specially the one in life position or with little re-working - indicates nearness to open marine conditions and normal salinity. Trace fossils of the *Skolithos-Cruziana* ichnofacies suggest conditions comparable to those at shoreface depth.

The conglomeratic-shelly bed is interpreted as a tidal ravinement surface. This surface indicates the onset of more nearly normal marine conditions.

Evolution of the depositional system

The available evidence suggests that the Man Aike Formation in the Lago Argentino area represents sedimentation from an incised valley to a probably outer estuarine environment (reflecting more normal marine conditions), during a period of a relative sea-level rise.

Based on lithology and bed geometry, the lowermost deposits of facies association 1 are thought to represent sedimentation in fluvial channels indicating the proximal part of the lowstand wedge and, towards the top of this facies association the beginning of the transgressive system tract.

The evolution from facies association 2 to 5 suggests progressive flooding of the valley during the relative sea-level rise. Sedimentation evolved from tidal channels and sand-flats at the inner or middle parts of an estuary to tidal deltas and channels of the estuary-mouth sand complex. Erosional surfaces within this complex are interpreted as tidal ravinement surfaces.

Isotopic age

Based on microscopic observations, the specimen of "*Ostrea*" *groeberi* dated retains the original calcitic and foliated mineralogy and microstructure. Although the sample has less Sr content (< 800 ppm) than modern low-Mg calcitic shells, it is still possible that they may not have suffered diagenetic loss of Sr, since concentrations < 800 ppm have been reported for oyster samples from Upper Cretaceous and Miocene deposits (McArthur *et al.*, 2000; Scasso *et al.*, 2001). This lower Sr concentration may be in part due to the inclusion of distinct small domains of secondary calcite, and not to partial re-crystallization, leaving the bulk of the shell unaltered (Veizer *et al.*, 1999). Furthermore, it must be taken into account that Sr content is not dependent only on diagenetic alteration but also on water chemistry, temperature, salinity, skeletal mineralogy and physiology of the organism (Dodd, 1967).

Table 1 summarizes the geochemical data. The sample was analyzed several times because of disparities in Sr concentration and $^{87}\text{Sr}/^{86}\text{Sr}$ values. A first analysis of two Sr determinations of the sample (MA1 y MA2) rendered different Sr concentration and $^{87}\text{Sr}/^{86}\text{Sr}$ values. Therefore, further analyses of six other small pieces (MA3 through MA8) were performed, using either acetic acid or HCL as dissolvent. These results confirmed that both Sr concentration and $^{87}\text{Sr}/^{86}\text{Sr}$ values are variable in the oyster specimen from the Man Aike Formation. Careful comparisons showed that there was no systematic difference independently of the dissolution acid used. Thus, we concluded that in the oyster shell studied the carbonate is heterogeneous in both Sr concentration and $^{87}\text{Sr}/^{86}\text{Sr}$ values.

Three of the separate small pieces (MA1, MA7 and MA8) rendered ages of 73.0, 73.96 and 74.22 My respectively, all of them late Campanian. These ages are older than real ages, and this could be attributed to subtle alteration of the original calcite and/or freshwater flux. Calcite alteration may be due to the presence of irregular and chalky deposits or the porous shell layers that can be developed in the oysters as an adaptive strategy for existence on soft substrates, and that can be susceptible to infilling with diagenetic calcite. Freshwater flux in marginal ma-

rine environments can influence the $^{87}\text{Sr}/^{86}\text{Sr}$ in mollusk shells and consequently the Sr-chronostratigraphy. Bryant *et al.* (1995) indicated that carbonates precipitating in estuarine settings may not always record the global marine $^{87}\text{Sr}/^{86}\text{Sr}$ values, and that once the marine signal has been measurably affected by freshwater flux, $^{87}\text{Sr}/^{86}\text{Sr}$ values change rapidly and age estimates become larger because of the hyperbolic shape of the mixing curves.

The other five samples (MA2, MA3, MA4, MA5, and MA6) rendered Eocene ages, a period in which the curve shows two inflection points, and thus two different ages for the same $^{87}\text{Sr}/^{86}\text{Sr}$ value. The ages obtained were: MA2= 35.12, 46.37 or 45.29 My (Middle or Middle Eocene); MA3= 37.08, 41.96, 49.59 My (Middle or Early Eocene); MA4= 37.84 or 41.29, 50.21 My (Middle or Early Eocene); MA5= 38.42-40.88, 51.36 My (Middle or Early Eocene); MA6= 39.12-40.42, 51.74 or 54.82 My (Middle or Early Eocene).

The sedimentary rocks of the Man Aike Formation were included into the second of the five major Maastrichtian-Cenozoic Patagonian sedimentary cycles distinguished by Malumián (1999). This sedimentary cycle spanned the middle to late Eocene (42 to 37 My). Based on microfossils, Malumián (1999) suggested that the Man Aike Formation would span planktonic forams Zone P11 to P14, i.e. latest middle Eocene. Camacho *et al.* (2000) also assigned this unit to the middle Eocene, stating that it was separated by unconformities from the underlying Calafate Formation and the overlying Río Leona Formation. The Calafate Formation has been considered late Maastrichtian in age (Marensi *et al.*, 2004) on the basis of its dinoflagellate cysts and mollusks. The Río Leona Formation, originated during the third of the cycles supported by Malumián (1999), and occurring in the Oligocene.

From the discussion above, it becomes clear that there is a strong discrepancy between the ages derived from $^{87}\text{Sr}/^{86}\text{Sr}$. However, the similarity of five of the $^{87}\text{Sr}/^{86}\text{Sr}$ ages with the foram and molluscs ages of previous authors, together with its stratigraphic relationship with the over- and underlying units, leads us to conclude that a late middle Eocene age is the most reliable estimate for the Man Aike Formation.

Systematic paleontology

Phylum BRACHIOPODA Duméril, 1806
Family TEREBRATULIDAE King, 1850

Genus *Terebratella* d'Orbigny, 1847

Type species. *Terebratula chilensis* Broderip, 1833.

"Terebratella" insignis Feruglio, 1937
Figure 5.1-2

1937. *Terebratella insignis* Feruglio: 94-96, pl. 11, fig. 3a-b, 4a-c.

Material. Twenty three specimens, variably preserved; GHUNLPam 26800/1-10, GHUNLPam 26806/1-3, GHUNLPam 26829/1-3, GHUNLPam 26880, GHUNLPam 26992/1-2, GHUNLPam 26994/1-4.

Occurrence. Locality 1.

Remarks. *"Terebratella" insignis* is not known from rocks other than the Man Aike Formation. The correct generic placement remains uncertain.

Genus *Bouchardia* Davidson, 1850

Type species. *Anomia rosea* Mawe, 1823.

Bouchardia conspicua Feruglio, 1937
Figure 5.3

1937. *Bouchardia conspicua* Feruglio: p. 96-98, pl. 11, fig. 5-10.

Material. One hundred and fifty one specimens; GHUNLPam 26797/1-24, GHUNLPam 26825/1-23, GHUNLPam 26835/1-8, GHUNLPam 26847/1-31, GHUNLPam 26861/1-2, GHUNLPam 26869/1-29, GHUNLPam 26870/1-26, GHUNLPam 26881/1-3, GHUNLPam 26889/1-5.

Occurrence. Localities 1 and 4.

Remarks. This species occurs in the Man Aike Formation, in the top beds of the Paleocene Cerro Dorotea Formation (Hünicken, 1955), and in the lower beds of the Middle Eocene Río Turbio Formation. It is very close to *Bouchardia antarctica* Buckman, 1910 (p. 14-17, pl. 1, fig. 1-6b, pl. 3, fig. 2a-b; see Owen, 1980, 132-135, text fig. 17-26b), from the Eocene La Meseta Formation in Antarctica (Elliot and Trautman, 1982; see Stilwell and Zinsmeister, 1992). Another similar species, *Bouchardia zitteli* Ihering, 1897 (p. 268-270, fig. 6; see Levy, 1964), appears in the upper Oligocene San Julián Formation, especially in the Gran Bajo Member, which according to Nández (1991) is equivalent to the Man Aike Formation.

Genus *Magellania* Bayle, 1880

Type species. *Terebratula australis* Quoy and Gaimard, 1834.

"Magellania" elinaecorreamoralesi Feruglio, 1937
Figure 5.4

1937. *Magellania* (?) *elinae-correamoralesi* Feruglio: 93, pl. 11, fig. 1a-c, 2a-c.

Material. Five specimens; GHUNLPam 26814, GHUNLPam 26830/1-4.

Occurrence. Localities 1 and 4.

Remarks. The uncommon species originally described based on a few specimens collected by
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Feruglio was East of Lago Viedma and just North of the mouth of the Río Leona. Our material is the first record in the Main Aike Formation south of Lago Argentino.

The smooth shell with straight commissure resembles that of *Aerothyris? patagonica* (Sowerby, 1846) as depicted by Levy (1961, p. 85, pl. 1, fig. 3a-d), a correct generic placement for this species must await a revision of the Cenozoic brachiopods from southern South America.

Phylum MOLLUSCA Linné, 1758

Class BIVALVIA Linné, 1758

Subclass PALAEO-TAXODONTA Korobkov, 1954

Order NUCULOIDA Dall, 1889

Superfamily NUCULANOIDEA Adams and A. Adams, 1858

Family MALLETIIDAE Adams and A. Adams, 1858

Genus *Spineilo* Finlay and Marwick, 1937

Type species. *Malletia elongata* Marshall, 1917.

Spineilo sp.
Figure 5.5

Material. Three moulds; GHUNLPam 26998/1-3.

Occurrence. Locality 1.

Remarks. The moulds are well enough preserved that they can be clearly distinguished from other Cretaceous and Paleocene related species from Patagonia and Antarctica. The closest species to our material appears to be *Leda perditia* Feruglio, 1935 (p. 70, pl. 2, fig. 2-5; 1937, p. 226, pl. 12, fig. 1-3) recorded from drillings in the Paleocene of the San Jorge Basin near Comodoro Rivadavia. The type material appears to be lost, but the illustrations provided by Feruglio suggest that it can be safely placed in *Spineilo* Finlay and Marwick, as they share the same elongate shell with a tapering posterior end. This is also noticeable in our specimens. These, however, show a very weak postumbonal sulcus running almost adjacent to the posterior dorsal margin, which is apparently absent in either the type species or the other Patagonian material. A comparable species probably also referable to *Spineilo* is *Malletia leanzai* Camacho, 1957 (p. 97, pl. 1, fig. 1) from Paleocene-Eocene rocks in Tierra del Fuego. Material referable

to this genus has not been reported from the Eocene Río Turbio Formation. Like the species from Man Aike, *Malletia leanzai* shows an anteroposteriorly elongate shell, with a tapering posterior end. However, the posterior part of the shell seems to show a slight truncation, a feature not observed in our specimens.

Genus *Neilo* Adams, 1854

Type species. *Neilo cumingii* Adams, 1854.

Neilo sp.
Figure 5.6

Material. Two internal moulds, one of them with parts of the shell still adhered to it. GHUNLPam 26795, GHUNLPam 26823.

Occurrence. Locality 1.

Remarks. Two small and incomplete specimens could be referred to *Neilo* because of their subquadrate shell with a conspicuous postumbonal keel and truncated posterior end. The shell ornamentation is similar to that of *Neilo* sp. from the Río Turbio Formation reported by Hünicken (1955).

Subclass PTERIOMORPHIA Beurlen, 1944

Order MYTILOIDA Férussac, 1822

Superfamily MYTILOIDEA Rafinesque, 1815

Family MYTILIDAE Rafinesque, 1815

Genus *Gregariella* Monterosato, 1884

Type species. *Modiolus sulcatus* Risso, 1826.

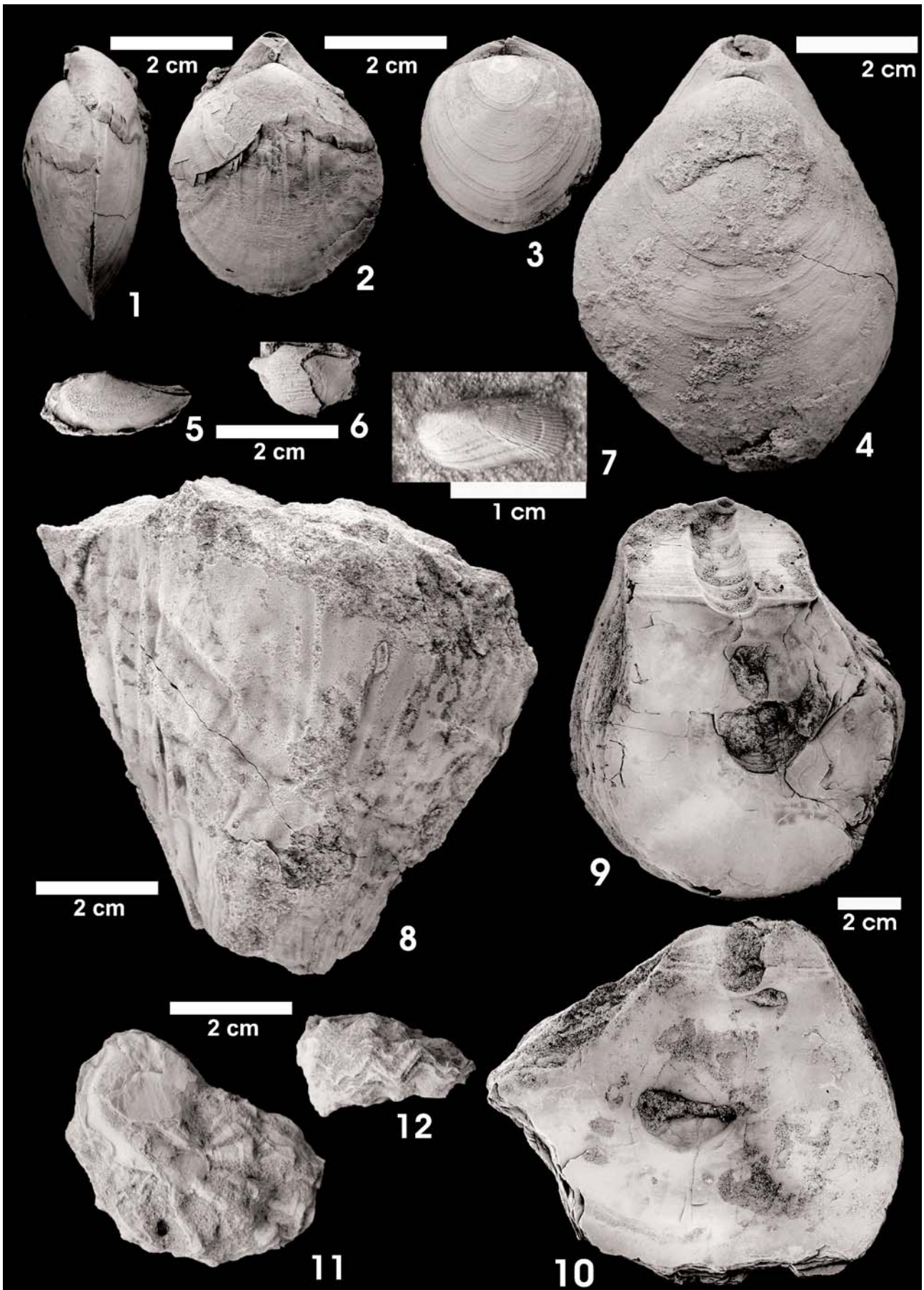
Gregariella sp.
Figure 5.7

Material. One mould of a left valve; GHUNLPam 26792.

Occurrence. Locality 1.

Remarks. The ornamentation indicates that it may be placed in *Gregariella* Monterosato. It shows the typical ribbed anterior and posterior areas of the shell separated by a smooth central zone in which only commarginal growth lines are visible. In a way, this specimen resembles *Modiolus aprilis* Feruglio, 1935 (p. 67, pl. 1, fig. 5) from the Paleocene of the Atlantic coast of Chubut. The illustration provided by Feruglio is unclear, but the description suggests that it may belong

Figure 5. 1-2, "Terebratella" insignis Feruglio, 1937. **1**, lateral view / *vista lateral*, **2**, dorsal view / *vista dorsal*, GHUNLPam 26800/1. **3, Bouchardia conspicua** Feruglio, 1937, dorsal view / *vista dorsal*, GHUNLPam 26797/1. **4, "Magellania" elinaecorreamoralesi** Feruglio, 1937, dorsal view / *vista dorsal*, GHUNLPam 26814. **5, Spineilo** sp., left valve / *valva izquierda*, GHUNLPam 26998/1. **6, Neilo** sp., left valve / *valva izquierda*, GHUNLPam 26795. **7, Gregariella** sp., Left valve / *valva izquierda*, GHUNLPam 26792. **8, Atrina rioturbiensis** Griffin, 1991, right valve / *valva derecha*, GHUNLPam 26798. **9-10, "Ostrea" groeberi** Feruglio, 1937. **9**, right valve interior / *interior valva derecha*, GHUNLPam 26846; **10**, left valve interior / *interior valva izquierda*, GHUNLPam 26789. **11-12, Lophaherminii** (Feruglio, 1937). **11**, left valve exterior / *exterior valva derecha*. **12**, view of ventral commissure / *vista de la comisura ventral*, GHUNLPam 26996.



in *Gregariella* too. In any event, our specimen is more elongate and the radial ribs are stronger and apparently more clearly differentiated from the smooth central area than in Feruglio's illustrated specimen.

Superfamily PINNOIDEA Leach, 1819

Family PINNIDAE Leach, 1819

Genus *Atrina* Gray, 1842

Type species. *Pinna nigra* Dillwyn, 1817.

Atrina rioturbiensis Griffin, 1991

Figure 5.8

1991. *Atrina rioturbiensis* Griffin: 128-129, fig. 5.1-5.3.

Material. One broken internal mould; GHUNLPam 26798.

Occurrence. Locality 1.

Remarks. The only available specimen is clearly identifiable as *Atrina rioturbiensis*, based on shape, section and ornamentation. Like the species from Río Turbio, our specimen resembles closely to *Pinna* cf. *tumida* Philippi *sensu* Steinmann and Wilckens (1908, p. 31-32, pl. 3, fig. 3) from the Cenozoic rocks exposed along the northern coast of Bahía Inútil, in Chilean Tierra del Fuego.

Order OSTREOIDA Férussac, 1822

Superfamily OSTREOIDEA Rafinesque, 1815

Family OSTREIDAE Rafinesque, 1815

Genus *Ostrea* Linné, 1758

Type species. *Ostrea edulis* Linné, 1758.

"Ostrea" groeberi Feruglio, 1937

Figure 5.9-10

1937. *Ostrea groeberi* Feruglio: 139-142, pl. 17, fig. 1-2; pl. 18, fig. 1-2.

2000. *Crassostrea groeberi* (Feruglio); Camacho, Chiesa, Parma and Reichler: 200, pl. 2, fig. 1.

Material. Two closed specimens; 10 right valves; 22 left valves; several fragments; GHUNLPam 26789, GHUNLPam 26804, GHUNLPam 26815/1-2, GHUNLPam 26819/1-2, GHUNLPam 26820, GHUNLPam 26833/1-3, GHUNLPam 26846, GHUNLPam 26855/1-3, GHUNLPam 26875/1-10, GHUNLPam 26876, GHUNLPam 26990/1-11.

Occurrence. Locality 1.

Remarks. This poorly known oyster was first described by Feruglio (1937), based on specimens from Calafate and the left margin of Río Leona. Camacho *et al.* (2000, p. 200, pl. 2, fig. 1) described material from several localities north of Calafate. The specimen AMEGHINIANA 46 (1), 2009

mens appear to be very poorly preserved and, in the only one illustrated – a right valve interior – the typical characters of this species such as the conspicuous chomata, the straight hinge margin and the relatively rounded posterior adductor muscle scar are missing. Moreover, the scar appears to be rather elongate, in a similar way to other large oysters from the Paleogene and Neogene of southern Patagonia, e.g. "*Ostrea" hatcheri* (Ortmann, 1897). They included their material in *Crassostrea* Sacco, 1897. Our specimens do not warrant such identification as they lack any trace of umbonal cavity and the chambering in the left valve remains to be confirmed.

The generic placement of this oyster is as yet uncertain. More specimens are needed in order to fully understand its variability but, however, it certainly does not belong in *Ostrea* s.s. It resembles *Odonotogryphaea* Ihering, 1902 (type species *Gryphaea concors* var. *rostrigera* Ihering, 1902).

However, the lack of a terebratuloid fold in all specimens collected seems to preclude it from this unique genus. It shows a striking resemblance to *Solidostrea hemiglobosa* (Romanovsky, 1884) from the Eocene of northern Afghanistan. Like the Patagonian species, the Asian taxon – type of *Solidostrea* Vyalov 1948 – has flat bourrelets, a ligament area with straight ventral margins, and large solid shells. This suggests that a better generic placement for the latter could be *Solidostrea*. Stenzel (1971, p. N1153) doubtfully synonymized *Solidostrea* Vyalov, 1948, with *Flemingostrea* Vredenburg, 1916 [type species *Ostrea* (*Flemingostrea*) *flemingi* d'Archaic and Haime, 1853]. The shells, however, are so different in the two type species that it is probably correct to place them in different genera. No other oyster from Cenozoic deposits in Patagonia shows such a combination of characters and the biogeographic origin of "*Ostrea" groeberi* remains as yet obscure.

Subfamily LOPHIINAE Vyalov, 1936

Genus *Lopha* Röding, 1798

Type species. *Mytilus cristagalli* Linné, 1758.

Lopha herminii (Feruglio, 1937)

Figure 5.11-12

1937. *Ostrea* (*Alectryonia*) *herminii* Feruglio: 147-149, pl. 16, fig. 1-8.

Material. Six right valves; seven left valves; two bivalved specimens; one internal mould; several fragments; GHUNLPam 26802, GHUNLPam 26805/1-3, GHUNLPam 26821, GHUNLPam 26832/1-2, GHUNLPam 26836/1-2, GHUNLPam 26844, GHUNLPam 26852, GHUNLPam 26867, GHUNLPam 26874/1-2, GHUNLPam 26991, GHUNLPam 26996.

Occurrence. Locality 1.

Remarks. This species seems to be quite common throughout the Man Aike Formation. Feruglio (1937, p. 149) mentioned that he had numerous specimens from Calafate. The large attachment area, the elongate to almost reniform adductor muscle scar, and the strongly plicate valves with the characteristically plicate commissure are enough to place this taxon in *Lopha*. This species of *Lopha* seems to be the only member of the genus recorded in Cenozoic rocks of Patagonia.

Superfamily PECTINOIDEA Rafinesque, 1815
Family PECTINIDAE Rafinesque, 1815

Genus *Amusium* Röding, 1798

Type species. *Ostrea pleuronectes* Linné, 1758.

Amusium ? cf. *A. bagualensis* (Wilckens, 1907)
Figure 6.1

1937. *Pecten* (?) *bagualensis* Wilckens; Feruglio: 137-138, pl. 15, fig. 7.

Material. One left valve with the shell preserved but with the exterior surface not available; GHUNLPam 26884.

Occurrence. Locality 1.

Remarks. The interior of the shell is smooth except for weak but clearly defined radial ribs that do not reach the margins of the shell. Such a lack of characters hampers any clarification on the systematic position and the specimen is tentatively placed in *Amusium* Röding. The ribs depicted in Feruglio's material seem to be quite stronger than in our material.

Subclass HETEROCONCHIA Hertwig, 1895
Superfamily CARDITIUDEA Fleming, 1828
Family CARDITIDAE Fleming, 1828

Genus *Venericardia* Lamarck, 1801

Type species. *Venericardia imbricata* (*Venus imbricata* Gmelin, 1791).

Subgenus *Venericor* Stewart, 1930

Type species. *Venericardia planicosta* Lamarck, 1799.

Venericardia (*Venericor*) *carrerensis* Griffin, 1991
Figure 6.2

1991. *Venericardia* (*Venericor*) *Carrerensis* Griffin: 132-133, Fig. 6.5-6.7.

2000. *Venericardia* (*Venericor*) sp. Camacho, Chiesa, Parma and Reichler: 201-202, pl. 2, fig. 2

Material. Twelve articulated specimens; five left valves, six right valves and a few fragments. GHUNLPam 26790/1-4, GHUNLPam 26807/1-4, GHUNLPam 26840/1-10, GHUNLPam 26842,

GHUNLPam 26860/1-5, GHUNLPam 26877/1-3, GHUNLPam 26999/1-3.

Occurrence. Localities 1 and 4.

Remarks. Most of the specimens are poorly preserved and generally deformed to some extent. However, they fall within the range of variation of *Venericardia* (*Venericor*) *carrerensis* Griffin, 1991 (p. 132-133, fig. 6.5-6.7). This species was described from the Río Turbio Formation in the Estancia Cancha Carrera. Like the material from Cancha Carrera, the one from the Man Aike Formation also shows specimens that are almost round and others fairly elongated, being up to 1.5 times longer than high. The shells in our material are rather poorly preserved, most of them being calcite replacements. Notwithstanding, the ornamentation agrees well with the specimens from Cancha Carrera, except for the fact that the rib pattern appears discordant in some of the bivalved shells. On the left valve, the ribs are completely flat and separated by very narrow intercostals spaces. On the right valve they seem to be narrower and the edges sharper, a fact that renders the intercostals spaces significantly wider. Whether this anomaly is due to the original shell conformation or to diagenetic processes remains unclear.

Venericardia (*Venericor*) has been traditionally considered to be a good Eocene index fossil, based on the fact that the type species – *Venericardia planicosta* Lamarck, 1799 – is typical of the Eocene of the Paris Basin. It has also been described from the Eocene of the Coastal plain of North America. The genus was early reviewed by Gardner and Bowles (1939), who supported an Eocene age for all the rocks bearing this bivalve.

Other species clearly belonging in this genus were described from rocks generally referred to the "Patagoniano", a term traditionally used to include most marine Cenozoic sediments exposed in Patagonia. A few remarks on them seem pertinent here, as it may be of help in understanding the confusing history of the stratigraphic nomenclature, as well as the many disagreements on the age of these deposits over the years.

Among the species of *Venericor*, *Venericardia* (*Venericor*) *abasolensis* Camacho and Fernández, 1956 (p. 44, pl. 1, fig. 1 and pl. 2, fig. 1) was described from the sediments exposed west of Comodoro Rivadavia, in central Patagonia. Camacho and Fernández's material comes from beds near the top of the sequence and were included by them in the "Estratos con *Venericor* y *Monophoraster*". Because of the presence of this bivalve, they firmly supported an Eocene age for the unit. These rocks are presently referred to the Chenque Formation (Bellosi, 1995), a unit that is considered to be late Oligocene to middle Miocene in age

(Barreda and Palamarczuk, 2000). Material from equivalent rocks some kilometres to the north was described as *Venericardia austroplata* by Gardner and Bowles (1939, p. 188, pl. 42, fig. 11-12). Both species undoubtedly belong in *Venericardia* (*Venericor*), but the age is clearly much younger than Eocene. Feruglio (1954, p. 31-33, pl. 7-11) also described material from approximately the same beds as Camacho and Fernández did later. He classed his specimens within *Megacardita* Sacco, 1899 (type species *Cardita jouanneti* Basterot, 1825), a genus that superficially resembles *Venericardia* (*Venericor*) but that shows hinge characters that clearly separate it (Griffin, 1991, p. 133). Rossi de García *et al.* (1980, p. 66) realized that the material described by Camacho and Fernández came from younger beds. Following the general assumption that *Venericor* was exclusively Eocene, they proposed a new genus - *Neovenericor* (type species *Venericardia* (*Venericor*) *abasolensis* Camacho and Fernández, 1956) - based on morphological characters that Camacho (1981) correctly showed as misinterpretations. Although their new generic status for the material was in fact incorrect, they do take credit for advancing the idea that the species was younger than previously thought.

Similarly, *Venericardia crassicosta* Borchert, 1901 (p. 32-33, pl. 3, fig. 6) from the Paraná Formation exposed along the left bank of the Paraná River between La Paz and Victoria (Province of Entre Ríos), may be a still younger representative of this group. The Paraná Formation yields a rich mollusc fauna that was studied by Philippi (1893), Borchert (1901), Ihering (1907), del Río (1988, 1991, 2000), and del Río and Martínez Chiappara (1998), and the presence of *Venericardia crassicosta* was acknowledged by all authors. However, the affinities of this bivalve were never discussed until Camacho *et al.* (2001, p. 68) described a fragment of *Venericardia* (*Venericor*) from Eocene beds exposed at Cerro Palique in the southwestern corner of Santa Cruz. According to these authors *Venericardia crassicosta* is probably a representative of *Megacardita*, but no reasons were given to such an assumption. Yet, the features preserved in the shell of the few known specimens - i.e. the shape of the shell, its massiveness and the flat ribs on the adult stages of the shell; (the juvenile stages are unknown as the specimens are worn near the umbo) - suggest that they seem to lie with *Venericor*. Besides

being very scarce, preservation itself is extremely poor, and as details of the hinge are still missing, there can be no certainty as to its true generic placement.

Uliana and Camacho (1974) described a specimen from the Eocene Vaca Mahuida Formation in northern Río Negro, which they referred to *Venericardia* (*Venericor*) sp. The seven available specimens were rather poorly preserved silicified valves. However, they appear to be lighter shells than *Venericardia* (*Venericor*) *carrerensis* and the hinges are also proportionally weaker. As pointed out by the authors, they resemble closely *Venericardia crassicosta* Borchert, 1901, from the Miocene Paraná Formation in Entre Ríos, Argentina.

Superfamily CRASSATELLOIDEA Ferussac, 1822

Family CRASSATELLIDAE Férussac, 1822

Genus *Crassatella* Lamarck, 1799

Type species. *Mactra cygnaea* Lamarck, 1799.

Crassatella brandmayri Griffin, 1991

Figure 6.3-4

1991. *Crassatella brandmayri* Griffin, p. 133-134, fig. 7.1-7.3.

Material. One specimen, shell well preserved, and one left valve; GHUNLPam 26873, GHUNLPam 26796.

Occurrence. Locality 1.

Remarks. Only two specimens of this taxon were found in the exposures of the Man Aike Formation, south of Lago Argentino. The large, thick-shelled specimens, belong undoubtedly in *Crassatella brandmayri* Griffin, 1991 (p. 133-134, fig. 7.1-7.3). The holotype of this species is a smaller juvenile specimen about half the size of ours, and it comes from the lower section of the Río Turbio Formation. A larger specimen collected recently in that unit shows that all characters agree well with the Man Aike material.

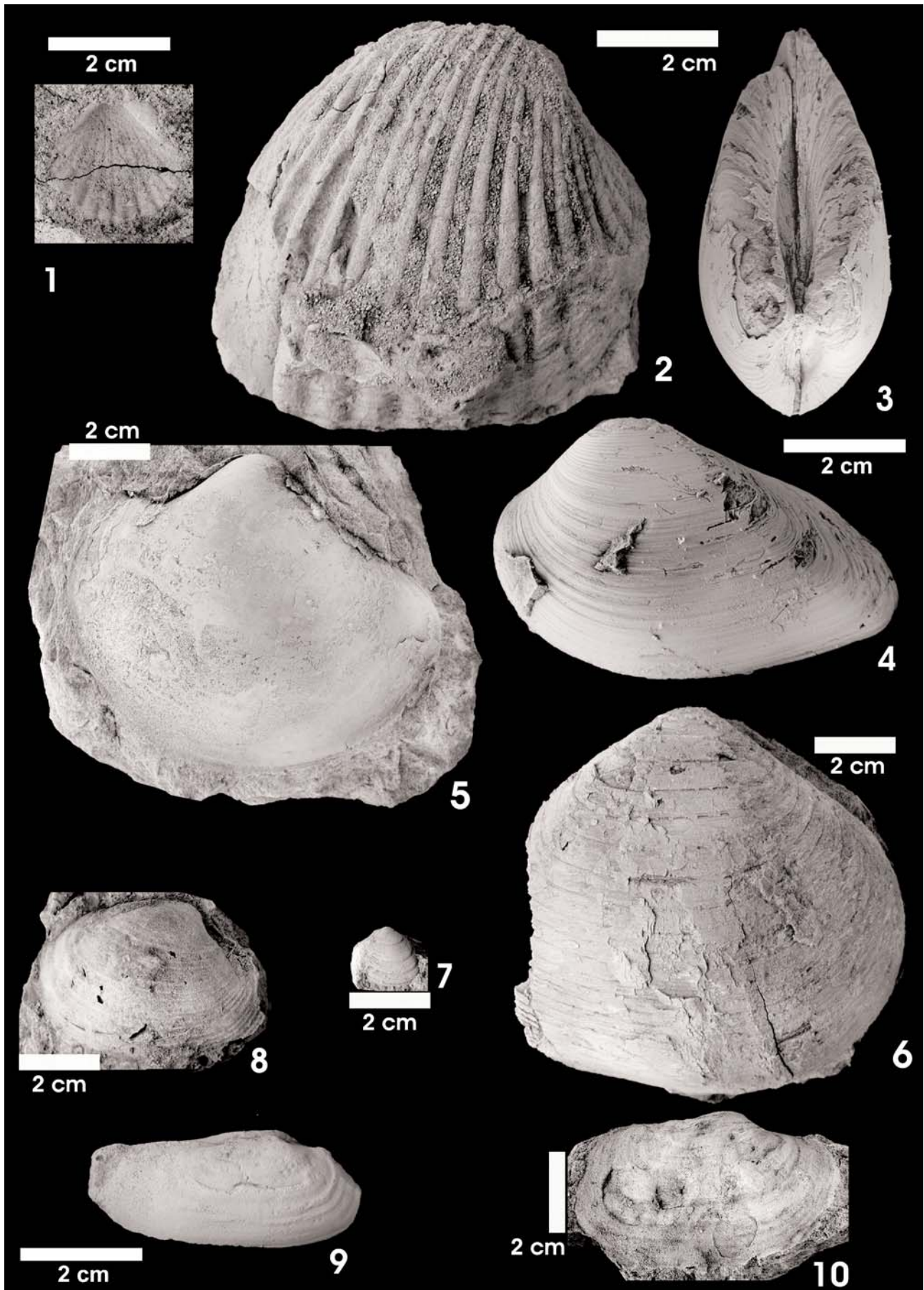
Superfamily CARDIOIDEA Lamarck, 1809

Family LAHILLIDAE Finlay and Marwick, 1937

Genus *Lahillia* Cossmann, 1899

Type species. *Amathusia angulata* Philippi, 1887.

Figure 6. 1, *Amusium* ? cf. *A. bagualensis* (Wilckens, 1907), left valve / *valva izquierda*, GHUNLPam 26884. **2, *Venericardia* (*Venericor*) *carrerensis*** Griffin, 1991, right valve exterior / *exterior valva derecha*, GHUNLPam 26807/1. **3-4, *Crassatella brandmayri*** Griffin, 1991. 3, dorsal view / *vista dorsal*, 4, left valve exterior / *exterior valva izquierda*, GHUNLPam 26796. **5, *Lahillia gigantea*** Feruglio, 1937, internal mould of left valve / *molde interno de valva izquierda*, GHUNLPam 26854. **6, *Lahillia tetrica*** Feruglio, 1937, exterior of right valve / *exterior de la valva derecha*, GHUNLPam 26878. **7, cf. *Mactra* (?) *impervia*** Feruglio, 1935, exterior of right valve / *exterior de la valva derecha*, GHUNLPam 26859/1. **8, *Retrotapes* cf. *R. australis*** (Feruglio, 1935), mould of left valve / *molde de la valva izquierda*, GHUNLPam 26995. **9, *Panopea pastorei*** Feruglio, 1937, mold of right valve / *molde de la valva derecha*, GHUNLPam 26863. **10, *Panopea undatoides*** (Ortmann, 1899), mould of right valve / *molde de la valva derecha*, GHUNLPam 26799.



***Lahillia gigantea* Feruglio, 1937**

Figure 6.5

1937. *Lahillia luisa* Wilckens var. *gigantea* Feruglio: 115-118, pl. 14, fig. 12a-b, 13.1991. *Lahillia* cf. *L. angulata* (Philippi, 1887); Griffin: 134-135, fig. 7.4.**Material.** One mould of a left valve; GHUNLPam 26854.**Occurrence.** Locality 1.

Remarks. Described as a variety of *Lahillia luisa* Wilckens, 1907 (p. 42, pl. 8, fig. 1-3) – a species from the Paleocene beds of Cerro Cazador, in southern Santa Cruz – the specimen from the Man Aike Formation is clearly a different taxon, characterized by its much larger shell and more prominent umbos. It is co-specific with the material described by Griffin (1991, p.134-135) as *Lahillia* cf. *L. angulata* (Philippi, 1887), from the lower section of the Río Turbio Formation near Cancha Carrera. Some specimens at this locality attain a size longer than 30 cm. Further study is needed but this species may prove to be a link between the Paleocene *Lahillia luisa* Wilckens, 1907, and the younger *Lahillia patagonica* Ihering, 1907 (p. 294-295), from the late Oligocene – early Miocene Monte León and Centinela formations in eastern and western Santa Cruz.

***Lahillia ? tetrica* Feruglio, 1937**

Figure 6.6

1937. *Lahillia* (?) *tetrica* Feruglio: 118-119, pl. 14, fig. 15.**Material.** One moderately well preserved specimen, one right valve, one left valve, fragments; GHUNLPam 26808, GHUNLPam 26878, GHUNLPam 26837.**Occurrence.** Locality 1.

Remarks. The specimens available are very poorly preserved, but can be readily identified with *Lahillia* (?) *tetrica* Feruglio, 1937 (p. 118-119, pl. 14, fig.15), a species originally described from rocks now included in the Man Aike Formation. It can be easily separated from *Lahillia gigantea* Feruglio, 1937, by its smaller size, proportionally thicker shell and less prominent umbos. It also seems to be furnished with more conspicuous commarginal lines near ventral margin of the shell.

Superfamily MACTROIDEA Lamarck, 1809

Family MACTRIDAE Lamarck, 1809

Genus *Maetra* Linné, 1767**Type species.** *Cardium stultorum* Linné, 1758.cf. *Maetra ? impervia* Feruglio, 1935

Figure 6.7

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cf. 1935. *Maetra* (?) *impervia* Feruglio: 74, pl. 2, fig. 18.cf. 1937. *Maetra* (?) *impervia* Feruglio: 237-238, pl. 24, fig. 4.**Material.** Fourteen specimens; several internal moulds; GHUNLPam 26859/1-14.**Occurrence.** Locality 1.

Remarks. None of the specimens collected in the Man Aike Formation show internal characters. Therefore, generic placement must remain uncertain. The shell outline, and external ornamentation remind of *Maetra ? impervia* Feruglio, 1935. However, in this case the shell interior also remains unknown and identity of our material with Feruglio's can not be confirmed.

Superfamily VENEROIDEA Rafinesque, 1815

Family VENERIDAE Rafinesque, 1815

Genus *Retrotapes* del Río, 1997**Type species.** *Retrotapes ninfasiensis* del Río, 1997.***Retrotapes* cf. *R. australis* (Feruglio, 1935)**

Figure 6.8

1935. *Cytherea australis* Feruglio: p. 80-81.1937. *Cytherea australis* Feruglio: 119-122, pl. 13, fig. 3-10.**Material.** Three right valves; GHUNLPam 26866, GHUNLPam 26872, GHUNLPam 26995.**Occurrence.** Locality 1.

Remarks. The specimens resemble closely Feruglio's original material. The hinge is not visible, but the shell outline and ornamentation agree with his species. Originally described as *Cytherea*, this generic placement seems inadequate and, upon close inspection of his original illustrations, it becomes clear that it belongs better in *Retrotapes* del Río, at least until more material with well preserved hinges becomes available. It is not a very common species and the only known specimens are those illustrated by Feruglio and those collected by us. A similar species was described from the Eocene of Antarctica as "*Eurhomalea*" *claudiae* Stilwell, 2000 (p. 285, pl. 4, fig. H, K, M, and P).

Superfamily HIATELLOIDEA Gray, 1824

Family HIATELLIDAE Gray, 1824

Genus *Panopea* Menard de la Groye, 1807**Type species.** *Panopea aldrovandi* Menard de la Groye, 1807.***Panopea pastorei* Feruglio, 1937**

Figure 6.9

1937. *Panopaea pastorei* Feruglio: 129, pl. 14, fig. 4-9.1991. *Panopea?* cf. *P. torresi* Philippi, 1887; Griffin: 138, fig. 8.9.

Material. Twenty eight specimens, all of them moulds; GHUNLPam 26809/1-3, GHUNLPam 26862/1-3, GHUNLPam 26863, GHUNLPam 26882/1-13, GHUNLPam 26883/1-5, GHUNLPam 26997/1-3.

Occurrence. Localities 1 and 4.

Remarks. This small species of *Panopea* is known only from the Man Aike Formation and from the lower section of the Río Turbio Formation (Griffin, 1991, p. 138). Some specimens in the latter unit appear to be identical to the material from Calafate. A similar species is *Panopea akerlundi* Stilwell, 2000 (p. 287-288, pl. 5, fig. D, E, and H) from the Eocene of Antarctica. They share the same general contour and size, although both taxa are represented by moulds, rendering further comparison difficult.

Panopea undatoides (Ortmann, 1899)

Figure 6.10

1899. *Lutraria undatoides* Ortmann: 429-430.

1902. *Lutraria* (?) *undatoides* Ortmann; Ortmann: 151, pl. 30, fig. 3.

1991. *Panopea* (*Panopea*) *undatoides* (Ortmann, 1899); Griffin: 136-137, fig. 8.1-8.3.

Material. Two specimens, both internal moulds; GHUNLPam 26799, GHUNLPam 26827.

Occurrence. Locality 1.

Remarks. This species is common in the Río Turbio Formation, where it occurs mainly in the upper section. The characteristic strong commarginal ornamentation on the thin shells and the higher anterior end are features that can be clearly distinguished in the specimens from Man Aike too. A possibly closely related species was described by Feruglio (1935, p. 76-77, pl. 3, fig. 2-3; 1937, p. 242, pl. 24, fig. 16-17) as *Panopea* sp. I, from the Paleocene Salamanca Formation along the coast of southern Chubut. The illustrations are inadequate for accurate comparisons, but they appear to show the same kind of strong commarginal plicae. Likewise, *Panopea ortmanni* Wilckens, 1921, from Cenozoic rocks around Punta Arenas (southern Chile) may be closely related. Better collections from the Chilean localities may prove its identity with *Panopea undatoides*.

Class GASTROPODA Cuvier, 1797

Subclass PROSOBRANCHIA M. Edwards, 1848

Order ARACHAEOGASTROPODA Thiele, 1925

Family Uncertain

Genus *Fagnanoa* Bonarelli, 1918

Type species. *Gibbula dubiosa* Ihering, 1907.

Fagnanoa sp.

Figure 7.1-2

Material. Two specimens preserved as broken moulds; GHUNLPam 26794 and GHUNLPam 26853.

Occurrence. Locality 1.

Remarks. The extremely short spire and the strongly quadrangular section of the whorls leave no doubts to the generic placement of this species. The material is identical with non described specimens (GHUNLPam 26787-26788) collected by us in the Lower Member of the Río Turbio Formation in Cancha Carrera.

The genus *Fagnanoa* Bonarelli included originally *Gibbula dubiosa* Ihering, 1907 (p. 130, pl. 14, fig. 91a-b), from the "Patagonian" beds along the southern rim of the San Jorge Gulf, and *Gibbula lehmannitschei* Steinmann and Wilckens, 1908 (p. 77-78, pl. 7, fig. 5a-b). In the original description, both were considered synonyms by Bonarelli, who stated that the type species was *Gibbula dubiosa*, which is unfortunately based on a sole poorly preserved specimen. del Río and Morra (1985) considered these two nominal species to be synonyms and introduced *Fagnanoa nagerai* del Río and Morra, 1985 (p. 113, pl. 1, fig. 2a-c), based on material coming from the late Oligocene - early Miocene Monte León Formation. However, the differences they pointed out as separating the two species can be attributed to the differences in preservation, as the specimen of *F. dubiosa* is a small and fragmentary one. The earliest representatives of this enigmatic genus are the specimens from the Río Turbio and Man Aike formations.

Superfamily TROCHOIDEA Rafinesque, 1815

Family TROCHIDAE Rafinesque, 1815

Genus *Astele* Swainson, 1855

Type species. *Astele subcarinata* Swainson, 1855.

Astele ? *andina* (Feruglio, 1937)

Figure 7.3

1937. *Pleurotomaria* (?) *andina* Feruglio: 156-157, pl. 18, fig. 4: pl. 19, fig. 2.

Material. Two internal moulds and fragments of the apical zone of a third specimen; GHUNLPam 26828, GHUNLPam 26865.

Occurrence. Locality 1.

Remarks. This remarkable species is only known from the Man Aike Formation from a handful of specimens. The massive shell has not been recorded from other Paleogene or Neogene units in southern South America. Our specimens have missed the shell, but Feruglio's illustrated specimen appears to have had parts still attached, as numerous very fine spiral cords can be observed on his figure. The exact affinities of

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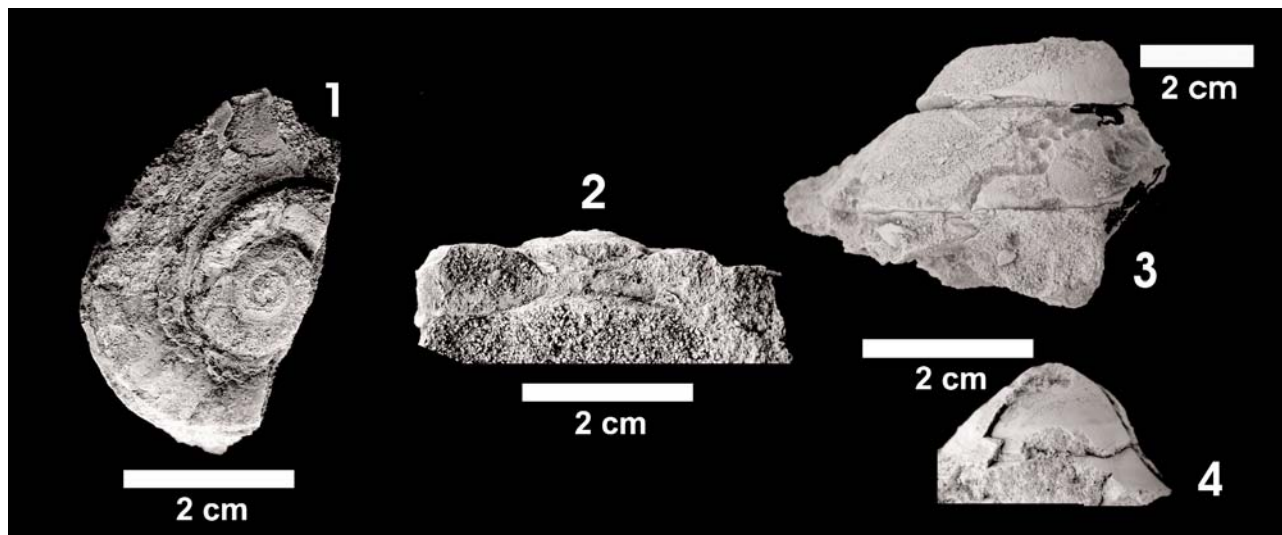


Figure 7. 1-2, *Fagnanoa* sp. 15, apical view of mold / *vista apical del molde*; 16, section of same specimen / *sección del mismo espécimen*, GHUNLPam 26853. 3, *Astele ? andina* (Feruglio, 1937), lateral view / *vista lateral*, GHUNLPam 26865. 4, *Spirogalerus* sp., lateral view / *vista lateral*, GHUNLPam 26793.

this species, and even its correct generic position, remain as yet hidden. However, a possible relationship to archaeogastropod genera common in younger beds in Patagonia and Chile such as *Astele* and *Valdesia* may be possible. Because of its conical shape and flat sided whorls, we tentatively place it in the former.

Order MESOGASTROPODA Thiele, 1925

Family CALYPTRAEIDAE Lamarck, 1809

Genus *Spirogalerus* Finlay and Marwick, 1937

Type species. *Spirogalerus lamellaria* Finlay and Marwick, 1937.

Spirogalerus sp.

Figure 7.4

Material. One broken specimen; GHUNLPam 26793.

Occurrence. Locality 1.

Remarks. Although the internal mould missed most of the shell, it can be readily identified with *Spirogalerus*? cf. *S.?* *laevis* (Philippi, 1887) in Griffin, 1991 (p. 262, fig. 3.6) from the uppermost beds of the Cerro Dorotea Formation in south-western Patagonia. Further comparisons, however, must wait until better material is collected.

Conclusions

The Man Aike Formation at the Estancia 25 de Mayo represents the evolution of an incised valley from fluvial to marine environments during a period of relative rise in sea-level.

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The lower section of Man Aike Formation has elements to define it as an incised valley system. First, the lower surface is erosive and corresponds to the base of fluvial channels which cut down up to 29 m into the underlying Maastrichtian sandstones of the Calafate Formation. This surface of regional extent marks a sequence boundary (SB). The sequence boundary is then covered by fluvial deposits (facies association 1) representing the typical basinward shift in sedimentary facies produced during the lowstand system tract. As the sea level raise, a gradual retrogradation of the depositional systems take place. Therefore, the accumulation of fluvial deposits continued even into the onset of the transgressive system tract (TST). Because of this, the transgressive surface is contained within the fluvial deposits. Estuarine deposits (facies association 2) rest on the former separated by an erosive surface that indicates a contact between continental and marginal marine facies. It is therefore interpreted as a flooding surface. Three tidal ravinement surfaces are represented by coarse, laterally continuous shelly deposits recorded at the base of facies association 3, 4 and 5 (i.e. at the base of each one of them).

The sandy section above the third tidal ravinement surface records sedimentation in a more open marine environment - possibly in outer estuarine settings.

The unconformity at the base of the Man Aike Formation at the studied localities may have been originated during the middle Eocene phase of the uplift of the Patagonian Cordillera (Ramos 2002; Kraemer *et al.* 2002), while the infilling of the incised valley may have occurred during the late middle Eocene. This is supported by three different lines of evidence: a) micropaleontological analyses (Malumián, 1990; Concheyro, 1991); b) fossil invertebrates

showing affinities with the fauna contained in the Upper Member of the Río Turbio Formation, which is middle to late Eocene (Malumián 2002), as pointed out by Camacho *et al.* (2000); and c) information drawn from $^{87}\text{Sr}/^{86}\text{Sr}$ ages.

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