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STRATIGRAPHY OF THE LA MESETA FORMATION (EOCENE), MARAMBIO (SEYMOUR) ISLAND, ANTARCTICA[1]

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ABSTRACT. La Meseta Formation is a discontinuity bounded sedimentary unit which crops out on Marambio (Seymour) and Cockburn islands, approximately 100 km SE of the northern tip of the Antarctic Peninsula. The base of this unit is a diachronous surface which intersects all other older units of the island. Along this surface the hiatus increases towards the West. The top is another unconformity below the glacimarine post-Pliocene deposits of the Weddell Formation. The lenticular geometry and the architecture of the internal units was interpreted as filling an incised valley, eroded on an emerging platform after the tilting of the Marambio Group and the Cross Valley Formation beds. The La Meseta Formation has a thickness of 620 m on Marambio island and was divided into three members (I to III from base to top). Nevertheless, the lithosome architecture, the relationships between facies and the sedimentary palaeoenvironments are better explained using an allostratigraphic scheme. The La Meseta alloformation is 720 m thick and was divided into six allomembers, each representing a sedimentary stage. Due to the regional importance of the unconformities which limit this unit, it is interpreted that it also represents a depositional sequence. The stratigraphy, structural characteristics and facies architecture of the La Meseta Aloformation are better explained considering a tectonic/erosive mixed origin of the unconformities and thus a tectonic control for the history of the valley is proposed.

RESUMEN. ESTRATIGRAFÍA DE LA FORMACION LA MESETA, ISLA MARAMBIO (SEYMOUR), ANTÁRTIDA. La Formación La Meseta es una unidad sedimentaria limitada por discordancias que aflora en las islas Marambio y Cockburn, ubicadas aproximadamente a 100 km al sudeste del extremo norte de la Península Antártica. La base de esta formación es una superficie diacrónica que intersecta a todas las unidades más antiguas de la isla. A lo largo de esta superficie el hiato se incrementa hacia el oeste. El techo de la unidad es otra discordancia por debajo del depósito glacimarino post-Plioceno de la Formación Weddell. La geometría lenticular y la arquitectura de las unidades internas fueron interpretadas como producto del relleno de un valle incidido, labrado sobre una plataforma emergente con posterioridad al volcamiento de las capas del Grupo Marambio y de la Formación Cross Valley. La Formación La Meseta presenta en la isla Marambio un espesor de 620 m y ha sido subdividida en tres miembros (I a III de base a techo). Sin embargo, la arquitectura de los litosomas, las relaciones entre facies y los paleoambientes sedimentarios son mejor interpretados utilizando un esquema de subdivisión aloestratigráfico. La aloformación La Meseta tiene un espesor de 720 m y fue subdividida en seis alomiembros cada uno de los cuales representa una etapa de sedimentación. Dada la importancia regional de las discordancias que limitan esta unidad se interpreta que la misma corresponde también a una secuencia depositacional. La estratigrafía, características estructurales y arquitectura de las facies de la aloformación La Meseta son explicadas de un modo más armónico considerando un origen mixto, tectónico-erosivo, de las discordancias y por lo tanto se propone un control tectónico en la historia del valle.

KEY WORDS. Stratigraphy. La Meseta Formation. Eocene. Antarctica.

PALABRAS CLAVE. Estratigrafía. Formación La Meseta. Eoceno. Antártida.

INTRODUCTION

Marambio (Seymour) Island is a small ice- and vegetation-free island located 100 km SE of the northern tip of the Antarctic Peninsula in the norwestern Weddell Sea (figure 1).

The first attempt to establish the stratigraphy of the sedimentary sequence outcropping on Marambio Island was made by geologists on Nordenskjöld´s Swedish South Polar Expedition 1901-1903 at the beginning of this century. Andersson (1906) distinguished the Cretaceous "Older Seymour Island Beds" and the Tertiary "Younger Seymour Island Beds". Seventy years later, Argentine and U.S. geologists proposed the current stratigraphic nomenclature for the island (Rinaldi *et al.*, 1978; Elliot and Trautman, 1982) (figure 2).

The sedimentary sequence exposed on Seymour Island (figure 3) is more than 2 km thick and represents the uppermost part of the infill of the James Ross Basin (del Valle *et al.*, 1992). The oldest units are the Maastrichtian-Danian López de Bertodano (Rinaldi *et al.*, 1978) and the

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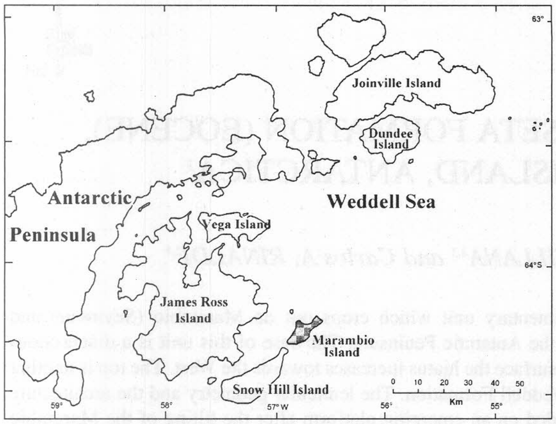

Figure 1. Sketch map showing the location of Marambio (Seymour) Island. / *Mapa de ubicación de la isla Marambio (Seymour).*

Danian Sobral (Rinaldi *et al.*, 1978) formations. They were included in the Marambio Group (Rinaldi *et al.*, 1978) and form a NNE-SSW homocline dipping 8º-10º east. The youngest beds, which outcrop on the northern part of the island, were grouped into the upper Paleocene Cross Valley (Elliot and Trautman, 1982) and the Eocene La Meseta formations (Elliot and Trautman, 1982), and placed together into the Seymour Island Group (Elliot and Trautman, 1982). Both formations represent infilling of incised valleys that were deeply cut into the underlying units (Sadler, 1988; Marenssi, 1995).

The name La Meseta Formation was first used by Rinaldi *et al.* (1978) to designate the Tertiary marine sedimentary rocks cropping out on the northeastern part of the island, north of Cross Valley. This unit was first described in detail by Trautman (1976), who named it the Marambio Formation; however, the name was abandoned, because "Marambio" had been used as a group name. Elliot and Trautman (1982) formally proposed the present name, which had been used informally by Argentine geologists, and included it in the Seymour Island Group; they subdivided the La Meseta Formation into three informal members designated I to III, from base to top, respectively. After extensive mapping, Sadler (1988), recognized seven major lithofacies with seven minor variations, which he named informally Telm 1-7 (acronyms for Tertiary Eocene La Meseta). After a detailed 7-year sedimentological and stratigraphical investigation, Argentine geologists proposed a subdivision based on unconformity-bounded (allostratigraphic) units (Marenssi and Santillana, 1994; Marenssi, 1995).

Although unconformity-bounded units were incorporated in the "Código Argentino de Estratigrafía" (1992), the proposed names for these units ("Secuencia", "Supersecuencia", and "Parasecuencia") have strong genetic implications not suitable for descriptive units. Instead, we follow the North American Stratigraphic Code (1983), because it proposes the non-genetic names of alloformation, allogroup, and allomember for the units.

The correlation between the three informal members (Elliot and Trautman, 1982), the Sadler (1988) lithofacies, and the allomembers is presented in figure 4. The selected datum is the base of the Cucullaea bed, because it is easily recognized in the field, and also is common to all three schemes.

The purpose of this paper is to clarify the stratigraphy

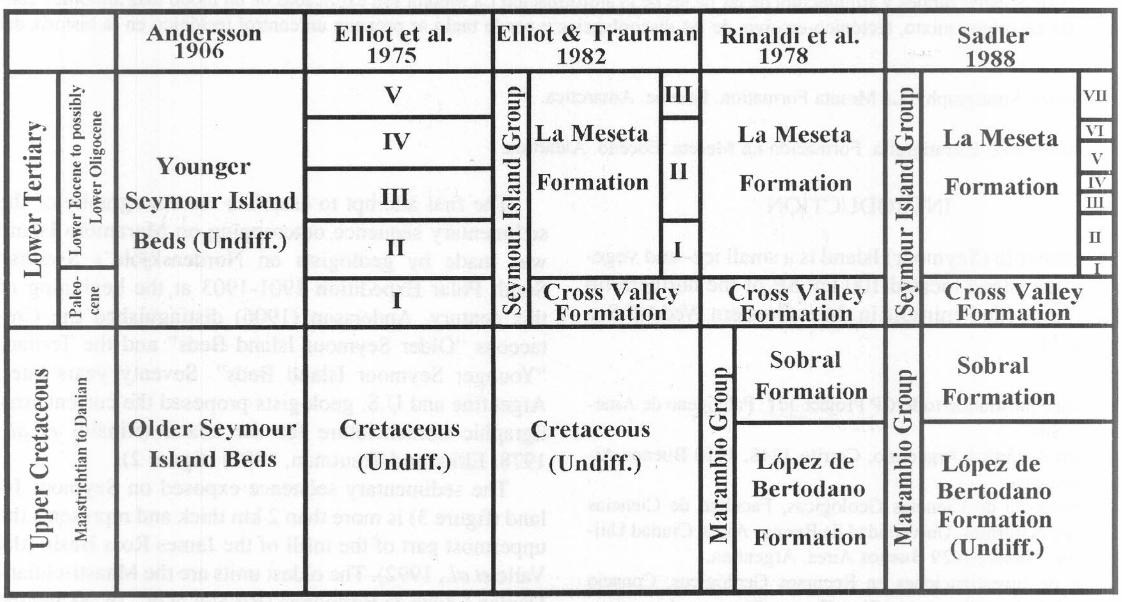

Figure 2. Evolution of the stratigraphy of Marambio (Seymour) Island. / *Evolución de la estratigrafía de la isla Marambio (Seymour).*

of the La Meseta Formation. We update the nature of its boundaries, describe its thickness and internal organization, and create a new allostratigraphic unit, the La Meseta alloformation. This will provide a framework for future paleoenvironmental reconstruction, and interpretation.

LITHOSTRATIGRAPHY

The La Meseta Formation rests unconformably on all the older sedimentary units of the island. Although relationship was first published by Rinaldi *et al.* (1978: 25), Adie (1958: 9) had earlier cited unpublished fieldwork of Standring, who recognized the unconformable relationship between the Cretaceous and Tertiary beds. The steep contact of the Eocene strata with the older units at the places where sections were measured lead Trautman (1976) and Elliot and Trautman (1982) to consider a fault relationship between them. Sadler (1988) recognized the true nature of this boundary. The upper boundary is an unconformity with the upper Cenozoic (Elliot and Trautman, 1982) and most probably post-Pliocene (Gazdzicki, pers. com. 1995) glaciomarine strata (Weddell Formation of Zinsmeister and De Vries, 1983).

The outcrops of the lower boundary form two almost E-W oriented strips on either side of the depositional basin; the strips are approximately 6 km apart. The southern unconformity dips to the north, forming a low-relief surface developed on nonresistant Cretaceous and Paleocene very fine, silty sands and muds of the López de Bertodano Formation. However, to the east, this surface develops a more regular but steep pattern in the narrows of Cross Valley. The northern unconformity dips to the south and is characterized by a very irregular, steep trace that resembles an eroded sinsedimentary fault (Santillana *et al.*, 1993). Therefore, the sedimentary fill has an overall lenticular form regarded by Sadler (1988) as a large channel, and referred to by Marenssi (1995) as an incised valley. The original relief of the valley should have exceeded the 70 m now exposed (Sadler, 1988; Marenssi, 1995), and would have been tectonically controlled (Santillana *et al.*, 1993). The basal unconformity has unusual angular relationships. The Eocene beds lapping onto the valley walls always dip more steeply than the older beds below the unconformity, and the unconformity itself is steeper than both. Attitudes of the beds close to the contacts are anomalous (dips and strikes being highly va-

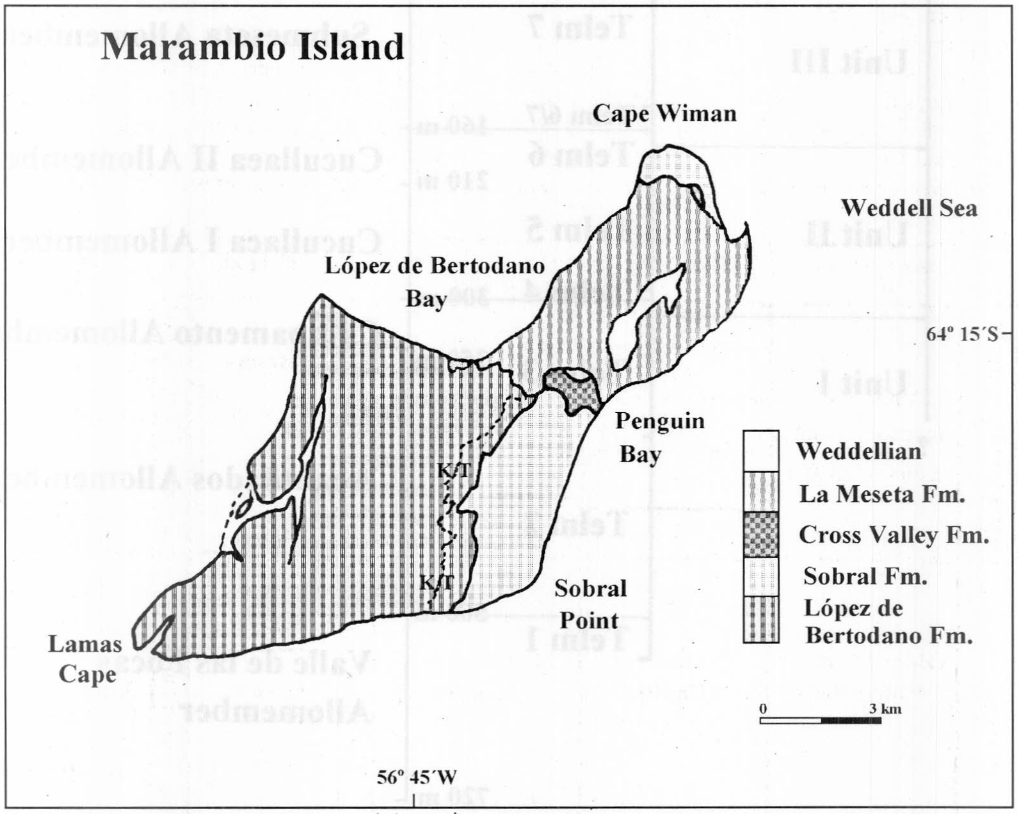

Figure 3. Simplified geologic map of Marambio Island. / *Mapa geológico simplificado de la isla Marambio.*

riable) compared to those of most of the formation. This angular relationship was characterized by Sadler (1988) as a variant of the "onlap", and is typical of margins of incised valley systems (Zaitlin *et al.*, 1994: 49).

The basal unconformity has a diachronous surface. The duration of the time gap along this unconformity increases toward the west. The maximum gap recorded on Seymour Island should be greater than 10 m.y. and occurs in the southernmost outcrops, where lower Eocene sediments are in contact with those of the uppermost Maastrichtian. The minimum gap is located at the SE boundary at the contact between the late lower Eocene strata of TELM 2 and the ?upper Paleocene Cross Valley Formation, and may represent a hiatus of less than 5 m.y., depending on the precise ages of both TELM 2 and Cross Valley Formation.

The uppermost unconformity has an irregular erosion surface with less than 3 m of relief. The overlying glaciomarine deposit fills shallow channels (less than 2 m deep) cut into the La Meseta Formation. Because the Weddellian deposit consists of thick, massive beds, it is uncertain whether the contact is conformable or marked by angular discordance. Although the ages of the uppermost strata of the La Meseta Formation are unresolved, the hiatus should exceed 30 m.y.

Rinaldi *et al.* (1978) described 264 m of strata from this unit, whereas Elliot and Trautman (1982) recorded about 450 m. Zinsmeister and De Vries (1982) reported that some 300 m of sedimentites previously regarded as the Cross Valley Formation should have been included in the La Meseta Formation, thereby increasing its thickness to about 750 m. However, had Zinsmeister and De Vries (1982) added this thickness to the base of the type section, the resulting stratigraphic thickness would approximate 595 m (Unit I= 300 m, Unit II= 170 m, Unit III= 125 m) (D.H. Elliot in litt. 1997). However, none of these authors recognized the lenticular nature of the La Meseta Formation and the important variations in thickness within it. Sadler (1988) described the architecture of the whole formation as a stacking of lenticular units within

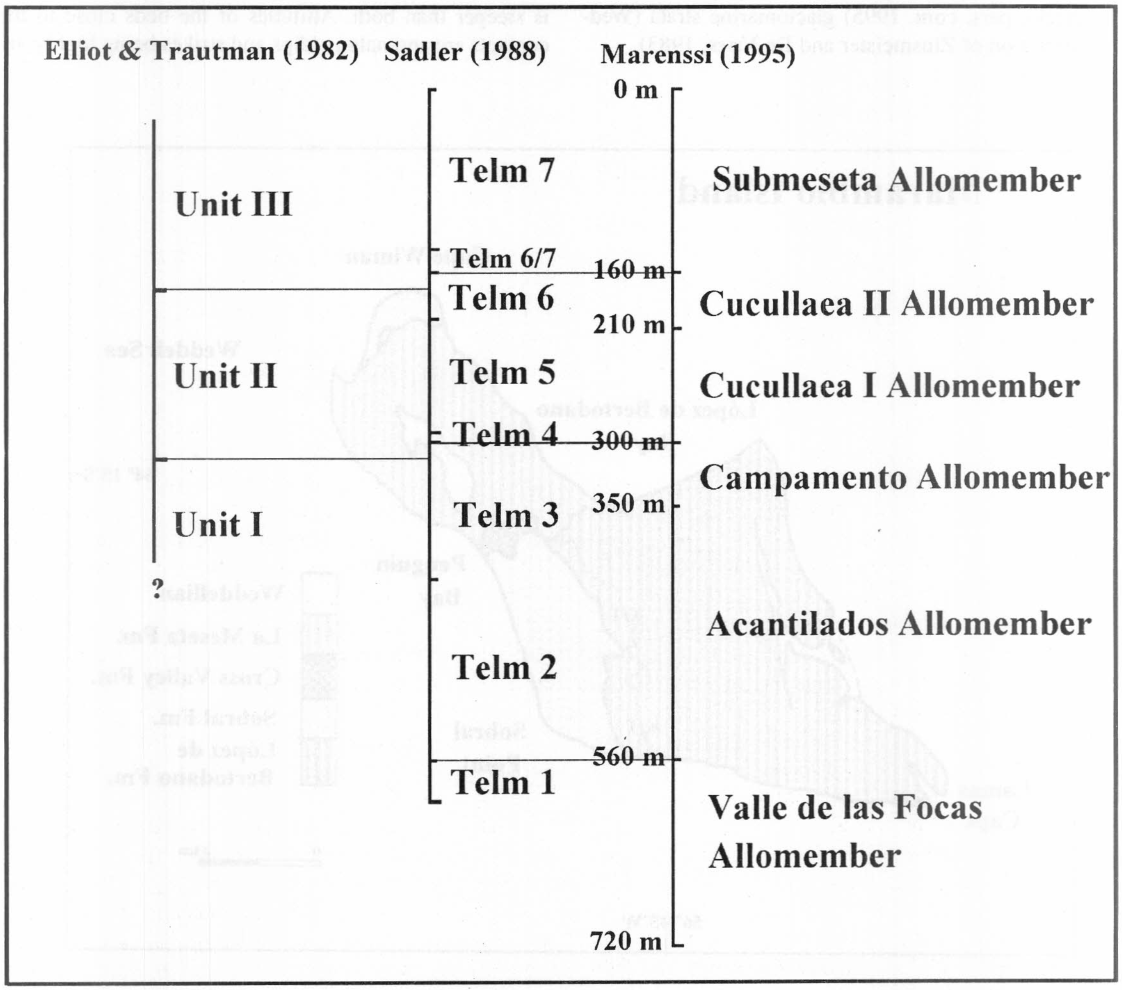

Figure 4. Correlation between different subdivision schemes for the La Meseta Formation. / *Correlación entre los distintos esquemas de subdivisión de la Formación La Meseta.*

an initial valley or trough, and he argued strongly for probable vertical errors in composite sections. The true stratigraphic thickness of the La Meseta Formation can not be determined from geologic field observations, because the base of the channel does not crop out.

Marenssi (1995) noted that owing to the lenticular nature of the internal units, particular patterns of the internal units, and the fact that the axes of the lenses are seldom coincident in a vertical sense, at least three composite sections are needed in order to establish a maximum thickness of exposed strata. Although these strata are not necesarily represented in the outcrops of the axial part of the basin (250 m), Marenssi (1995) reported that the strata or parts of them must be present at the subsurface (370 m), thereby resulting in a stratigraphic thickness of about 620 m. However, this value should be regarded as a minimum thickness of deposited sediments, because the top of each lenticular unit would have eroded. Marenssi (1995) proposed a maximum of thickness of 720 m, based on the sum of the maximum thickness recorded at the axis of each lens. Whereas this value is necessary to calculate the participation of each of the lithofacies in the sedimentary column of the La Meseta Formation and to plot the samples in their correct position, it may yield an erroneous estimate of the stratigraphic thickness. Recent magnetotelluric soundings (Mammani, pers. comm., 1996) have yielded an impedance contrast some 750 m below the surface of the meseta, at the supposed axis of the La Meseta Valley. At another locality, near the southwestern edge of the meseta, this contrast was recorded at a shallower depth and was interpreted as the base of a large channel. In summary, the most accurate estimate of the stratigraphic thickness of the La Meseta Formation, based on the thickness of sediments in the axial region of the basin, is at least 620 meters.

Elliot and Trautman (1982) divided the La Meseta Formation into three informal members (figure 4), which were thought to represent different parts of a prograding deltaic system. Unit I is the prodelta, Unit II the delta front, and Unit III a tide-dominated subaqueous delta plain. More recent and detailed sedimentological studies have shown that the La Meseta Formation represents a more complex and somewhat different set of depositional settings (Marenssi, 1995). Nevertheless, three large-scale units can be recognized based on outcrop characteristics and changes in the overall grainsize of the clastic beds.

Marenssi (1995) presented granulometric analysis of more than 300 samples of a total of 500 studied from this unit. From these data, he concluded that Unit I is composed of 50% muddy, very fine sands, 40% muds and sandy muds, and 10% very fine sands. Unit II comprises 45% very fine to fine sands, 35% muddy, very fine sands, and 20% muds and sandy muds. Unit III is composed of 70% fine to very fine sand, 20% muddy, fine sands, and 10% muds and sandy muds. This progressive coarsening in the sedimentological characteristics of the Elliot and Trautman´s informal members reflects a progressive change in depositional conditions of the La Meseta Formation. There was a transition from a dominantly deltaic stage to an estuarine stage, and finally, to a tide-dominated shelf stage.

In the field, Unit I is characterized by a progressively thicker, coarser upward column dominated by fine grained "muddy", well-stratified sediments with scarce macrofauna. Bioturbation, fossil content, and channel frequency also increase upward. Unit II has an heterogeneous lithology. Shell beds, heterolithic sand-mud alternation, and cross-bedded sands make up most of this part of the column. The macrofauna is diverse and abundant. Unit III bears thick beds of fine-grained sands and concretionary "sandstones", gravel sheets, that are a single clast thick, and thin-shelled mollusks. Based on these well-defined characteristics, we propose that the three lithostratigraphic divisions of the La Meseta Formation (Elliot and Trautman, 1982) be accorded formal status (members), but that they retain the original (I, II, III) designations of Elliot and Trautman (1982).

Member I is 20 m thick at the axial section, but its maximum thickness is 420 m measured at the type section. It comprises a coarsening upward column that begins at the unconformable base of the formation and is composed of silts and interlaminated very fine sands, and muds with large-scale synsedimentary deformational structures. The macrofauna is very scarce compared to the remainder of the formation. This unit principally records deltaic sedimentation within an incised valley. The type section for this member begins at the contact between the Sobral and La Meseta formations along the cliffs near Cape Wiman and trends SSE up to the crest of the highest hill dominating Valle de las Focas (sections A, B, and C in figure 5).

Member II is 90 m thick at the axial section, but has a maximum thickness of 140 m at the type section. It is composed of thick, monotonous, laminated sand/mud alternations, and contains abundant plant debris and bored tree trunks. This gives way to bioturbated muddy sands that coarsen upwards and are replaced by cross-bedded fine sands with mud drapes. Laterally, extensive shell beds dominated by bivalves are intercalated in the sequence. The macrofauna is dominated by robust mollusks. The sequence predominantly records sedimentation in transgressive estuarine settings. The type section is located at the center of the outcrops of the La Meseta Formation and trends east toward the meseta (sections I, E, and F in figure 5).

Member III is 140 m thick at the axial section, but 160 m thick at the type section. It is composed of a predominantly sandy column with layers of pebbles and thin muddy intervals. The sand is fine and either cross-bedded or bioturbated, massive, and muddy. This column presents a slight fining upward tendency. The macrofauna is dominated by thin-shelled mollusks and the phosphatic brachiopod *Lingula* sp. The strata represent sedimentation in

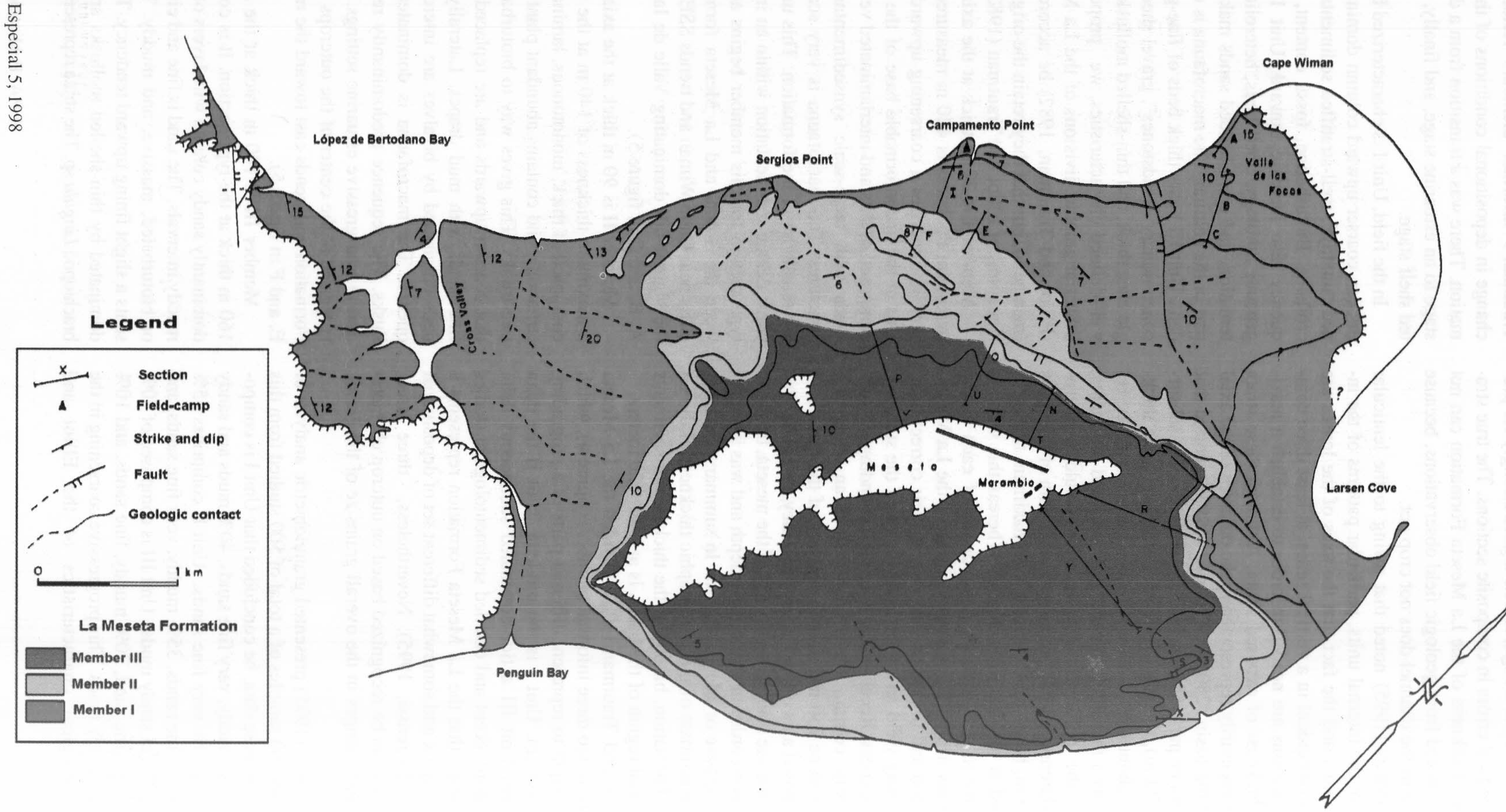

Figure 5. Map showing the distribution of the internal units (Members) of the La Meseta Formation. / *Mapa mostrando la distribución de las unidades internas (Miembros) de la Formación La Meseta.*

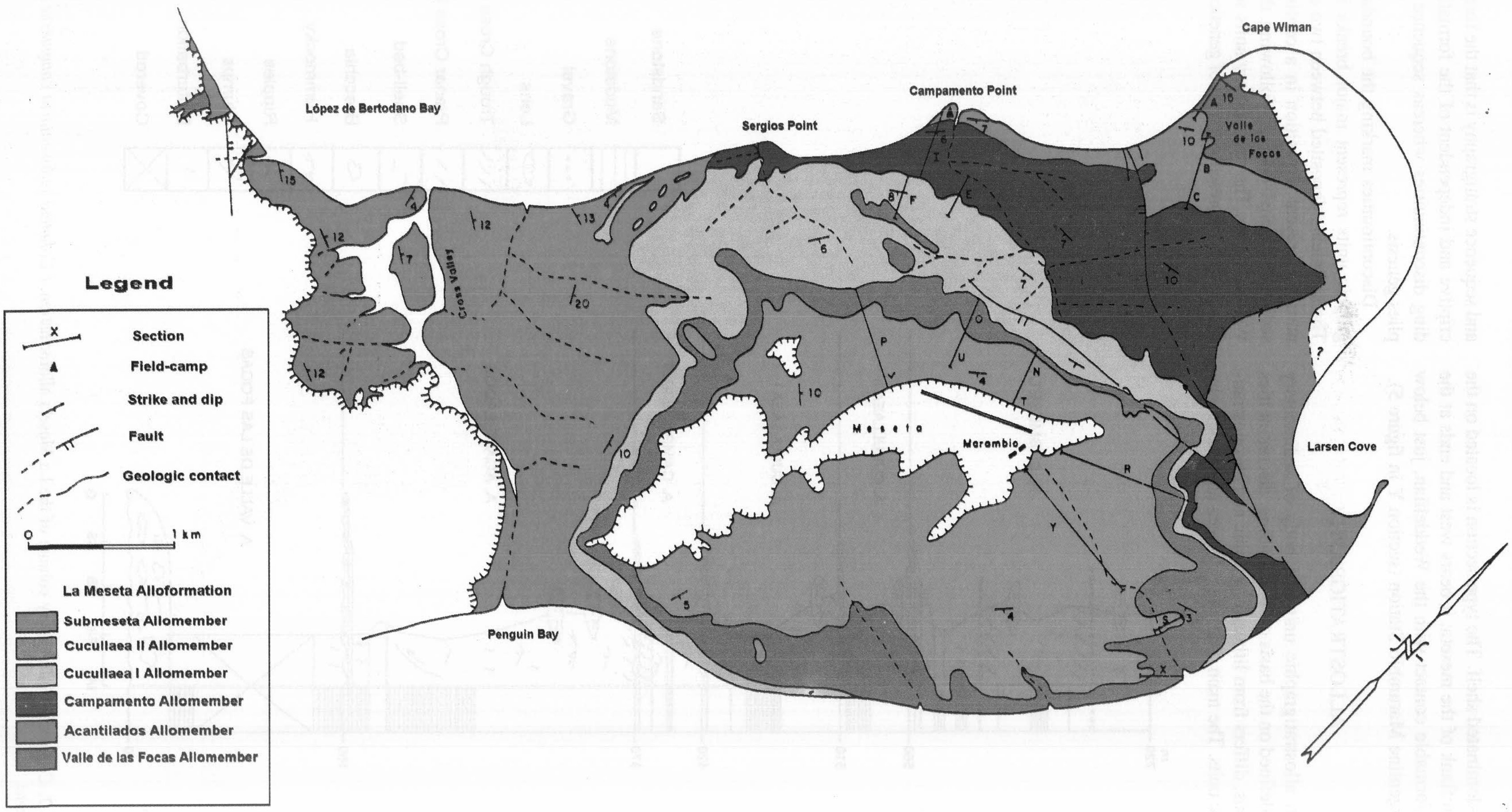

Figure 6. Map showing the distribution of the internal units (allomembers) of the La Meseta alloformation. / *Mapa mostrando la distribución de las unidades internas (alomiembros) de la aloformación La Meseta.*

a tide-dominated shelf. The type section is located on the eastern flank of the meseta; it bears west and ends at the unconformable contact with the Weddellian, just below the Argentine Marambio Station (section Y in figure 5).

ALLOSTRATIGRAPHY

An allostratigraphic unit is a body of sedimentary rocks defined on the basis of its bounding discontinuities and thus, differs from lithostratigraphic and chronostratigraphic units. The main difference between allostratigraphy and sequence stratigraphy is that the former is purely descriptive and independent of the formation of the bounding discontinuities whereas sequence stratigraphy implies genesis.

Discontinuities marking the boundaries of allostratigraphic units represent major breaks in sedimentation. The sediments deposited between two adjacent discontinuities represent deposition in a continuously evolving sedimentary environment, following the predictions of Walther´s Law. The sedimentary units within an allostratigraphic unit represent deposits of genetically related facies.

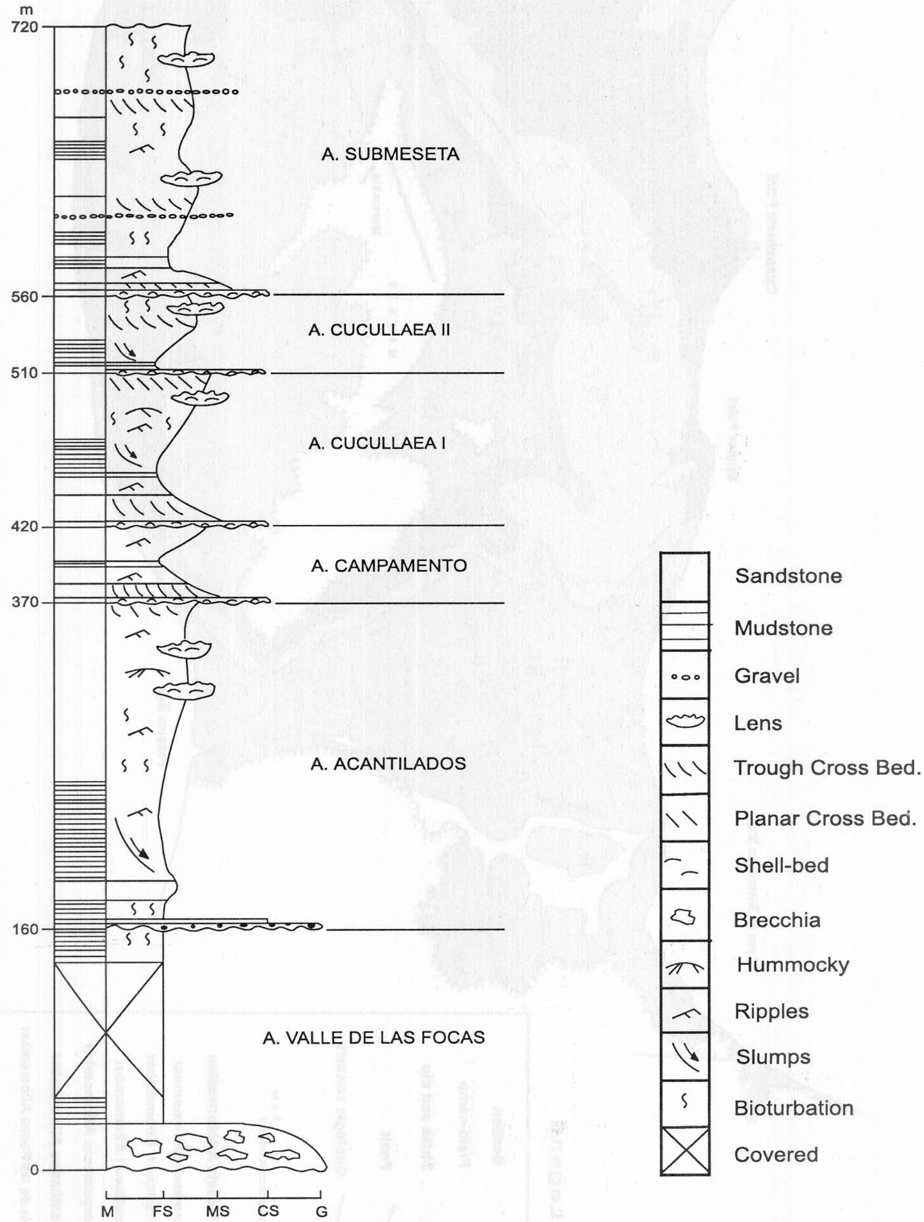

Figure 7. Composite sedimentary column of the La Meseta alloformation. / *Columna sedimentaria compuesta de la aloformación La Meseta.*

As discussed above the strata comprising La Meseta beds are bounded by unconformities allowing the definition of a new allostratigraphic unit. The La Meseta alloformation (*nov. nom.*) crops out in the northern third of Seymour Island. It is 720 m thick, and its boundaries and geographical extension are the same as those of the La Meseta Formation (figure 6).

Detailed field work led to the recognition of five internal discontinuities within the La Meseta alloformation (figure 7) and the division of the alloformation into six allomembers (Marenssi and Santillana, 1994; Marenssi, 1995). All of these surfaces display significant relief (between 5 and 30 m), and most of them are covered by a coarse-grained lithofacies. Any allomember represents a single lenticular architectural element. Their axes commonly are displaced laterally from one to the next, and not stacked vertically, thereby resulting in a nesting of lenticular units (figures 6, 7).

The lowermost unit is named the Valle de las Focas ("Valley of the Seals") allomember, and crops out in the northwestern corner of the island (section A). It is at least 160 m thick, and composed of sedimentary breccias (olistostrome of Elliot and Hoffmann, 1989) and silty muds. Based on the dinoflagellate flora, the age of this unit is late early Eocene (Askin, 1993), and the depositional setting is inferred to be inner estuarine or prodelta (Marenssi, 1995).

The next unit, the Acantilados ("Seacliffs") allomember, crops out along the seacliffs facing López de Bertodano Bay and extends inland toward the east (sections B and C). Its maximum thickness is 210 m, and it comprises a coarsening upward sedimentary column made up of interlaminated sand/mud with large-scale synsedimentary deformational features, cross-bedded and hummocky-bedded, muddy, very fine sands, and lenticular channel fills with coquinas. The depositional setting is interpreted as a prograding delta front to tide-dominated and storm-influenced subaqueous delta plain (Marenssi,1995) developed within the incised valley.

The Campamento ("Camp-site") allomember, crops out in the center of the La Meseta outcrop, from sea level at López de Bertodano Bay and extends inland toward the east, along the NW edge of the meseta (section I). It comprises 50 m of shelly channel fills and mud/sand interlamination with current and wave structures. The depositional setting is interpreted to be outer and middle estuary (Marenssi, 1995).

The Cucullaea I allomember, crops out all around the foothills of the meseta, except for a short segment on the Weddell Sea flank (section F). Its maximum thickness is 90 m, and it is composed of shelly channel fills, sand/mud alternations and cross-bedded fine sands with mud drapes. The depositional setting was described as estuarine to shallow marine off the mouth of the estuary (Marenssi, 1995).

The Cucullaea II allomember is exposed continuously around the meseta (section O). The maximum thickness is 50 m and the lithology and sedimentary environments are the same as the Cucullaea I allomember below (Marenssi, 1995).

The final unit, the Submeseta allomember, is 160 m thick and also crops out continuously around the uppermost flanks of the meseta (sections N and T). Its lithology and depositional setting are similar to the Cucullaea I and Cucullaea II allomembers, although the uppermost segment of cross-bedded sands is thicker and includes bioturbated, muddy, fine sands, and gravel sheets.

Marenssi (1995) interpreted the basal unconformity as cut down into an emergent shelf by rivers during a relative retreat of the sea. The latter may have been caused by regional tectonic uplift that might have been coupled with the late Ypresian global low-stand of the sea level. The deposition of the sediments began after marine flooding of the incised valley. The downcutting occurred after the Marambio Group and the Cross Valley Formation tilted (Elliot *et al.*, 1993; Barnes and Riding, 1994). This tectonic event marked at least partial inversion of the James Ross Basin, therefore, it can not be placed within the Seymour Island Group. Instead, it may be more suitable to include the Cross Valley Formation in the Marambio Group or to leave it as an independent unit and give up the Seymour Island Group. This issue will be addressed in detail in a future paper; therefore no formal proposal is given here.

The unconformity at the top involves a hiatus greater than 30 m.y. and is a surface or regional extent between the non-glacial mega-regressive Cretaceous-Paleogene sequence and the younger glaciomarine strata. All these descriptive details support the view that the La Meseta sediments also constitute a depositional sequence (Mitchum, 1977) or syntem (Chang, 1975).

The relief of the La Meseta aloformation basal unconformity currently observed is some 70-80 m (Sadler, 1988; Marenssi, 1995). However the reconstructed stratigraphy shows that, except for the uppermost allostratigraphic unit (allomember Submeseta), all other units seem to have been located within the incised valley; thus, the valley had a minimum relief exceeding 445 m (depending on the true stratigraphic thickness). Therefore, a purely eustatic sea-level drop can not be invoked to explain such deep erosion. Instead, the genesis of the valley is attributed to tectonism and the erosion associated with the eastward tilting of the basin. The internal stratigraphic and structural features of the La Meseta Valley fill also are best explained by a mixed tectonic-erosional origin for the unconformities, and a sea-level control for the facies distribution (Marenssi, 1995). Thus, the valley margins and the basal unconformity may represent deformational-erosive features as interpreted by Santillana *et al.* (1993: 328) for the northern margin. However weak biostratigraphic control and absence of dated marker beds preclude fitting the descriptive units presented here with the global sea-level curve or evaluating how large the eustatic component would have been.

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