

Heavy mineral suites as provenance indicators: La Meseta Formation (Eocene), Marambio (Seymour) Island, Antarctic Peninsula.

*Sergio A. MARENSSI *#+, Sergio N. SANTILLANA *#,
Laura I. NET #+ y Carlos A. RINALDI *+*

* *Instituto Antártico Argentino. Cerrito 1248, 1010 Buenos Aires, República Argentina.*

Departamento de Ciencias Geológicas, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires. Pabellón II – Ciudad Universitaria, 1428 Buenos Aires, República Argentina.

+ *CONICET. Consejo Nacional de Investigaciones Científicas y Técnicas.*

Abstract. Transparent heavy mineral suites from forty two samples of the Eocene La Meseta Formation, Marambio (Seymour) Island, Antarctica, were studied in order to obtain new data of heavy mineral detrital modes and to assess the source rocks and tectonic setting of the provenance area.

This unit is the youngest formation exposed in the James Ross Basin. It developed at the rear of an active magmatic arc and holds some 6-7 km of Cretaceous-Paleogene clastic sedimentary rocks. The magmatic arc was related to oblique subduction of the Pacific and associated plates below the Antarctic Plate. Calc-alkaline magmatism migrated to the northwest and by Eocene times the arc would have been located some 150 km to the north-northwest of the Marambio area.

The La Meseta Formation represents deltaic, estuarine and shallow marine sediments deposited mostly within a NW-SE incised valley cut down into Late Cretaceous and Paleocene sedimentary rocks. The 720 meters thick sedimentary column has been subdivided into six allomembers. Heavy mineral suites are dominated by green-brown hornblende, green-colorless augite-diopside?, garnet, opaques and epidote with minor amounts of hyperstene, zircon, apatite, kyanite, staurolite, zoisite, sphene and tourmaline. They were determined to represent those originally present in the parent rocks namely the metasedimentary Trinity Peninsula Group (TPG) and the calc-alkaline igneous (mainly volcanic) Antarctic Peninsula Volcanic Group (APVG) cropping out along the Antarctic Peninsula. Although garnets would also come from reworked Cretaceous and Paleocene rocks, textural evidences were not able to demonstrate it. Moreover, the unconsolidated nature of most of the rocks of the basin precludes the preservation of sedimentary rock fragments in the light mineral fraction.

The relative abundances of MF, MT and GM mineral assemblages (Nechaev & Ispahring, 1993) has permitted the characterization of the source area as a convergent continental margin. This is in agreement with most other data from the James Ross Basin.

On the other hand, published data of QFL detrital modes from La Meseta Formation showed an upward increase in quartz and feldspar content interpreted as an unroofing trend. However, the heavy mineral suites do not record the same increase in basement participation, but they keep a high proportion of minerals belonging to the MF association.

Non opaque heavy minerals from the La Meseta Formation have provided new data not recorded through the study of light minerals. In this particular case, they allowed to challenge earlier hypothesis of a simple unroofing trend and to envisage a more complex scenario with a still active volcanism for the Eocene of the northern Antarctic Peninsula.

Key words: Heavy mineral suites, Provenance, Eocene, Antarctica.

Palabras clave: Asociación de minerales pesados, Procedencia, Eoceno, Antártida.

RESUMEN EXPANDIDO

Con el fin de establecer las rocas que actuaron como fuente de sedimentos y el régimen tectónico del área de procedencia, se estudiaron las asociaciones de minerales pesados translúcidos de cuarenta y dos muestras de la Formación La Meseta (Eoceno), aflorante en la isla Marambio (Seymour), Antártida.

La Formación La Meseta representa la unidad más joven reconocida para la Cuenca James Ross. Esta cuenca se desarrolló por detrás de un arco magmático acumulando durante el Cretácico y el Paleógeno entre 6 y 7 km de sedimentos. Dicho arco magmático fue generado a partir de la subducción de la Placa Pacífica por debajo de la Placa Antártica. El magmatismo calco-alcalino fue migrando con el tiempo debido a la subducción oblicua y para el Eoceno se habría localizado a unos 150 km al NNW de la isla Marambio.

La Formación La Meseta comprende sedimentitas de ambientes deltaicos, estuáricos y de plataforma mareal depositados mayormente dentro de un valle incidido con rumbo NW-SE que ha sido labrado sobre depósitos previos del Cretácico superior y Paleoceno. La asociación de minerales pesados está dominada por hornblenda verde y castaña, augita y/o diópsido incoloro a verde, granate y epidoto, con participación menor de opacos, hipersteno, cianita, estaurolita, titanita, circón, zoicita, turmalina y apatito. Se estableció que estos minerales se hallan presentes en las metasedimentitas del Grupo Trinity Peninsula (TPG) y en rocas ígneas (predominantemente volcánicas) calcoalcalinas del Grupo Volcánico Antarctic Peninsula (APVG) que afloran extensamente en la Península Antártica. Aún cuando los granates podrían provenir del retrabajo de rocas sedimentarias cretácicas y paleocenas, no hay evidencias que permitan demostrarlo.

El análisis de la abundancia relativa de las asociaciones minerales MF, MT y GM permitió caracterizar el área de procedencia como un margen continental convergente. Esta asignación es concordante con otros estudios realizados en la Cuenca James Ross.

Por otra parte, en estudios previos que involucraron la fracción de minerales livianos, las modas detriticas QFL indican el progresivo descabezamiento del arco magmático. Sin embargo las asociaciones de minerales pesados no muestran un cambio concomitante con esa tendencia y mantienen una alta participación de minerales pertenecientes a la asociación MF.

El estudio de los minerales pesados translúcidos ha aportado nueva información que permite confrontar la hipótesis de un descabezamiento simple del arco magmático y sugerir un contexto más complejo con vulcanismo aún activo durante el Eoceno.

INTRODUCTION

Although heavy minerals have been recognized to indicate source rocks, problems with their chemical stability and density-driven selective deposition prevented their extensive use as provenance indicators. The application of QFL detrital modes and geochemical analysis have become the rule for determining provenance of siliciclastic sedimentary rocks. However, recently Nechaev & Ispahordig (1993) have showed the potential of heavy mineral assemblages as indicators of plate-tectonic environments.

The Eocene La Meseta Formation (Elliot & Trautman, 1982) is included in the Seymour Island Group representing the youngest unit of the sedimentary infill of the James Ross Basin (del Valle *et al.*, 1992) cropping out on Marambio (Seymour) and Cockburn islands (Fig. 1). The provenance of these sedimentary rocks and specially the tectonic setting of the source area have been approached mainly from the study of the light mineral detrital modes (Trautman, 1977; Elliot & Trautman, 1982; Pezzetti, 1987; Marenssi, 1995).

Specific references to La Meseta Formation heavy minerals come from Trautman (1977), Pezzetti (1987), Browne (1995) and Marenssi (1995). The first of them point-counted 15 sandstones and found that heavy minerals form up to 5% of the total, being the hornblende the most abundant species. The second one analyzed only the medium sand size fraction of 16 samples which contained 0 to 9% of heavy minerals; the lower 400 meters of the unit were not represented because these samples contained less than 1% of them. Browne (1995) point-counted the very fine sand size fraction of only two samples from the lower half of La Meseta Formation (unknown localities) and provided quantitative data of each identified species, indicating that opaques are by far the most abundant heavy minerals (75%) followed by hornblende (13.3%), garnet (3.2%), zircon (3.2%) and epidote (1.2%). Finally, this paper is based on the database presented by Marenssi (1995) who analyzed the fine sand fraction of some 70 samples but point-counted only those containing more than 1% of heavy minerals corresponding to the upper half of the unit (Fig. 2).

The aim of this paper is to present data of heavy mineral detrital modes obtained for La Meseta Formation, to associate each suite to their probable source rock and to discuss the tectonic setting of the source area based on heavy mineral assemblages.

GEOLOGICAL SETTING

The James Ross Basin (del Valle *et al.*, 1992) constitutes the northern sub-basin of the larger Larsen Basin (Macdonald *et al.*, 1988) developed behind an

Heavy mineral suites as provenance indicators: La Meseta Formation (Eocene), Antarctic Peninsula.

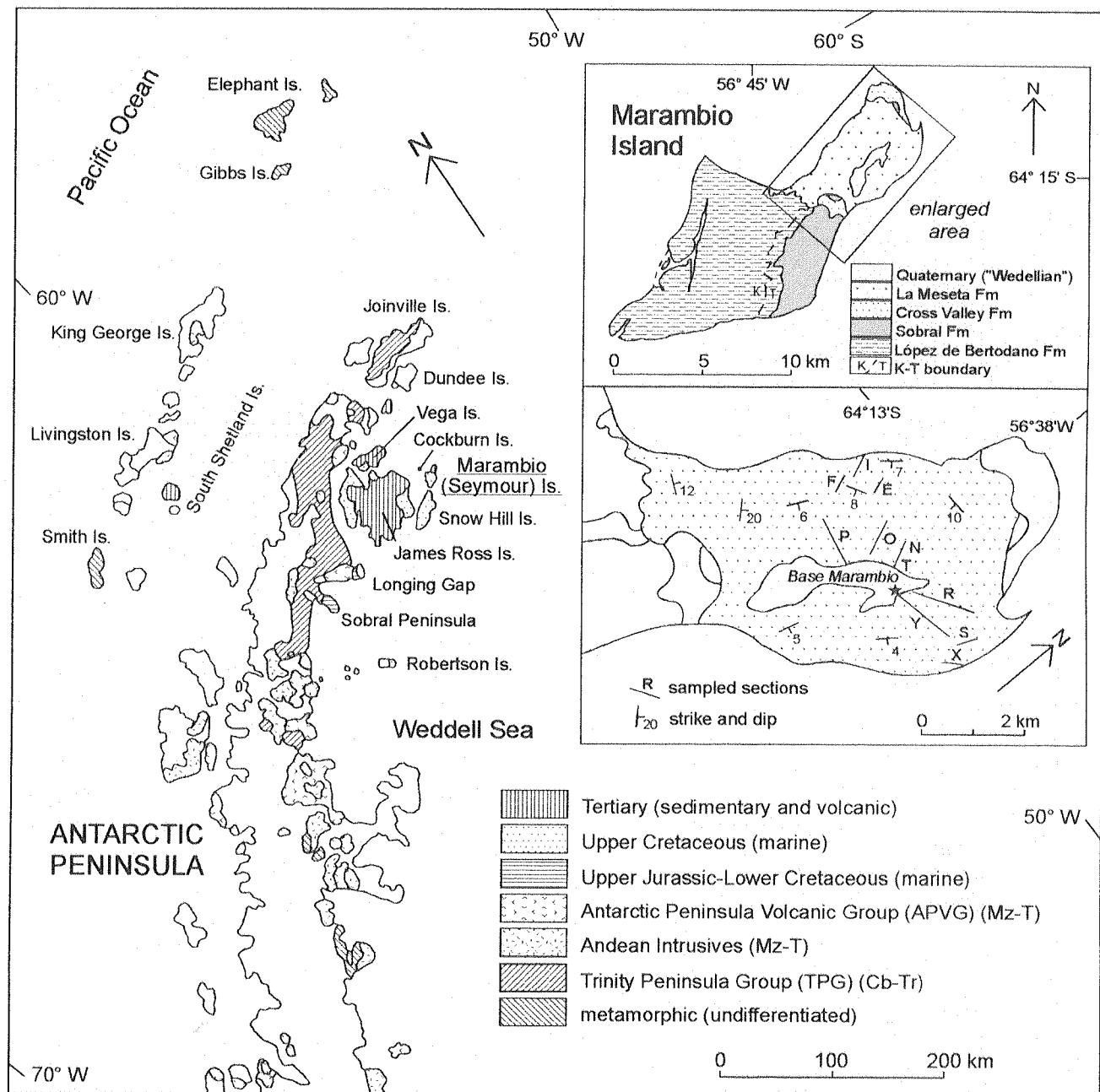


Figure 1. Geologic sketch map of the northern Antarctic Peninsula and location of the Marambio (Seymour) Island (after Sadler, 1988 and Macellari, 1993). Enlarged areas show the geology of the study area and sampling locations.

Figura 1. Mapa geológico simplificado del extremo norte de la Península Antártica y ubicación de la isla Marambio (Seymour) (según Sadler, 1988 y Macellari, 1993). Las áreas detalladas muestran la geología del área de estudio y los perfiles muestreados.

active magmatic arc (Fig. 3). Its history is closely tied to the north-eastward subduction of the Pacific and associated plates below the Antarctic Plate. Magmatism connected with subduction of the Phoenix Plate (Barker, 1982) is represented by plutonic and volcanic rocks exposed along the northern Antarctic Peninsula and the offshore islands to the west. Dating of these rocks demonstrates a northwestward migration of the magmatic

activity that during the Paleogene was concentrated along the South Shetland Islands (Elliot, 1997). Taking into account the Late Cenozoic opening of the Bransfield Basin, the Marambio Island area would have been located some 150 km to the southeast of the principal magmatic arc and about 300 km from the trench (Elliot, 1997).

Additionally, northwestward subduction of Weddell Sea oceanic crust in the Scotia Sea region during the

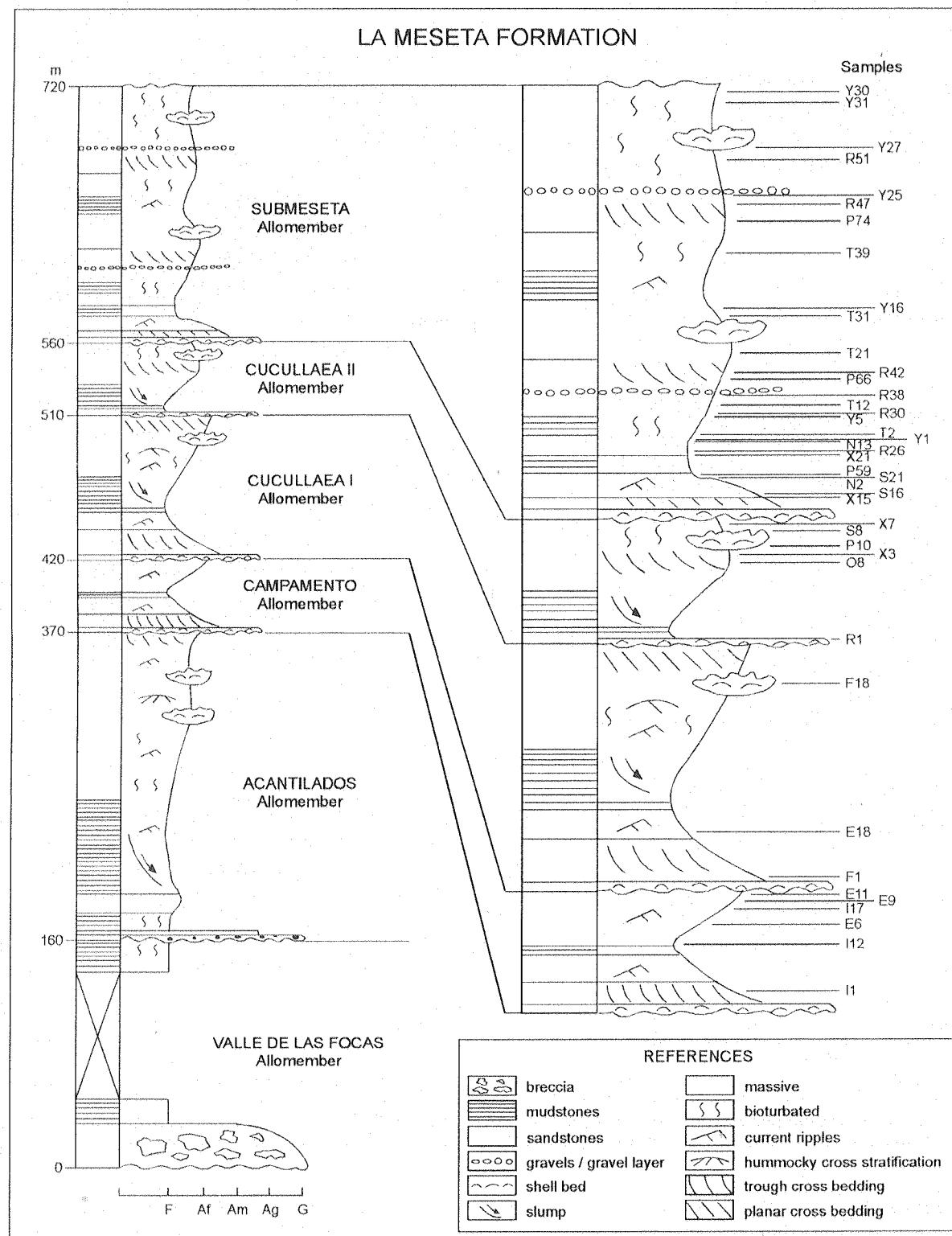


Figure 2. Simplified stratigraphic column of the La Meseta Formation showing the location of the samples.
Figura 2. Columna estratigráfica esquemática de la Formación La Meseta mostrando la ubicación de las muestras.

Paleogene has been recently suggested by Elliot (1997) based on the study of Paleocene volcaniclastic rocks on

Marambio Island.

In spite of being classified as a backarc basin

Heavy mineral suites as provenance indicators: La Meseta Formation (Eocene), Antarctic Peninsula.

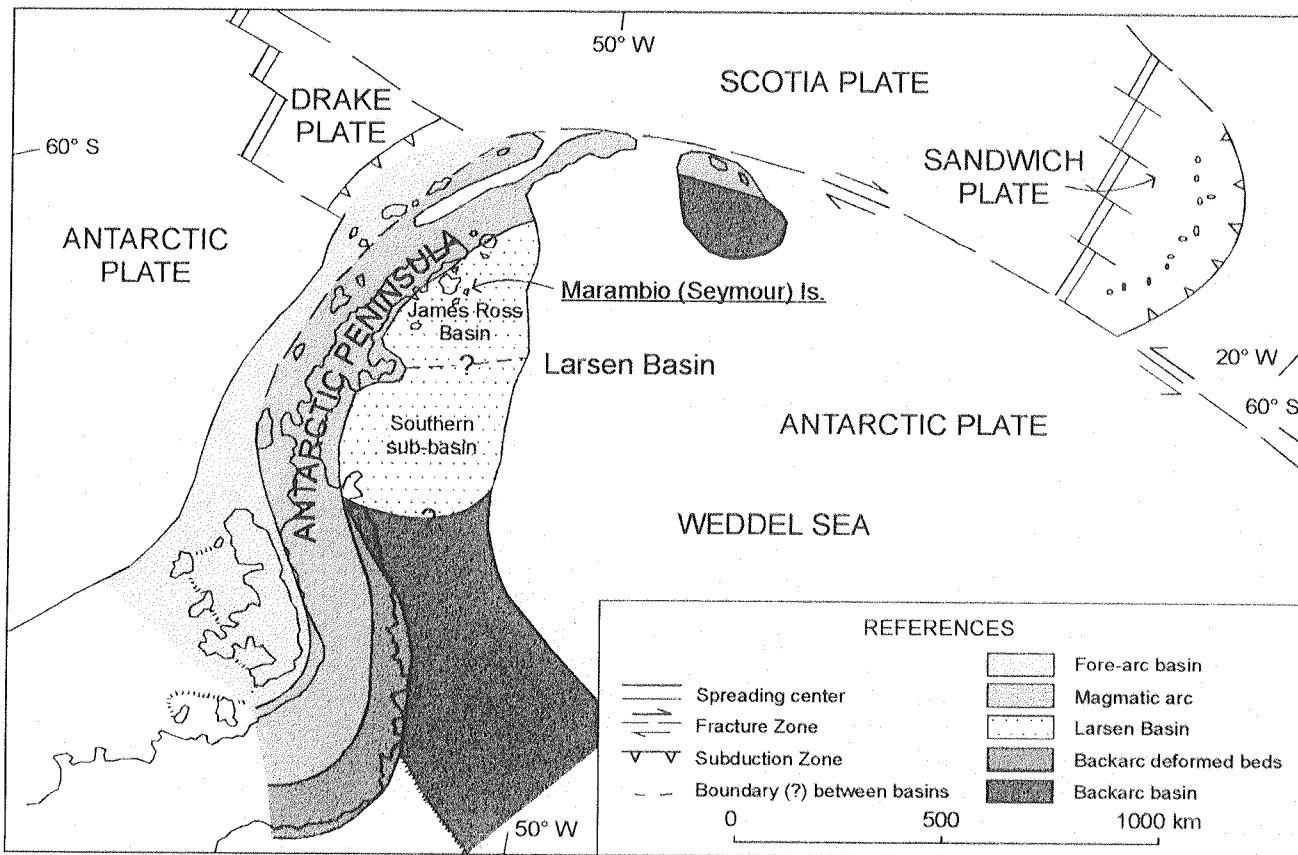


Figure 3. Present geotectonic setting and lithotectonic units for the Antarctic Peninsula (after Elliot, 1988).
Figura 3. Ambientes geotectónicos actuales y unidades litotectónicas para la Península Antártica (según Elliot, 1988).

(Macdonald et al., 1988) regarding its location with respect to the active magmatic arc (the Antarctic Peninsula), the evolution of the James Ross Basin might have been complicated by strike-slip or oblique extension along the eastern margin of the Antarctic Peninsula which may have controlled the development of sedimentary basins along this margin (Storey & Nell, 1988). The eastern margin of the Antarctic Peninsula continental crust abuts the Weddell Sea floor but unfortunately details of this continent-ocean boundary are lacking. This margin may be a passive margin originated during the early stages of the Gondwana dispersal (opening of the Weddell Sea) or a transform boundary now deeply buried by sediment derived from the arc (Elliot, 1988). During Paleogene times it may have been located about 100 km to the southeast of the Marambio area (Elliot, 1997). Additionally, there is no evidence of an elevated heat flow (Ineson, 1989), typical of most back-arc basins. Moreover, it is likely that during Marambio Group deposition (Upper Cretaceous-Paleocene) the area was a continental shelf acting as the passive extending margin of the Weddell Sea (Pirrie, 1994).

Taking in account the aforementioned, we envisage that the Eocene James Ross Basin would have acted as a passive continental margin basin, receiving sediments mainly from a magmatic arc located along an active continental margin.

The James Ross Basin is filled up with a mega-regressive clastic sequence 6-7 km thick of Barremian to Oligocene age (Macdonald et al., 1988). It has been divided into three groups, named from older to younger Gustav (Lagrelius Point, Kotick Point, Whisky Bay and Hidden Lake Formations), Marambio (Santa Marta, Rabot, López de Bertodano and Sobral Formations) and Seymour Island (Cross Valley and La Meseta Formations) (Ineson et al., 1986; Elliot & Trautman, 1982; Olivero et al., 1986; Marenssi et al., 1992). Volcanism was intermittent since the Jurassic up to the Paleocene as well as sinsedimentary tilting of the beds.

In summary, an active proximal magmatic arc supplied sediments to the James Ross Basin from Cretaceous to Paleocene times, and distal sources persisted at least during Eocene times.

La Meseta Formation crops out on the northern third of Marambio (Seymour) Island (Fig. 1). Recent detailed

stratigraphic and sedimentological work allowed Marenssi (1995) to distinguish six erosionally-based internal units, named from base to top Valle de Las Focas, Acantilados, Campamento, Cucullaea I, Cucullaea II and Submeseta allomembers (fig. 2). This 720 m thick unit represents a composite, tectonically controlled, incised valley system cut into Maastrichtian to Paleocene rocks (Marenssi, 1995; Marenssi et al., 1996). Deposition took place during Eocene times in deltaic, estuarine and shallow marine settings mostly within a NW-SE trending valley (Marenssi, 1995). Sediments were delivered to the basin by fluvial transportation and subsequently reworked by waves and tides. Paleocurrent measurements, although sparse, consistently indicate dispersal to the SE (Marenssi, 1995). The climate in the source area evolved from humid warm during the late Early Eocene to cold and dry toward the Eocene-Oligocene boundary (Dingle & Lavelle, 1998).

METHODOLOGY

There are two main approaches to the study of heavy minerals. One is to analyze the entire size fraction and the second is to study a relatively narrow size fraction. The method adopted for this study was the selection of one fraction in order to produce uniform observational conditions, to remove apparent variations in heavy mineral proportions caused by grain size, and to reduce the effect of hydraulic sorting. This would involve the risk of having undetected from minerals if they were only present in other grain size ranges. However, it seems to be unlikely as far as the number of mineral species recognized in this paper is greater than any other quoted previously for La Meseta Formation obtained from different techniques, rock types and grain sizes (Trautman, 1977; Pezzetti, 1987; Browne, 1995). The only variation detected was a subtle increase in zircon content in the very fine sand-sized fraction.

The 0,125-0,25 mm size fraction (fine sand) of 42 samples from the upper half of La Meseta Formation were separated by wet sieving during grain-size analysis and heavy minerals were isolated using tribromomethane (S.G. 2.9 g/cm³). Heavy minerals were identified using standard petrographic procedures. Mineral abundance were then determined by counting between 200 and 300 grains in each mount (Table 1). Opaque heavy minerals were not taken into account for this study.

Some researchers have studied and published data from other grain-size fractions. Specifically, Nechaev & Ishphording (1993) derived their graphs from the 0,05-0,1 mm size fraction but they confirmed the possibility of contrasting the results in the coarse silt to fine sand range.

PETROGRAPHY

Sandstones compose approximately 70 % of the bulk of the La Meseta Formation (Marenssi, 1995). They range from very fine to fine (occasionally medium) grained arenites and wackes, well to poorly sorted. Most of them (fairly 90%) are exposed as loose or very weakly consolidated and the rest as carbonate-cemented concretionary horizons. Petrographically, they are mainly feldspathic arenites and wackes (Dott, 1964 modified by Williams et al., 1982) or lithic feldsarenites (Folk et al., 1970). The matrix content ranges from 0 to 50%.

Heavy minerals constitute from 0,1 to 21,5 weight percent of the total sample but common values range from 0,5 to 7% with mean of 1,6% (Marenssi, 1995). The percentage of heavy minerals roughly increases from the base to the top of the formation following the coarsening-up trend within the unit and reflecting the transition from deltaic/estuarine to shallow marine environments (Marenssi, 1995). The muddy lower half of the La Meseta Formation provided no samples suitable for point counting since they contain less than 0,5% of heavy minerals, although a qualitative determination of heavy minerals suites showed to be essentially consistent with the upper half. Therefore we present here quantitative data from Campamento, Cucullaea I, Cucullaea II and Submeseta allomembers (Fig. 2).

The identified minerals are: hornblende (green and brown), garnet (colorless and pink), epidote, opaques, augite, diopside, hyperstene, apatite, basaltic hornblende, zircon, titanite, zoisite, kyanite, staurolite, tourmaline and micas. However, except for the micas, only the first seven are volumetrically important.

One of the arguments against the use of heavy minerals in provenance studies is related to their low chemical and mechanical stability and their survival time during transportation and diagenesis. However, studies carried out on rocks of the underlying Marambio Group have shown that they have never been deeply buried (less than 1 km) nor exposed to more than 80° C (Whitham & Marshall, 1988; Pirrie, 1991; Pirrie et al., 1994). Additionally, La Meseta heavy minerals show no petrographic evidence of intrastral solution or replacement in the poorly consolidated sandstones (concretionary levels were not taken into account for this study due to extensive cementation and replacement of grains observed in thin sections). Therefore selective chemical destruction of the minerals due to diagenesis seems unlikely. Furthermore, the presence of minerals of low to moderately low mechanical stability like kyanite, augite, hyperstene and hornblende (Boggs, 1992, p. 328, tables 8.4 and 8.5) supports the assumption that the heavy mineral suite recorded from the La Meseta Formation closely reflects those minerals originally present in the parent rocks. Some more resistant minerals, as garnet and

Heavy mineral suites as provenance indicators: La Meseta Formation (Eocene), Antarctic Peninsula.

Sample	M (phi)	So	MF			GM			Ap	MF	MT	GM	Ol+Id+Cpx1	Hb	Opx+Cpx2		
			Hb	Opx	Cpx2	Ep	Gr	Zr									
Submeseta allomember																	
Y30	VFS	PS	56,9	2,8	6,0	4,8	29,5	-	-	-	65,7	34,3	0,0	0,0	86,6	13,4	
Y31	VFS	PS	55,8	4,2	7,5	7,1	24,7	-	-	0,8	68,0	32,0	0,0	0,0	82,7	17,3	
Y27	VFS	PS	56,4	3,5	6,4	5,2	28,2	-	-	0,3	66,5	33,5	0,0	0,0	85,1	14,9	
R51	FS	PS	50,9	1,7	8,1	19,7	19,7	-	-	-	60,7	39,3	0,0	0,0	83,8	16,2	
Y25	FS	PS	50,0	0,5	20,8	15,0	13,6	-	-	-	71,4	28,6	0,0	0,0	70,1	29,9	
R47	MS	MS	30,2	3,4	5,4	23,4	36,9	0,4	-	0,4	39,1	60,5	0,4	0,0	77,5	22,5	
P74	FS	MS	51,5	1,3	5,7	26,9	14,5	-	-	-	58,6	41,4	0,0	0,0	88,0	12,0	
T39	VFS	PS	58,6	2,5	4,0	14,6	20,2	-	-	-	65,2	34,8	0,0	0,0	89,9	10,1	
Y16	FS	WS	62,8	4,2	4,7	21,4	6,4	-	-	0,5	72,1	27,9	0,0	0,0	87,6	12,4	
T31	MS	PS	33,1	2,5	5,1	17,8	41,5	-	-	-	40,7	59,3	0,0	0,0	81,3	18,7	
T21	VFS	PS	33,7	1,0	10,9	23,8	30,1	0,5	-	-	45,6	53,9	0,5	0,0	73,9	26,1	
R42	VFS	PS	52,0	1,5	4,0	39,9	2,5	-	-	-	57,6	42,4	0,0	0,0	90,3	9,7	
P66	FS	MS	44,6	0,5	10,4	21,3	23,3	-	-	-	55,4	44,6	0,0	0,0	80,3	19,7	
R38	FS	PS	42,2	2,2	7,6	31,4	16,8	-	-	-	51,9	48,1	0,0	0,0	81,2	18,8	
T12	VFS	PS	45,9	1,0	13,4	20,6	19,1	-	-	-	60,3	39,7	0,0	0,0	76,1	23,9	
R30	FS	PS	38,3	-	12,0	29,0	20,8	-	-	-	50,3	49,7	0,0	0,0	76,1	23,9	
Y5	FS	MWS	30,7	3,1	22,7	36,8	6,1	0,6	-	-	56,4	42,9	0,6	0,0	54,3	45,7	
T2	FS	WS	65,0	-	7,0	19,1	8,9	-	-	-	72,0	28,0	0,0	0,0	90,3	9,7	
Y1	FS	MS	43,2	7,9	4,5	33,1	10,1	-	0,6	0,6	56,0	43,4	0,6	0,0	77,7	22,3	
N13	VFS	MS	64,2	-	9,4	7,6	17,0	-	1,9	-	73,6	24,5	1,9	0,0	87,2	12,8	
R26	FS	MS	30,1	-	21,2	34,2	14,5	-	-	-	51,3	48,7	0,0	0,0	58,6	41,4	
X21	FS	PS	56,3	2,6	5,6	25,4	8,7	0,4	-	0,9	65,1	34,4	0,4	0,0	87,2	12,8	
P59	FS	MS	59,5	1,0	10,3	25,2	3,5	-	-	0,5	71,2	28,8	0,0	0,0	84,0	16,0	
S21	FS	MS	48,2	4,1	10,2	21,3	16,2	-	-	-	62,4	37,6	0,0	0,0	77,2	22,8	
N2	FS	PS	39,2	-	11,5	13,4	35,9	-	-	-	50,7	49,3	0,0	0,0	77,4	22,6	
S16	FS	PS	35,0	2,2	23,7	14,5	24,2	0,5	-	-	60,8	38,7	0,5	0,0	57,5	42,5	
X15	MS	MS	36,9	3,5	10,9	11,8	36,4	-	-	0,5	51,5	48,5	0,0	0,0	72,0	28,0	
mean			47,1	2,6	10,0	20,9	19,6	0,5	1,9	0,6	0,6	59,3	40,6	0,2	0,0	79,0	21,0
st. dev.			11,1	1,7	5,8	9,5	10,8	0,1	0,0	0,0	0,2	9,6	9,6	0,4	0,0	9,8	9,8
Cucullaea II allomember																	
X7	FS	MS	45,7	7,1	8,1	18,6	20,5	-	-	-	61,0	39,1	0,0	0,0	75,0	25,0	
S8	FS	PS	45,9	1,5	13,0	26,1	13,5	-	-	-	60,4	39,6	0,0	0,0	76,0	24,0	
P10	MS	MS	27,3	4,6	8,8	29,4	29,9	-	-	-	40,7	59,3	0,0	0,0	67,1	32,9	
X3	FS	MS	50,9	2,8	22,9	10,1	13,3	-	-	-	76,6	23,4	0,0	0,0	66,5	33,5	
O8	MS	MS	31,0	1,5	16,2	12,2	39,1	-	-	-	48,7	51,3	0,0	0,0	63,5	36,5	
R1	VFS	PS	24,1	1,5	9,7	36,9	27,7	-	-	-	35,4	64,6	0,0	0,0	68,1	31,9	
mean			37,5	3,2	13,1	22,2	24,0	0,0	0,0	0,0	0,0	53,8	46,2	0,0	0,0	69,4	30,6
st. dev.			11,3	2,3	5,7	10,4	10,1	0,0	0,0	0,0	0,0	15,2	15,2	0,0	0,0	5,0	5,0
Cucullaea I allomember																	
F18	FS	MWS	58,4	0,8	18,7	11,3	10,9	-	-	-	77,8	22,2	0,0	0,0	75,0	25,0	
E18	FS	MS	43,3	1,8	15,5	19,1	20,3	-	-	-	60,6	39,4	0,0	0,0	71,4	28,6	
F1	FS	PS	14,0	-	14,0	5,6	66,5	-	-	-	27,9	72,1	0,0	0,0	50,0	50,0	
mean			38,6	1,3	16,1	12,0	32,6	0,0	0,0	0,0	55,5	44,5	0,0	0,0	65,5	34,5	
st. dev.			22,6	0,7	2,4	6,8	29,7	0,0	0,0	0,0	25,3	25,3	0,0	0,0	13,5	13,5	
Campamento allomember																	
E11	FS	PS	26,0	0,5	25,4	12,4	35,7	-	-	-	51,9	48,1	0,0	0,0	50,0	50,0	
E9	MS	MS	32,9	2,6	15,8	20,9	27,8	-	-	-	51,3	48,7	0,0	0,0	64,2	35,8	
I17	VFS	PS	33,1	2,5	5,1	17,8	41,5	-	-	-	40,7	59,3	0,0	0,0	81,3	18,7	
E6	FS	MS	25,2	0,8	17,9	19,5	35,8	0,8	-	-	43,9	55,3	0,8	0,0	57,4	42,6	
I12	VFS	PS	33,9	-	12,5	33,9	16,1	3,6	-	-	46,4	50,0	3,6	0,0	73,1	26,9	
I1	FS	MS	37,2	-	20,9	27,9	14,0	-	-	-	58,1	41,9	0,0	0,0	64,0	36,0	
mean			31,4	1,6	16,3	22,1	28,5	2,0	0,0	0,0	0,0	48,7	50,6	0,7	0,0	65,0	35,0
st. dev.			4,8	1,1	7,0	7,7	11,3	2,0	0,0	0,0	0,0	6,3	6,1	1,4	0,0	11,1	11,1
Mean all allomembers			42,8	2,5	11,8	20,6	22,4	1,0	1,9	0,6	0,6	56,7	43,1	0,2	0,0	74,7	25,3
St. dev. all allomembers			12,6	1,7	6,2	9,3	12,8	1,1	0,0	0,0	0,2	11,7	11,7	0,6	0,0	11,2	11,2

Table 1. Database of the non-opaque heavy minerals determined for the La Meseta Formation samples. M(phi)=mean grain size of the samples in phi units; VFS=very fine sand; FS=fine sand; MS=medium sand. So=Sorting: PS=Poorly sorted; MS=moderately sorted; MWS=moderately well sorted; WS=well sorted. HB=hornblende; Opx=orthopyroxene; Cpx2=clinopyroxene (green diopside-augite); Ep=epidote; Gr=garnet; Zr=zircon; Tm=tourmaline; Ky=kyanite; Ap=apatite.

Tabla 1. Base de datos de los minerales pesados no opacos determinados en las muestras de la Formación La Meseta. M(phi)=media del tamaño de grano de la muestra en unidades phi: VFS=arena muy fina; FS=arena fina; MS=arena mediana. So=selección: PS=Pobemente seleccionada; MS=moderadamente seleccionada; MWS=moderadamente bien seleccionada; WS=bien seleccionada. HB=hornblendita; Opx=ortopiroxeno; Cpx2=clinopiroxeno (diopsido-augita verde); Ep=epidoto; Gr=granate; Zr=circón; Tm=turmalina; Ky=cianita; Ap=apatita.

zircon, may also indicate reworking of basinal Cretaceous-Paleocene sediments. This is specially true for the upper levels of the Marambio Group and the Cross Valley Formation rocks since they are cut by the La Meseta Formation paleo-valley. However, the shape (subhedral to euhedral) and roundness (subrounded to subangular) of these minerals are similar to that of the rest of the heavy suite, precluding a reliable discrimination between first cycle and reworked grains. An additional tool to recognize reworked sediments, like the presence of basinal sedimentary rock fragments in the light mineral association, could not be used here since most of the rocks of the basin are fine grained and poorly consolidated.

PROVENANCE FROM HEAVY MINERAL SUITES

Source rock lithology.

Most of the research on provenance of siliciclastic sedimentary rocks using heavy mineral suites has been concerned with attempts to interpret source rock lithology. Specifically, Boggs (1992, p 327, table 8.3) provides a list of the heavy-mineral suites characteristic of principal kinds of rocks.

From our samples we have found that in spite of its presence in different source rocks, hornblende in the James Ross Basin is strongly associated to intermediate volcanic rocks (Macellari, 1993; Hoffman, 1991). Garnets may come either from volcanic rocks, granitic pegmatites, contact metamorphites or dynamothermal metamorphic rocks. Epidote, kyanite and zoisite represent dynamothermal metamorphic rocks, although epidote may also suggest the existence of mafic to intermediate igneous rocks subjected to alteration or low-grade metamorphism (Elliot et al., 1992). Augite, diopsid and hyperstene represent basic to intermediate igneous rocks. Apatite, titanite and zircon all are thought to come from acidic igneous rocks.

In summary, heavy minerals of La Meseta Formation indicate two main types of primary source rocks: dynamothermal metamorphites represented by epidote, garnet, kyanite, staurolite and zoisite, and basic to intermediate igneous rocks revealed by the presence of hornblende, augite, diopsid and hyperstene. A third subordinated acidic igneous source is suggested by apatite, titanite and zircon. A fourth source from recycling through sedimentary rocks can not be ruled out for garnets and zircons.

Tectonic setting of the source area.

Determining source rock lithology is only a part of

the process of provenance analysis. Other important part is to understand the tectonic setting of the provenance area. Assessing of plate tectonic setting encompasses two features: major provenance terrains and types of plate boundaries.

The model of Nechaev & Ispahordig (1993) involves the second point. They have grouped heavy minerals in three main associations called MF (related to common mafic minerals of magmatic rocks: olivine, iddingsite, all pyroxenes and green-brown hornblende), MT (indicative of common minerals of basic metamorphic rocks like greenstones, greenschists and amphibolites: pale-colored and blue-green amphiboles, epidote and garnet) and GM (indicative of granitic and silicic metamorphic complexes: zircon, tourmaline, staurolite and less commonly sillimanite, andalusite, monazite and kyanite), providing that the relative abundance of key subsets of the minerals forming the former assemblages can be used as indicators of various tectonic settings associated with continental margins.

Tectonic settings associated with both continental margins and volcanism may be distinguished in more detail by relative abundance of Ol+Id+Cpx1 (olivine, iddingsite and brown, titanium-rich augite), Hb (hornblende) and Opx+Cpx2 (orthopyroxene and green diopside-augite). In this case the first three minerals indicate rifting or intraplate volcaniclastic material, and the last two species suggest arc type volcaniclastic material.

Samples from the La Meseta Formation (Table 1) plot within the active continental margin field on the MF-MT-GM triangle (Fig. 4a) and in the convergent plate boundary field of the Ol+Id+Cpx1-Hb-Opx+Cpx2 triangle (Fig. 4b). The convergent plate boundary indicated from this data is in accordance with most of the evidence available for the James Ross Basin.

DISCUSSION

Either paleocurrent measurements as light mineral petrographic analysis published for La Meseta Formation testify a provenance from the northwest of Marambio Island at the location of the Antarctic Peninsula (Trautman, 1977; Elliot & Trautman, 1982; Pezzetti, 1987; Marenssi, 1995).

The Antarctic Peninsula was an active magmatic arc during most of the Mesozoic and Tertiary times but, at least in the northwest, the batholithic core is not exposed. The arc shed the bulk of the detritus sedimented in the James Ross Basin. The background sources were the low-grade metamorphic complex of the Trinity Peninsula Group (TPG), the calc-alkaline volcanics from the Antarctic Peninsula Volcanic Group (APVG), and a minor acid plutonic (APVG-cohorts or Andean Intrusive Suite)

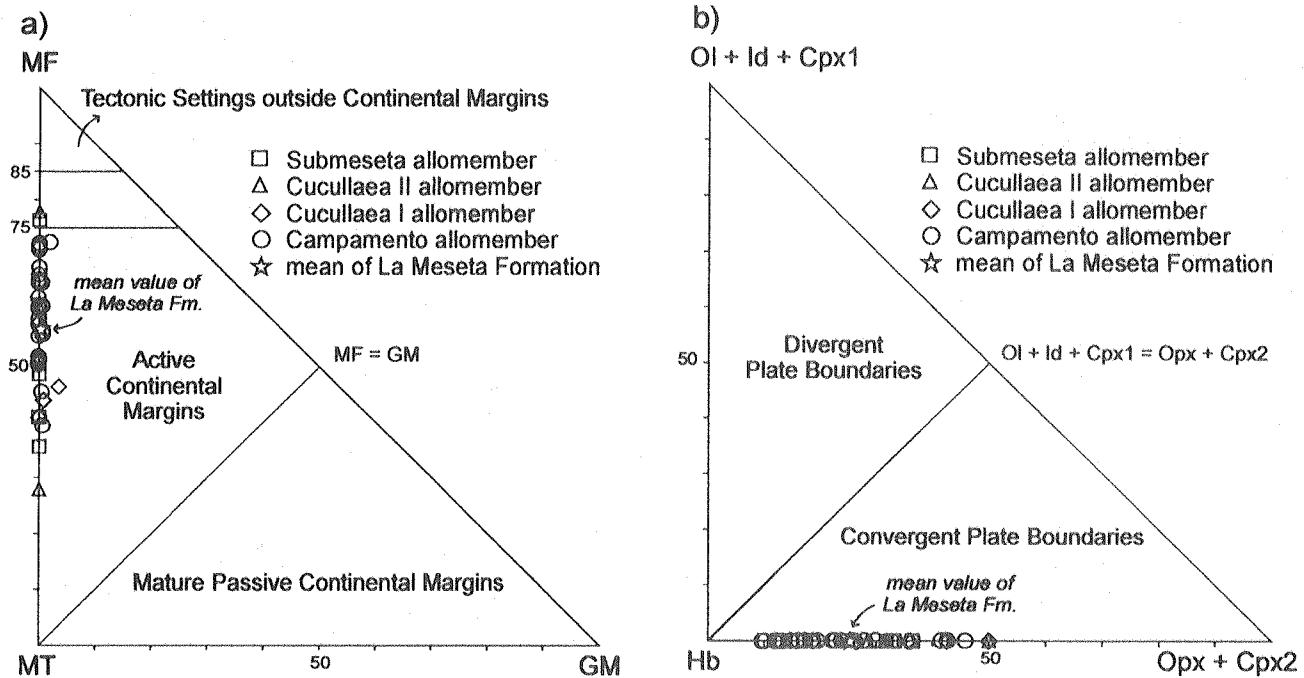


Figure 4. Plotting of the La Meseta Formation transparent heavy mineral associations in the a) MF-MT-GM and b) OI+Id+Cpx1-Hb-Opx+Cpx2 diagrams of Nechaev & Ispahring (1993). Stars indicate mean values.

Figura 4. Diagrama de las asociaciones de minerales pesados traslúcidos de la Formación La Meseta en los gráficos a) MF-MT-GM y b) OI+Id+Cpx1-Hb-Opx+Cpx2 de Nechaev & Ispahring (1993). Las estrellas indican los valores medios.

(Fig. 1).

As mentioned above, heavy mineral suites of La Meseta Formation indicate provenance from a convergent continental margin terrain. Heavy minerals from APVG and TPG provide for the MF and MT associations respectively (mean MF=56,7% and mean MT=43,1%) (Table 1). Hornblende, green clinopyroxene and minor orthopyroxene make the bulk of MF assemblage; garnet and epidote contribute to the MT values. Albeit the presence of garnets in volcanic rocks of the APVG (Hamer & Moyes, 1982), Hoffman (1991) established a low-rank metamorphic origin after a varietal study of this mineral in Paleocene formations. Or proven the garnets to be recycled from older sedimentary rocks, they should be excluded from the graphs because they can not be assigned to any of the defined suites, thus increasing the MF/MT ratio. The very low proportion of the GM association (mean GM=0,2%) is related to minor tourmaline, zircon and kyanite derived from sparse acid plutons included in the APVG cohorts. On the other hand, being the OI+Id+Cpx1 association absent, the dominance of Hb and Opx+Cpx2 (mean Hb=74,7% and mean Opx+Cpx2=25,3% respectively) denotes clearly a convergent plate source environment (Fig. 4b).

It is clear that sedimentary rocks of the James Ross Basin and therefore heavy mineral suites of the La Meseta

Formation have been strongly influenced by the magmatic arc activity in the northern Antarctic Peninsula. Specifically, Macellari (1993) used light mineral detrital modes to propose a petrographic evolutionary model for the Upper Cretaceous-Lower Tertiary of the Marambio Island, indicating that during the Eocene phase of the basin fill (stage IV) sediments were derived from a deeply-eroded magmatic arc with marked volcanic inactivity.

By contrast, mean values of MF, MT and GM suites along the studied sections of La Meseta Formation, do not show changes that could be attributed to a simple unroofing trend (fig. 5). Moreover, the slight increase in the MF suite along with a decrease in the MT and GM suites from Campamento to Submeseta allomembers suggest a progressive dominance of the volcanic source over the metamorphic and plutonic ones. Additionally, the shift in the mean percentages of hornblende vs. pyroxene may indicate a trend towards more evolved magmatic source rocks. As a result of this, a more complex scenario with waning volcanism or more distal volcanic sources is envisaged.

CONCLUSIONS

The La Meseta Formation non-opaque heavy mineral suites are dominated by hornblende (green and brown),

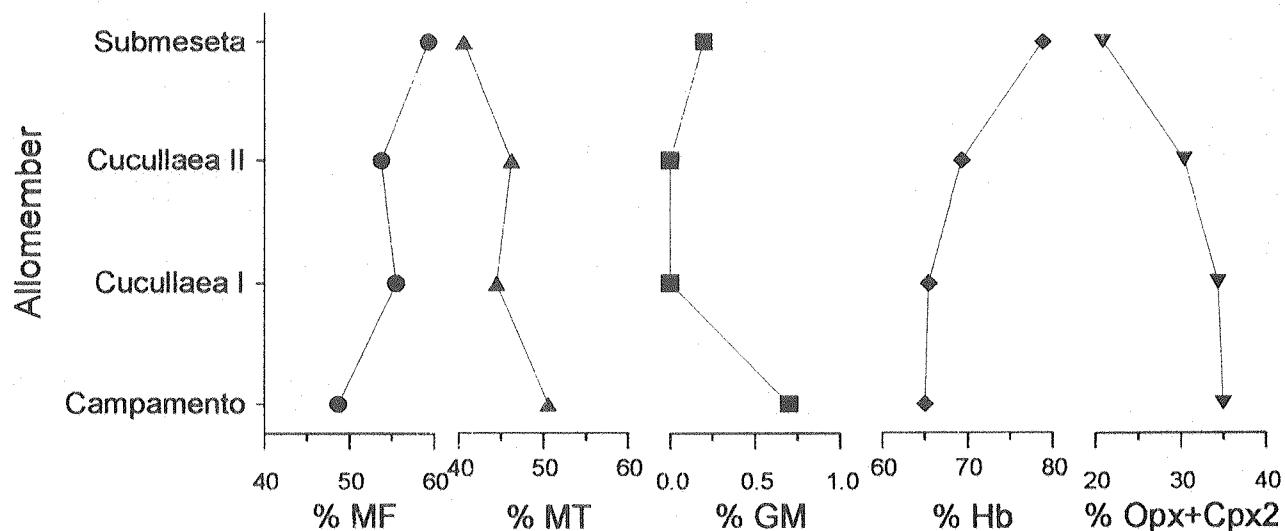


Figure 5. Plot of mean values of heavy mineral associations in the upper half of the La Meseta Formation.

Figura 5. Variación de los valores medios de las asociaciones de minerales pesados en la mitad superior de la Formación La Meseta.

garnet (colorless and pink), epidote, and green clinopyroxene, with minor amounts of apatite, basaltic hornblende, zircon, titanite, zoisite, kyanite, staurolite, tourmaline and micas. They indicate mainly magmatic (mostly volcanics and minor plutonics) and dynamothermal metamorphic source rocks. Recycling through older sedimentary rocks for the most resistant minerals can not be demonstrated from textural evidences.

MF-MT-GM and Ol+Id+Cpx1-Hb-Opx+Cpx2 suites reveal that the source area of the sediments was a convergent continental margin related to the subduction of the Pacific (and allied plates) below the Antarctic Plate.

Hornblende, green clinopyroxene and minor orthopyroxene make the bulk of the MF assemblage and were mostly derived from the Antarctic Peninsula Volcanic Group (APVG). Garnet and epidote constitute the MT suite and are thought to come from the Trinity Peninsula Group (TPG). Participation of GM suite is minimal due to the very low content of tourmaline, zircon and kyanite from sparse acid plutons included in the Andean Intrusive Suite (APVG cohorts).

The increase of the MF/MT ratio toward the top of the La Meseta Formation do not entirely support the hypothesis of the simple unroofing trend proposed for the uppermost fill of the James Ross Basin. On the contrary, it is consistent with a slight growth of the volcanic source with respect to the basement supply. This tendency might be assigned to waning volcanism or a more distal volcanic source.

In any case, the study of heavy mineral suites of the La Meseta Formation has provided important information that had not been recognized before through standard petrography.

Acknowledgements. We wish to thanks logistical support of the Dirección Nacional Del Antártico and Fuerza Aérea Argentina for field work on Marambio Island. Samples were prepared and studied at LAQUIGE (CONICET) laboratories.

We are grateful to Dr. Carlos O. Limarino for his valuable comments on an early version of the manuscript and reviewers Dr. M Manassero and R. Scasso who helped to improve this paper.

REFERENCES

- BARKER, P. F., 1982. The Cenozoic subduction history of the Pacific margin of the Antarctic Peninsula: ridge crest-trench interactions. *Journal of the Geological Society*, 139: 787-801.
- BOGGS, S. Jr., 1992. Petrology of sedimentary rocks. *Macmillan Publishing Company*. New York. 707 pp.
- BROWNE, J. R., 1995. Sandstone provenance and diagenesis of arc-related basins; James Ross Island and Alexander Island, Antarctica. *University of Exeter*. Vol.I. 246 pp. Ph.D. Thesis (unpublished).
- DEL VALLE, R. A., D. H. ELLIOT & D. I. M. MACDONALD, 1992. Sedimentary basins of the east flank of the Antarctic Peninsula: proposed nomenclature. *Antarctic Science* 4: 477-478.
- DINGLE, R. V. & M. LAVELLE, 1998. Antarctic Peninsular cryosphere: Early Oligocene (c. 30 Ma) initiation and revised glacial chronology. *Journal of the Geological Society of London*, 155: 433-437.
- DOTT, R. H., 1964. Wacke, graywacke and matrix-what approach to immature sandstone classification?. *Journal of Sedimentary Petrology* 34: 625-632.
- ELLiot, D. H., 1988. Tectonic setting and evolution of the James Ross Basin, northern Antarctic Peninsula. In: R.M. Feldman & M.O. Woodburne (Eds.), *Geology and Paleontology of Seymour Island, Antarctic Peninsula*. Geological Society of America, Memoir 169: 541-555.
- ELLiot, D. H., 1997. Paleogene volcaniclastic rocks on

Heavy mineral suites as provenance indicators: La Meseta Formation (Eocene), Antarctic Peninsula.

- Seymour Island, northern Antarctic Peninsula. In: C.A. Ricci (Ed.), *The Antarctic Region: Geological Evolution and Processes*: 367-372. Terra Antarctica Publication, Siena.
- ELLIOT, D. H. & T. A. TRAUTMAN, 1982. Lower Tertiary strata on Seymour Island, Antarctic Peninsula. In: C. Craddock (Ed.), *Antarctic Geoscience*: 287-297. University of Wisconsin Press, Madison.
- ELLIOT, D. H., S. M. HOFFMAN & D. E. RIESKE, 1992. Provenance of Paleocene strata, Seymour Island. In: Y. Yoshida (Ed.), *Recent Progress in Antarctic Earth Science*: 347-355. Terra Scientific Publishing Company, Tokyo.
- FOLK, R. L., P. B. ANDREWS & D. W. LEWIS, 1970. Detrital sedimentary rock classification and nomenclature for use in New Zealand. *New Zealand Journal of Geology and Geophysics* 13: 937-968.
- HAMER, R. D. & A. B. MOYES, 1982. Composition and origin of garnet from the Antarctic Peninsula Volcanic Group of Trinity Peninsula. *Journal of the Geological Society of London*, 139: 713-720.
- HOFFMAN, S., 1991. Petrology and provenance of the Paleocene strata at Cape Wiman, Seymour Island (Antarctic Peninsula). M. Sc. Thesis. *The Ohio State University*, 197 pp. (unpublished).
- INESON, J. R., 1989. Coarse-grained submarine fan and slope apron deposits in a Cretaceous back-arc basin, Antarctica. *Sedimentology* 36: 793-819.
- INESON, J. R., J. A. CRAME & M. R. A. THOMSON, 1986. Lithostratigraphy of the Cretaceous strata of west James Ross Island, Antarctica. *Cretaceous Research* 7: 141-159.
- MACDONALD, D. I. M., P. F. BAKER, S. W. GARRETT, J. R. INESON, D. PIRRIE, B. C. STOREY, A. C. WHITHAM, R. R. F. KINGHORN, & J. E. A. MARSHALL, 1988. A preliminary assessment of the hydrocarbon potential of the Larsen Basin, Antarctica. *Marine and Petroleum Geology* 5: 34-53.
- MACELLARI, C., 1993. Petrografía sedimentaria del Cretácico Superior-Terciario Inferior de la isla Marambio (Seymour), Península Antártica. *Revista de la Asociación Geológica Argentina* 47 (1): 9-21.
- MARENSSI, S. A., 1995. Sedimentología y paleoambientes de sedimentación de la Formación La Meseta, isla Marambio, Antártida. Ph. D. Thesis, *Universidad de Buenos Aires*. Part I: 330 pp., Part II: 172 pp (unpublished).
- MARENSSI, S. A., J. M. LIRIO, S. N. SANTILLANA, D. R. MARTINIONI & S. PALAMARCUK, 1992. The Upper Cretaceous of southeastern James Ross Island, Antarctica. In C. A. Rinaldi (Ed.) *Geología de la isla James Ross*. Instituto Antártico Argentino, 89-99. Buenos Aires.
- MARENSSI, S. A., S. N. SANTILLANA & C. A. RINALDI, 1996. Stratigraphy of La Meseta Formation (Eocene), Marambio Island, Antarctica. *I Congreso Paleógeno de América del Sur*, Abstracts: 33-34. Santa Rosa.
- NECHAEV, V. P & W. C. ISPHORDING, 1993. Heavy-mineral assemblages of continental margins as indicators of plate-tectonic environments. *Journal of Sedimentary Petrology* 63 (6): 1110-1117.
- OLIVERO, E. B., R. A. SCASSO & C. A. RINALDI, 1986. Revision of the Marambio Group, James Ross Island, Antarctica. *Instituto Antártico Argentino Contrib.* 331, 29 pp.
- PEZZETTI, A., 1987. The sedimentology and provenance of the Eocene La Meseta Formation, Seymour Island, Antarctica. M. Sc. Thesis, *The Ohio State University*. 165 pp. (unpublished).
- PIRRIE, D., 1991. Controls on the petrographic evolution of an active margin sedimentary sequence: the Larsen Basin, Antarctica. In Morton, A. C., Todd, S. P. & Haughton, P. D. W. (Eds), *Developments in Sedimentary Provenance Studies*. Geological Society of London Special Publication 57: 231-249. London.
- PIRRIE, D., 1994. Petrology and provenance of the Marambio Group, Vega Island, Antarctica. *Antarctic Science* 6 (4): 517-527.
- PIRRIE, D., P. W. DITCHFIELD & J. D. MARSHALL, 1994. Burial diagenesis and pore-fluid evolution in a Mesozoic back-arc basin: the Marambio Group, Vega Island, Antarctica. *Journal of Sedimentary Research* A64 (3): 541-552.
- SADLER, P. M., 1988. Geometry and stratification of uppermost Cretaceous and Paleogene units on Seymour Island, northern Antarctic Peninsula. In Feldman R. M. & M. O. Woodburne (Eds.), *Geology and Paleontology of Seymour Island, Antarctic Peninsula*. Geological Society of America, Memoir 169: 303-320.
- STOREY, B. & P. A. R. NELL, 1988. Role of strike slip faulting in the tectonic evolution of the Antarctic Peninsula. *Journal of the Geological Society of London*, 145: 333-337.
- TRAUTMAN, T. A., 1977. Stratigraphy and petrology of Tertiary clastic sediments, Seymour Island, Antarctica. M. Sc. Thesis, *The Ohio State University*. 170 pp. (unpublished).
- WHITHAM, A. G. & J. E. A. MARSHALL, 1988. Syn-depositional deformation in a Cretaceous succession, James Ross Island, Antarctica. Evidence from vitrinite reflectivity. *Geological Magazine* 125 (6): 583-591.
- WILLIAMS, H. F., F. J. TURNER & C. M. GILBERT, 1982. Petrography: an introduction to the study of rocks in thin section. 2nd. Edition. W.H. Freeman, San Francisco, 626pp.

Dr. Sergio A. MARENSSI
Dr. Carlos A. RINALDI
Dr. Sergio S. SANTILLANA
Instituto Antártico Argentino
Cerrito 1284
1010 BUENOS AIRES
República Argentina
Teléfono: 54-11-4812-4064
Fax: 54-11-4812-2039

Lic. Laura I. NET
Departamento de Ciencias Geológicas
Facultad de Cs. Ex. y Naturales (U.B.A.)
Pabellón II – Ciudad Universitaria
1428 BUENOS AIRES
República Argentina
Teléfono: 54-11-4576-3329

Recibido: 21 de julio de 1997.

Aceptado: 15 de julio de 1998.

