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Mineralogy of sea-bottom sediments from the Strait of Magellan

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Abstract. A mineralogical investigation ("powder" X-ray diffractometry) was carried out on the < 62 μm fraction of sea-bottom sediments from the Strait of Magellan (Southern Chile). Our data have been integrated with the results of the analyses previously carried out by Setti and Veniale (1991) on the samples from other areas of the Strait of Magellan, in order to achieve a complete description of the mineralogical characteristics of the sea-bottom sediments. The recognized minerals are quartz, feldspars, amphiboles, calcite, aragonite, mica, chlorite and the clay minerals smectite and mixed-layers. The variations in composition are related to the different physiographic characteristics of the basin, the lithology of the outcropping rocks and the climate and vegetation. The distribution of the mineral phases allowed for a better understanding of the sources of the sediments and the means terrigenous supplies occurring in the Strait of Magellan.

1. Introduction

With the aim of acquiring a better comprehension of the environmental characteristics of the Magellanic area, the PNRA ("Italian National Program for Antarctic Research") promoted the "Magellan Project", which is focused on the study of the sedimentology and the hydrological and biological aspects (for further details, see Brambati, 1991). Two oceanographic cruises were carried out in 1989 and 1991 on the R/V "OGS EXPLORA" to collect samples of sea-bottom sediments and waters (Brambati, 1991; Brambati et al., 1991; Fontolan and Panella, 1991; Mosca and Fontolan, 1991; Panella et al., 1991; Simeoni et al., 1991). The cruise undertaken in 1989 concentrated on the central and eastern parts of the Strait of Magellan and the data regarding the mineralogy of the sea-bottom samples collected during this cruise were published by Setti and Veniale (1991). The second cruise examined the Pacific arm, the Atlantic and Pacific shelves and the southern channels (Canal Beagle, Ballenero, Brecknock, Cockburn, and Magdalena) flowing

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from Seno Magdalena towards the Pacific Ocean. Mineralogical analyses of the sea-bottom sediments sample (< 62 μm fraction) collected during the second expedition were carried out, and the results are here presented together with the data published by Setti and Veniale (1991). We present these results together in order to achieve a complete description of the mineralogical characteristics of the sea-bottom sediments and to better comprehend the mechanisms of modern sedimentation.

2. Geographical, morphological and geological setting

The Strait of Magellan, located at the southernmost tip of South America (at latitude 52° to 54° S), separates Patagonia from Tierra del Fuego (Fig. 1). A detailed description of its geographical and morphological settings is reported in Brambati et al. (1991); a short synthesis is reported here.

The Strait of Magellan stretches from the Atlantic to the Pacific Ocean for about 500 km, and consists of an Atlantic and a Pacific arm, intersecting southward at right angle near Seno Magdalena. The eastern arm faces the Atlantic Ocean forming a broad bay and is composed of three basins separated by two narrow channels (Primera and Segunda Angostura). The Paso Ancho Basin, occupying the central part of the Strait, is the largest of these basins. Two secondary basins branch off from the Paso Ancho Basin: the first is Bahia Inutil, whereas the second is formed by the Canal Whiteside-Seno Almirantazgo. South of Cabo S. Isidro, the Atlantic part of the Strait opens into a further basin (Seno Magdalena) which splits into several channels (Magdalena, Cockburn, Beagle), and finally flows into the Pacific Ocean. The Pacific sector of the Strait of Magellan extends for about 250 km in a NW-SE direction from Cabo Froward to the Pacific Ocean; its shape is narrow and elongated, the width varies from 2 to 15 km. Water depths in the Strait of Magellan are quite variable: the first and the second Atlantic basins have a depth of about 40 m, while the Paso Ancho Basin has a depth increasing from 50 to 550 m from N to S. In the Pacific sector, the water depth increases to 1000 m as far as NW of Carlos III Island, then it decreases to 50 m near the Pacific entrance. The tides are particulary strong and the tidal range decreases from the Atlantic (about 9 m) to the Pacific sector (1.5 m); surface currents, which follow the same pattern, vary from 4.5 m/s at Primera Angostura to 3 m/s in Segunda Angostura (Medeiros and Kjerfve, 1988).

The lithology outcropping in the area presents remarkable variations (S.N.G.M, 1978; Winslow, 1982), and can be outlined (from NE to SW) as follows:

- glacio-fluvial sediments (Quaternary) of morainal origin, occurring around the first and second basins, and part of the Paso Ancho Basin;

- continental and marine sediments (Cretaceous) outcropping in the areas around the central sector of the Paso Ancho Basin and Bahia Inutil;

- metamorphic, volcanic and intrusive rocks (Andean batholith) along the Pacific sector of the Strait.

The Magellanic area is characterized by climatic features which differ considerably from the Atlantic to the Pacific side. Temperatures are colder and rainfall is much more abundant in the

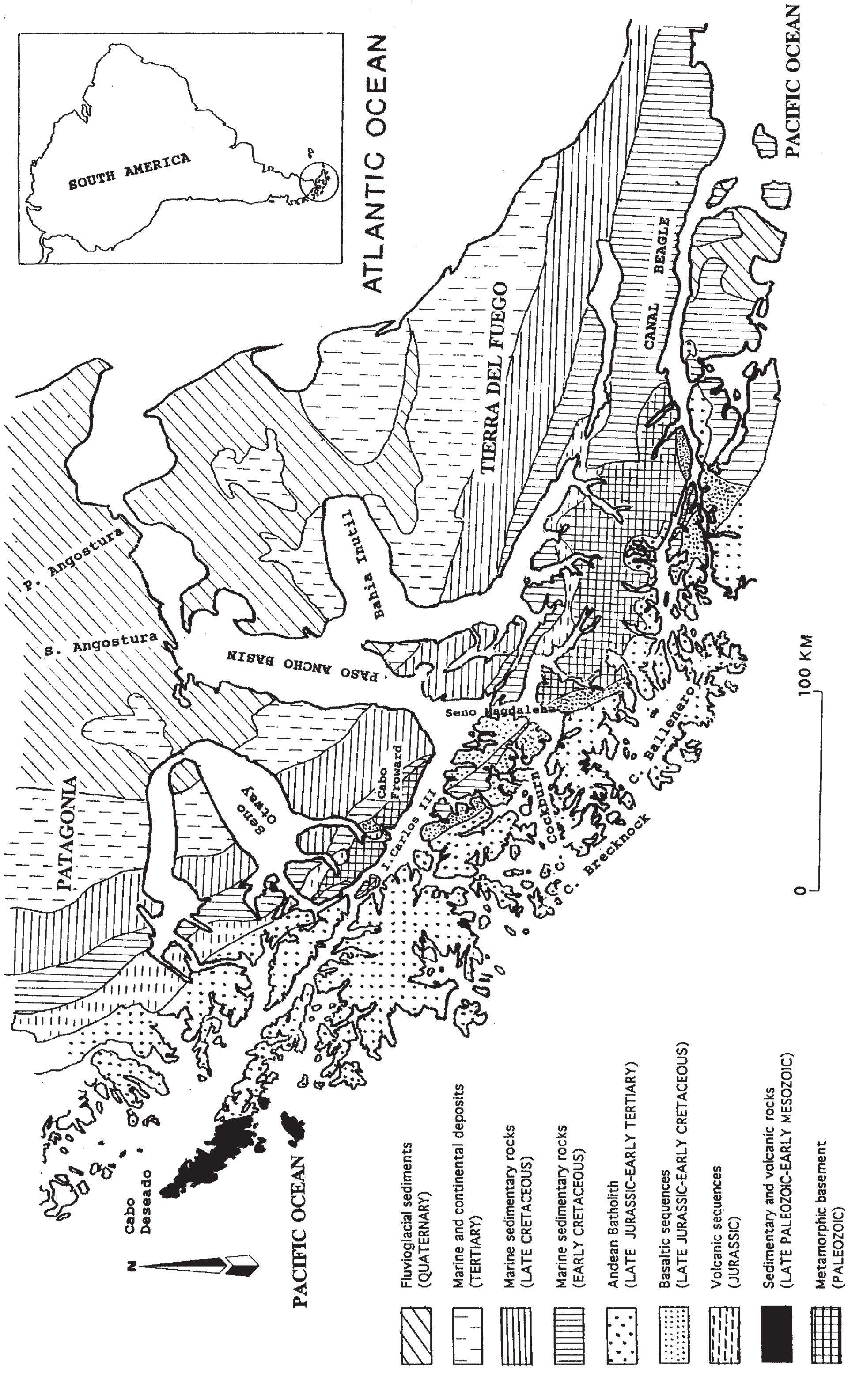

Fig. 1 - Geo-lithological sketch of the Strait of Magellan (after SNGM 1982, modified).

western part (up to 5000 mm/year) while in the eastern part, lower precipitations (250 - 350 mm/year), higher temperatures and more continental conditions are found (Zamora and Santana, 1981). Soils and vegetation are in parallel with the climatic zones and with the rainfall regimes. From East to West four main types of vegetation have been described (Balduzzi, 1991): Patagonic steppe, deciduous Magellanic forest, evergreen Magellanic forest and Magellanic tundra. In the western part of the Magellanic area, which is characterised by high erosive activity, mainly podzol, peaty poor and acid soils are present, while in the eastern part, brown, chestnut-coloured soils and prairie grounds occur (Balduzzi, 1991).

3. Sediment distribution

Brambati et al. (1991 and 1994) showed that the grain-size of the sea-bottom sediments in the Atlantic sector of the Strait of Magellan is strictly controlled by the hydrodynamic conditions. These conditions are mainly related to the decrease of the tidal regime and the increase of water depth when passing from the Atlantic inlet to the inner sectors of the Paso Ancho Basin. Coarse sediments (e.g. sands and gravels) were found in the first and second Atlantic basins and in the northern sector of the Paso Ancho Basin, which are characterised by shallow waters and strong stream currents. In the central sector of the Paso Ancho Basin and in Bahia Inutil, which are characterised by greater depths and weaker currents, muddy sediments prevail. Because of the relatively scarce hydrographic network, the Atlantic sector of the Strait of Magellan appears to be a sedimentary basin mainly fed at its eastern extremity through transport processes due to tides and currents, while lateral terrigenous supply is less relevant.

In the Pacific branch of the strait, three areas have been identified by grain-size analysis. Sands and gravel prevail in the basin between Cabo Froward and Isla Carlos III; muds are more abundant between Isla Carlos III and the shoal of the Pacific entrance, whereas gravels and sands prevail in the Pacific shoal. In addition, important glacio-fluvial sedimentary inputs from the glaciers (i.e., Cordillera Darwin) and from the numerous fjords and channels of the Chilean-Andean archipelago have been highlighted along the Pacific arm.

Lastly, remarkable differences were noted between the entrance areas of the Strait of Magellan (Brambati, 1991): sands and lag moraine deposits were found within about 250 km of the wide Atlantic shelf, while biogenic sands were sampled in the narrow Pacific continental shelf and slope.

4. Materials and methods

Sea-bottom sediments were collected using a Van Veeb grab of 20 litre capacity (Brambati et al., 1991). The mineralogical analyses were carried out on the < 62 μm fraction by X-ray diffractometry of random "powder" preparations, following the standard procedures for the analysis of clay minerals (Veniale et al., 1987; Wilson, 1987). The X-ray traces were recorded in natural conditions (air-dried), after ethylene glycol saturation at 60 °C/3 hrs, and heating at 550 °C/2

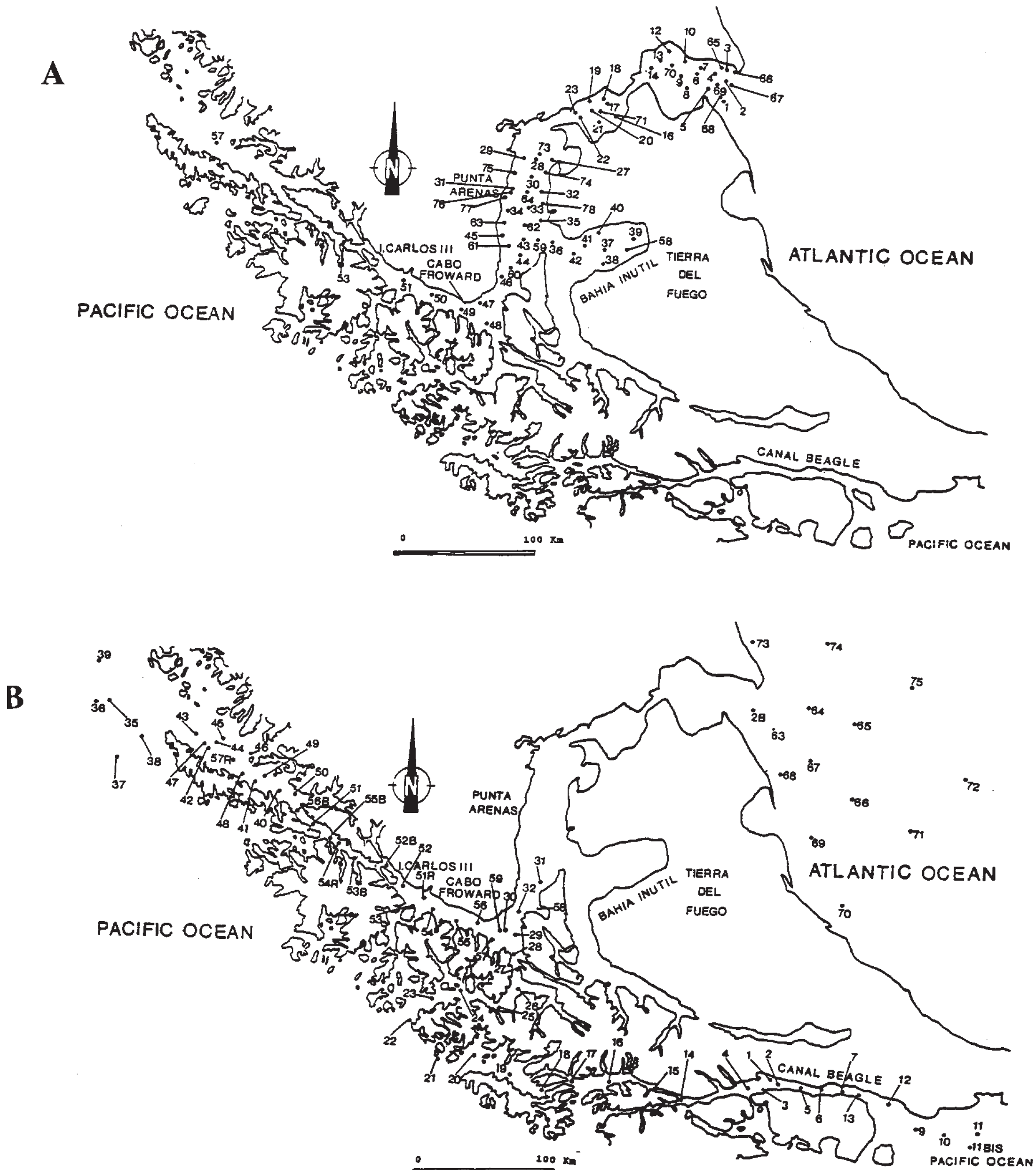

Fig. 2 - Sample location: (A) 1989 cruise, (B) 1991 cruise.

hrs. The X-ray diffraction data were analyzed considering the intensity of the reflections diagnostic for each mineral, and the semi-quantitative percentages of the various mineral phases were checked using the Software Package SIROQUANT (Taylor, 1991). Table 1 shows the mineralogical composition of the sediments collected during the cruise 1989 (marked MG89; previously discussed by Setti and Veniale, 1989) and the 1991 cruise (marked MG91). Fig. 2 shows the locations of sampling sites during the two cruises.

Table 1 - Mineralogical composition of the sea-bottom sediment samples.

		Sm	Ch	M-L	M	Q	K-F	Pl	LMC	HMC	Ar	Amp	
MG89	38	19	16	7	12	22	6	14	1	0	0	3	100
MG89	39	16	13	8	13	31	4	17	0	0	0	1	100
MG89	40	14	12	7	11	28	6	20	0	0	0	2	100
MG89	41	8	14	5	11	30	8	16	2	0	0	4	100
MG91	2B	20	12	6	7	32	7	12	2	0	0	2	100
MG91	63	14	17	8	11	23	7	11	3	0	0	6	100
MG91	64	20	15	9	7	29	5	10	2	0	0	3	100
MG91	65	14	10	7	7	28	5	9	17	0	0	3	100
MG91	66	14	8	4	6	00	3	11	14	8	7	3	100
MG91	67	17	13	7	8	26	7	11	8	0	0	3	100
MG91	68	12	11	7	7	27	7	23	1	0	0	5	100
MG91	69	17	10	8	7	23	5	25	3	0	0	2	100
MG91	70	16	12	8	8	28	9	14	2	0	0	3	100
MG91	71	3	5	5	5	20	15	12	21	0	9	5	100
MG91	72	7	7	5	4	28	2	8	21	8	6	4	100
MG91	73	11	7	4	6	31	24	13	1	0	0	3	100
MG89	66	24	16	6	11	23	7	10	1	0	0	2	100
MG89	67	16	17	6	9	28	6	13	2	0	0	3	100
MG89	68	16	14	6	10	26	7	13	1	0	0	7	100
MG89	65	10	10	8	9	27	10	16	2	0	0	8	100
MG89	2	13	10	8	7	30	19	15	1	0	0	3	100
MG89	3	18	13	5	8	27	7	16	8	0	0	4	100
MG89	4	12	12	7	8	29	8	18	4	0	0	2	100
MG89	8	12	16	6	3	27	10	16	1	0	0	3	100
MG89	9	14	13	6	8	30	4	14	8	0	0	3	100
MG89	10	13	10	8	9	25	4	14	12	1	0	4	100
MG89	12	14	13	6	7	31	6	13	6	1	0	3	100
MG89	13	19	13	6	10	26	7	11	4	0	0	4	100
MG89	14	12	12	3	9	32	5	15	4	0	0	8	100
MG89	16	16	15	6	9	28	7	13	3	0	0	3	100
MG89	17	16	15	6	9	08	7	13	3	0	0	3	100
MG89	18	11	13	6	10	28	7	13	6	0	0	6	100
MG89	19	10	10	5	8	19	7	20	7	0	0	4	100
MG89	21	11	13	6	8	31	6	12	6	0	0	7	100
MG89	71	17	15	7	9	26	5	13	2	0	0	6	100
MG89	27	12	9	4	9	22	5	18	7	0	0	3	100
MG89	28	9	9	4	8	28	7	21	5	1	0	8	100
MG89	29	11	14	3	9	29	6	11	13	0	0	4	100
MG89	30	11	11	5	10	33	6	15	3	0	0	6	100
MG89	31	7	12	4	9	30	7	22	1	0	0	8	100
MG89	32	11	11	4	8	28	10	22	1	0	0	5	100
MG89	33	11	11	6	11	30	7	16	8	0	0	6	100
MG89	34	12	15	7	9	30	6	18	0	0	0	3	100
MG89	35	11	16	5	12	25	5	12	10	0	0	4	100
MG89	36	8	17	5	12	29	5	16	4	0	0	4	100
MG89	43	12	16	7	12	30	6	13	1	0	0	3	100
MG89	44	12	19	7	11	28	4	12	2	0	0	2	100
MG89	45	10	13	8	13	29	13	12	1	0	0	4	100
MG89	46	11	16	9	16	20	10	12	4	0	0	6	100
MG89	59	11	13	6	10	26	4	11	9	3	0	7	100
MG89	60	8	17	9	16	25	5	12	3	0	0	5	100
MG89	61	11	17	8	19	24	6	12	2	0	0	3	100
MG89	62	7	13	8	7	34	13	14	1	0	0	3	100
MG89	63	9	12	7	11	26	7	22	1	0	0	5	100
MG89	64	14	17	6	9	30	7	13	2	0	0	3	100
MG89	74	6	13	5	7	3	9	19	6	0	0	5	100
MG89	75	7	12	4	9	32	8	26	1	0	0	4	100
MG89	76	7	16	8	9	31	8	18	0	0	0	3	100
MG89	77	12	9	4	7	28	10	21	4	0	0	5	100
MG89	78	10	10	4	8	30	7	15	7	0	0	9	100
MG91	31	15	14	8	10	29	5	11	2	0	0	6	100
MG91	32	11	14	9	20	27	3	12	1	0	0	3	100
MG91	58	7	8	5	6	25	11	19	18	0	0	4	100
MG89	37	17	16	8	9	27	5	11	5	0	0	2	100

Table 1 - continued

		Sm	Ch	M-L	M	Q	K-F	PI	LMC	HMC	Ar	Amp	
MG89	42	18	17	6	11	29	5	11	1	0	0	2	100
MG89	47	4	28	7	16	18	5	10	7	0	0	5	100
MG89	48	0	13	2	14	21	7	21	7	0	0	15	100
MG89	49	8	18	6	18	21	6	11	2	0	0	10	100
MG91	29	0	12	7	11	31	7	16	6	0	0	10	100
MG91	30	6	27	4	22	22	2	10	3	0	0	4	100
MG91	57	3	20	4	17	16	5	20	3	0	5	7	100
MG91	59	0	31	4	26	26	6	11	2	0	0	3	100
MG91	56	8	23	4	25	17	7	9	1	0	0	6	100
MG91	55	8	22	6	17	18	7	11	3	2	2	8	100
MG91	54	9	16	5	10	20	4	12	11	0	8	5	100
MG89	50	9	21	7	12	20	6	13	5	0	0	7	100
MG89	51	4	17	7	15	17	8	12	13	0	0	7	100
MG91	52	0	8	0	5	10	2	4	45	14	9	3	100
MG91	53	9	22	7	13	15	5	13	9	0	0	7	100
MG91	51R	8	15	3	11	20	6	11	12	0	9	5	100
MG91	10	0	6	0	10	12	2	8	35	14	8	5	100
MG91	12	0	10	2	6	21	8	25	9	2	5	12	100
MG91	13	0	12	3	13	34	4	16	10	0	0	8	100
MG91	5	0	20	7	31	17	6	11	1	0	0	7	100
MG91	2	0	20	7	31	14	6	13	2	2	0	5	100
MG91	1	0	22	5	33	17	6	10	2	0	0	5	100
MG91	3	0	28	5	35	13	4	10	1	0	0	4	100
MG91	4	0	23	4	38	11	7	12	0	0	0	5	100
MG91	15	0	6	2	40	17	10	17	0	0	0	8	100
MG91	16	0	30	2	42	9	4	10	0	0	0	3	100
MG91	17	0	33	1	38	14	4	8	1	0	0	1	100
MG91	18	0	21	0	26	5	1	5	32	0	7	3	100
MG91	19	0	31	0	18	11	6	14	3	0	0	17	100
MG91	20	0	18	6	13	14	6	10	16	0	11	6	100
MG91	21	0	8	0	6	10	2	19	23	16	9	7	100
MG91	22	0	7	0	3	9	2	5	25	31	15	3	100
MG91	24	0	14	3	13	10	17	9	15	0	13	6	100
MG91	25	0	29	6	23	11	4	15	2	0	0	10	100
MG91	26	5	31	4	27	16	3	9	0	0	0	5	100
MG91	27	0	21	2	16	17	3	13	10	0	9	9	100
MG91	28	0	20	3	16	19	3	14	10	0	8	7	100
MG91	53B	9	13	3	10	15	7	12	15	0	9	7	100
MG89	53	0	6	3	9	15	7	12	18	0	11	9	100
MG91	54R	9	14	3	10	14	8	13	14	0	10	5	100
MG91	55B	4	16	0	11	14	8	13	18	0	9	7	100
MG91	51	8	15	3	9	14	8	11	17	0	10	5	100
MG91	56B	4	15	3	10	12	6	11	20	0	11	8	100
MG91	50	0	6	5	5	11	7	26	21	0	10	9	100
MG91	40	8	13	3	9	15	7	11	20	0	10	4	100
MG91	41	0	10	6	10	10	8	8	20	8	17	3	100
MG91	49	0	8	6	6	13	9	21	18	0	8	11	100
MG91	48	0	10	0	7	13	6	11	21	11	17	4	100
MG91	46	0	9	0	10	17	5	8	21	9	18	3	100
MG91	57R	0	9	0	10	10	9	8	23	12	17	2	100
MG89	57	0	8	0	6	11	3	6	25	15	21	5	100
MG91	42	0	10	3	11	7	7	8	21	12	17	4	100
MG91	44	0	8	0	8	15	2	12	18	17	16	4	100
MG91	45	0	5	0	6	15	2	17	18	14	14	9	100
MG91	47	0	12	4	15	20	7	19	4	5	5	9	100
MG91	43	0	7	0	7	8	4	5	22	23	20	4	100
MG91	35	0	3	0	3	4	2	3	43	24	15	3	100
MG91	36	1	10	2	11	20	14	20	11	0	2	9	100
MG91	37	0	8	0	8	12	2	9	39	6	12	4	100

Sm = Smectite; Ch = Chlorite M-L = Mixed-Layers; M = Mica; Q = Quartz; K-F = Alkali feldspar; PI = Plagioclase; LMC = Low Mg-Calcite; HMC = Hig Mg-Calcite; Ar = Argonite; Amp = Amphibole.

5. Mineral distribution

Quartz is present at percentages between 4% and 34%; the highest values (20-30%) were found in the areas of the Atlantic shelf and of the Atlantic arm of the Strait as far as Cabo Froward. Along the Pacific sector and the southern channels, the average quartz percentages slightly decrease to values around 10-20% or less.

Plagioclase percentages are between 3% and 25%. A compositionally homogeneous area (10-20%) comprises the Atlantic branch of the Strait as far as Cabo Froward, and the sectors of Atlantic shelf closer to the coast. The content of plagioclase decreases (< 10%) in areas of the outer continental shelf and in the western and southern Pacific outlets. Along the Canal Beagle, the amount of plagioclase ranges from about 10-20%.

Alkali feldspar is present in percentages between 0 and 23% and shows a distribution trend similar to plagioclase.

Amphibole is comprised between 1% and 17%. The Atlantic shelf, Bahia Inutil and the Atlantic sector of the Strait of Magellan as far as Cabo Froward are compositionally homogeneous (2-5%). The values slightly increase in the Pacific tract (5-10%). In the Pacific shelf low percentages (2-5%) of amphibole are still present.

Chlorite percentages range between 3% and 33%. The inner Atlantic shelf and the Atlantic branch of the Strait are compositionally homogeneous (10-20%), while lower percentages (< 10%) are present in the Pacific shelf and in the outer Atlantic shelf. Higher percentages of chlorite (20-30%) are encountered along a large part of the Pacific branch and near Cabo Froward, Canal Magdalena, Canal Cockburn and part of Canal Beagle.

Mica content varies from 3 to 42%, and its distribution pattern is rather close to that of chlorite.

Carbonates represent the association of three different mineral phases: aragonite, High Mg-Calcite (HMC) and Low Mg-Calcite (LMC). Total carbonate content ranges between 0% and 82%, which is mainly composed of LMC, with minor amounts of HMC and subordinate aragonite. The Atlantic and central sectors present small amounts of carbonates (generally < 15%). The carbonate fraction increases in the Pacific tract of the Strait and the highest values are present at the Pacific shelf and at the end of Canal Beagle. Geochemical, petrographic and skeletal characteristics of the carbonates of the Strait of Magellan have been described elsewhere (Brambati et al., 1994; Marinoni, 1995).

The association of smectite and random mixed-layers ranges between 0% and 39%. The Atlantic shelf and the Atlantic sector of the Strait are characterized by the highest contents of smectite and mixed-layers (25-35%). These contents decrease along the central and Pacific sectors, from Cabo Froward to the Pacific outlet (10-20%). The lowest values (< 10%) are present in the Pacific shelf and along the southern channels.

6. Discussion and conclusions

The Atlantic shelf and the Atlantic sector of the Strait of Magellan (including the Paso Ancho

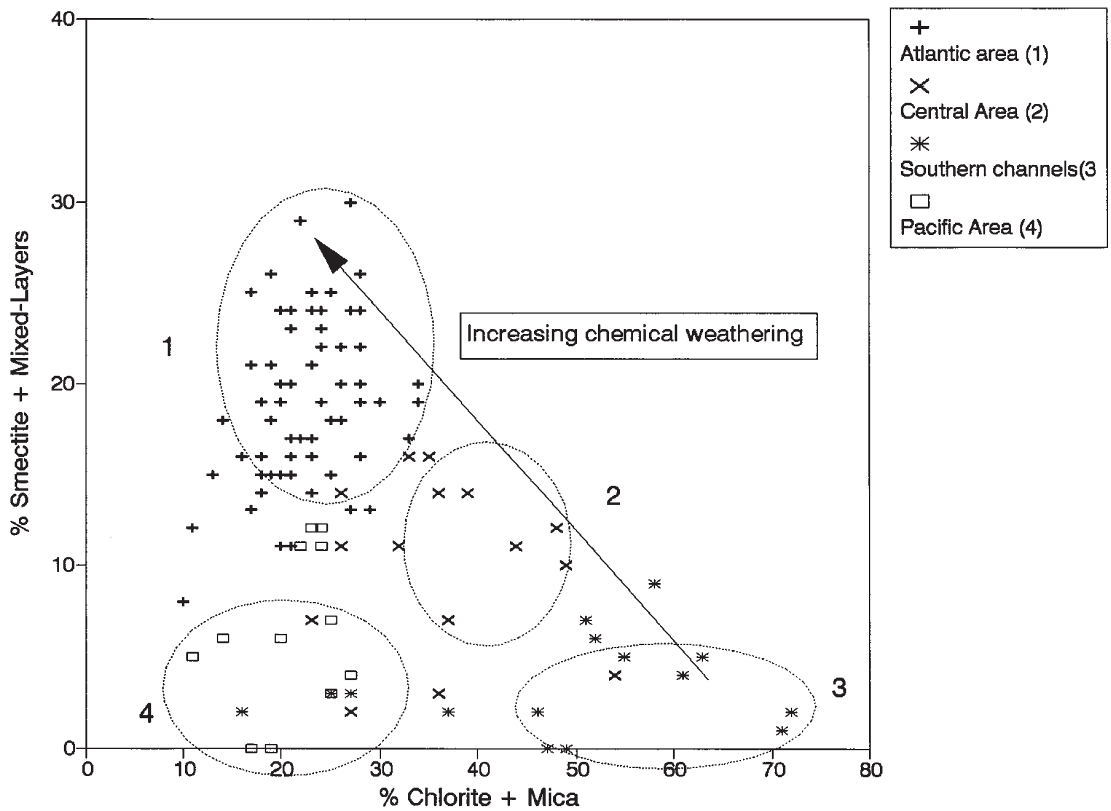

Fig. 3 - Distribution scatter diagram for clay minerals.

Basin) are characterised by a mineralogical association made up of quartz, feldspars and clay minerals (mainly smectite and mixed-layers with lower amounts of chlorite and mica). The sediments collected along the central part of the Strait, as far as Isla Carlos III, show an increasing in chlorite and mica contents and a decrease in smectite and mixed-layers. Along the Pacific branch, this siliciclastic association is mixed with biogenic carbonates that become particularly abundant in the Pacific shelf. The disappearance of smectite and mixed-layers and the strong increase of chlorite and mica along the southern channels (Magdalena, Cockburn, Brecknock, Ballenero, Beagle) is evident.

With the exception of the biogenic carbonates, the mineralogical association of the < 62 μm fraction of the sediments of the Strait of Magellan is of continental and detrital origin. It is therefore, possible to recognize the source rocks, the main weathering processes and the transport-distribution pathways into the basin. As quartz and feldspars exhibit a homogeneous distribution along the Strait, the most important indicators appear to be the phyllosilicates (mica and chlorite) and the "swelling" clay minerals (smectite and mixed-layers).

It is known that chlorite and mica in marine sediments are mainly of detrital origin as they are the product of the physical weathering processes acting on continental crystalline outcrops, which are very widespread in high latitude areas (Biscaye, 1965; Griffin et al., 1968; Chamley, 1989; Ehrmann et al., 1992). These minerals become more abundant towards the polar areas because of the decreasing of chemical weathering processes, which are more typical of humid and warm areas. Chemical weathering processes lead to the formation of other kinds of clay minerals (i.e., kaolinite, gibbsite and smectite). Generally, chlorite is typical of low-grade metamorphic and basic complexes, while mica mainly tends to derive from more acid rocks.

The origin of smectite in marine sediments is rather controversial. In most of the sediment cores collected in Antarctic seas, smectite is considered to be of continental origin (Chamley, 1989; Robert and Maillot, 1990; Ehrmann et al., 1992), but a different origin can also be assumed, due to the presence of this mineral in marine environments. Smectite may directly form on the sea-floor through halmyrolisis processes (submarine weathering) on volcanic rocks and ashes: this is particularly evident where modern volcanic activity is present (Biscaye, 1965; Güven, 1988; Chamley, 1989). In general, smectite in sediments of the world ocean seems to be particulary concentrated near areas with warm-humid climatic conditions, where continental brown to vertisolic soils may develop (Chamley, 1989). Nevertheless, smectite and mixed-layers can also form on continental soils of temperate and polar areas, like in Antarctica and in New Zealand, and their origin is generally attributed to chemical weathering alteration of micas and chlorites (Churchman, 1980; Campbell and Claridge, 1987).

In the Strait of Magellan, chlorite and mica are concentrated near the outcroppings of crystalline rocks, just as they occur along the southern channels and near Seno Magdalena, where they are derived through physical weathering processes performed by glaciers and streams.

Smectite and mixed-layers are likely to be derived from the morainal and glacio-fluvial Quaternary deposits located on the eastern side of the Magellanic area and in the Atlantic shelf, where they are transported to the Atlantic sector of the Strait.

The control on the weathering intensity that is also exerted by the different climates and types of vegetation occurring along the Strait of Magellan is evident. The Pacific branch and the southern channels are characterised by colder temperatures and heavy rainfall. The typical vegetation is the "Magellanic Tundra" and the "Evergreen Magellanic Forest" (Balduzzi, 1991). Such environmental conditions permit a high soil erosion and allow for the physical weathering processes responsible for the greater amounts of chlorite and mica in the sea-bottom sediments of this area. Prairies, like those occurring on the Atlantic side, are favourable to the formation of smectite and mixed-layers. A distribution scatter diagram of the different clay minerals may help in the recognition of primary sources and active weathering processes. As shown in Fig. 3, the Paso Ancho Basin and the Atlantic shelf contain the highest amounts of smectite and mixed-layers and the lowest amounts of chlorite and mica. This indicates a strong alteration degree, which is mainly due to the source of these materials (glacio-fluvial Quaternary deposits) and to the climatic and environmental conditions. The central areas of the Strait feature sediments with intermediate degradation of the original chlorite and mica; in fact, the source rocks are mainly Tertiary and Cretaceous marine sedimentary rocks. Furthermore, the climate in this area is colder. Chlorite and mica are abundant in the sediments of the southern channels; these minerals derive from the surrounding crystalline rocks and are better preserved because of the colder climate (weathering due to physical processes prevails over that due to chemical processes). The content of clay minerals is low in the sediments of the Pacific shelf of the Strait where skeletal carbonates prevail.

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