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Characterization of the glacio-marine sedimentary environment of "Campos de Hielo Sur"

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ABSTRACT

The soft bottoms of the fiord inlets adjacent to the glacial system of "Campos de Hielo Sur" are studied. A sedimentological characterization is made, resulting in the recognition of the main factors controlling the sedimentary process through the use of textural and grain-size parameters. Based on the spatial distribution of these parameters, the fiord inlet system is divided into two energy zones. This energy-based differentiation would be mainly determined by the geomorphological characteristics of the area.

RESUMEN

Se estudian los fondos blandos de los fiordos y canales adyacentes al sistema glaciar "Campos de Hielo Sur". Se realiza una caracterización sedimentológica, a través de parámetros texturales y granulométricos. En base a la distribución espacial de los parámetros sedimentológicos, el sistema de fiordos y canales se divide en dos zonas de energía. Esta diferenciación energética estaría determinada principalmente por las caracteristicas geomorfológicas del área.

1. INTRODUCTION

"Campos de Hielo Sur", one of the biggest glaciers in the temperate regions of the southern hemisphere, has been the center of local attention over the last years, due to territory disputes with the neighbouring Republic of Argentina. For this reason, the local scientific community has struggled to meet the increasing need for information that has arisen regarding this natural system. In view of this situation, in 1994, the National Oceanographic Committee requested the Chilean Navy the participation of the oceanographic ship "Vidal Gormaz", to conduct research in the fjord inlets adjacent to "Campos de Hielo Sur". During the months of August and September of 1995, a number of local scientist commited to conduct several investigations in an area comprising latitudes 48° 20' and 51° 30' S and longitude 73° 30' W. The following results are part of the valuable information obtained during this cruise, being so important as the historical voyage of the C.S.S. Hudson in 1970.

"Campos de Hielo Sur" are connected to the Pacific Ocean through a complex network of inlets and fiords that have particular features with respect to the rest of the chilean coast, mainly characterized by a rectilinear morphology due to the collision of plates.

Fiords are drowned cliff valleys of glacial origin, showing U-shaped cross section and often several hundred meters deep. They often show a rock sill on the seaward side, and a freshwater source on the landward side (Reineck & Singh 1980), usually presenting a estuarine circulation, however, a shallow sill may affect its circulation, restricting, at depth, the inflow of saltwater into the basin, creating stagnant conditions.

Fiords represent one of the most important coastal geomorphological features in high latitudes, since they control, in great manner, due to its circulation and morphological characteristics, the flux of terrigenous sediments to the sea. Most of the material produced by glacial activity, is retained by these land-locked environments through sedimentation. This way, by studying the sediments it is possible to rebuild somehow the geomorphological history that has taken place on the continent, since the anlysis is directly done on the result of erosion: the sediments, which in turn explain the present landforms. Future studies concerning this research, should include information regarding the physical characteristics and spatial distribution of superficial sediments.

In this way, the present investigation will accomplish the first sedimentological characterization of the fiord inlets adjacent to "Campos de Hielo Sur". In order to achieve this goal, the textures of sediments will be classified, that is, to recognize the physical characteristics of the sedimentary populations using the granulometry as a first approximation.

2. MATERIALS AND METHODS

2.1 Setting

Geomorphologically, the area is the result of the intense activity of the andine ice fields (Figure 1). The region has also been subjected to tectonic subsidence, allowing the sea to enter along the western troughs. This transgression generated many landforms (gulfs, straits, inlets, bays, estuaries and fiords) that keep islands and archipelagos separated. (IGM, 1987). Zonally, the coast can be divided into two zones; to the east, the landforms are represented by the sheltered heads of drowned valleys with a direct influence from the glaciers, on the other side, to the west, the fiord inlets are more open and exposed to the action of the sea. Börgel (1983), made a geomorphological division of the sector of "Campos de Hielo Sur"; the eastern part comprises the "Pacific Patagonian ranges with rivers and fiords controlled by tectonics" with positive andine relief characteristics, and the western sector defined by the "Insular Patagonian ranges" controlled by tectonic subsidence.

The sector´s climate is regulated by the presence of the polar front and the westerly winds (with maximum velocities > 100 km/h). The area records a low insolation with temperatures below 10° C and an annual thermic oscillation of 5° C. The rainfall averages about 4.485 mm per year and is determined by the geomorphology and the sea influence. This conditions produce a cold-rainy temperate climate without a dry season (IGM, 1983).

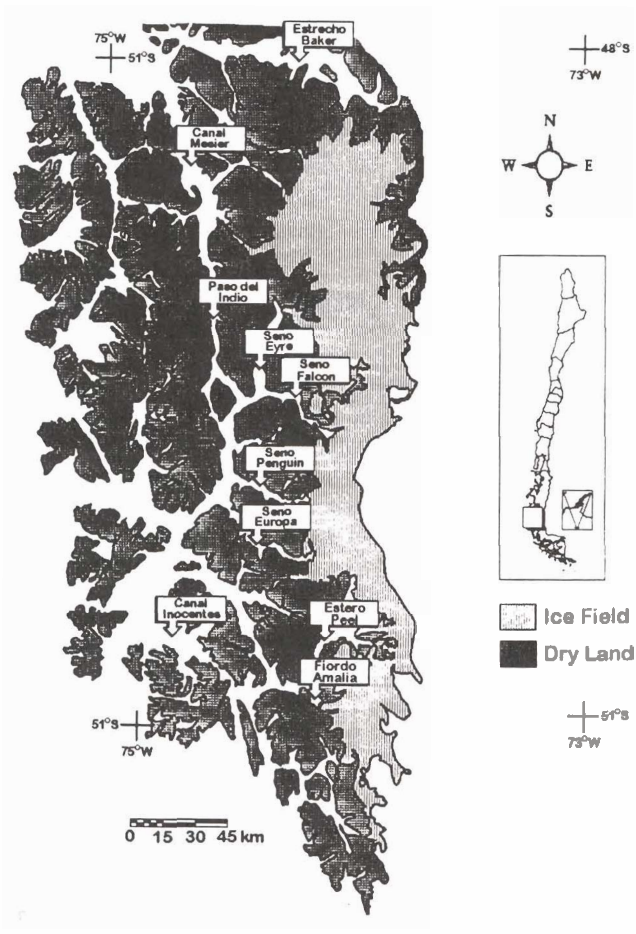

Figure 1: Sketch map of the fiord inlet system adjacent to "Campos de Hielo Sur".

The oceanography of the region is influenced by the flow of surface antartic waters, with water temperatures ranging between –1,8° C and –1,0° C. Salinity ranges between 34-35 (reaching values lower than 33 (during the summer season, due to thawing (IGM, 1987). The wave climate is characterized by high, short-steep waves, and is regulated by the strong and variable polar front winds. The range of spring tides is about 2 m (SHOA 1996).

2.2 Sampling Procedures

Between the months of August and September of 1995, seventeen sediment samples were taken from the oceanographic ship "Vidal Gormaz", of the Chilean Navy (Figure 2). The samples were collected from the middle part of the fiord inlets using a Reineck box corer (sampled area: 20 x 20 cm), selecting the top 10 cm of sediments for their analysis. The positioning of sampling sites was determined with a Global Positioning System receiver (GPS; Table 1).

2.3 Techniques

From every sample collected two subsamples were obtained. One of them was used to calculate the relative organic matter content, drying it at 60° C for 72 hours and later burned at 550° C for 4 hours. The percentages were obtained by measuring the loss of weigth on ignition (Mills, 1978).

The remaining subsample was dispersed, dissolved in an electrolyte, with an ultrasonic device during 5 minutes. Subsequently, the analysis of grain size was carried out with an Electronic Particle Size Analyser, Elzone (model 282PC (Particle Data, Inc. 1991). In the Electrozone instrument a quantity of electrolite containing particles of sediments, is drawn through a small orifice. A constant electrical current is caused to flow through the orifice, which constitutes the principal resistance in the electrical path. As a particle moves through the orifice, a voltage pulse is created whose amplitude is proportional to the volume of the particle. The magnitude of each pulse is measured, classified and the information stored in the proper channel indicating that an equivalent sphere in a specific size range passed through the orifice and was counted. This measuring and classifying was accomplished by an analog to digital converter and a computer.

The method of moments (Seward-Thompson & Hails, 1973)* was used to obtain the statistical parameters (mean size, standard deviation, skewness and kurtosis). Histograms were built using the percentage frecuency of each class interval. The textural classification of the samples was made according to the mean size of the grain-size distribution (Wentworth, 1922). Finally, the sediment samples were classified according to their color, using a color chart for this purpose (Geological Society of America, 1975).

(*) The data are presented using the ϕ (phi) unit scale, which is a convenient way of presenting the size classes as whole numbers: $\phi = -\log_2$ (diameter in mm).

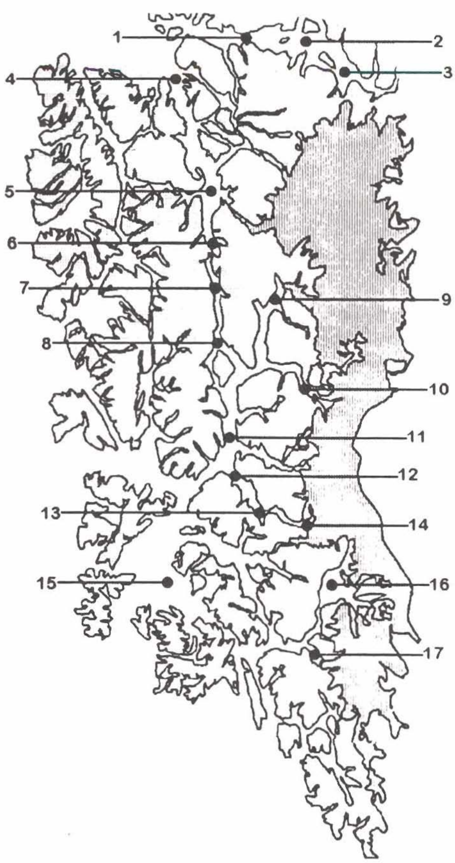

Figure 2: Location of samplingn stations.

3. RESULTS

The study area is characterized by the presence of fine fractions in the bottom sediments, especially very fine silt and clay. Very fine silt is the most abundant sediment, covering a great part of the area of the fjord inlets. The samples did not contain any gravel and sand fractions.

Table 2 shows the size fraction percentages of the 17 sediment samples. The silt fraction ranges between 43,02% and 66,34% with a mean value of 55,22%. The clay percentage varies from 32,93% to 56,98%, with an average of 44,78%.

Table 1

Location and depth of sampling stations

Sampling	Location	Latitude (S)	Longitude (W)	Depth (m)
1	Estrecho Baker	47° 58,6'	74° 14,7'	734
2	Estrecho Baker	47° 59,5'	73° 47,0'	1.066
3	Estrecho Baker	48° 00,7'	73° 37,3'	382
4	Canal Messier	48° 07,2'	74° 36,8'	684
5	Canal Messier	48° 42,1'	74° 24,8'	348
6	Canal Messier	48° 54,4'	74° 23,9'	367
7	Paso del Indio	49° 02,5'	74° 26,0'	161
8	Paso del Indio	49° 22,4'	74° 25,4'	236
9	Seno Eyre	49° 20,2'	74° 04,4'	283
10	Seno Falcon	49° 38,7'	73° 49,6'	363
11	Seno Penguin	49° 53,7'	74° 19,8'	487
12	Seno Europa	50° 07,3'	74° 13,8'	453
13	Seno Europa	50° 12,7'	74° 04,4'	167
14	Seno Europa	50° 14,4'	74° 01,6'	186
15	Canal Inocentes	50° 34,1'	74° 45,5'	45
16	Fiordo Peel	50° 31,3'	73° 44,9'	204
17	Fiordo Amalia	50° 52,1'	73° 51,2'	150

Table 2

Size fractions percentages, Total Organic Matter (TOM), textural classification and color of sediments

Sampling Stations	Silt (%)	Clay (%)	T.O.M (%)	Texture	Color
1	58.16	41.84	5.91	Very fine silt	Olive gray (5Y4/1)
2	57.22	42.78	4.43	Very fine silt	Brownish gray (5YR4/1)
3	45.91	54.09	4.21	Clay	Olive gray (5Y4/1)
4	57.04	42.96	7.02	Very fine silt	Light olive gray (5Y6/1)
5	64.22	35.78	4	Very fine silt	Olive gray (5Y4/1)
6	58.59	41.41	5.92	Very fine silt	Olive gray (5Y4/1)
7	56.82	43.18	9.19	Very fine silt	Olive gray (5Y4/1)
8	46.12	53.88	4.77	Clay	Dark greenish gray (5GY4/1)
9	44.28	55.72	2.47	Clay	Medium dark gray (N4)
10	53.59	46.41	2.9	Very fine silt	Olive gray (5Y4/1)
11	62.76	37.24	4.61	Very fine silt	Olive gray (5Y4/1)
12	63.98	36.02	5.01	Very fine silt	Olive gray (5Y4/1)
13	67.07	32.93	3.3	Very fine silt	Light olive gray (5Y6/1)
14	43.02	56.98	2.5	Clay	Olive gray (5Y4/1)
15	43.85	56.15	3.79	Clay	Brownish gray (5YR4/1)
16	49.75	50.25	2.45	Clay	Light olive gray (5Y6/1)
17	66.34	33.66	2.85	Very fine silt	Yellowish gray (5Y8/1)

The spatial distribution of the textural classes, shows on one hand, that the clay fraction is mainly associated with the sheltered heads of the inlets directly influenced by the glaciar system (heads of the "Estrecho Baker", "Seno Eyre", "Seno Europa" and "Estero Peel"). On the other hand, the very fine silt is distributed over the western part of the area, in the exposed mouths of the "Estrecho Baker", "Canal Messier", "Paso del Indio", "Seno Penguin", "Seno Europa" and "Fiordo Amalia".

The statistical parameters and some representative examples of the grain size distribution are presented in Table 3 and Figure 3 respectively. The mean grain size ranges between 8,12 f and 7,67 f with an average of 7,89 f (very fine silt). The higher values, with respect to the mean, occur in the heads of the inner inlets (heads of the Baker, Eyre, Falcon, Europa and Peel). Lower values occur in the exposed mouth of the inlets (Baker, Messier, Penguin, Europa and Amalia).

Table 3

Statistical grain-size parameters of sampled sediments

Sampling Stations	Mean Size (ϕ)	Sorting (ϕ)	Skewness	Kurtosis
1	7.86	0,63	–0.23	3.1
2	7.86	0.6	–0.3	3.11
3	8.05	0.62	–0.35	3.69
4	7.86	0.66	–0.3	3.11
5	7.71	0.74	–0.26	2.9
6	7.81	0.72	–0.34	3.06
7	7.85	0.69	–0.36	3.19
8	8.03	0.76	–0.47	3.34
9	8.09	0.63	–0.09	3.04
10	7.94	0.62	–0.17	3.1
11	7.75	0.72	–0.25	2.94
12	7.74	0.69	–0.33	3.17
13	7.69	0.7	–0.11	2.85
14	8.12	0.61	–0.04	3.01
15	8.07	0.82	–0.11	2.71
16	8.03	0.71	0.02	2.72
17	7.67	0.75	–0.19	2.81

According to Folk´s classification (1980), the sorting of sediments vary between moderately well sorted (0,62 f) and moderately sorted (0,82 f), with an average of 0,69 f (moderately well sorted). The spatial distribution of sorting shows that lower values (well sorted) occur in the Baker and heads of the Eyre, Falcon and Europa. Moderately sorted-sediments occur throughout the Messier extending through the Paso del Indio to the mouth of Seno Europa, southward all stations show the same trend.

Most sediments are negatively-skewed ranging between –0,47 (strongly coarse-skewed) to 0,02 (near-symmetrical), with an average of –0,23 (coarse-skewed). The sediments of the Baker, Messier, Paso del Indio and mouth of the Penguin and Europa exhibit the highest skewness, on the other hand, the heads of the Eyre, Falcon, Europa, Peel and Amalia present the least skewness of all the area.

The Kurtosis of the analyzed samples is in the range 2,71 (very leptocurtic) to 3,69 (extremely leptocurtic) with an average of 3,05 (extremely leptocurtic). The north part (Estrecho Baker and mouth of the Messier) exhibits sediments with excessively peaked curves (> 3,05), while the south part of the study area (Europa, Peel, Amalia and Canal Inocentes) exhibits kurtosis values less than 3,05.

The relative organic matter content of the sediments of the fiord inlets (Table 2) varies from 2,45 to 9,19%, with an average of 4,43%. The lowest values (< 4,43%) are found at the inner head sectors proximal to the glacier (the heads of the Baker, Eyre, Falcon, Europa and Peel).The exposed and sea-proximal inlets (the mouths of the Baker, Messier, Penguin, Europa and Paso del Indio) are characterized by higher contents of organic matter (> 4,43%).

Based on the rock-color chart (1975), the color of sediments (Table 3) ranges between yellowish gray (5Y 8/1), light olive gray (5Y 6/1), medium dark gray (N4), brownish gray (5YR 4/1), olive gray (5Y 4/1) and dark greenish gray (5GY 4/1). The darker sediments are mostly found in the exposed sea-proximal inlets.

4. DISCUSSION

The distribution of sediments in the study area mostly shows silty cover in the deep parts, this result is similar to those reported by other authors for other fiords (Pickrill *et al.*, 1981; Skei & Melsom, 1982; Bogen, 1983). According to Seibold & Berger (1993), the presence of silt would be caused by continental mechanical weathering through the freeze-thaw cycle. The apparent absence of gravel and sand fractions, could be explained by the sediment distribution model proposed by Piper *et al.* (1983), where the coarse size fractions are found in the nearshore platforms, while silt progrades over or is advected beyond basin slopes. According to this, it seems reasonable the collection of only fine sediments during our campaign, since all sampling stations were located in the central part of the inlets.

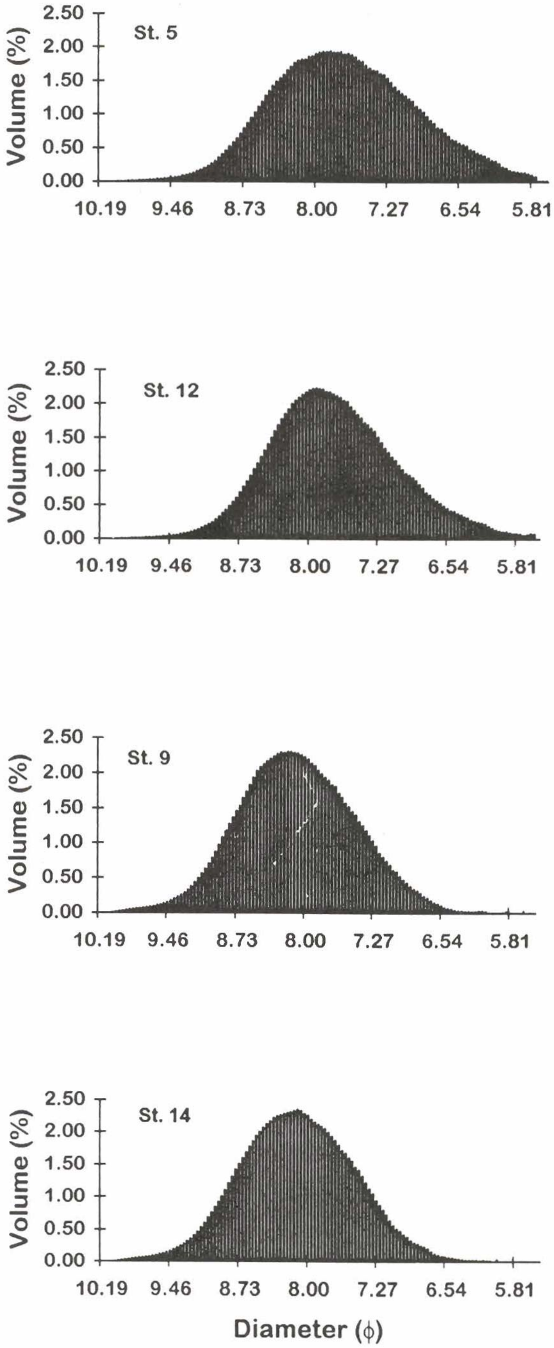

Figure 3: Representative grain-size distribution curves of the sheltered (stations 9 and 4) and exposed (stations 5 and 12) environments in the fjord inlets of Campos de Hielo Sur.

The spatial distribution of textures shows, that clay is more abundant in the fiord heads while the silt content increases toward the mouth of the inlets. This situation would be related, on one hand, to the location and geomorphological characteristics of the heads, turning them into sheltered low-energy level environments (with less influence from winds), allowing the deposition of the clay fractions. Besides, the action of tides produce in this kind of environment, a selective transport of clays toward the heads of the inlets (Clifton, 1982). For this reason, the silt fraction are found in the more exposed sea-proximal sectors, where the winnowing of the finest particles by waves and tide currents is greater (Reineck & Singh, 1980). This clear spatial demarcation of the area (western heads and eastern mouths of inlets), inferred from the textural characteristics, agrees with the geomorphological boundaries proposed by Börgel (1983), distinguishing the sectors of the "Pacific Patagonian Ranges with rivers and fiords controlled by tectonics" (presenting an uplifting trend) from the sectors of the "Insular Patagonian Ranges" (controlled by tectonic subsidence).

The mean grain size reflects the hydrodynamic conditions that acted during the transport and deposition of particles (Folk, 1980). Generally, the coarses particles are associated with a high-energy level, while finer grains occur in sectors with less hidrodynamism. In this way, the recognition of finer grains (clays) at the heads of the inlets suggest that this are low-energy level environments, while the silty grained-mouths, would be characterized by a higher level of energy. This energy levels might be controlled as much by the degree of exposure to the prevailing winds (due to the geomorphological characteristics) as by tidal currents.

With respect to currents, the sorting of sediments shows evidence of the strength of the flow acting on the deposits, with currents of relatively constant strength producing better sortings than currents which fluctuate rapidly from almost slack to violent (Folk, 1980). In this manner, the distribution of sorting in the study area shows that the Baker and the heads of the Eyre, Falcon and Europa are subjected to currents of intermediate strength. Likewise, it is recognized that the Canal Messier, Paso del Indio, the mouths of the Seno Penguin and Seno Europa, and the Canal Inocentes, are identified as one unit subjected to dynamic processes of greater variability. This variability could be related with the fluctuation of the tide currents, since the greatest spring tidal ranges recorded in the area (1.74-2.40 m), occur in the Canal Messier, Paso del Indio and the Canal Inocentes (SHOA, 1996).

The skewness of sediments, shows the excess of particles in the tails of the frecuency curves. The excess of coarse particles are represented as negative values, while the excess of fines are expressed as positive values. The dynamic interpretation for the present study area, characterized by negative skewness, could be attributed to currents acting during a period of time with a higher level of energy than the average, supplying coarser particles (Sahu, 1964). Sagga (1992), associates the fluctuations in skewness with the variations in the physical energy of the various dynamic agents. Thus, based on the spatial distribution of skewness, it is possible to suggest that the tide currents that operate along the Canal Messier, Paso del Indio, and prolonging southward, may explain the negative trends in the fjords sediments. Once again, the inlet situated between stations 4 through 12 is identified as being one sedimentary unit controlled by similar dynamic processes. On the other hand, the heads of the inlets seem to be dominated by the deposition of finer material due to the lower-energy levels prevailing in these sectors.

In relation to kurtosis, no clear trends were identified regarding this parameter. Nevertheless, it is suggested that the presence of leptocurtic sediments could be explained by the dominance of one sediment source for the fiord inlets. The main sediment source would be the glaciers, delivering fine sediments and predominating over any other sources.

According to Friedman (1978), the sediments of fiords having stagnant bottom waters posses high organic matter contents, while the proportion of organic matter in fine-grained sediments deposited under oxidizing bottom waters is low. The ventilation of bottom waters, dependant on the sill depth, controlls the amount of organic matter in sediments, due to the fact that ventilated bottom waters contain a higher supply of dissolved oxygen capable of oxydizing the organic fraction. In basins with deficient ventilation, the oxygen content decreases, reducing the oxidation rate of the organic matter, leading to its buildup in sediments.

Considering that in the study area, darker sediments with higher relative contents of organic matter occur in the exposed sea-proximal inlets, it is recognized that the area is in agreement with the principle that relates the organic matter to the color of sediments (Reineck & Singh, 1980). According to this statement and based on the organic matter content and color results obtained, it may be suggested that the system as a whole, is subjected to relatively periodic renewals of the bottom waters, creating sub-oxic conditions within the basins. This result agrees with the observation made by Pickard (1971) regarding the uncommon presence of stagnant basins in the area, been ascribed to the absence of shallow sills in the inlets studied.

Furthermore, it is suggested that the organic carbon supply does not derive from the mainland, since the finest fraction (clays), found at the fiord heads, is associated with low contents of organic matter and light gray sediments. If the mainland were to supply the organic matter, the latter would be deposited along with the fine particles at the fiord heads (Seibold & Berger, 1993). This way, it is concluded that the source for organic matter in the study area, derives mainly from the sea (marine productivity) since the sea-proximal sediments samples present darker coloration and higher contents of organic matter. Thus, the mainland would mainly supply mineral fractions produced by the glacier action, reducing the relative abundance of organic matter in the sediments of the fiord heads.

5. CONCLUSIONS

a) Silt is the most abundant sediment in fiord inlets of "Campos de Hielo Sur", covering great parts of the soft bottoms of the system. The silty texture is probably the result of the glacier action over the landforms, through the freeze-thaw cycle.

b) Based on textural classification and textural parameters of sediments, two energy zones can be recognized in the study area: a low-energy level environment restricted to the east sector, and represented by the geomorphologically-sheltered fiords heads with direct influence from the glacier, where clayey, more sorted and less-negatively skewed sediments are found, indicating the lower physical energy of the sedimentary process involved; and a moderate-energy level environment located in the west sector comprising the sea-proximal inlets where silty, least-sorted and more-negatively skewed sediments ocurr, reflecting the presence of processes of higher energy.

c) The two energy levels identified, would be mainly determined by the geomorphological characteristics of the study area. The low-energy head sectors are sheltered by a high relief, while the mouth of the fiord inlets are exposed to the wind action due to the lower height of the landforms.

d) According to textural and grain-size parameters, the Canal Messier, Paso del Indio, the mouths of the Seno Penguin and Seno Europa behave as one sedimentary unit, probably controlled by action of tide currents and winds.

e) On the basis of contents of organic matter and color of sediments, it is inferred that the system is subjected to periodic renewals of the bottom waters, creating a sub-oxic sedimentary environment.

f) Based on grain-size results and distribution of organic matter, it is concluded that the organic fraction supply derives mainly from the marine sector. Whilst the mainland would only deliver mineral fractions to the system, decreasing the relative organic content in the sheltered fiords heads.

e) The recognized sedimentary characteristics for the study area delimit two environments, fitting well with the location of the geomorphological clasification proposed by Börgel (1983), for the sector.

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REFERENCES

BOGEN, J. (1983): Morphology and sedimentology of deltas in fiord and fiord valley lakes. Sediment. Geol., 36: 245-267.

BÖRGEL, R. (1983): Geomorfología. In Instituto Geográfico Militar (De.), Colección Geografía de Chile (Tomo II), 178 pp.

CLIFTON, H.E. (1982): Estuarine deposits. *In*: P.A. Scholle & D.R. Spearing (Eds.), Sandstone depositional environments. The American Association of Petroleum Geologists. pp. 179-190.

COMITE OCEANOGRAFICO NACIONAL (1996): Informe de crucero. Crucero de investigación científica marina a los fiordos y canales adyacentes a Campos de Hielo Sur. Secretaría Ejecutiva del Comité Oceanográfico Nacional, Valparaíso, 122 pp.

FOLK, R.L. (1980): Petrology of sedimentary rocks. Hemphill, Austin,T x, 182 pp.

FRIEDMAN, G.M. & J.E. SANDERS. (1978): Principles of sedimentology. John Wiley & Sons, New York, 792 pp.

GEOLOGICAL SOCIETY OF AMERICA (1975): Rock-color Chart.

INSTITUTO GEOGRAFICO MILITAR. (1983): Atlas de la República de Chile. Instituto Geográfico Militar, Santiago, 349 pp.

INSTITUTO GEOGRAFICO MILITAR (1987): Geografía de Chile. Geografía XII Región de Magallanes y de la Antártica Chilena. Instituto Geográfico Militar, Santiago, 368 pp.

MILLS, A. (1978): A comparison of methods of determining organic carbon in marine sediments with suggestions for a standard method. Hydrobiologia, 57(1): 45-52.

PARTICLE DATA INC. (1991): Instruction Manual. Elmhurst, Ill. 45 pp.

PICKARD, G.L. (1971): Some physical oceanographic features of inlets of Chile. J. Fish. Res. Bd. Canada, 28(8): 1077-1106

PICKRILL, R.A., J. IRWIN & B.S. SHAKESPEARE. (1981): Circulation and sedimentation in a tidal-influenced fiord lake: Lake McKerrow, New Zealand. Estuarine, Coastal and Shelf Science, 12 (1): 23-37.

PIPER, D.J.W., J.R.J LETSON, A.M. DE IURE & C.Q. BARRIE (1983): Sediment accumulation in low-sedimentation, wave dominated, glaciated inlets. Sediment. Geol., 36: 195-215.

PRITCHARD D.W. (1976): La circulación y la mezcla en las regiones costeras y los estuarios. *En:* R.C. Vetter (Ed.). Oceanografía, la última frontera. Editorial "El Ateneo", Buenos Aires, pp. 273-282.

REINECK, H. E. & I.B. SINGH (1980): Depositional sedimentary environments. Springer-Verlag, Berlin, 549 pp.

SAGGA, A.M. (1992): The use of textural parameters of sand in studying the characteristics and depositional processes of coastal sediments on Saudi Arabian beaches. Mar. Geol., 104: 179-186.

SAHU, B. (1964): Depositional mechanism from the size analysis of clastic sediments. Journ. Sed. Petrol., 34: 73-83.

SEIBOLD, E. & W.H. BERGER (1993): The sea floor. An introduction to marine geology. Springer-Verlag, Berlin, 355 pp.

SERVICIO HIDROGRAFICO Y OCEANOGRAFICO DE LA ARMADA DE CHILE (SHOA), (1996): Tablas de marea de la costa de Chile y puntos de la costa sudamericana. SHOA, Valparaíso, 337 pp.

SEWARD-THOMPSON, B.L. & J.R. HAILS. (1973): An appraisal of the computation of statistical parameters in grain size analysis. Sedimentology, 20: 161-169.

SKEI, J.M. & S. MELSOM. (1982): Seasonal and vertical variations in the chemical composition of suspended particulate matter in an oxygen-deficient fiord. Estuarine, Coastal and Shelf Science, 14(1): 61-78.

WENTWORTH, C.K. (1922): A scale of grade and class terms for clastic sediments. J. Geol., 30: 377-392.