Seismic Echo-characters and Sedimentary Distribution on South Shetland Continental Margin, Antarctica.

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Abstract

The present work emphasizes on the geological characterization of the South Shetland Islands continental margin, Antarctica, and its sedimentary distribution. Data were interpreted through echo-characters and geological samples analysis.

Echo-characters and seismic amplitudes showed good correlation with the sedimentary distribution along South Shetland's continental margin.

Five different echo types have been identified and classified. Echo types I and II have good seismic resolution and are characterized by continuous sharp bottom echoes with sub-parallel reflexions. Echoes III and IV are characterized by very prolonged bottom echoes with no sub-bottom reflectors. Echo V/Hyperbolic are associated to glacial deposits, in response to deglaciation and the transport of coarse grains in a muddy matrix, and shows large irregular overlapping hyperbolae.

Introduction

The use of echo-characters from high-resolution seismic profiles (3.5, 7.0 and 12 kHz) are efficient in the analysis of superficial sediments distribution (Damuth 1975; Baptista Neto 2004; Hong & Cheen 2000).

This work investigates the distribution of superficial sediments on South Shetland continental margin, Antarctic Peninsula.

The understanding and characterization of the area was made trough amplitude maps, echo-characters and geological samples analysis. Seismic data and superficial sediments samples were acquired during the survey in order to correlate different echo-types with the samples. Thus, enhancing their comparison and providing a better sedimentary distribution along South Shetland Islands and Bransfield Strait (Figure 1).

Nowadays, the Antarctic Peninsula is being focus of a series of studies, since this region is one of the most affected by global warming. The understanding of its geological process can lead to a better comprehension of paleoclimates and ocean currents dynamics.

Geology

The South Shetland Islands, located northwest of the Antarctica Peninsula, are a magmatic arc associated to a subduction and separated from the South Shetland Islands by a rift.

The Bransfield Strait is a recent back-arc rift (Barker, 1982; Barker & Austin, 1998), with maximum depths of 2,500 meters. The Strait is 470 Km long, from Clearence to Low Islands and is 100 Km wide.

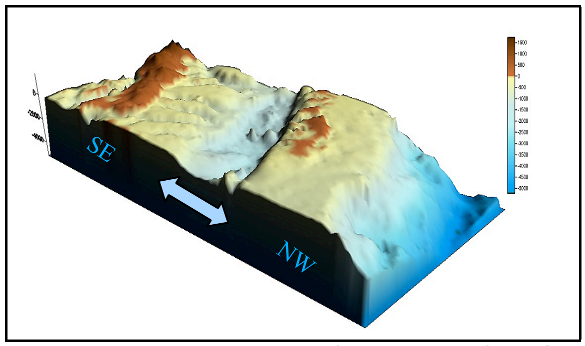


Fig. 1 – Digital terrain model for the Bransfield Strait, Antarctica.

The Antarctic Peninsula continental margin is characterized by inclined layers dipping into the basins axis, due to its steeper slope.

Bransfield Strait has an asymmetrical profile, with a steeper slope and a conspicuous spreading center closer to the South Shetland Islands (Gamboa et al., 1988).

Inside the Admiralty Bay and other glacier-influenced bays, the seafloor is dominated by glacier deposits, such as eskers, moraines, flutes, kame terraces and clasts pavements (Rosa et al., 2010).

According to Birkenmajer (2003), the Bransfield Strait's tectonic model has dynamics of a subduction zone, with back-arc basins and an active rift on the Strait.

Gamboa et al. (1988) analyzed seismic sections in Bransfield Strait and characterized the area by smooth relief and layers with parallel reflexions deposited above the embassament. Gamboa (1988) also demonstrates an alternation of pelagic sediments and turbidites in the central portion of the basin.

The formation axis of the oceanic crust is a continuous lineament that works as a barrier, avoiding the transport of sediments from the margin into the basin. The bottom layers present parallel reflectors from the deep part of the basin up to the volcanic axis.

The active volcanism in that portion is originated from the Pacific's crust subduction underneath Antarctica's continental crust. The volcanism, associated to Bransfield rift, occurs along its spreading axis and outcrops on Bridgeman, Penguin, Deception islands and in other submarine volcanoes, which constitute most of the volcanism in the rift (Gamboa et al., 1988).

Method

The seismic data were acquired in November 2009, using the Sub-Bottom Profiler Edgetech 3200 during OPERANTAR XXVIII, in a total of 350 Km in fifteen seismic lines within an area of approximately 700 Km² (Fig. 2).

The sub-bottom profiler was set to the following parameters: Pulse: 50 – 100 ms; Source power: 100%; Frequencies: 0.5 - 2.7 kHz and 0.5 – 4.5 kHz.

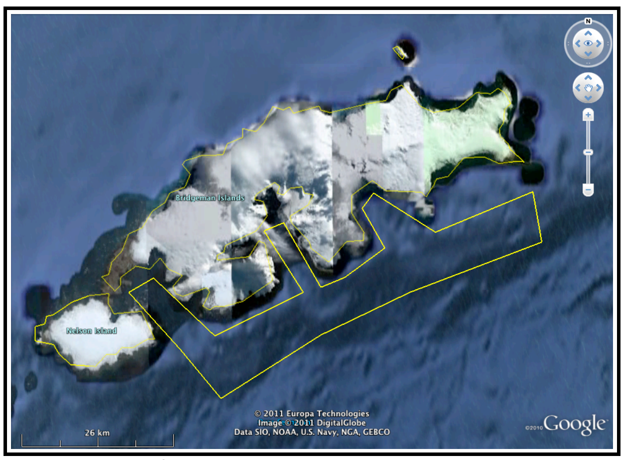


Fig. 2 – Area for the seismic survey, data were acquired during the OPERANTAR XVIII, 2009.

Ten geological samples (five were used in this work) were collected along Bransfield Strait and inside Admiralty and Maxwell Bays in King George islands (Fig. 3). The Gravity Corer (Fig. 4) has approximately 400 Kg and is six meters long.

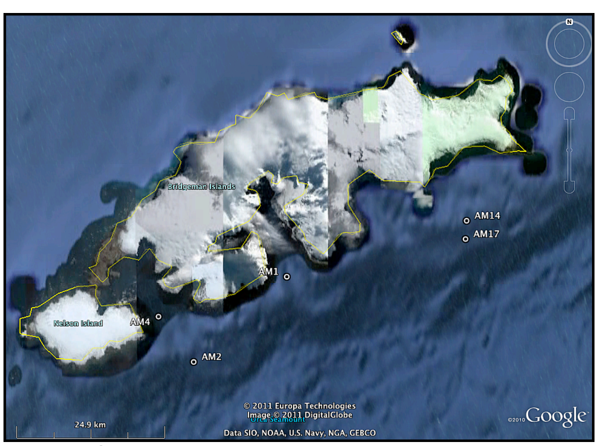


Fig. 3 – Geological samples acquired during the survey around King George Islands, Antarctica.

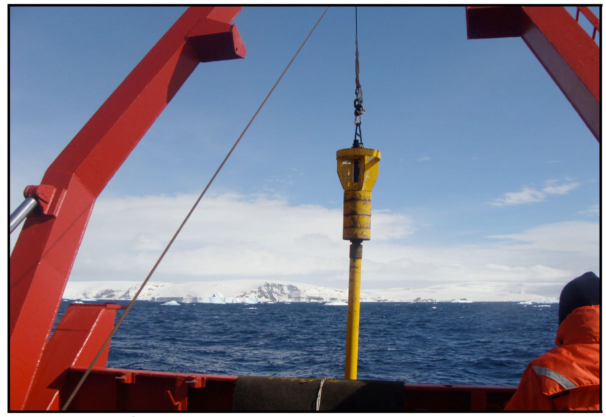


Fig. 4 – Gravity corer being lowered. Antarctica, November, 2009.

Echo-characters and Seismic Amplitudes

The occurrence and distribution of sonographic patterns of high-resolution seismic profiles have a strong relation with the types and characteristics of the sediments (Morang et al., 1997; Ayres Neto, 2000).

Echo responses are produced by impedance contrasts between different mediums. This contrast is related to the material present on the bottom layer (size, compaction, etc.), sub-superficial layers (reflexion coefficient, layer's thickness, interference between layers, multiples, etc.) and seabed's morphology (diffraction, layers extension, lateral variations, etc) (Junior et al., 2009).

Echo analysis are important to map and characterize acoustically the seabed. The combination of echoes and sonograms allows the interpretation of the sedimentary processes, past and present, occurring in the area.

The term facies, associated to acoustic signals, indicates the bottom's acoustic response (whether for sub-bottom profilers or side-scan sonars), depending on it's grain size, morphology, texture and compaction maturity).

Seismic amplitudes from the returning signal are due to acoustic impedances (product of velocities and densities) and depends on elastic rock proprieties.

When a seismic wave interacts with an interface, the wave is partially reflected and transmitted to the second medium. According to the reflexions that occur in lithologies, the seismic waves will have it's velocity changed, producing variations in amplitudes.

The interpretation of seismic amplitudes usually have two main objectives: identify the geometry of geologic structures that may trap hydrocarbons or to correlate amplitudes present on seismic profiles with different lithologies or bottom sediments.

Thus, the correlation between the geophysical data acquired enabled the identification of different patterns and its interpretation, leading to the sedimentary distribution of South Shetland continental margin, Antarctica.

RESULTS

Sedimentary Analysis

The Multi-sensor Core Logger was used to obtain densities, P-wave velocities, impedances and the porosities from the samples. The result of the analysis of impedances within the collected samples are shown below (Table 1).

Table 1 – Mean Impedances on geological samples.

MEAN IMPEDANCES	
Sample:	Mean Impedances ($N \cdot s \cdot m^{-3}$)
Sample 1 (AM-01)	2994,95
Sample 2 (AM-02)	3107,92
Sample 4 (AM-04)	2603,13
Sample 14 (AM-14)	2580,32
Sample 17 (AM-17)	2677,44

The region around the second sample (AM-02), has higher seismic amplitudes, due to its higher impedance, causing a stronger reflexion pattern (Fig. 5). Analogously, the sample 14 (AM-14) has a low impedance, with an average of 2580,32 $N \cdot s \cdot m^{-3}$, resulting in lower amplitudes and weaker reflexions (Fig. 6).

Examples

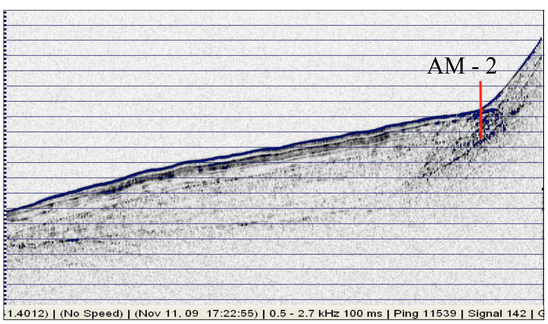


Fig. 5 – Seismic profile with the location of the sample AM-2.

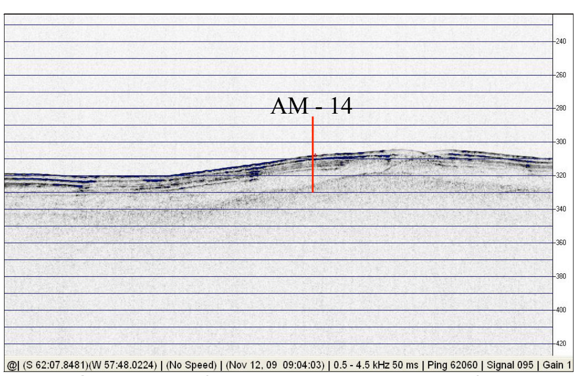


Fig. 6 – Seismic profile around AM-14, the reflexions are less intense than the ones around AM-02.

Echo-characters Classification

Geological characterization was made through echo-character analysis, maps of seismic amplitude and its correlation with the collected superficial sediments (maximum penetration into seafloor: 5m).

Through amplitude analysis, geological samples and seismic profiles, five different echo-characters have been identified. The echo-characters were grouped into five distinct categories in order to create maps from the distribution of sediments. The echo-characters were highly associated to the ocean's floor morphology, micro topography and subsurface geometry and texture.

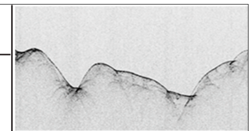
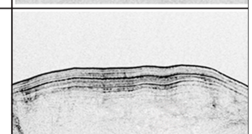
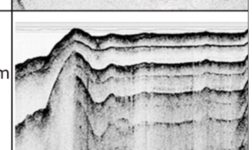
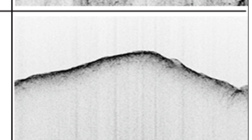
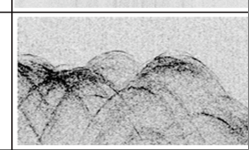
ECHO	DESCRIPTION	
I	Continuous sharp bottom echo with weak sub-parallel reflexions	
II	Continuous sharp bottom echo with strong sub-parallel reflexions	
III	Very prolonged bottom echo with multiples and no sub-bottom reflectors	
IV	Very prolonged bottom echo and no sub-bottom reflectors	
V	Large irregular overllaping hyperbolae with widely varying vertex elevations	

Fig. 7 – Seismic profiles showing five different echo-characters.

Echo I is characterized by a continuous sharp bottom echo with weak sub-parallel reflexions. This echo is distributed along all Bransfield Strait, except in shallow areas with depths less than 200 meters. (Fig. 8, blue echo).

Echo II is characterized by a continuous sharp bottom echo with numerous strong parallel sub-bottom reflectors, and can be found mainly between 800 and 400 meters deep (Fig. 8, purple echo). In Damuth's (1975; 1977) works, this echo is classified as IB.

Echo III is characterized by a very prolonged diffuse bottom echo with multiples and no sub-bottom reflectors. This type is related to shallow areas with depths between 0 and 250 meters. In Damuth's (1975) work, this echo is classified as IIA-1 and in Damuth's (1977) as IIB. (Fig. 8, red echo).

Echo IV is also characterized by a very prolonged bottom echo with no sub-bottom reflectors, but since its depths ranging from 200 to 600, there are no strong multiples in seismic profiles. (Fig. 8, green echo).

Echo V/Hyperbolic is characterized by large irregular overlapping hyperbolae with widely varying vertex elevations above the sea floor and low seismic resolution. It is found at depths ranging from 600 to 1,400 meters. Damuth (1975) classifies it as Echo IIB-1 and Damuth's (1977) classifies it as IIIA (Fig. 8, yellow echo).

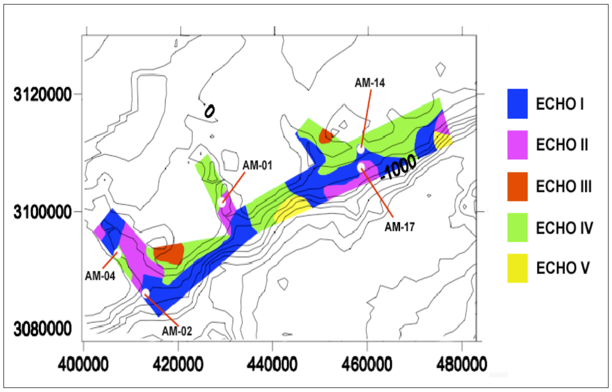


Fig. 8 – Echo-characters map. Blue - Echo I. Purple – Echo II. Red – Echo III. Green – Echo IV. Yellow – Echo V/Hyperbolic.

Geological Samples Characteristics and Amplitude Analisys

According to Shepard's (1954) texture classification, samples AM-01, AM-04, AM-14 and AM-17 corresponds to sandy silts textures (or silt loam, according to the United States Department of Agriculture classification). AM-02, on the other hand, is the only one classified as silty sand (sandy loam, in USDA's classification). The percentages of sand, silt and clay (average through the sample) are displayed below (Fig. 9).

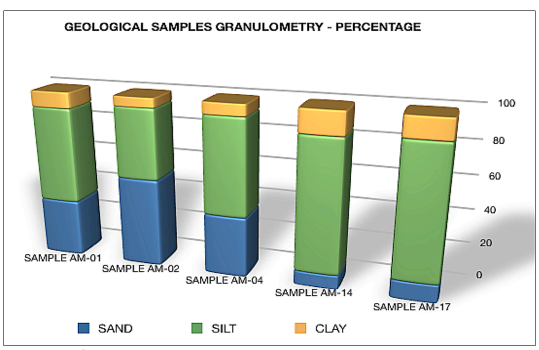


Fig. 9 – Geological samples with sand, silt and clay average percentages.

As a result of seismic interpretation and horizon mapping through "Wiggle Trace" visualization on SMT KINGDOM, an amplitude map was created (Fig. 10) and a direct relationship between amplitudes and its correspondent geology could be established.

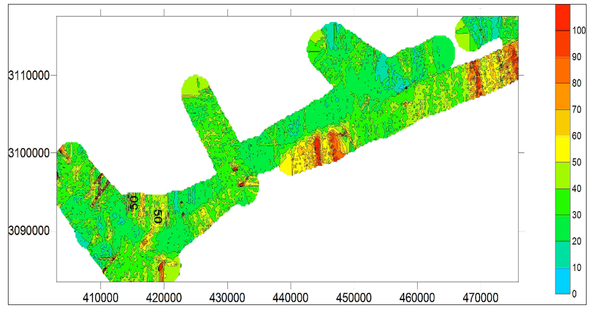


Fig. 10 – Amplitude map, color scale with seismic amplitudes.

In general, the regions with the highest amplitude values (red area) corresponds to Echo V/Hyperbolic.

Echo I showed medium-high amplitudes, and the geological samples AM-02 and AM-14 indicates, respectively, a silty sand and a sandy silt content. AM-02 shows the highest percentage of sand (52,3%) within the collected samples, providing high amplitude values.

Echoes III and IV, demonstrate medium-low values and are related to samples AM-01 and AM-04 (both classified as sandy silt) with a content of sand of approximately 35%.

Echo II showed the lowest values of amplitude, due to the high amount of silt and clay as indicated in sample AM-17 (almost 90% of mud), within the area dominated by Echo II.

Other high values occur onward into the sea and are related to glacial deposits.

Conclusions

The samples AM-01 and AM-04 are coincident with Echo IV and although AM-04 is located between echoes II and IV on the echo-characters map (Fig. 8), its sedimentary characteristics, with approximately 34% to 36% of sand and 56% to 57% of silt, reflects more of Echo IV characteristics, with coarser sediments (more sand than AM-17 collected on Echo II). AM-01 and AM-04 are both located inside the bays (Admiralty bay for AM-01 and Maxwell bay for AM-04) and have similar granulometry.

Despite different in composition (AM-14 is mainly mud, with 91.7% of mud, while AM-02 has only 47.7%), both are located on the blue area of the echo-character map, corresponding to Echo I.

AM-17 is located on Echo II and concentrates almost 90% of mud on it's geological sample, a result of pelagic sedimentation.

Echo III and Echo IV are very similar, except for the series of multiples on Echo III due to it's shallow depth (Echo III occurs only in areas less than 200 meter deep). The multiples were created by the sub-bottom profiler high potency during the survey in shallow depths. Thus, echoes III and IV are equivalent, except for the depths.

No samples were acquired on echoes III and V/hyperbolic. Samples in Echo V/Hyperbolic could not be recovered during the geological sampling due to the limited capacity of the gravity corer to penetrate in the coarse sediments of glacial deposits. The irregular overlapping hyperbolae are due to the rugged morphology produced by the unstratified, poorly sorted sediments deposit.

Thus, based on high-resolution seismic profiles (3.5 kHz), geological samples and amplitudes analysis on South Shetland continental margin, this work provided a understanding of the overall superficial sedimentary distribution on South Shetland continental margin.

Nevertheless, a full understanding of the sedimentary processes acting on Bransfield Strait and South Shetland Islands requires further surveys with more geological samples positioned inside each echo, and also transversal to the direction of glaciers movement.

Acknowledgments

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