British Journal of Applied Science & Technology
9(3): 307-312, 2015, Article no.BJAST.2015.269
ISSN: 2231-0843

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Stratigraphic Interpretation of an Antarctic Shelf Edge

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Authors' contributions

This work was carried out in collaboration between all authors. Author AM processed the data; authors AM and ASR interpret the data. Authors FAR, MBS and MH wrote the first draft of the manuscript and managed literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJAST/2015/9809
Editor(s):
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(3) Anonymous, University of Manitoba, Winnipeg, Canada.
Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=1138&id=5&aid=9323

Short Research Article

Received 1st March 2014
Accepted 11th December 2014
Published 21st May 2015

ABSTRACT

A stratigraphic interpretation was carried out on the processed single-channel data. Four major sequence boundaries were interpreted; two are sub-horizontal erosional surfaces while the other two show permanent onlap. Four major sedimentary units were interpreted on the single-channel data within a time range of 730 ms. Shelf break exists at a water depth of 640±17 m on profile Fig. 2, 480±16 m on profile Fig. 3. The profiles were interpreted to show sequences of glacially prograded sediments lying underneath the outer continental shelf. These sediments were deposited by grounded ice during times of glacial maximum which caused deposition in an overall progradational style and the grounded ice must have reached the continental shelf edge many times on most parts of the Bellingshausen Sea margin. The continental shelf across the area where these lines are located is relatively horizontal and the movement of ice front was across the whole area.

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Keywords: Stratigraphic; sequence; sediments; Bellingshausen Sea; continental shelf.

1. INTRODUCTION

Antarctica is the most southerly continent located about the southern point of the Earth's rotational axis (the Geographic South Pole). Out of the seven continents in the world, it is the fifth largest and it covers 10% of the earth's land area. In the eighteenth century, Captain James Cook concluded that the southern polar continent must be "doomed by Nature . . . to lie for ever buried under everlasting snow and ice" [1]. Cook's opinion was formed as a result of the large size and number of icebergs, and the turbulent and cold weather encountered during his Southern Ocean journeys. What Cook assessed during his eighteenth century voyage is what is now known as Antarctica. 2% of the Antarctic land surface is exposed bedrock, while 98% is covered with ice [1]. This 98% creates a difficult and challenging fieldwork environment, which is a large part of the attraction for the earth scientists from many nations who choose to pursue their profession at the end of the earth.

The identification and strata geometry of glacially deposited sediments on the Antarctic continental shelves provide significant clues for the reconstruction of the glacial history of West Antarctica [2,3]. The sediment stratigraphy and the physiography of the sea floor reflect the history of the West Antarctic glaciation as well as the processes that eroded, transported and deposited sediments on the outer shelf, slope and rise of the continental margin [4]. Multichannel seismic (MCS) reflection investigations of the Antarctic continental margin have revealed thick Cenozoic prograding sequences in several areas [5,6].

Almost all the previous studies on the continental margin of the Bellingshausen Sea made a common recommendation that further geophysical and geological investigations on this margin are required to verify their respective conclusions and improve the general knowledge of the area. This work aim to improve the general knowledge of glacially deposited sediments on Antarctic continental shelves.

2. LOCATION

The single-channel seismic lines to be interpreted were located within longitude 86° W to 89° W and latitude 69.8° S and 70.7° S which is in the Bellingshausen Sea in Antarctica.

3. THE GEOLOGY OF ANTARCTICA

The geology of Antarctica includes Eastern and Western Antarctica [1]. [1] defines the larger segment (East Antarctica) as the area, mostly in eastern longitudes, bounded on the seaward and the northern side by the South Atlantic and Indian Oceans and on the landward side by the Transantarctic Mountains, Pensacola Mountains, and eastern Filchner Ice Shelf. East Antarctica includes all known Antarctic exposures of Archaean rocks, and the great majority of outcrops of Proterozoic rocks. West Antarctica includes the Antarctic Peninsula, Marie Byrd Land, and other land areas not included in East Antarctica [1]. [7] explained the tectonic evolution of the Scotia Arc/Antarctic Peninsula region in a Mesozoic-Cenozoic plate tectonic framework. From their account, it is clear that the two areas consist almost entirely of Mesozoic and Cenozoic rocks. The British Antarctic Survey published the best available portrayal of the geology of the Antarctic Peninsula in 1979. This publication is the 1:500 000 scale regional geological maps published as BAS series 500 G (Sheets 1-5). Volcanic and plutonic rocks dominate the outcrop, but sedimentary and metamorphic rocks are also present.

3.1 Seismic Reflection Data

Based on seismic reflection and bathymetric data, the continental slope of West Antarctica and the Antarctic Peninsula was formed by sediments released from broad line sources associated with ice grounded at the shelf break [8,4].

The multichannel seismic (MCS) data across many parts of the Antarctic continental shelf from the Weddell Sea eastward to Marie Byrd Land show features characteristic of passive margins, such as layered sedimentary and possible volcanic deposits filling deep fault-bounded rift structures, widespread intermediate-depth unconformities and overlying prograding sedimentary sequences that are bounded by unconformities [5]. These deposits are principally Cenozoic glacial marine strata.

Cenozoic sedimentary sequences observed beneath at least five segments of the Antarctic continental margin were categorized by [5] using two general categories based on acoustic geometry largely near the present and palaeocontinental shelf edges as follows;

Type IA: Sequences that mostly, but not exclusively, prograde the palaeocontinental shelf, building it outward. Type IA sequences have complex geometries, and include some features that may occur only on polar margins with grounded ice sheets.

Type IIA: Sequences that mostly, but not exclusively, aggrade the palaeocontinental shelf, building it upward. Type IIA sequences have less complicated geometries that are common on low-latitude, nonglaciated margins. The Cenozoic sedimentary sections of the Antarctic margin are composed principally of type IA sequences.

[5,6] Further explained that Antarctic type IA sequences are most commonly characterized by strongly prograding strata that have relatively thin topset beds and steeply dipping (4-15°) foreset beds, particularly on the palaeoupper continental slope near the palaeo-shelf edges.

The pervasive occurrence of type IA sequences, particularly beneath the outer continental shelf, suggested by [5] that grounded ice sheets have strongly controlled the location and depositional environments of the thick offshore prograding sedimentary sections since at least middle Cenozoic time. These grounded ice sheets probably extended to the continental shelf edge many times, as it is evident from the numerous unconformities within the type IA sequences and from the drilling evidence of numerous high-velocity near-seafloor layers and multiple over-compaction events [5].

4. SEQUENCE STRATIGRAPHIC ANALYSIS

The stratigraphic interpretation involves the definition of sequence boundaries and picking of reflection terminations, the steps adopted in the interpretation was to identify the very visible and prominent events. The sea-bed reflection was identified at roughly 0.92s as the light-green marked event of Fig. 1. The red-marked event of the same figure at roughly 1.83s is the sea-bed multiple which is caused by the sound waves bouncing twice between the sea-surface and sea-bed, and being recorded at a two way time twice that of the sea-bed. This reflection does not have any significance to this interpretation and it was subsequently ignored in the rest of the interpretation.

As a follow-up to the picking of the sea-bed and its multiple, the data was then divided into discrete natural stratigraphic packages that make up the section. In order to do this, reflection terminations were first identified and marked (shown in Fig. 1). Based on the terminations of reflections in a consistent manner, four major surfaces were identified, resulting in the four sequence boundaries.

4.1 Stratigraphic Surfaces

The major stratigraphic surfaces identified were sequence boundaries. These sequence boundaries were recognized on the seismic data by the presence of reflection terminations and downward shift in coastal onlap across the boundaries. Between the Sea-bed and its multiple, four major sequence boundaries were interpreted on lines Fig. 2; and they were named sequence boundary 1 to 4 from the bottom of the section. Line Fig. 3; was acquired in a shallower part of the shelf; only sequence boundary 4 was clearly interpreted, all other possible sequence boundaries were masked by multiples. Sequence boundary 2 and 4 are sub-horizontal erosional surfaces, they show visible erosion and they have similar characteristics. The other two sequence boundaries show permanent onlap and they are similar as well.

4.2 Sediment Units

Profile line Fig. 3; shows four sedimentary units that have been interpreted, Unit 1 to Unit 4. Unit 1 consists of parallel, relatively gently dipping and continuous reflections which appear to prograde the buried palaeo-shelf edges. The upper boundary of this unit is characterised by erosional truncation and toplaps and the lower boundary is characterised by downlaps. Internally, the reflections appear divergent in the northern side of the sequence, but they are generally evenly parallel except for the wavy parallel nature of the sequence towards the western side of line. This unit also consist of high amplitude and relatively high frequency reflections. The thickness of Unit 1 varies between 0.1 s to 0.25 s. This unit closely resembles the **Type IA** sequence as defined by [5,6].

Unit 1 and Unit 2 are separated by an erosional surface. Unit 2 and Unit 3 shows prograding character on the outer shelf, building sediment wedge on the palaeo-slope. These units have relatively thin topset beds and they show strong prograding character on the upper palaeo-continental slope near the palaeo-shelf edges. The upper boundary of Unit 2 is characterised by toplaps and the lower boundary is characterised by downlaps. Internally, the reflections are generally evenly parallel with some fairly noticeable contortions towards the western side of the line. This unit also consist of moderate to high amplitude and relatively high frequency reflections.

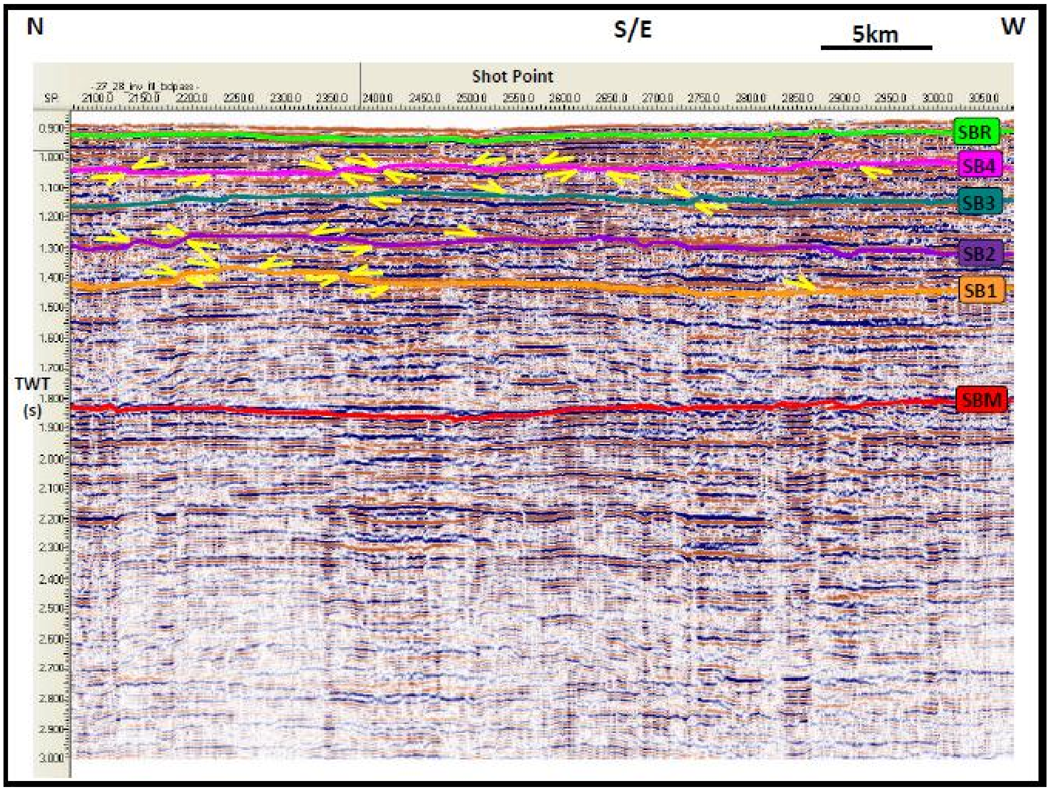

Fig. 1. Prominent events have been identified. SBR is the sea-bed reflection, SB1 to 4 are the sequence boundaries, and SBM is the sea-bed multiple. The yellow arrows are the reflection terminations

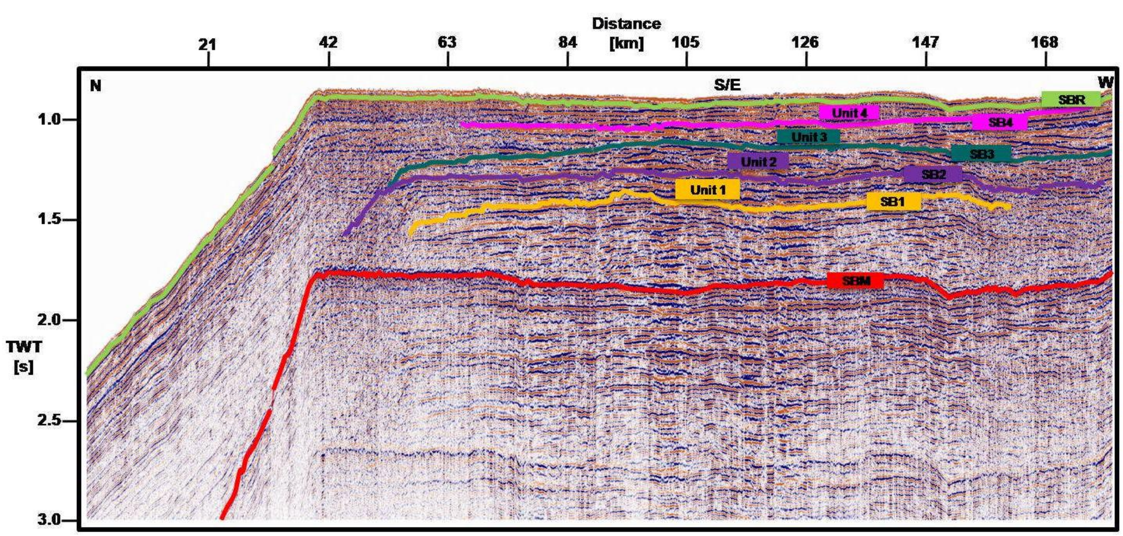

Fig. 2. Sequence boundaries and Sediment units interpreted. SBR is the sea-bed reflection, SB1 to 4 are the sequence boundaries, and SBM is the sea-bed multiple

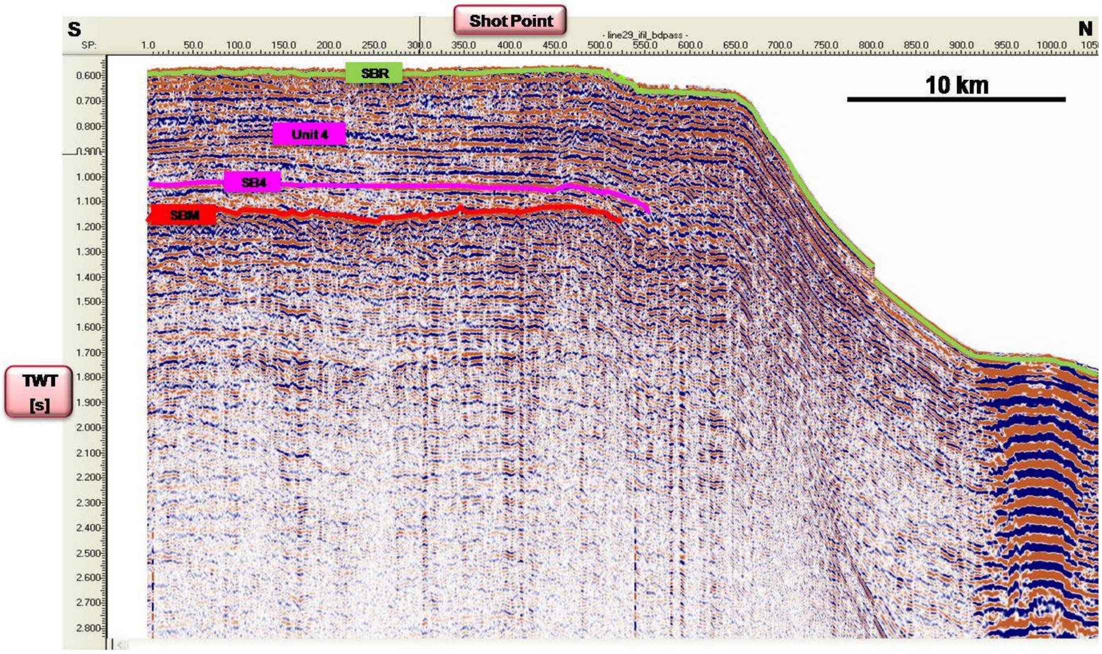

Fig. 3. Sequence boundaries and Sediment units interpreted

The upper boundary of Unit 3 is characterised by both erosional truncation and toplaps and the lower boundary is characterised by downlaps. Internally, the reflections are generally evenly parallel. This unit also consist of high amplitude and relatively high frequency reflections. Both Units 2 and 3 clearly show the characteristics of Type IA sequence as defined by [5], which was interpreted to have been influenced by glacial erosion and transport processes. The thickness of Unit 2 varies between 0.05 s to 0.15 s while that of Unit 3 varies between 0.04 s to 0.18 s.

The uppermost part of the section is Unit 4. Unit 4 is fairly similar in character to Units 2 and 3 except that it progrades further down to the present-day continental slope. The thickness of Unit 4 varies between 0.03 s to 0.15 s. The upper boundary of this unit is the ocean floor which is quite smooth and no visible lap geometry was seen. The lower boundary is characterised by downlaps. Internally, the reflections are generally parallel, and it consist of high amplitude and relatively high frequency reflections.

5. CONCLUSION

The major question here is that "Is there any distinct feature in the depositional sequences that shows that the prevailing processes at the time of deposition was as a result of glacial movement or river action?". On the basis of the 2D lines for this work, the answer is "no". If there has been a 3D seismic data, then the features can be differentiated. When a series of ice lobes are advancing towards the shelf edge, then shallow and broad unconformities develop unlike a situation where a series of rivers cuts through an exposed shelf resulting in mappable incised canyons. A very good circumstantial evidence from the data of this work is that the same sequences and sequence boundaries exist within profiles line Fig. 2 and Fig. 3. It can therefore be assumed that the movement of the ice front was across the whole area; this could be a confirmation that the action was by ice. But the fact remains that this could also be as a result of sea level fall/rise, since sea level fall/rise is relatively uniform across the affected area. It is thought that the movement of ice creates boulders/ridges as it moves across the shelf, which may be represented as chaotic units on the seismic. These units are obviously absent, what is seen are some rather well organised progradational packages. It is quite possible that the ridges could have been reworked by marine processes to produce normal shelf geometries.

The main conclusions of this interpretation were summarized as follows.

- Identified on the profiles are sequences with steeply dipping prograded foresets, which are truncated on their upper limit by erosional unconformities. These sediments were deposited by grounded ice during times of glacial maximum which caused deposition in an overall progradational style.

- Although all the profile lines (Fig. 2 and Fig. 3) shows similar depositional sequences, some differences were observed in the steepness of the continental slope, the depth of the shelf break and the amount of progradation observed on individual profiles. These differences could be due to the type of material been eroded, the path that this erosion was taking, and different glacial drainage patterns.
- Grounded ice must have reached the continental shelf edge many times on most parts of the Bellingshausen Sea margin.
- It was presumed that the sediments corresponding to all the units identified were possibly transported at the base of an ice sheet and deposited where the ice was detached from the sea floor. When the ice sheet was grounding near the shelf edge, the resulting glacial sediments were deposited directly onto the upper slope, leading to the generation of foresets and shelf-edge progradation observed on all profiles.

ACKNOWLEDGEMENTS

Authors are grateful to British Antarctic Survey (BAS) for providing the datasets for this work.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
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