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Audrey S. Loth
University of North Carolina at Chapel Hill

L. R. Bartek III
University of North Carolina at Chapel Hill, bartek@email.unc.edu

B. P. Luyendyk
University of California - Santa Barbara, luyendyk@geol.ucsb.edu

D. S. Wilson
University of California - Santa Barbara, wilson@geol.ucsb.edu

Christopher C. Sorlien
University of California-Santa Barbara

Scale of subglacial to sub-ice shelf facies variability, Eastern Basin, Ross Sea

Audrey S. Loth,[1] Louis R. Bartek III,[1] Bruce P. Luyendyk,[2] Douglas S. Wilson,[2] and Christopher C. Sorlien[3]

[1]Department of Geological Sciences, University of North Carolina, Mitchell Hall, 104 South Road, CB3315, Chapel Hill, North Carolina 27599, USA
[2]Department of Earth Science, University of California-Santa Barbara, Santa Barbara, California 93106, USA
[3]Institute for Crustal Studies, University of California-Santa Barbara, Santa Barbara, California, 93106, USA

Summary The Eastern Basin within the Ross Sea records changes in the volume of the West Antarctic Ice Sheet (WAIS). Examination of multibeam data revealed four acoustic facies that vary from west to east in a 900 km^2 area. It is hypothesized that these facies, that formed nearly contemporaneously, are the result of differences in proximity to the grounding line and its relationship with the seafloor. The four facies are 1. Mega-Scale Lineation, 2. Slightly-Lineated Ridge Crest, 3. Discontinuous Ridges, 4. Irregular Mounds. These trends were also seen in SCS data, distinctively on the seafloor and mutedly at depth. Through determining the extent of fluctuation in these facies and their distribution in the Ross Sea it will be possible to apply this scale to the core record to determine if facies were generated via global processes or were local in origin.

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Introduction

Much about the nature of Antarctic cryosphere-when it formed; how ice masses relate to one another; if changes in the volume of ice are driven by climate and eustatic sea level fluctuations, or whether variations in grounding line position merely reflect autogenic processes; are unknown (Anderson and Bartek, 1992; De Santis et al., 1995; Shipp et al., 1999; Bart, 2003). Within this paper the term autogenic refers to episodic sedimentologic processes that may appear cyclical and are driven by internal dynamics of the ice sheet, not by external forcing of the depositional system by changes in climate or sea level. An example of non-glacial autogenic process would be delta lobe switching in marginal marine environments. Of all of the areas surrounding Antarctica, an ideal setting to study changes in ice sheet volume, with respect to climate change, is the Ross Sea, (Figure 1). The embayment experiences growth and decay of both of Antarctica's ice sheets, the East Antarctic Ice Sheet (EAIS) and West Antarctic Ice Sheet (WAIS), which are separated by the Transantarctic Mountains (TAM) on the mainland and in the Ross Sea, a drainage divide at approximately 180°. The study area is located in the Eastern Basin, an area that is singularly affected by the WAIS (Figure 1). The WAIS is a marine ice sheet and it is thought that small perturbations in sea level and climate can cause changes in ice sheet volume (Anderson et al., 1984; Alley and Whillans, 1991; Anderson and Bartek, 1992; Anderson, 1999; De Santis et al., 1999) Data for the area consists of numerous geophysical surveys and cores acquired by the Deep Sea Drilling Project (DSDP) (Figure 2). However, poor core recovery has made it difficult to extract a complete paleoclimate record (Alonso et al., 1992). Since initial collection began, geophysical data density and quality continues to improve, however the collection of seismic data has reached critical mass, and no longer does a new survey vastly improve the basic framework of the glacial history of the Ross Sea.

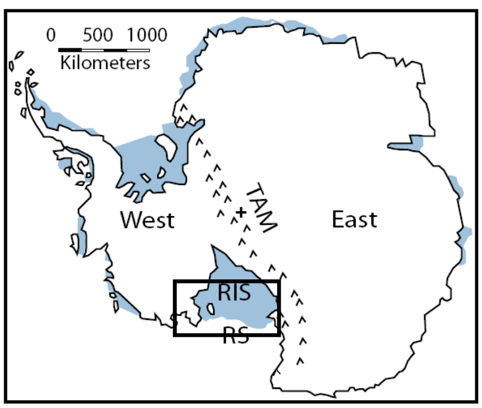

Figure 1. Geographic map of Antarctica, boxed area represents location of study area. RS, Ross Sea, RIS, Ross Ice Sheet, TAM, Transantarctic Mountains. Adapted from Anderson, 1999.

This research builds upon efforts to ascertain paleoclimactic conditions as well as insight into ice sheet deposition and erosion through existing geophysical data, to improve upon knowledge of the history of the Antarctic cyrosphere. Three features make data collected for this research unique. First, prior to 2000, the Ross Ice Shelf covered the location where seismic profiles and swath bathymetric data were acquired. Once the B-15 iceberg calved in 2000, it exposed the most up dip stratigraphic record of the Eastern Basin providing access to the strata that formed most proximal to the ice sheet in both younger and older sediments. Additionally, the calving event revealed older strata at shallow depths beneath the seafloor. This is ideal because it minimizes the destructive interference from the seafloor multiple that impedes studying rocks at depth. It also makes it possible to interpret the older data at a higher resolution than typically possible since they are shallow enough to not be affected by attenuation in the Multi-Channel Seismic Record. This situation creates opportunities to examine old deposits for subtle characteristics that would determine if they were deposited in a glacially dominated environment and potentially unlock the timing of ice sheet onset. Secondly, the high

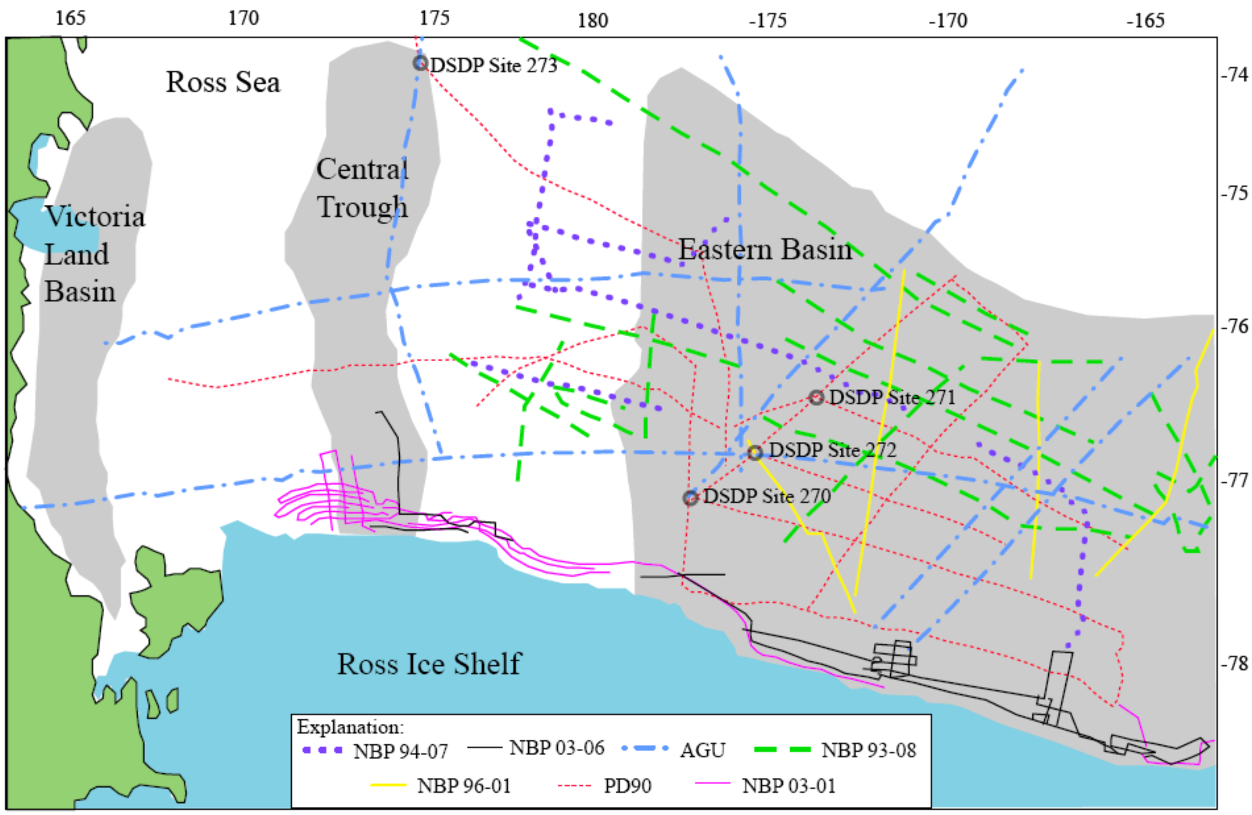

Figure 2. Map of the Ross Sea showing the location of major sedimentary basins, some geophysical surveys that have been taken in the region, and the location of DSDP Leg 28 core locations. Boxed area represents data that are the focus for this project. Adapted from Davey (1987).

frequency content of the acoustic source used to acquire the Single-Channel Seismic profiles improved the vertical resolution of the strata and enhances the value of the data collected. Lastly, spacing between profiles is very low, on average 4.6 kilometers, compared to previous cruises with average profile intervals that are triple this value. Densely spaced profiles provide an opportunity to resolve facies with limited distribution, observe facies transitions that occur over short distances, and discern the details of the morphologies of stratigraphic surfaces and units. Through having such high-resolution, up-dip data it will allow description of the scale of stratigraphic variability in ice sheet depositional processes. This is a critical issue to resolve when attempting to distinguish facies and surfaces in core that represent major changes in the climate system from those that are the product of small autogenically produced changes in the location of grounding line.

Methods

Approximately1600 km of seismic data were collected aboard the R/V IB Nathaniel B. Palmer (R/V IB NBP 0306). These data, along with 30,000 km collected from previous cruises, are being used to reconstruct the glacial history of the ice sheets that drain into the eastern portion of the Ross Sea. Two types of data are being used to interpret ice sheet growth and decay; Single Channel Seismic (SCS), and sonar data. High-resolution Two-Dimensional (2-D) SCS data were collected by using a 50 cubic inch G/I gun source, this produced an acoustic pulse in the frequency spectrum of 30-1000 Hz and have a vertical resolution of 1-3 m. Four types of sonar data, having a resolution of 0.1-0.5 m were collected; sub-bottom chirp, side-scan sonar, deep-tow chirp, and multibeam bathymetry. Using the Seismic Processing Workshop software suite from the Parallel Geoscience Corporation. Primary processing steps for SCS consist of spiking deconvolution, band pass filtering, and gain recovery. Digital interpretation is done using The Kingdom Suite Version 7.5 software published by Seismic MicroTechnology, Incorporated. Stratigraphic units are identified using reflection termination patterns as described by Vail et al. (1977). Seismic facies are identified using reflection characteristics described by Vail et al. (1977) such as lateral continuity, frequency, amplitude and geometry. Structure, isopach, and facies distribution maps are constructed to evaluate spatial changes in facies and surfaces. Major surfaces are correlated to DSDP sites to gain insight into associated lithofacies and for chronostratigraphic control.

Discussion

The multibeam record (Figure 3) is used to identify major sedimentologic elements and acoustic facies in an area of approximately 900 km^2 on the sea floor. The facies represent subtle changes in the relationship of the ice sheet to the sea floor, and are not the result of an artifact in the data. The largest trend in the grid of multibeam data is the presence of a north-south oriented large-scale bathymetric ridge that slopes off to adjacent troughs. This large-scale ridge and trough morphology is common throughout the Ross Sea, with ridges ranging in size up to hundreds of meters in height to tens of kilometers in width, while troughs are hundreds of kilometers wide and hundreds of meters deep (Shipp et al., 1999; Anderson, 1999; Bart, 2004. Four very different acoustic facies, that were generated nearly simultaneously, are distinguishable across the grid (from west to east). It is hypothesized that the variation in facies is related to the location on the continental shelf relative to the grounding line. Characterizing the facies and their extent provides a tool to distinguish facies generated by climate events, from those that formed due to minor autogenic migration of the grounding line. The facies that is associated with the most up-dip (SE) sub-ice sheet position is a set of Mega-Scale Lineations that formed as the ice sheet advanced across the continental shelf [Mega-Scale Lineations,A] (Shipp et al., 1999; Anderson; 1999). These are oriented SW-NE, the same direction of ice sheet expansion, and are tens of meters in width, tens of meters in height, and reoccur approximately every half kilometer. Eastward from the Mega-Scale Lineations, the facies is present on the crest of the large-scale ridge and is characterized by a lower density of lineations [Slightly-Lineated Ridge Crest, B]. Here, there is an increase in spacing between ridges coupled with a decrease in relief of the ridges, suggesting that the ice sheet was much less firmly coupled to the bed. Since the ice sheet was not firmly coupled to the seafloor, there were places that did not receive the intense scouring that occurred in the Mega-Scale Lineations facies. Along the east side of the large-scale ridge is a zone that is covered with irregular, small ridges with their long-axes oriented parallel to that of the large-scale ridge and trough topography [Discontinuous Ridge, C].

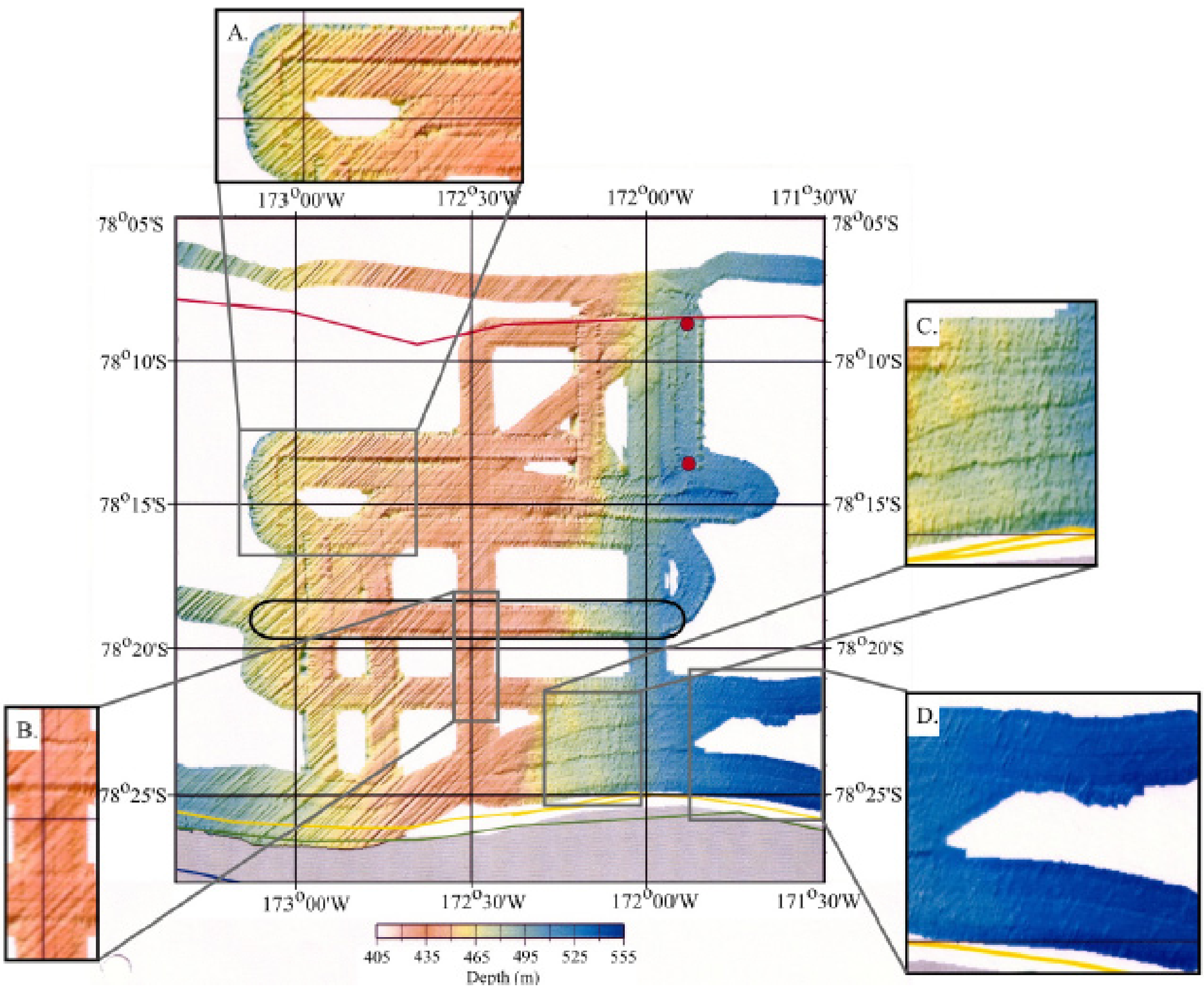

Figure 3. Entire multibeam grid with insets showing the four facies that occur across the sea floor. A. Mega-Scale Lineation, B. Slightly-Lineated Ridge Crest, C. Discontinuous Ridges, D. Irregular Mounds. Line outlined in black is the seismic line shown in Figure 4.

In the context of adjacent acoustic facies, the genesis of this facies is interpreted as a product of the zone where the ice sheet is slightly decoupled from the sea floor. Debris eroded by the ice sheet in the zone of Mega-Scale Lineations was piled up in this area and pushed into a series of discontinuous ridges. On the east side of the large-scale ridge, the contact between the ice sheet and bed was broken due to the slope of the sea floor. The final facies that is present within the multibeam grid is a series of erratically distributed, small mounds [Irregular Mounds, D]. There is a range of sizes for these mounds, but many are roughly 0.5-0.75 km wide, 3-8 km long and 40-100 m high. In this zone is the ice sheet was fully decoupled from the bed, and debris from the base of the ice sheet rained-down onto the topography of the trough. As with the Mega-Scale Lineations, many of the mounds appear to be oriented SW-NE. The similarity with the orientation of the lineations suggests that some of these mounds are associated with sub-glacial depositional processes. Their similarity to features described by Shipp et al., 1999, suggests that they may be drumlins deposited in the trough when it was occupied by the ice sheet. Other mounds may simply be piles of debris, rafted to the sites of deposition by the decoupled ice sheet. These four facies are highlighted across the multibeam grid in insets of Figure 3.

In the seismic record these features and facies changes are preserved on the sea floor, however, without the multibeam record it would be difficult to discern the features that comprise the multibeam facies (Figures 3 and 4). The only features that are as easily observed in the seismic record as in the multibeam record are the large-scale ridge and trough. Beginning on the west side of the seismic profile, there are irregularities in the sea floor, which correspond to the Mega-Scale Lineation facies in the multibeam record (highlighted in red in Figure 4). Moving east up the side of the large-scale ridge to its crest, the number of lineations significantly decreases in the Slighty-Lineated Ridge Crest zone (highlighted in yellow in Figure 4). Continuing toward the east, down the flank of the ridge, is the Discontinuous Ridge facies (highlighted in blue in Figure 4). On the seismic profile this facies appears very similar to the Mega-Scale Lineation facies, only after studying the multibeam data is it possible to recognize characteristics that can be used to identify them as being different from one another on the seismic profiles. Moving down into the trough, it is very difficult to see the Irregular Mound facies (highlighted in green in Figure 4). There are a couple of slight humps on the sea floor, but they are not as abundant and defined in the seismic profile as they are in the multibeam. In addition to revealing features on the sea floor, the seismic data also captures features that are present at depth. It appears that on the seismic profile it is possible to see slices through older large-scale ridges and troughs (outlined in orange on Figure 4). Thus, as suggested by Bart (2004) the ice sheet has not expanded in the same direction throughout its history. At

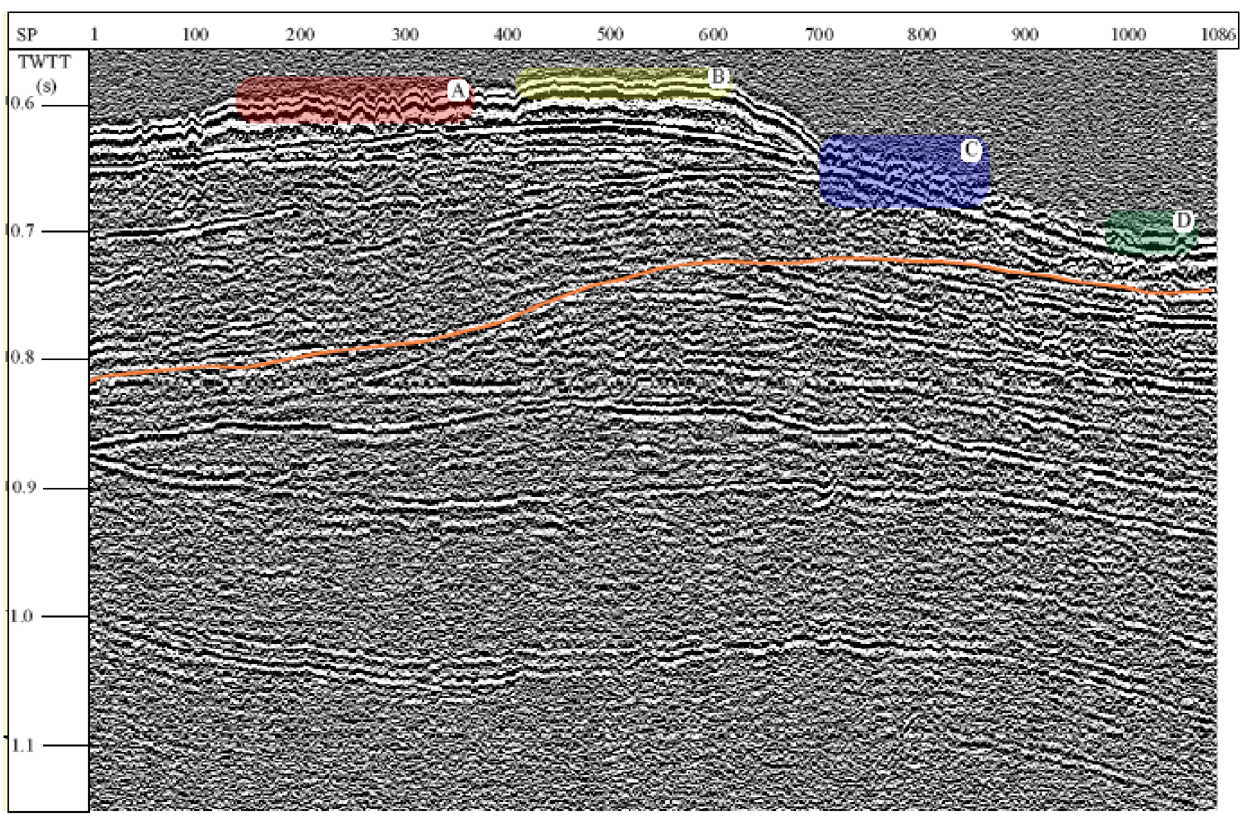

Figure 4. High-resolution single channel seismic profile from R/V IB NBP 0306, circled on Figure 3. The orange line represents an ancient ridge and trough complex. Facies A-D are positioned where they occur on the profile.

depth on the seismic profile, there appear to be some remnants of the acoustic facies that are present on the surface, however, they are difficult to distinguish and identify at depth. From the multibeam and SCS data it is possible to see four different facies, in a narrow swath (30 km). Had the interval between the multibeam swaths in Figure 3 been larger, facies and transitions between them would have been missed. This suggests that there are rapid transitions in depositional environment that may not be included in existing climatic interpretations using the coarse seismic profile spacing that is common on the Antarctic margin.

Part of ongoing research is determining the density of data that is required to capture the scale of lateral variation in acoustic facies that is documented in Figures 3 and 4. Without knowledge of the scale of this variability it is difficult to assess the completeness of the record at any location and whether interpretation of vertical successions recorded on seismic profiles and within drillcore represent changes associated with significant climate change, or are associated only with localized autogenic movement of the ice sheet. The key to discerning whether an event in drillcore reflects a regionally significant event, is to place that event in a regional context through correlation of facies and surfaces to a dense grid surrounding the drill site, within a regionally extensive seismic database. It should be possible to correlate events that are climatically significant across the region, while those that represent autogenic processes should only correlate locally.

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