

Buried Oligocene glacial topography beneath a smooth middle Miocene unconformity in the southeast Ross Sea: Evolution of West Antarctic glaciation

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Summary Buried U-shaped troughs as much as 20 km-wide and flat-topped ridges adjacent to western Marie Byrd Land have recently been proposed as the result of late Oligocene West Antarctic glaciation. Here, additional evidence for pre-25 Ma glaciation is presented for the southeast Ross Sea, together with a different stratigraphic correlation path that establishes age constraints. Buried rough glacial topography interpreted to be of Oligocene age contrasts with a buried smooth and planar middle Miocene “Red” angular unconformity. The Red unconformity extends east-west 160 km near the ice shelf edge, and is 700 m-deep. Part of a 2 km section of Oligocene to middle Miocene strata was removed by erosion. Any smooth post-rift subsidence profile requires that the Red unconformity was carved in water depths of several hundred meters. Several early through middle Miocene glacial erosion surfaces merge to form this unconformity, suggesting multiple advances of thick grounded ice.

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Introduction

For given atmospheric and oceanographic conditions, an ice cap is more likely to grow at high elevations than low ones (e.g., DeConto and Pollard, 2003). LeMasurier and Landis (1996) hypothesized Oligocene and younger uplift of the northern Marie Byrd Land dome, while subsidence from high elevations existing prior to Cretaceous rifting was proposed for parts of Marie Byrd Land and Ross Sea (Fig. 1; Luyendyk et al., 2001). The former hypothesis predicts lower paleo-elevations for Oligocene time while the latter predicts higher elevations. Oligocene glaciation has been proposed for northern (Rocchi et al. 2006) and southern Marie Byrd Land (Sorlien et al., 2007). The early existence of

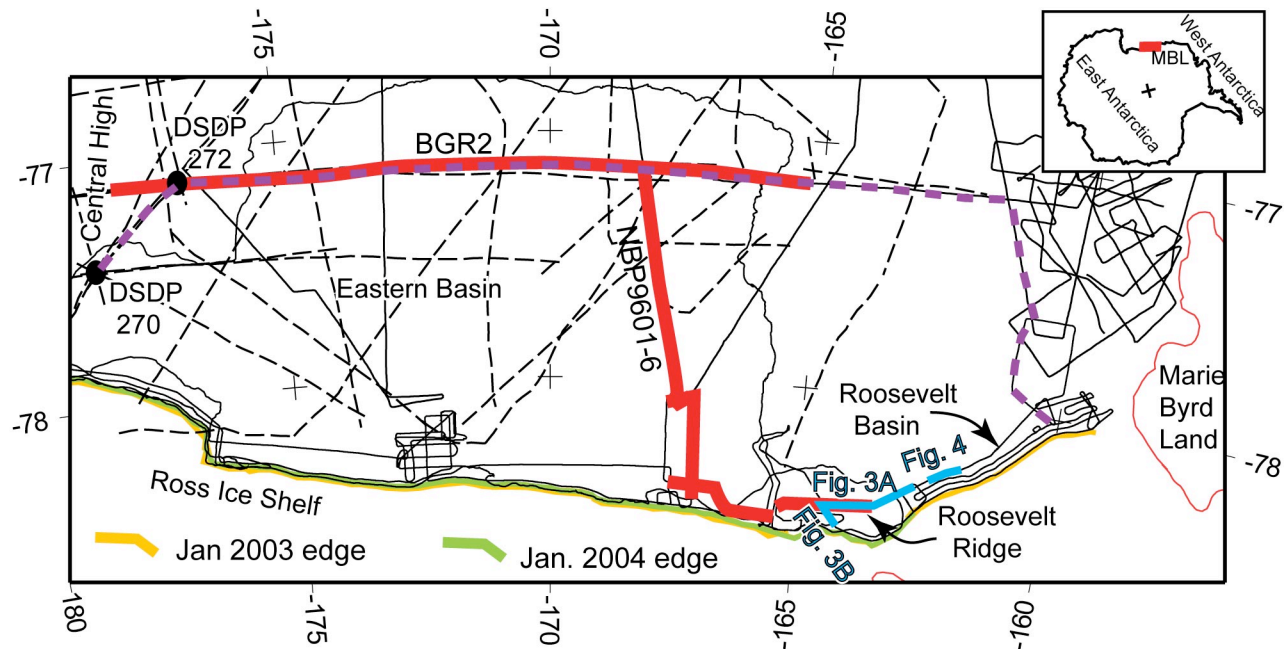


Figure 1. ANTOSTRAT and our RV Palmer seismic reflection tracklines for Ross Sea east of the date line. Profiles included in Fence diagram (Figure 2) are red, the correlation path discussed in Sorlien et al., 2007 is dashed violet, and Figures 3 and 4 are located by labeled cyan lines. The inset shows the location of the figure relative to the Antarctic continent as a red rectangle; MBL=Marie Byrd Land.

West Antarctic ice caps would help explain recent estimates that late Oligocene ice volume was as much as 125% of the modern volume of the East Antarctic Ice Sheet (Pekar et al., 2006).

High-resolution multichannel seismic reflection data were acquired using the RVIB Palmer along the edge of the Ross Ice Shelf across the Eastern Basin of Ross Sea, in an area where calving of the ice shelf has exposed seafloor that has not been accessible to marine geophysics in several decades (Fig. 2). We use these seismic profiles to provide a closer look at the glacial troughs and moraines discussed in Sorlien et al. (2007). These features were inferred to be late Oligocene by stratigraphic correlation along seismic reflection profiles from DSDP-270 to a Paleogene basin east of the Roosevelt Ridge basement high (Fig. 1).

Interpretations and discussion

The oldest dated sedimentary strata above metamorphic basement are late Oligocene at DSDP Site 270 (Leckie and Webb, 1986). Although diatoms were rarely preserved, an assemblage from 105 meters below sea floor (mbsf) at DSDP Site 270 is diagnostic of an early Miocene age, ~20–21 Ma (Steinhauff et al., 1987). Calcareous nannofossils supporting an early Miocene age were recovered from ~220–130 mbsf at Site 270 (Leckie and Webb, 1986). A reflector at about 200 mbsf at Site 270 (within the lower Miocene or uppermost Oligocene) can be traced to the lower part of RSS-2-upper that we map at the eastern margin of the Ross Sea (dashed violet path in Figure 1). RSS2-lower therefore predates 20 Ma, and likely predates the late Oligocene strata cored at site 270. However, limited resolution of the multichannel seismic reflection data across Eastern Basin precludes ruling out a pinchout of late Oligocene strata, in which case an early Miocene age for the top of RSS2-lower cannot be completely ruled out.

The Roosevelt Basin in the far southeast corner of Ross Sea contains a succession of sediment-filled troughs, each capped by an unconformity (Sorlien et al., 2007). These troughs range between 2 and 20 km across, and are 100 to 150 m-deep, with the narrower troughs separated by flat-topped ridges interpreted as moraines (Figure 4). The correlation path from DSDP site 270 to Roosevelt Basin includes 30 km where the interval containing the troughs and moraines is missing due to erosion (dashed violet path in Figure 1). Reflections just 100 m below this interval are continuous across that 30 km distance, and the troughs interval above is near the top of RSS2-lower by comparison (Figure 4 in Sorlien et al., 2007). The age of the troughs thus predates 20 Ma and is probably late Oligocene. In Roosevelt Basin, a stack of offlapping sequences associated with a flat-topped ridge lies beneath the troughs interval and consequently are also interpreted to be pre-20 Ma, probably Oligocene, and possibly early Oligocene (Figure 4 in Decesari et al., 2007b). These offlapping successions are interpreted as till deltas (Bart, 2003), and the flat-topped ridge is inferred to be a moraine (Sorlien et al., 2007).

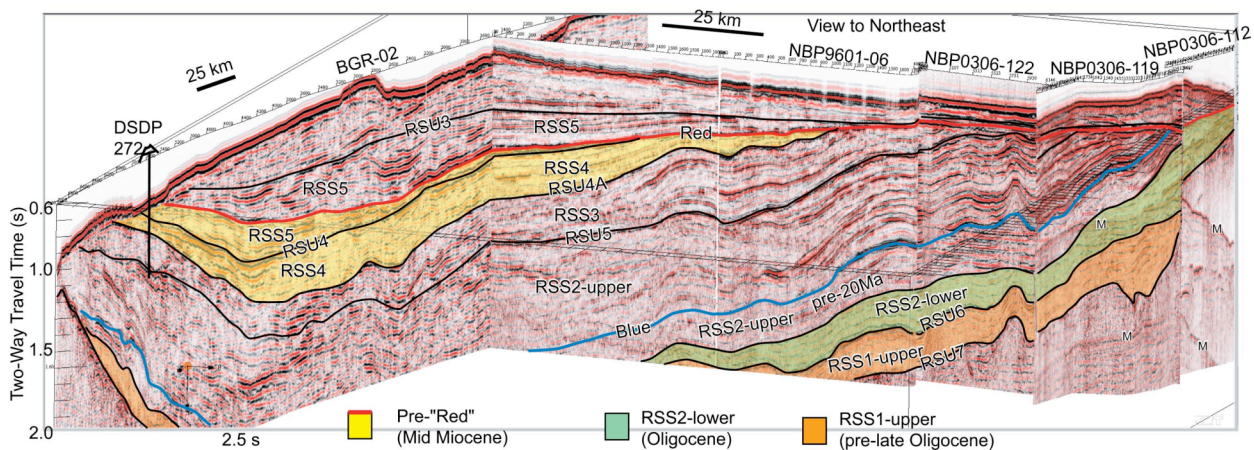


Figure 2. Regional seismic-stratigraphic correlation from DSDP 272 to Roosevelt Ridge in southeast Ross Sea. Profiles located in Figure 1; view to northeast. DSDP site 270 cored updip/downsection from site 272 and encountered late Oligocene strata above metamorphic basement. The interval between the blue horizon and top RSS2-lower can be correlated to pre-20 Ma strata in DSDP site 270 and may include late Oligocene (see text). Mounds and troughs shown in Figure 4 are within RSS2-lower and so also predate 20 Ma, and are probably Oligocene. "Red" is a regional unconformity in the Eastern Basin. Reflections just below Red are dated at ~14 Ma in DSDP site 272; RSS3 and RSS4 are early and middle Miocene respectively (Steinhauff et al., 1987); RSS5 is middle Miocene or younger. Red is flat and level in the south (right), adjacent to the ice shelf edge. Much of the late Oligocene through Middle Miocene section was removed by erosion associated with the Red unconformity. Although initially we thought that waves were the best way to erode a thick interval of sedimentary rocks and still produce a smooth and level unconformity, basin modeling does not permit subsidence from near paleo-sea level to Red's present 700 m depth (Decesari et al, 2007a). Therefore, Red likely was carved by thick ice grounded hundreds of meters below sea level.

Pre-20 Ma strata sampled at DSDP Site 270 (part of RSS2-upper) can be traced without any gaps along the seismic reflection profiles presented in Figure 2 to near Roosevelt Ridge, where they overlie RSS2-lower. Although less dramatic than those in Figure 4, buried troughs and mounds (may be ridges in three dimensions) are seen within RSS2-lower strata (Fig. 3). The shallowest of the unconformities capping the troughs and moraines (Fig. 4) (east) was projected across Roosevelt Ridge to a regional angular unconformity (“Red”), that is prominent for 160 km westward across the sedimentary Eastern Basin (Figs. 3A). This unconformity represents about 2 km of missing stratigraphic section, part of which was never deposited due to thinning, and part of which was removed by erosion (Decesari et al., 2007b). The Red unconformity is smooth and level, and splits into several unconformities within the deeper parts of Eastern Basin (Fig. 2). The second shallowest of these unconformities is dated about 14 Ma at DSDP site 272 (Steinhauff et al., 1987; Bart, 2003). This unconformity was cut by regionally extensive expansion of the ice sheet that caused it to ground on the continental margin at depths that were several hundred meters below sea level. The several unconformities that combine to make “Red” may be related to separate early and middle Miocene glacial advances.

Pre-20 Ma, probably Oligocene strata show evidence of narrow erosional troughs and reflective mounds or ridges on the west flank of the basement ridge (Fig. 3), but such features are not present in southern deep Eastern Basin near the ice shelf edge. This is evidence that the troughs were carved by glaciers issuing from distant highlands of Marie Byrd Land and not from East Antarctica. The presence of offlapping strata and unconformities of Late Oligocene through middle Miocene age farther north in Eastern Basin indicate that the ice sheet expansions onto the margin at this time were regionally significant events (Bartek et al., 1991, 1992; Bart, 2003; DeSantis et al., 1999). One possible interpretation is that “Red” was cut by thick, grounded ice that affected all of the Eastern Ross Sea paleo-shelf, while the Oligocene glaciers affected only the area proximal to Marie Byrd Land.

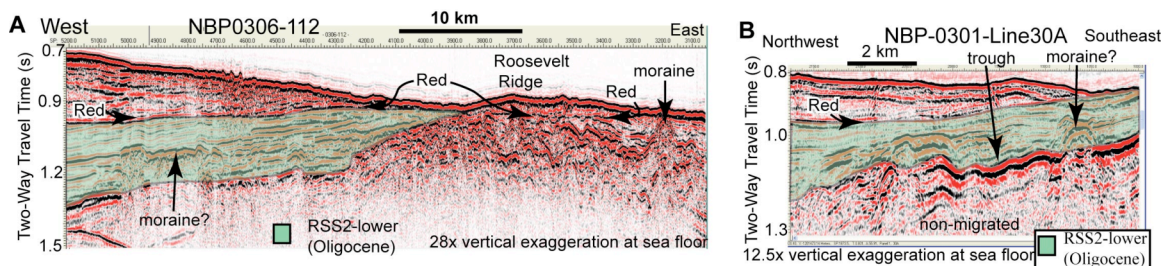


Figure 3. Multichannel non-migrated stacks, located in Figure 1. **A.** The middle Miocene “Red” unconformity was projected across the northern plunge of the Roosevelt basement ridge. This projection is uncertain because strata above and below Red are not continuous across the ridge. Troughs and mounds/ridges underlie Red both east and west of Roosevelt Ridge. High amplitude reflections from mounds and troughs underlie a sequence (green) that pre-dates 20 Ma by direct correlation to DSDP-270, and that is probably Oligocene (see Figure 3). These are interpreted to be glacial features. **B.** Troughs and mounds on west flank Roosevelt Ridge. Mounds may be ridges in 3D. These are within pre-20 Ma strata. If these are glacial troughs and moraines, then they may correlate to the late Oligocene troughs and flat-topped ridges imaged on Figure 4.

Late Oligocene glaciation on the outer shelf of the deep Eastern Basin may have been sourced from East Antarctica and/or the Central High. Evidence for Oligocene glaciation proximal to Marie Byrd Land, combined with evidence for Oligocene ice caps at widely-separated localities of West Antarctica, allow the interpretation that portions of the West Antarctic Ice Sheet developed then. The broad troughs and the stack of offlapping sequences may be related to dynamic ice caps and sea level falls in middle Oligocene and earliest Oligocene time (Pekar et al., 2006). The Middle Miocene Red unconformity may be related to development of polar (cold-base) ice sheets. Subsidence modeling suggests that the now 700 m-deep Red unconformity must have been carved several hundred meters below sea level (Decesari et al., 2007a), requiring a thick ice sheet. Deposition and preservation of Oligocene moraines rather than erosion produced much of the rough buried topography. Deposition of the widely distributed Oligocene subglacial deposits may have occurred near the grounding lines of the ice sheet, implying that a series of large expansions of the West Antarctic Ice Sheet onto the continental margin occurred during that time (Bartek et al., 1991, 1992). Oligocene glaciation implies that Marie Byrd Land and eastern Ross Sea have subsided from higher elevation due to lithosphere cooling and contraction after late Cretaceous crustal thinning. The northern Marie Byrd Land dome (LeMasurier and Landis, 1996) is geographically distinct from the source area for Oligocene glaciers near the Rockefeller Mountains (Sorlien et al., 2007) and may have uplifted while other areas subsided, or may have subsided less than areas around it (appearing uplifted relative to its subsiding margins).

Summary and conclusions

Regional correlations suggest that buried troughs and flat-topped ridges in the far southeastern Ross Sea pre-date 20 Ma strata cored at DSDP Site 270 and thus they are probably Oligocene. We interpret the troughs to be carved by glaciers and the ridges to be moraines. The glaciers responsible for the troughs were fed from an Oligocene ice cap over at least part of western Marie Byrd Land. Western Marie Byrd Land has subsided since the end of Cretaceous rifting, and the topography supporting the glaciers was at higher elevation during Oligocene time than at present. A regional unconformity ("Red") was eroded below sea level by grounded ice during the mid Miocene and has since subsided to its present ~700 m depth.

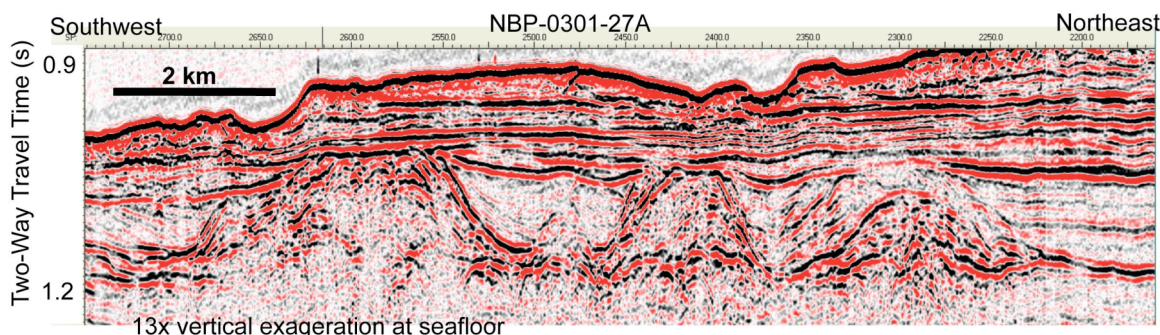


Figure 4. Non-Migrated single channel profile 27A, located in Figure 1. Features suggestive of moraines were deposited in successive stages. Internal structure of mounds (flat-topped ridges in 3 dimensions) is consistent with them being moraines; relief is about 150 m on depth migrated coincident multichannel seismic reflection profiles. Part of the lowest of a succession of Broad U-shaped troughs interpreted to be cut by ice is imaged at the northeast end: see Sorlien et al. (2007) for more regional view of this profile.

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