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Seismic stratigraphy of the Plio-Pleistocene Ross Island flexural moat-fill: a prognosis for ANDRILL Program drilling beneath McMurdo-Ross Ice Shelf

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Abstract

Ross Island volcanic complex began forming with the emplacement of the basaltic shield volcanoes of Mt. Bird and Mt. Terror between ca. 4.6 and 1.3 Ma, though it has developed most significantly over the last 1 Ma during an eruptive phase resulting in the 3794-m-high composite vent of Mt. Erebus. Throughout this time, loading of the lithosphere at the southern end of the Terror Rift by the Ross Island volcanic pile has progressively depressed the crust, resulting in a subcircular flexural moat around the periphery of the island.

Multichannel seismic reflection data collected from the McMurdo-Ross Ice Shelf (MRIS) reveal the stratigraphic architecture of the moat-fill on the southeastern side of Ross Island. The moat region has accommodated a well-stratified, regionally extensive sedimentary succession of at least 1.2 km below the seafloor in the deepest part of the depression. Three seismic stratigraphic units are identified that generally thicken and dip towards Ross Island and are bounded by angular (onlap) unconformities. We infer that the three units were deposited in accommodation space created during discrete phases of volcanic load-induced subsidence:

1. Unit III. Moderate to low-amplitude discontinuous reflectors are dislocated and tilted by normal faulting and interpreted to represent coarse-grained glacigenic and fine-grained marine sediments with likely intercalated volcanic ash. These strata may have started to accumulate during loading of the crust by Mt. Bird between ca. 4.6 and 3.8 Ma.
2. Unit II. Moderate to high-amplitude continuous reflectors that onlap Unit III and are interpreted to represent coarse-grained glacigenic and fine-grained marine sediments with likely intercalated volcanic ash. These strata are inferred to have accumulated in the crustal depression resulting from loading by Mt. Terror between ca. 1.8 and 1.3 Ma.
3. Unit I. Relatively continuous low-amplitude to seismically-opaque reflectors (Unit IB), onlap Unit II and grade upwards into moderate to high amplitude reflectors below the seafloor (Unit IA). Unit IB is interpreted to represent fine-grained pelagic marine sediments and volcanic ashes which may have accumulated during a phase of rapid subsidence at the

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initiation of Mt. Erebus loading between ca. 1.0 and 0.8 Ma. Unit IA is interpreted to represent progressive infilling of the flexural moat with more coarse-grained, probably glacigenic sediments during continuation of Mt. Erebus loading between ca. 0.8 and 0.2 Ma.

These phases of load-induced subsidence may have periodically overdeepened the moat, making it likely that the sedimentary fill is relatively continuous and has largely escaped erosion by ice grounding during past glacial expansions of the West Antarctic Ice Sheet (WAIS) and the MRIS. The age relationships provided by radiometric dating of the various volcanic loads imply that the sediments here have the potential to provide a relatively continuous and high-resolution glacimarine record of the past behavior of the WAIS–MRIS and the climate history of the western Ross Sea region back to ~5 Ma. This stratigraphic record is scheduled to be drilled by the ANDRILL Program in the austral summer of 2006. From the interpretation of seismic facies, we present a stratigraphic prognosis for the proposed drill site.

Keywords: McMurdo-Ross Ice Shelf; Seismic stratigraphy; Ross Island flexural moat; ANDRILL; Plio-Pleistocene

1. Introduction

Gravity and seismic studies have shown that the emplacement of oceanic island and seamount volcanoes on the lithosphere can produce up to 4 km of downward flexure over horizontal distances of 150–300 km (summarized in Watts, 2001). Within the resulting subcircular flexural moat basins, rates of tectonic subsidence may be as high as 1 m/k.j. (Watts and ten Brink, 1989), thus providing the potential to accommodate high-resolution stratigraphic records, particularly in high sediment delivery settings that have experienced minimal erosion.

The pattern of subsidence revealed in seismic reflection data from some of the best known examples [Hawaiian Islands (Watts et al., 1985), the Canary Islands (Watts et al., 1997) and the Cape Verde Islands (Ali et al., 2003)] show that the crust thickens beneath individual islands and that the moat-fill strata dip and thicken concentrically in towards the volcanic load.The intraplate alkaline volcanic cones of Ross Island have been progressively emplaced on rifted submarine crust beneath southern McMurdo Sound during the last 5 Ma (Kyle, 1990). The older edifices of Mt. Bird and Mt. Terror evolved as basalt (basinite) shield volcanoes between ca. 4.6–3.8 and 1.7–1.3 Ma, respectively (Wright and Kyle, 1990a; Wright and Kyle, 1990b). However, the most significant loading has occurred over the last 1 Ma during an eruptive phase from the composite phonolitic volcano of Mt. Erebus (Moore and Kyle, 1990). Previous modeling of instantaneous flexure of the lithosphere involving the entire Erebus Volcanic Province estimated a deflection of up to 1800 m centered on Mt. Erebus with significant accommodation for accumulation of Plio-Pleistocene sediments created in a moat basin around Ross Island (Stern et al., 1991; ten Brink et al., 1997).

Here we present 40 km of multichannel seismic reflection data of the Ross Island moat-fill, collected between 2001 and 2002 from the McMurdo-Ross Ice Shelf (MRIS) on the southeastern side of Ross Island (Fig. 2). The data, which build on previous seismic reflection pilot studies from the region (Stern et al., 1991; Melhuish et al., 1995; Fig. 2), were acquired during site surveys (Bannister and Naish, 2002; Horgan et al., 2003) for a stratigraphic hole to be drilled from the ice shelf in the austral summer of 2006 as part of the ANDRILL Program (Harwood et al., 2003). From the analysis of seismic geometry, stratal terminations and the interpretation of seismic facies presented in this paper, we develop a stratigraphic architecture for the moat-fill succession and speculate on the timing of development of accommodation in response to the evolution of the Ross Island volcanic complex. The data presented here form the basis for a stratigraphic prognosis for a 1.2-km-deep drilling target beneath the MRIS. Our results suggest that the region affords a unique opportunity to recover a highly sensitive and complete record of the dynamics and variability of the West Antarctic Ice Sheet (WAIS) and MRIS in western Ross Sea, and its influence on ocean circulation, climate and polar biota.

2. Tectonic and stratigraphic setting

Ross Island lies at the southern end of the Victoria Land Basin (VLB), a structural half-graben, approximately 350 km long, hinged on its western side at the Transantarctic Mountain front (Wilson, 1999). Rifting in the VLB has occurred since the latest Eocene (Wilson et al., in preparation), but that may have initiated in the Cretaceous, and has accommodated up to 10 km of sediment (Cooper and Davey, 1985; Brancolini et al., 1995). Late Cenozoic extension in the VLB is associated with alkalic igneous intrusions (e.g. Beaufort Island and Ross Island) and led to the development of the Terror Rift (Cooper et al., 1987). Ross Island volcanic complex lies at the southern end of the Terror Rift (McGinnis et al., 1985) and is considered to be associated with the latest phase of rifting. The radial distribution about Mt. Erebus at 120° of the major basaltic volcanic centers of Mt. Bird, Mt. Terror and the younger Hut Point Peninsula was first suggested by Kyle and Cole (1974) to result from crustal doming due to mantle upwelling as a plume or hotspot creating radial fractures. Such a model also considered to explain the considerable volume of phonolitic lava from the active Mt. Erebus vent. The Ross Island volcanoes define the northern extent of a lineation (Erebus Volcanic Province) of similar composition, but progressively older volcanoes to the south that include Black Island, Mt. Discovery and Mt. Morning (Fig. 1). Kyle (1990) argues that this distribution represents the early manifestation of the mantle plume currently underlying Mt. Erebus. Subsequent loading of the crust by the Mt. Erebus volcanic pile has resulted in as much as 1.8 km net subsidence beneath Ross Island and the development of an enclosing moat (Stern et al., 1991). This accommodation space is superimposed on the regional pattern of accommodation space created by rifting.

While Cretaceous and Paleogene sediments have been inferred from seismic stratigraphy within the axis of the VLB (e.g. Davey and Brancolini, 1995), the oldest sediments recovered to date by stratigraphic drilling along the western margin of the basin are of latest Eocene and unconformably overlie Devonian sediments of the Taylor Group (Davey et al., 2001). Since the latest Eocene, sedimentation along the western margin of the VLB has evidently kept pace with or exceeded the rate of subsidence resulting in the development of a 1.5–2-km-thick sediment wedge, (thickening to up to 10 km seaward). The wedge comprises glacimarine conglomerates, diamicts, and sandstones with interbedded mudstones of nearshore and shelf affinity (Barrett, 1989; Cape Roberts Science Team, 2001). Numerous unconformities occur within the Oligocene and Miocene strata recovered in CIROS-1 and CRP drill cores (Fig. 1). A number of these unconformities have been correlated with subhorizontal erosion surfaces in regional seismic lines (Henrys et al., 2000; Fielding et al., 2001), implying widespread grounding of an extensive ice terminus on the continental shelf during glacial periods. Coastal glacier behavior has been linked to mass changes in the interior East Antarctic Ice Sheet, which feeds through outlet glaciers in the Transantarctic Mountains during glacial periods. Interglacial periods are recorded by sedimentary sequences displaying vertical cyclical facies successions of ice retreat and re-advance in association with relative bathymetric deepening and shallowing, respectively (Naish et al., 2001a). The frequencies of oscillations in the ice extent, which control the finer scale stratigraphic architecture of the basin-fill, correspond to Milankovitch orbital forcing as inferred from global oxygen isotope records (Naish et al., 2001b). The lack of long and continuous Plio-Pleistocene glacimarine drill core records in western VLB is probably due to erosion of these younger strata during periodic glacial expansions of the West Antarctic Ice Sheet and grounding of the Ross Ice Shelf over the last 5 Ma. However, marine seismic data (Bartek and Anderson, 1991; Wilson et al., 2004, unpublished data NBP-0401), and new seismic data presented here, suggest such records do exist further east in the VLB and within the flexural moats of Plio-Pleistocene volcanoes.

3. Multichannel seismic data

Traditionally, seismic reflection surveys in McMurdo Sound have collected predominantly marine multichannel and single channel data (e.g. Cooper et al., 1987; Bartek et al., 1996). However, over recent years, sea-ice (e.g. McGinnis et al., 1985; Bannister and Naish, 2002) and ice-shelf (e.g. Stern et al., 1991; Beaudoin et al., 1992; ten Brink et al., 1993; Horgan et

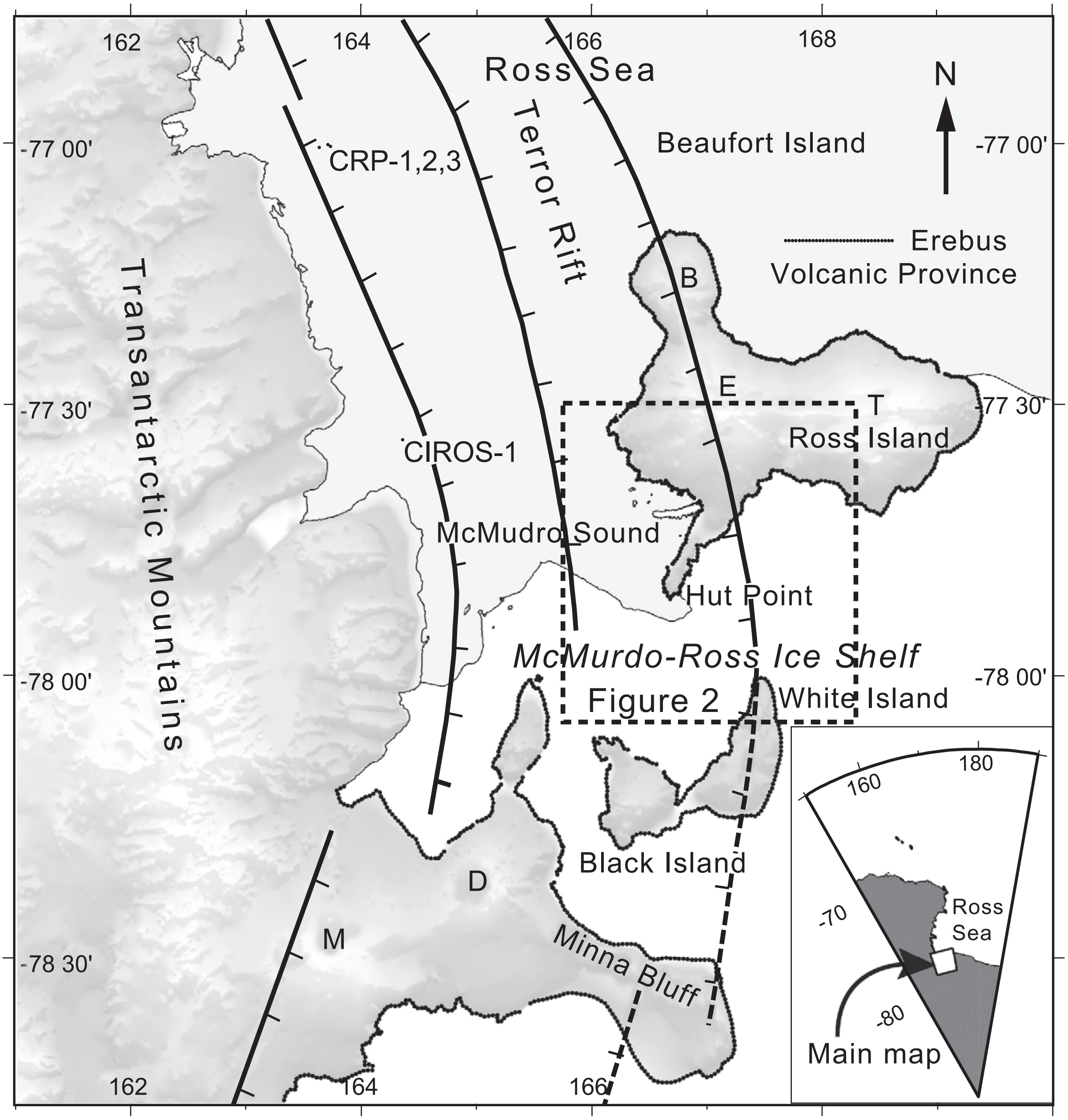

Fig. 1. Location of key geographical and tectonic features in southern McMurdo Sound, Antarctica. Dotted coastline outlines the extent of the Erebus Volcanic Province (Kyle and Cole, 1974), while the volcanic centers of Erebus (E), Terror (T), Byrd (B), Discovery (D), and Morning (M) are annotated with their respective letters. Also shown are the stratigraphic drill sites of the Cape Roberts Project (CRP-1,2,3) and CIROS-1 Project. The boundary fault locations for the Victoria Land Basin and the Terror Rift are shown and adapted from Harwood et al. (2003). The dashed box indicates the region shown in Fig. 2. (Topographic data source: Antarctic Digital Database).

al., 2003) surveys have become increasingly viable, and have provided important data for regions of the VLB that are inaccessible to research ships. When combined with modern processing techniques, the data resulting from over ice-shelf surveying are of a quality comparable to those acquired in either land or marine settings. Here we outline data acquisition, characteristics, and processing for newly acquired profiles on the McMurdo-Ross Ice shelf (MRIS), HPP-2, MIS-1, and MIS-2 (Fig. 1). We also integrate these data with a previously acquired profile running from eastern Hut Point Peninsula onto the edge of the MRIS (HPP-1; Bannister, 1993; Melhuish et al., 1995). The full seismic data set and navigation information are available in Bannister and Naish (2002) and Horgan et al. (2003).

3.1. Data acquisition

Multichannel seismic (MCS) data acquisition utilized modified land-based techniques with logistics similar to those outlined by Beaudoin et al. (1992) (for details see: Bannister and Naish, 2002; Horgan et al., 2003). Twelve-fold coverage was obtained by combining a 48-channel recorder with a shot spacing of 96 m and a geophone spacing of 48 m. Shots consisted of 3.2 kg primers (Anzomex PPP) that were drilled to a depth of 18 m and well tamped. Coupling in the near surface snow and firn was achieved by extending the single string, 40 Hz geophones with 40-cm spikes. A split-symmetric spread geometry was used in all three of the newly acquired profiles resulting in near and far offsets of 24 and 1128 m, respectively. This differed from profile HPP-1 (Bannister, 1993; Melhuish et al., 1995), where an off-end geometry was used, resulting in an offset range of 100 to 2450 m. Additional differences between the two generations of surveying included the use of six string 15 Hz geophones and a shot size of 4 kg for acquisition of the HPP-1 profile.

3.2. Data characteristics

Seismic data acquired aboard floating ice shelves combine marine like characteristics with characteristics unique to snow and ice. Long path, water column multiples occur together with short path intra-ice multiples originating from within the ice shelf. Additionally, linear move out direct arrivals emanate from the shots in a fanlike manner. These arrivals occur at a variety of velocities ranging from 500 to 3800 m/s and represent direct paths through the increasingly dense firn and ice layers. A significant component of source related incoherent noise is also observed in the early portion (<1 s) of the seismic record due to shot dissipation through the ice shelf.

The relationship between bathymetry and data quality is direct and strong. Deeper bathymetry not only provides a longer window of unambiguous data before the arrival of the first long-path water column multiples, it also allows time for the shot related incoherent noise to dissipate before the arrival of the primary data. In shallow water depths, the linear move out arrivals are significant contaminants of the data from the medium to far offset traces.

3.3. Data processing

Processing was performed using Globe Claritas™ processing software (Ravens, 1999), which allows advanced seismic processing with rigorous parameter testing. As well as processing standards the processing stream included a number of procedures that result in significant improvement to over-snow acquired MCS. These consisted of a two-step predictive deconvolution, residual static correction, and the creation and application of a detailed velocity model.

Autocorrelation of the seismic shot records revealed periodicities at 18 and 45–90 ms, which are interpreted as coherent noise components within the data. The 18 ms periodicity remained relatively constant throughout the surveys and corresponds to the ghost arrival associated with the buried shot. Predictive deconvolution successfully removed this effect. The 45–90 ms periodicity is thought to result from intra-ice multiple paths and corresponds in duration to the early arrival time of the long path seafloor multiple. The early arrival time (defined as the difference between the expected long-path-multiple arrival time, i.e. twice the seafloor arrival time, and the actual long-path-multiple arrival time) is considered to be a function of ice shelf thickness. The assumption being that the early arrival results from the ray reflecting off the water–ice interface at the base of the ice shelf instead of repeating the full travel path and reflecting off the ice–air interface at the ice shelf surface. By spatially varying the second deconvolution operator in conjunction with the varying periodicity (and/or the early arrival time), the intra-ice multiple was successfully targeted and removed.

Velocity analysis consisted of creating a spatially and temporally varying model using constant velocity gathers and constant velocity stacks. Care was needed to ensure that no intra-ice multiples were targeted and enhanced during the velocity analysis stage. Also, the inclusion of events resulting, primarily, from high amplitude, long offset noise was avoided. Additionally, it was possible to account for variability in the near surface conditions and differences in shot depth by employing a residual static correction. Residual static corrections were performed iteratively and alternated with velocity model reviews. This resulted in significant improvements to the final stacked sections.

4. Seismic stratigraphy

The four seismic profiles (lines HPP-1 and 2, MIS-1 and 2; Figs. 3–5) provide a three-dimensional stratigraphic architecture for the Ross Island moat-fill succession beneath the ice shelf between Hut Point Peninsula and White Island.

4.1. Seafloor and bathymetry

A high amplitude seafloor arrival is observed in all profiles with the exception of the western end of the HPP-1 line, where the profile runs up onto Hut Point Peninsula. Shallow sediment cores (up to 80 cm) acquired from the seafloor in 2002 at the hot water drilling sites HWD-1 and HWD-2 (near the intersections of MIS-2 with both MIS-1 and HPP-2; Fig. 2) indicate an unconsolidated muddy seafloor passing down into the upper part of diamicton unit of last glacial age (Barrett et al., 2004). Thus, the high amplitude seafloor reflection is considered to represent the velocity and density contrast between seawater and the diamicton.

Bathymetry appears to deepen away from Ross Island to a maximum water depth of 950 m (1.2 s two way time) ca. 7 km east of Hut Point Peninsula along the HPP-1/HPP-2 composite line (Fig. 3). Further eastward along this line the moat begins to shallow to a depth of 810 m. South and further to the east a pronounced bathymetric shallowing from 950 to 400 m occurs along the MIS-1 line as it passes over the northern sub-seafloor extension of deformation associated with White Island volcano, and then progressively deepens beyond this to 700 m. We note that all bathymetric conversions from two way time to meters require assumptions concerning ice shelf thickness and the velocity characteristics of the ice shelf and water column.

4.2. Faulting and deformation

High-angle, north–south trending faults, aligned with the structural grain of the Terror Rift, offset horizontal to subhorizontal strata below 1.7 s or 1600 m, with normal throws of up to 100 ms, or 90 m, in lines MIS-2 and HPP-2 (Figs. 3 and 4). While these faults do not offset strata above seismic Unit III, they do appear to deform subhorizontal reflectors in the base of seismic Unit II (see below). The strike of the easternmost faults in line MIS-2, interpreted in Fig. 4, are inferred to intersect line MIS-2 at a very acute angle and this may explain the loss of coherency below seismic Unit II in the line.

4.3. Description of seismic stratigraphic architecture

Seismic profiles image a well-stratified, regionally extensive sedimentary succession of up to 1.2 km in thickness below the seafloor in the deepest part of the moat depression. Three regionally extensive, depositional units, that generally thicken towards Ross Island have been identified and correlated within the data set on the basis of their internal seismic characteristics and geometric relationships exhibited at their bounding surfaces (Figs. 3–5). Recently acquired marine multichannel seismic data to the west and north of Ross Island confirm that these units infill accommodation space concentrically about Ross Island (Wilson et al., 2004; unpublished data NBP-0401). Descriptions for these units and their bounding surfaces from oldest to youngest follow:

Surface C. The deepest observable surface characterized by onlap of superjacent strata onto a high amplitude reflector at 2.4 s or 1900 m at the HWD-1 site near the MIS-1/MIS-2 intersection (Figs. 4B and 5). The surface is tilted and disrupted by normal faulting and is not easily identified and correlated along the length of MIS-2 due to loss of seismic reflectivity where N–S-trending normal faults are inferred to intersect the line at an acute angle.

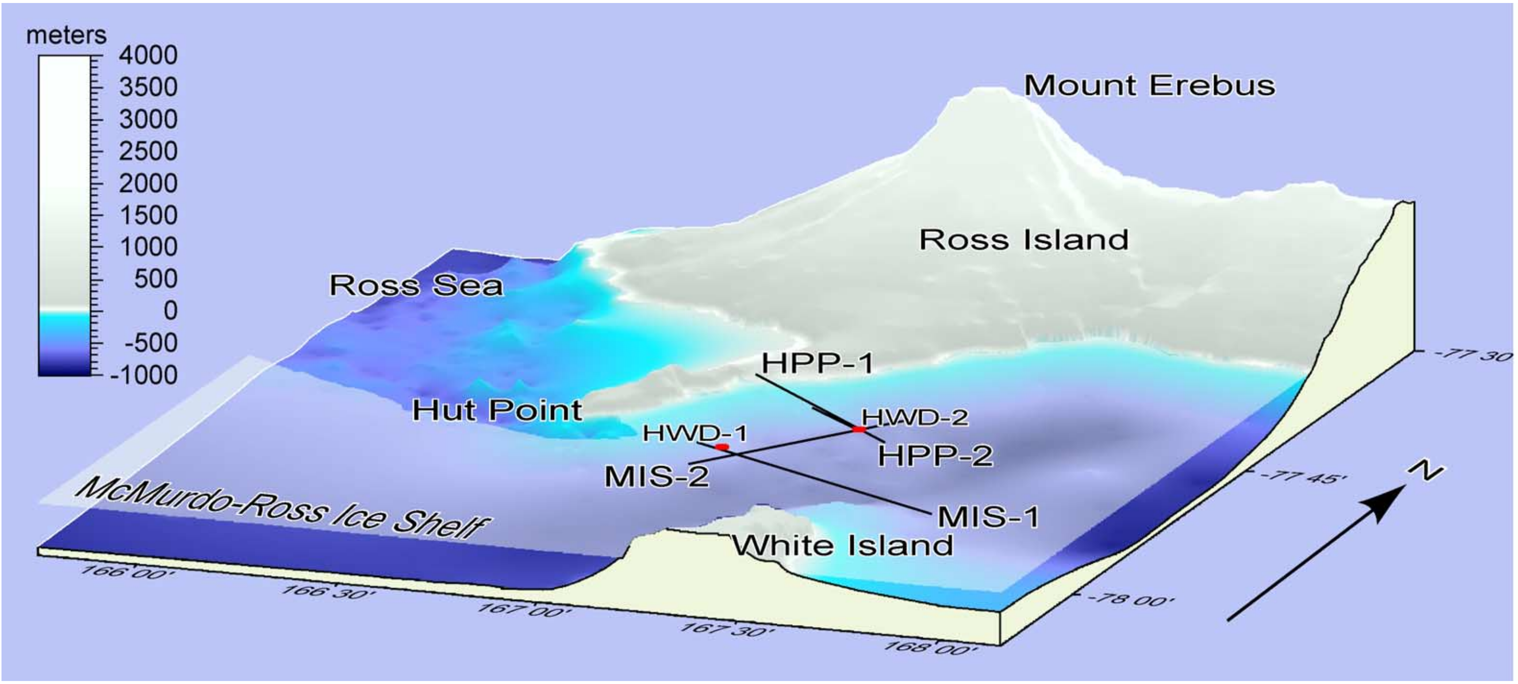

Fig. 2. Bathymetry of the Ross Island flexural moat within the study area. The locations of over-ice shelf seismic reflection lines (HPP-1, HPP-2, MIS-1, and MIS-2) and hot water drilling and seafloor sampling sites (HWD-1 and HWD-2) are shown. The hot water drilling sites, HWD-1 and HWD-2, represent two possible locations for the ANDRILL McMurdo Ice Shelf drill site. Viewpoint is from 150° at 30° elevation. Topographic data is sourced from the Antarctic Digital Database while bathymetric data is sourced from Geological and Nuclear Sciences archives.

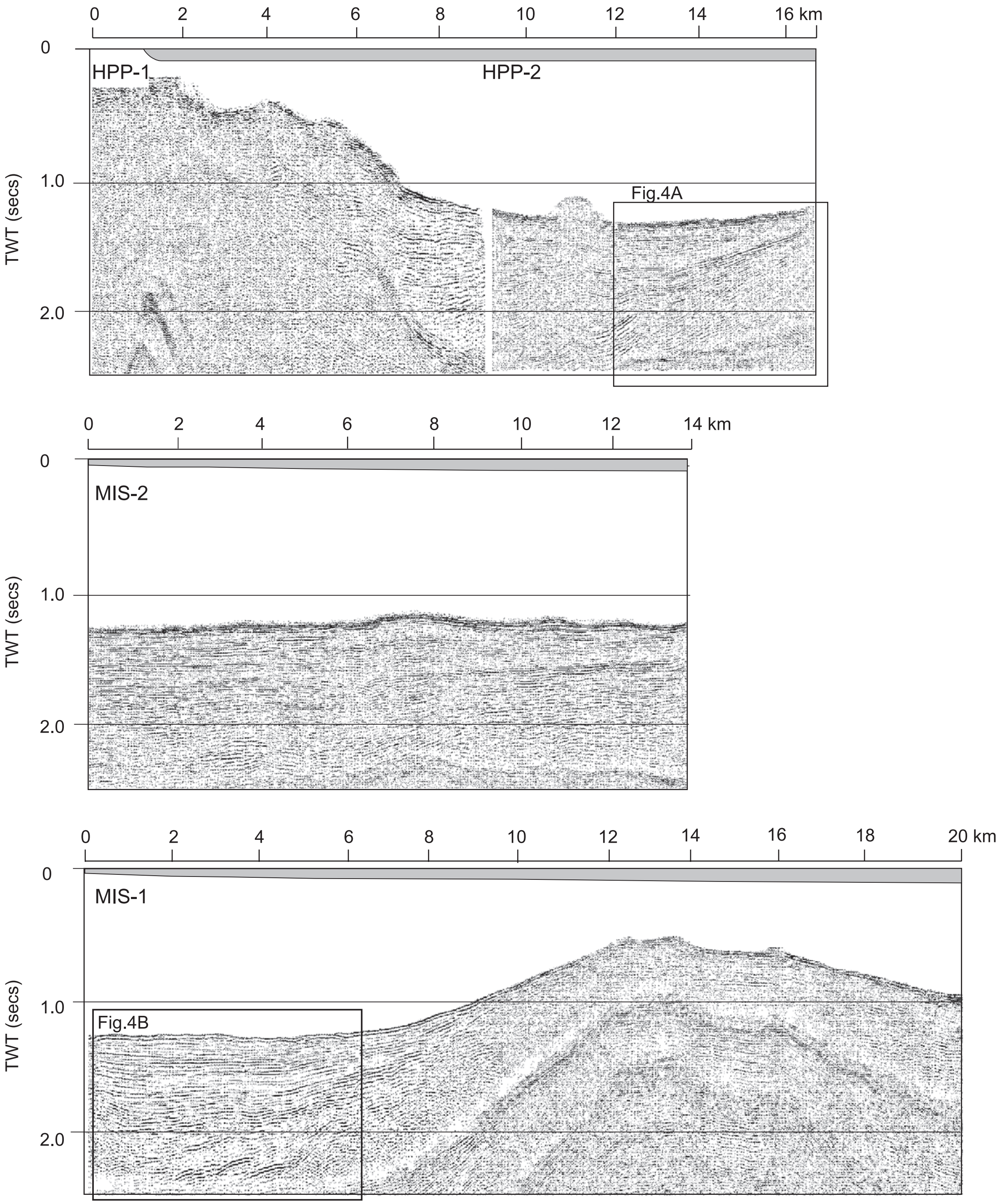

Fig. 3. Processed multichannel seismic reflection profiles of the Ross Island flexural moat-fill, in Windless Bight east of Hut Point Peninsula. All lines are orientated with east to the right, boxes correspond to the enlarged sections shown in Fig. 4, and annotation is provided in kilometers along line. For fully annotated seismic sections, see Bannister and Naish (2002) and Horgan et al. (2003).

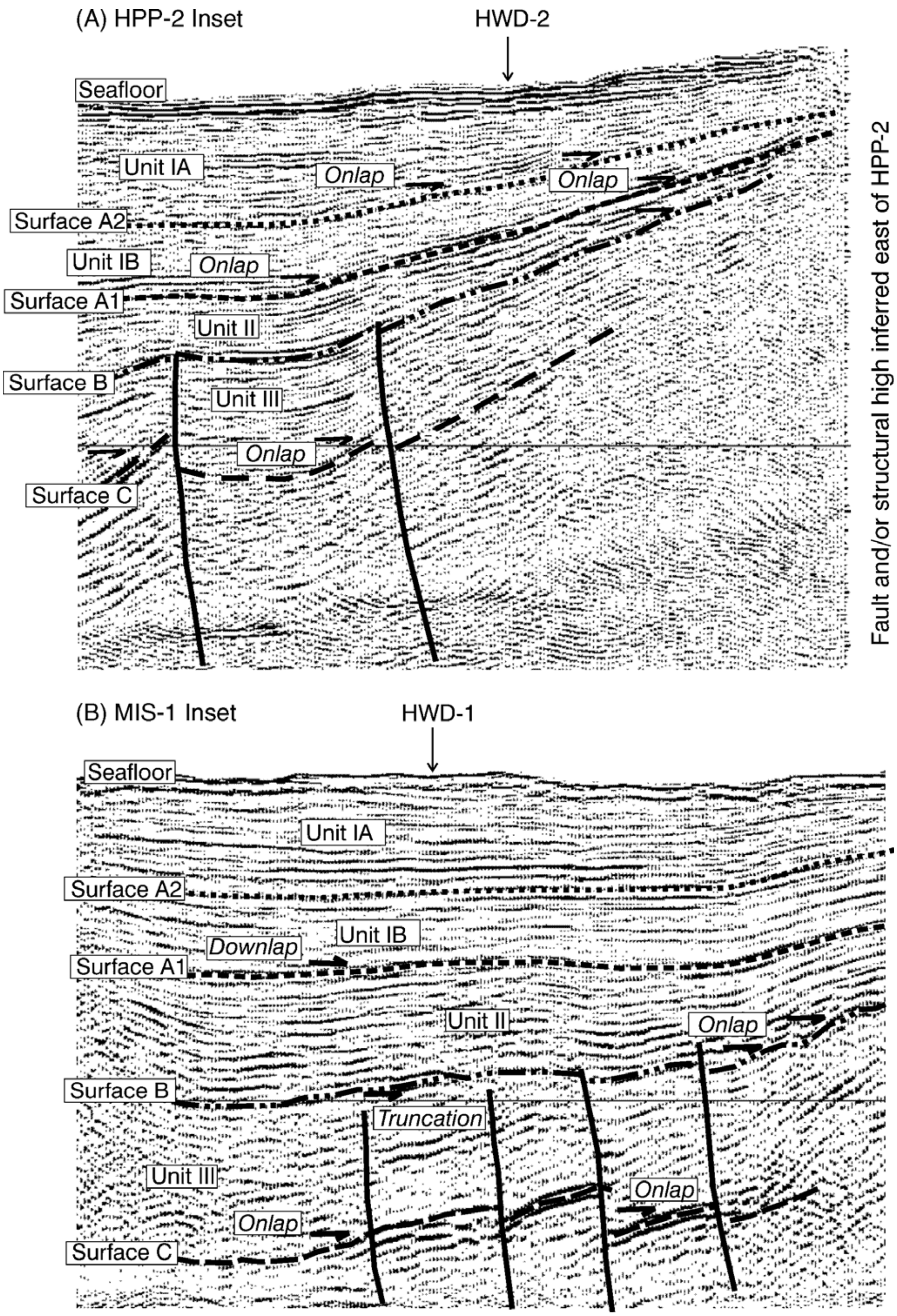

Fig. 4. Representative exploded views of the seismic data show the interpretation of stratal terminations, unit-bounding unconformities, and stratigraphic units for (A) the eastern end of HPP-2 line and (B) the western end of the MIS-1 line. Location shown in Fig. 3.

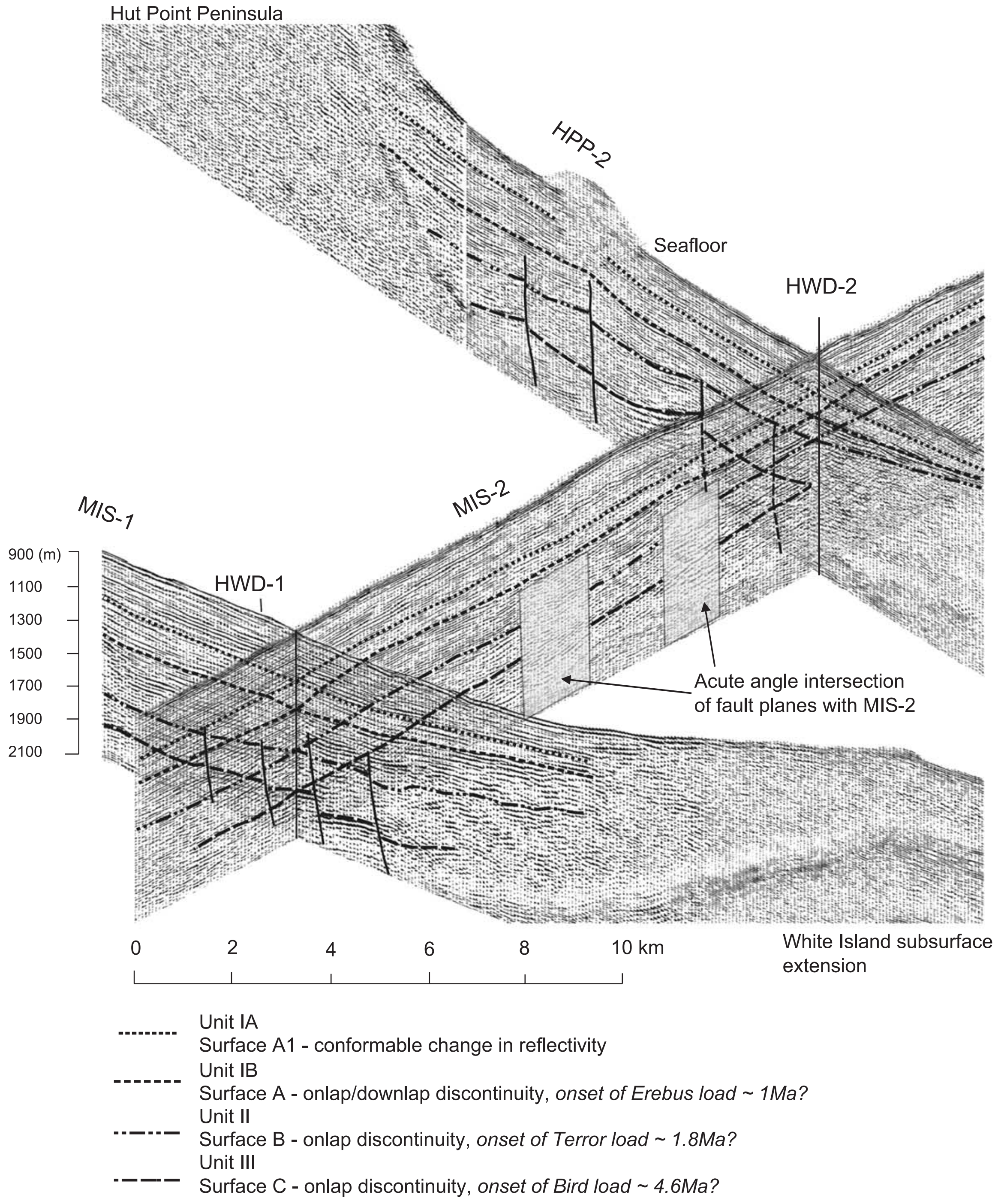

Fig. 5. 3D panel diagram of seismic reflection profiles show the regional geometry of the moat succession in the study area. All interpreted surfaces correspond to unconformities characterized by onlap of overlying strata and/or truncation of underlying reflectors and are discussed in the text. Interpreted normal faults are shown as black lines with a region of disruption due to faulting shown shaded in grey. Hot water drilling, sampling and prospective stratigraphic drilling sites (HWD-1 and HWD-2) are also shown.

Unit III. (ranges from 250 to 350 m thick) Alternating moderate and low amplitude discontinuous reflectors that are dislocated, tilted and deformed into a series of broad hummocks and swales by normal faulting. Basal strata of the unit terminate by onlap against surface C, and are locally truncated at the upper boundary of the unit by surface B.

Surface B. This surface occurs at a depth of ca. 2.0 s or 1500 m at the HWD-1 site near the MIS-1/MIS-2 intersection (Fig. 4B), where it locally truncates and displays angular discordance with the subjacent tilted strata of Unit III. Basal reflectors of Unit II terminate against surface B by onlap. N–S trending normal faults cause minor offset of surface B.

Unit II. (ranges from 200 to 300 m thick). Moderate to high amplitude continuous reflectors that are mildly deformed by normal faulting and onlap at the top of subjacent Unit II (surface B). The lower ca. 150 m of the unit is dominated by high-amplitude reflectivity, which passes upwards into moderate amplitude reflectors in its upper 100–150 m.

Surface A. Occurs at a depth of 1.65 s or 1300 m at the MIS-1/MIS-2 intersection (Figs. 4B and 5), where it marks a major change in seismic character from high- to moderate-amplitude reflectivity in the upper part of Unit II to a seismically bland, low-amplitude subunit (IB) in the base of superjacent Unit I.

Unit I. (ranges from 250 to 400 m thick). This unit consists of a 100–150-m-thick package of low amplitude seismically opaque, horizontal to subhorizontal reflectors (Unit IB), which onlap surface A and pass up into a 250–300-m-thick package of moderate to high amplitude continuous reflectors (Unit IA). The upper boundary is marked by the seafloor reflection.

Seafloor. As previously discussed, the seafloor is represented by a variable relief, high amplitude subseafloor reflection.

5. Discussion

5.1. Interpretation of the moat-fill stratigraphy and a prognosis for the ANDRILL McMurdo-Ross Ice Shelf drill site

We interpret the geometry of the three seismic units described above in terms of inferred accommodation space generated by the progressive emplacement of the Ross Island volcanic centers on the crust in southern Terror Rift. The nature of the reflectivity of the units forms the basis of a seismic facies interpretation that enables inferences to be made regarding the probable lithological characteristics of the sediments.

The interpretation presented here includes the following assumptions. It is assumed that the first order control on seismic stratigraphy is the creation of accommodation space due to flexure of the crust in response to volcanic loading. However, rift-related normal faulting does cause localized deformation of the moat-fill geometry (Figs. 3–5). An example of this occurs at the eastern end of HPP-2 where an inferred fault or structural high to the east of the line oversteepens the dip towards Ross Island. Additionally, the interpretation of the emplacement history of the various volcanic loads is based on radiometric dating of the surficial geology. As older deposits may yet be identified within the Ross Island Volcanic Complex, the ages considered here represent a minimum for the onset of loading at each volcanic center.

The chronology of the eruptive history of Ross Island (Kyle, 1990; and summarized above) indicates three phases of volcanism and associated load-induced subsidence within the adjacent flexural moat: Mt. Bird loading between 4.6 and 3.8 Ma (Wright and Kyle, 1990a), Mt. Terror loading between 1.7 and 1.3 Ma (Wright and Kyle, 1990b), and Mt. Erebus loading between 1 Ma and today (Moore and Kyle, 1990).

Flexural modeling of the lithosphere in response to these loads being emplaced at their respective times is being carried out presently and will be presented in a future paper (Wilson et al., in preparation). Initial results (Wilson et al., 2003) are consistent with the accommodation-space implied from the seismic stratigraphic architecture of the moat-fill presented in this paper. Our seismic lithology interpretation is based on the nature of reflectivity, continuity and internal geometry of the strata within the context of their depositional setting. In general, we interpret seismically opaque or low-amplitude units as predominantly fine-grained lithologies (e.g. mudstone and volcanic ash). Intervals of moderate to high-amplitude reflectivity are interpreted as coarse-grained, or alternating coarse- and fine-grained lithologies (e.g. diamictite, conglomerate, sandstone, and/or coarse volcanic deposits). The stratigraphic interpretation and prognosis for a single drill hole to be sited near the intersection of lines MIS-1 and MIS-2 (Fig. 2) is presented in Fig. 6 and described below.

Unit III, which comprises up to 350 m of moderately reflective strata deformed by normal faulting, is interpreted to be alternating coarse- (diamictite, conglomerate, lapilli and sandstone) and fine-grained (pelagic mud and ash) lithologies deposited in a flexural moat basin resulting from Mt. Bird loading.

Unit II, which comprises up to 300 m of relatively continuous moderately to highly reflective strata, is interpreted as infilling of the Mt. Terror flexural moat with alternating coarse- (diamictite, conglomerate, lapilli and sandstone) and fine-grained (pelagic mud and ash) lithologies, that progressively fine upwards. The local truncation of subjacent strata near normal fault blocks at the top of Unit III is intriguing and may represent significant bathymetric shallowing and erosion by currents and or grounding ice on structural highs prior to the emplacement of the Mt. Terror load. Subsequent onlap of the strata at the beginning of deposition of Unit II implies rapid regional subsidence and reorientation of the seafloor perhaps in association with the beginning of Mt. Terror volcanism. The cessation of the normal faulting within Unit II may represent a change in the local stress regime, as the concentric pattern of crustal flexure is progressively superimposed on the pre-existing regional pattern of extension within the Terror Rift.

Unit I, which comprises up to 400 m of relatively continuous strata that display increasing reflectivity upward, is interpreted to represent progressive infilling of the Mt. Erebus flexural moat with seismically opaque fine-grained sediments (pelagic mud and ash) at the base passing upwards to highly reflective coarse-grained deposits (diamictite, conglomerate, lapilli and sandstone) with intervening fine-grained (pelagic mud and ash) lithologies. Onlap of strata at the beginning of deposition of Unit I is interpreted to indicate rapid regional subsidence and reorientation of the seafloor coincident with the onset of significant volcanic activity and crustal loading associated with Mt. Erebus. The predominance of seismically opaque facies within the lower 150 m (Unit IB) is consistent with initial rapid subsidence and bathymetric deepening, prior to infil-

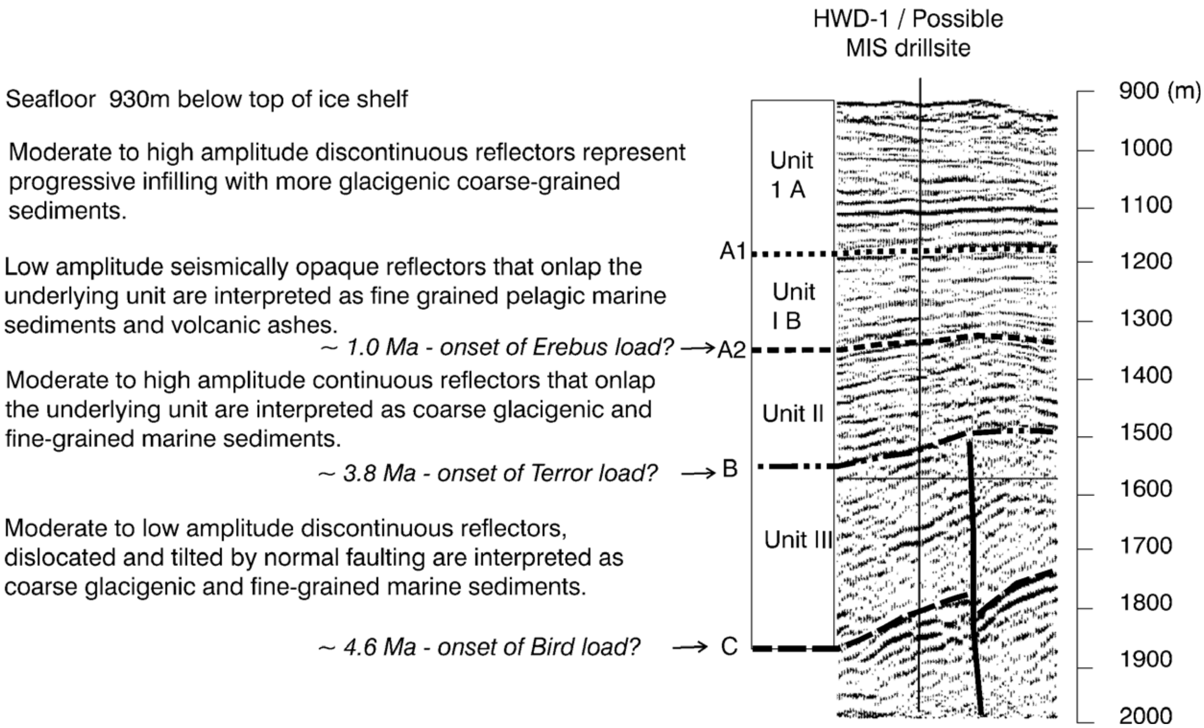

Fig. 6. Summary interpretation and stratigraphic prognosis of the moat-fill succession in the vicinity of the proposed drill site HWD-1 (near the intersection of MIS-1 and MIS-2 lines). See text for discussion and Fig. 2 for location.

ling and shoaling to more proximal coarse-grained glacimarine facies in the upper 250 m of the unit.

5.2. Implications for Antarctic glacial and climate history

We suggest that these phases of load-induced subsidence may have periodically overdeepened the moat, making it likely that the sedimentary fill is relatively continuous and has largely escaped erosion by ice grounding during glacial expansions of the WAIS and the MRIS. The age relationships of the moat-fill strata inferred from radiometric dating of the various volcanic loads are exciting in the context of the proposal to drill a 1.2-km-deep water, continuously cored stratigraphic hole beneath the MRIS in this region by the ANDRILL Program. Our results indicate that the cored interval will have the potential to provide a continuous and high-resolution (10^2–10^3 years) glacimarine record back to 5 Ma of the past variability of the WAIS and MRIS, and therefore, allow its influence on climate, ocean circulation and polar biota in western Ross Sea region to be evaluated. The target, which is scheduled to be drilled in the austral summer of 2006, will be the first attempt to recover a long stratigraphic record from beneath Earth's largest ice shelf system. The specific scientific objectives and rationale are outlined in the 2001 ANDRILL Planning Oxford Workshop Report (ANDRILL Contribution 1; Harwood et al., 2003) and ANDRILL International Science Proposal (ANDRILL Contribution 2), and are summarized at a generic level briefly below.

The primary motivation for the drilling is the recognition that ice shelves, large floating bodies of ice attached to ice sheets, are extremely sensitive early indicators of climate changes affecting ocean and atmospheric temperatures, yet their long-term behavior is poorly understood. Warming around the Antarctic Peninsula over the last 50 years has led to catastrophic collapse of some of its fringing ice shelves, most notably the Larsen B Ice Shelf collapse of March 2002. Future stability of the MRIS, which is intimately linked to the behavior of the West Antarctic Ice Sheet (WAIS), is of wide interest in the context of current global warming projections (IPCC, Houghton et al., 2001). Anecdotal evidence suggests that the MRIS maybe becoming less stable. It may be increasingly starved of ice with one of the ice stream feeders slowing down (e.g. Joughlin and Tulaczyk, 2002). This has heightened awareness of ice shelf vulnerability. Of particular concern is that the origin and fundamental behavior of the MRIS is poorly understood and models on which predictions are based need to be constrained by palaeoenvironmental data from records of the ancient ice shelf, particularly during past times when Earth was known to be warmer than it is today (e.g. during Marine Oxygen Isotope Stage 11, ca. 450 ka). Collapse of this ice shelf could affect climate significantly in two ways; firstly, by altering the salinity structure of the world oceans with the potential to slow or shut down key sectors of the global thermohaline circulation system, in particular the North Atlantic and Antarctic deep-water water production sectors, which, in the past, have caused climate changes of global extent in several decades or less (Weaver et al., 2003), and secondly, by amplifying global warming through the loss of permanent ice cover (ice-albedo feedback). While glacial reconstructions of the MRIS using sedimentological and biological proxies will be a key aim of the project, reconstructions of past sub-ice shelf and ocean circulation in the region linked to correlative Southern Ocean records will also be key to understanding the role of the ice shelf system on ocean circulation.

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