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Seismic facies and stratigraphy of the Cenozoic succession in McMurdo Sound, Antarctica: Implications for tectonic, climatic and glacial history

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Abstract A new stratigraphic model is presented for the evolution of the Cenozoic Victoria Land Basin of the West Antarctic Rift, based on integration of seismic reflection and drilling data. The Early Rift phase (?latest Eocene to Early Oligocene) comprises wedges of strata confined by early extensional faults, and which contain seismic facies consistent with drainage via coarse-grained fans and deltas into discrete, actively subsiding grabens and half-grabens. The Main Rift phase (Early Oligocene to Early Miocene) comprises a lens of strata that thickens symmetrically from the basin margins into a central depocenter, and in which stratal events pass continuously over the top of the Early Rift extensional topography. Internal seismic facies and lithofacies indicate a more organized, cyclical shallow marine succession, influenced increasingly upward by cycles of glacial advance and retreat into the basin. The Passive Thermal Subsidence phase (Early Miocene to ?) comprises an evenly distributed sheet of strata that does not thicken appreciably into the depocentre, with more evidence for clinoform sets and large channels. These patterns are interpreted to record accumulation under similar environmental conditions but in a regime of slower subsidence. The Renewed Rifting phase (? to Recent, largely unsampled by coring thus far) has been further divided into 1, a lower interval, in which the section thickens passively towards a central depocentre, and 2. an upper interval, in which more dramatic thickening patterns are complicated by magmatic activity. The youngest part of the stratigraphy was accumulated under the influence of flexural loading imposed by the construction of large volcanic edifices, and involved minimal sediment supply from the western basin margin, suggesting a change in environmental (glacial) conditions at possibly c. 2 Ma.

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Introduction

In recent years, efforts to resolve the Cenozoic history of Antarctica have increasingly focused on the westernmost part of the West Antarctic Rift System, a north-south-elongate sub-basin named the Victoria Land Basin. Data from fully cored drillholes, together with seismic reflection records, have shown that the Victoria Land Basin preserves a relatively complete archive of Cenozoic environmental change, from the latest Eocene (>34 Ma) onward. To date, however, no study has fully integrated the drilling dataset with information from the extensive array of seismic reflection records from the region.

In this paper, we present a stratigraphic framework for the Victoria Land Basin. It draws on seismic reflection records from the McMurdo Sound region and integrates all available drilling data. The internal seismic reflection character of each stratigraphic interval is then described from oldest to youngest, and the insights that these data provide to understanding of Cenozoic basin history and environmental change are summarized. The seismic stratigraphic scheme presented herein is an extension of that published by Fielding et al. (2006), with numerous additions to the younger part of the succession. It recognizes numerous laterally traceable events, many of which correlate to key surfaces of previous workers (Table 1).

Stratigraphy

Based on integration of regional seismic reflection surveys with available drillcore data, the stratigraphic succession of the western Victoria Land Basin in McMurdo Sound, Antarctica, has been resolved into a series of intervals each reflecting changes in basin-forming tectonic processes (Table 1). “Phase 1” of Table 1 refers to formation and exhumation of the Transantarctic Mountains prior to commencement of sediment accumulation in the VLB.

The Early Rift phase (34-29 Ma: “Phase 2” of Table 1) is characterized by a thick succession of mainly coarse-grained lithologies that largely lacks evidence of cyclicity. Lithofacies and seismic facies together suggest progradation of coarse-grained fan and delta systems into progressively opening half-graben infra-basins. Available data suggest that sediments were accumulated in shallow water throughout this interval, indicating a ready supply of terrigenous clastic sediment was able to balance the rapid rate of subsidence. The Main Rift phase (29-23 Ma: “Phase 3” of Table 1) is characterized by a more parallel, continuous reflection character, with a gradual eastward expansion of accommodation associated with the transfer of the depocentre to a more basin-central location. This has been interpreted in terms of repeated cycles of shallow marine to coastal facies, with a cyclical motif becoming increasingly recognizable up-section. Cyclicity

Table 1. Seismic stratigraphic framework for this study, showing interpretation in terms of rift history and correlation to other seismic stratigraphic schemes for the region (modified after Fielding et al., 2006).

Cooper et al., 1987	Brancolini et al., 1995	Bartek et al., 1996	Anderson and Bartek 1992	Horgan et al., 2005	This PAPER		RIFT PHASE
V1							5b
				Surface A0		Rk	
		A-B					
	RSU 1?	C-D?	3/2?	Surface A1	?2 Ma ↑	Rj	
		A-H					
	RSU 2	E-F	5/6	Surface A2	4.6-4.0 Ma	Ri	
	RSS 5-8 (MIDDLE MIOCENE IN DSDP273) RSU4 (LOWER MIOCENE IN DSDP 273) RSS4	G-H			Rv ↓		
	RSU 4a		9/10	Surface B	?7.5 Ma	Rh	5a
V2	RSS 3						
	RSU 5	L-M	10/11	Surface C		Rg	4
V3	RSS 2						
	~RSU 6	P/Q			17 Ma	Rf	
	RSS 1					■	
		R/S				■	
V4					23 Ma	Re	3
						Rd	
		T					
V5					29 Ma	Rc	
						Rb	2
					34 Ma	Ra	
V6		("volcanics")					1
V7		("basement")					

1 – Exhumation of the Transantarctic Mountains, 2 – Early Rift, 3 – Main Rift, 4 – Passive Thermal Subsidence, 5a – Renewed Rifting, lower interval (no significant magmatic products), 5b – Renewed Rifting, upper interval (significant magmatic products). Flexural loading of the lithosphere in the region around Ross Island commenced at about the time of the turquoise reflector.

has been interpreted to derive from glacial advance-retreat patterns and associated eustatic sea-level fluctuations, while the thickness of cycles has been attributed primarily to changes in tectonically-driven accommodation. The glacial character of the sediments becomes more apparent during this interval. This long term cooling trend is consistent with increased physical weathering indicated by clays and various palaeontological and other proxies.

The Passive Thermal Subsidence phase (23-<17 Ma: "Phase 4" of Table 1) is again characterized by parallel, mainly concordant reflections, but contains more abundance for incision of channel scours at sequence boundaries, and of clinoform sets within sequences. In core, it comprises many short, condensed and strongly top-truncated stratal cycles with continued, periodic glacial influence. These patterns are interpreted to record accumulation under similar environmental conditions but in a regime of slower subsidence. Lithofacies data from drillcores indicates a progressively more austere climatic regime through this time, but subsidence analysis also indicates a substantially lower rate of subsidence as is expected for a postrift, thermal subsidence regime. Accordingly, the changes in seismic facies are attributed herein primarily to the lower rate of subsidence preferentially preserving channels and clinoform sets within the stratigraphy.

The lower part of the Renewed Rifting (lower Terror Rift) phase ("Phase 5a" of Table 1) is seismically similar to, and homoclinal with, the underlying section, and is interpreted to record similar conditions. The upper part of this section, however ("Phase 5b" of Table 1), shows substantial changes both in cross-sectional geometry and internal seismic facies that are worthy of review. The dark green reflector ("Rh": ?7.6 Ma), separating the two parts of the Renewed Rifting phase, clearly records a substantial tectonic upheaval along the western margin of the basin, causing progressive uplift of the proximal section and presumably a depositional hiatus. Erosion of material from the western margin provided sediment for renewed sediment accumulation, initially in a single, thick, seismically defined sequence with a prominent lowstand wedge and displaying subsequent downlapping and onlapping relationships onto this body. The substantial vertical interval of this sequence implies a major rise in relative sea-level, and it may coincide with a massive rise in sea-level (~100 m) between 6 and 5 Ma that preceded Pliocene climatic deterioration. The red event ("Ri": Table 1) also records a major change in seismic facies, marking the base of an interval of significant clinoform sets. This again is interpreted as reflecting a further interval of significant terrigenous clastic sediment input to the basin. However, the apparent dip directions of the clinoforms suggests that here, the dominant direction of sediment dispersal may have changed from transverse (from the west) to axial (from the south). Relationships between the red event and inferred volcanics and microfossil data suggest that the red event may be c. 4.6-4.0 Ma in age. The clinoform-dominated section between the red ("Ri") and turquoise (Rj") reflectors represents the youngest interval of thick sediment accumulation along the western margin of the VLB in possible shelf-margin delta environments, and clearly records a change in sediment dispersal patterns.

The uppermost part of the section, above the turquoise reflector ("Rj": Table 1), was formed during a period of little to no sediment input from the western basin margin. In this interval, thickness distribution patterns and seismic facies indicate that sedimentation was dominated by downslope mass wasting and basin floor filling in deep water, caused by flexural loading and formation of the Erebus Moat. This suggests that supply of voluminous terrigenous clastic sediment was shut off at c. 2 Ma, since the turquoise event must postdate construction of the Ross Island volcanoes. Most of the erosional relief evident at the modern sea-floor, such as the Mackay Sea Valley and other valleys offshore from the Ferrar valley and New Harbor, and near-surface channel fills such as are found near CIROS-1, is interpreted to postdate the turquoise event, from cross-cutting relationships. This suggests that the shutdown in clastic sediment supply noted above was accompanied by a regime of profound erosional scouring across the Western Slope of the VLB and elsewhere.

Discussion and summary

Despite the manifest glacial influence on sedimentation and stratigraphic stacking patterns within the western VLB section (or at least, the latest Eocene to Early Miocene part that has been cored to date), the cross-sectional geometry of broad intervals, individual sequences and seismic facies within sequences are believed to owe their character more to the subsidence pattern that characterizes each basin phase. This suggests that it would be unwise to interpret drilling records solely in terms of climatic history, in isolation from the regional context of the succession. This pattern is also consistent with recent research on rift basins, including glaciated rift basins, that suggests that the overriding control on facies architecture is tectonic. Nonetheless, the coincidences between key stratigraphic surfaces and evidence for major environmental change through the Cenozoic succession in the southern Victoria Land Basin suggest some causal link between tectonic and climatic drivers through this time.

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