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Gravity anomalies of sedimentary basins and their mechanical implications: Application to the Ross Sea basins, West Antarctica

Garry D. Karner*, Michael Studinger, Robin E. Bell

Lamont–Doherty Earth Observatory of Columbia University, 61 Route 9W, Palisades, NY 10964, USA

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Abstract

In general, sedimentary basins are characterized by negative free-air and Bouguer gravity anomalies. However, the extensional basins of the Ross Sea are paradoxical in that positive gravity anomalies overlay the Victoria Land Basin, Northern Basin, Central Trough and Northern Central Trough while basement highs are associated with negative gravity anomalies. Measured basement densities from DSDP basement cores give values between 2600–2800 kg/m^3 while bulk sediment densities range from 1210–2200 kg/m^3, indicating a normal density relationship between basement and sediment infill. In contrast, the relatively young and narrow Terror Rift is associated with negative free-air and Bouguer gravity anomalies, but has a different geological history as compared to the larger Ross Sea basins. Process-oriented gravity modeling indicates that magmatic underplating and crustal intrusions are inconsistent with the observed gravity and basement geometry of the Ross Sea basins. The magma volume necessary to account for the distribution and amplitude of the positive gravity anomaly of the Central Basin and be isostatically balanced would need to be comparable to the tholeiitic flood basalt volume of the Columbia River province—it is thus unlikely that the volume of Neogene volcanics of the Ross Sea region is sufficient to explain the observed gravity relationship by modifying the bulk density of the crust.

We demonstrate that positive free-air and Bouguer gravity anomalies over extensional basins are the consequence of a relatively low flexural strength of the lithosphere during rifting being contrasted by higher flexural strengths later during sedimentation. As the difference between the rigidity of the lithosphere during sedimentation increases relative to the rigidity of the rifted lithosphere, the gravity over the basin becomes progressively more positive but only for a limited range of wavelengths. The narrow width of the Terror Rift precludes it from having a positive gravity anomaly while the opposite is true for the large Ross Sea basins. For the Ross Sea region, such a loading scenario requires a significant delay between extension and the timing of sediment infilling of the basins, consistent with the late Cretaceous extension of the Ross Sea region and the sedimentary succession being dominated by large-scale late Eocene–Neogene glaciogenic progradational sequences. Sediment source was presumably from the denudation of the Transantarctic Mountains, which commenced in the late Paleogene. The time delay between the late Cretaceous formation of the Transantarctic Mountains, late Paleogene exhumation,

* Corresponding author. Tel.: +1 845 365 8355.
E-mail addresses: garry@ldeo.columbia.edu (G.D. Karner), mstuding@ldeo.columbia.edu (M. Studinger), robinb@ldeo.columbia.edu (R.E. Bell).

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and the generation of significant Paleogene paleobathymetry requires either the Ross Sea region to be sub-aerial and sediment starved for most of the Paleogene and/or the Paleogene climate was ineffective in producing clastics until the onset of glaciation in the late Eocene–early Oligocene.

Keywords: gravity anomalies; isostasy; lithospheric flexure; extensional basins; Paleogene climate; Antarctica

1. Introduction

In general, sedimentary basins are characterized by negative free-air gravity anomalies and by symmetry, ridges and interbasinal highs are associated with positive free-air gravity anomalies. In marked contrast, Liu et al., [1] and Holt and Stern [2] discovered that the 85° Ridge in the Central Indian Ocean and the western platform of New Zealand are characterized by negative and positive gravity anomalies, respectively. In each case, the unusual gravity association was a consequence of a significant delay between the formation of the feature and the timing of sedimentation. For the western platform of New Zealand, the Plio–Pleistocene Giant Foreset Formation loaded a sediment-starved margin produced during the late Cretaceous rifting of the Lord Howe Rise from the Australian continent. For the 85° Ridge, Neogene sediments of the Bengal Fan completely engulfed a ridge that had been magmatically emplaced on young oceanic crust in the late Cretaceous. These studies underscore the important relationship between the changing mechanical properties of the lithosphere, load history, and gravity anomalies.

Positive free-air and Bouguer gravity anomalies exist over the large extensional basins of the Ross Sea while negative anomalies overly the intervening basement highs. If this gravity relationship is also a consequence of variations in the flexural rigidity of the lithosphere during and after rifting coupled with a delay in the main phase of sedimentation, then the gravity anomalies of the Ross Sea basins have profound implications for the flexural behavior of rifted continental lithosphere, the history of sedimentation, development of the Transantarctic Mountains, and the Paleogene climate of West Antarctica.

The West Antarctic rift system, a region of thinned continental crust, is bounded to the south and west by the Transantarctic and Whitmore Mountains and to the north by Marie Byrd Land [3]. This low lying region, similar in size to the Basin-and-Range Province of North America, is 550 km wide adjacent to the Whitmore Mountains and reaches a maximum width of 1000 km in the Ross Sea. Sedimentary basins parallel the Transantarctic Mountains in the Ross Sea and are believed to continue beneath the Ross Ice Shelf into the Interior Ross Embayment [4,5]. Two distinct phases of extensional activity help explain the thinning of the crust and the formation of sedimentary basins in West Antarctica, a significant and broadly-distributed late Cretaceous (105–85 Ma) extension event [3,6] and a locally-distributed relatively minor Neogene event [7–10]. The progressive fragmentation of Gondwana led to the establishment of a series of major sedimentary basins in the Ross Sea (Fig. 1). Neogene extensional fault reactivation in the western Ross Sea resulted in the development of minor accommodation in a relatively narrow and linear basin, the Terror Rift. Minor extension is consistent with the high angle, small offset normal faults that characterize the region. From the reflection seismic sections across the Ross Sea summarized by Cooper et al. [11], the Terror Rift is more appropriately described as a disrupted zone of Cenozoic igneous intrusions rather than a region of major extension.

A flexural rebound origin is often invoked for the formation of the Transantarctic Mountains in response to late Cretaceous or late Paleogene–early Neogene extension [12–16]. Because of the high average elevation of the mountains, extreme extension is required [17] to induce sufficient flanking uplift, thus implicating late Cretaceous extension as the causative event. However, the exhumation of the mountains occurred significantly after late Cretaceous rifting. Fission-track data suggest that the main period of denudation is in the early Cenozoic [6,18] (50–55 Ma) but geological and geophysical evidence for significant Tertiary deformation does not exist. Most of the sediments in the Ross Sea basins are Neogene in age, although late Cretaceous syn-rift sediments are