Identifying Major Sedimentary Basins Beneath the West Antarctic Ice Sheet from Aeromagnetic Data Analysis

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Abstract. In the Ross Sea, large sedimentary basins reflect primarily the major extensional event associated with the Late Cretaceous breakup of Gondwana. Within the Interior Ross Embayment, no similar large basins have been identified to date. We have used aerogravity and Werner deconvolution methods applied to aeromagnetic data to map depth to magnetic basement, which helped delineate three major sedimentary basins, the Bentley Subglacial, Onset, and Trunk D Basins.

Introduction

The West Antarctic rift is a region of thinned continental crust, bounded to the south and west by the Transantarctic and Whitmore Mountains and to the north and east by Marie Byrd Land (Tessensohn and Wörner 1991) (Fig. 3.2-1).

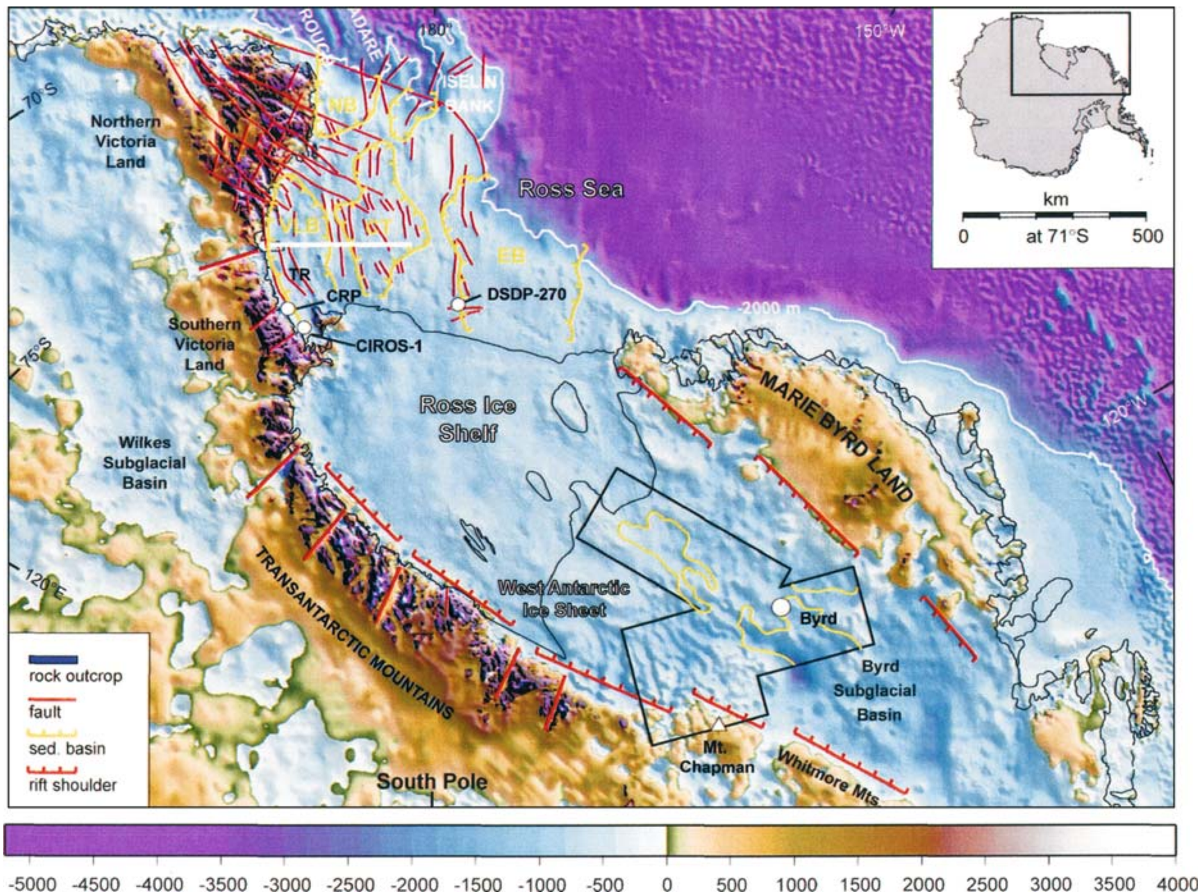

Fig. 3.2-1. Location figure for aerogeophysical data. Aerogeophysical survey area is outlined in *black* and the basins derived from this analysis are shown in *yellow*. The profile shown in Fig. 3.2-2 is illustrated as a *white line* in the western Ross Sea. Image is using data from the BEDMAP compilation of Lytte et al. (2000). Ross Sea basins (*yellow*) are from Busetti et al. (1999) and faults (*red*) from Salvini et al. (1979) and Fitzgerald (2000), and references therein. *CRP:* Cape Roberts Project; *CT:* Central Trough; *EB:* Eastern Basin; *NB:* Northern Basin; *TR:* Terror Rift; *VLB:* Victoria Land Basin

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Three distinct phases of tectonic activity have been advanced to explain the formation of this broad low-lying region, an early extensional phase, associated with the Jurassic intrusion of the Ferrar dolerites (Wilson 1992), a Late Cretaceous event linked with the progressive fragmentation of Gondwana (e.g., Cooper et al. 1991; Wilson 1992; Wilson 1995), and a final but minor phase of activity evidenced by Cenozoic faulting in the western Ross Sea as evident in the Terror Rift, dextral offset structures, and the extrusion of bimodal alkalic volcanic rocks (e.g., Behrendt et al. 1991). The amount of extension associated with each of these phases of tectonic activity remains under discussion.

The major basins of the Ross Sea, the Eastern, Central Trough and Victoria Land Basins, are interpreted as primarily the result of Late Cretaceous regional lithospheric stretching and subsidence (Davey and Cooper 1987). The western Ross Sea basins are 100–150 km wide while the Eastern Basin is 300 km wide. These basins parallel the Transantarctic Mountains and are thought to continue beneath the Ross Ice Shelf into the Interior Ross Embayment (Cooper et al. 1991; Munson and Bentley 1992).

Aerogeophysical surveys and seismic studies of the Interior Ross Embayment have imaged several small sedimentary basins but no large basins equivalent in scale to the Ross Sea basins have been recognized. The basins identified to date are relatively narrow (10–40 km wide), with maximum sediment thicknesses of 1–2.5 km (Bell et al. 1998; Studinger et al. 2001; Studinger et al. 2002).

Generally, the sedimentary basins in the ice-covered portions of Antarctica have been identified on the basis of gravity lows and reflection seismic data. However, in the Ross Sea, all the major basins are associated with broad and regional Bouguer gravity highs. While such gravity anomalies can be produced by crustal intrusions, the regional and organized nature of the gravity highs are simply explained in terms of the strengthening of the rifted lithosphere prior to sedimentation (Karner et al. 2005). We use Werner deconvolution of aeromagnetic data to define basement geometry and identify the location of the major sedimentary basins in the Interior Ross Embayment. The gravity sign, positive or negative, helps distinguish between Late Cretaceous (positive) and Cenozoic (negative) extension.

Methodology: Application of Werner Deconvolution to Aeromagnetics

Magnetic data are often used to estimate the depth to magnetic basement in sedimentary basins and passive continental margins (e.g., Klitgord and Behrendt 1979). Magnetic methods can accurately trace the depth of the magnetic basement over sedimentary basins when the sedimentary rocks have weak magnetic susceptibilities relative to the underlying crystalline/volcanic basement. The basic assumption of the Werner method is that all magnetic anomalies are the result of either a sequence of dykes or an interface between juxtaposed half-spaces of

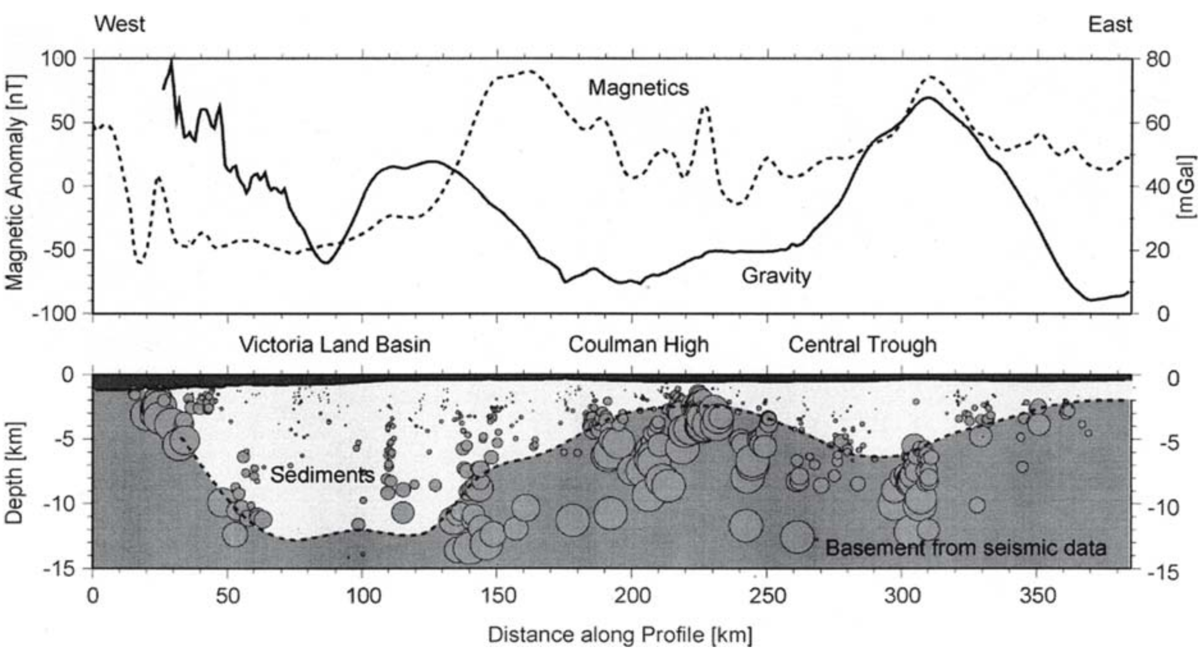

Fig. 3.2-2. Werner solutions along a seismic profile in the Ross Sea located in Fig. 3.2-1. The *circles* are the Werner solutions for depth to magnetic basement with the size of the circles being scaled to the magnetic susceptibility. Magnetic data (Bosum et al. 1989) as well as gravity, bathymetry and basement data are also shown (Childs et al. 1995)

different magnetic susceptibility (Werner 1953). Our Werner deconvolution algorithm uses simple models for the source and a quadratic form for the source/noise interference to determine the magnetization properties of the causative bodies. We use both interface and dike solutions to define the magnetic basement.

To demonstrate the power of the Werner approach, we used Werner deconvolution solutions in the Ross Sea where the basement structure has been determined seismically. The clustering of the high susceptibility Werner solutions along the seismically determined basement (Fig. 3.2-2) demonstrates that the Werner approach can be used to define the basement structure even in the presence of widespread highly magnetic intrusives. The diameter of the plotted solutions relates to susceptibility magnitude.

In order to define the basin structure in the Interior Ross Embayment, we used airborne geophysical data collected onboard a ski-equipped DeHavilland Twin Otter (Bell et al. 1998; Bell et al. 1999; Brozena et al. 1993). The aeromagnetic data were collected with a towed Geometrics 813 proton-precession magnetometer with an estimated precision of about 1 nT (Sweeney et al. 1999). The composite grid was draped from its original flight elevation surface onto a surface 1 500 m above the bedrock elevation surface (Fig. 3.2-3b). Ice-thickness measurements from ice-penetrating radar and laser altimetry of the ice surface topography have been used to derive subglacial topography (Blankenship et al. 2001).

In order to define the basement structures and subsequently the sedimentary basins in the Interior Ross Embayment, we have applied the Werner deconvolution method along 22 profiles (500–800 km long spaced ~25 km apart). Using the upper limit of the Werner solution clusters along each profile, we estimated the depth to magnetic basement and thus regional basin geometry. The resulting magnetic basement depth estimates were gridded to produce a depth to magnetic basement map for the region. (Fig. 3.2-3c).

Definition of Major Interior Ross Embayment Sedimentary Basins

The West Antarctic study area traverses both the Whitmore Mountain block, a region of elevated rugged topography in the southeast, and the generally low-lying thinned crust of the Interior Ross Embayment (Fig. 3.2-3a). To date, no major sedimentary basins equivalent to the large Ross Sea basins have been identified from the subglacial elevation, the Bouguer gravity or the magnetic data over the Interior Ross Embayment. The Werner deconvolution magnetic depth to basement solutions for the entire region varies from 1 800–4 500 m (Fig. 3.2-3c). In the southeast, the Whitmore Block delineated by topography, Bouguer gravity (Fig. 3.2-3d) and seismic constraints on crustal thickness (Clarke et al. 1997), is characterized by relatively deep magnetic basement, on average 3 800 m occasionally disrupted by isolated regions of shallow magnetic depths. The regions of shallow magnetic basement tend to be discrete points or circular structures (82° S 110° W) and are interpreted as Late Cenozoic volcanic edifices (Blankenship et al. 1993).

In contrast to the Whitmore Mountain Block, the Ross Embayment is characterized by generally very shallow magnetic basement depths on average 2 600 m. The northern margin of the study area, adjacent to Marie Byrd Land, is characterized by shallow magnetic basement as is the region to the west of the Whitmore Mountains. We interpret these broad regions of shallow magnetic solutions as basement highs, akin to the Ross Sea basement highs. Between these bordering areas of uniformly shallow basement are regions of much deeper magnetic basement. We have defined regions with magnetic basement depths greater than 3 800 m as sedimentary basins. These regions of deeper magnetic basement are disrupted by small localized, often circular points of shallow magnetic basement, similar to the isolated points of shallow magnetic basement in the Whitmore Block. We interpret the isolated points of shallow magnetic basement as volcanic intrusions. Three large well defined sedimentary basins greater than 100 km in width are delineated in the Werner solutions (Fig. 3.2-3c). The three large basins with average magnetic basement depths of 4 500 m are the Bentley Subglacial Trench north of the Whitmore Mountains, the Onset Basin west of the Whitmore Mountains, and the Trunk D Basin underlying Ice Stream D. The Werner solutions also delineate a smaller basin (at 80.5° S, 127° W) about 40 km in width to the west of Byrd Station and one edge of a sedimentary basin in the northeast.

In the east, the Bentley Subglacial Trench is 100 km wide and over 300 km long and parallels the Whitmore Mountain Front. Situated in the deepest portion of West Antarctica, the topography over the basin varies smoothly from 900–1 700 m below sea level. The Bouguer gravity over this basin is a broad 30 mGal positive anomaly relative to the regional trend (Fig. 3.2-3d). The shape and gravity anomaly of the Bentley Basin is very similar to the Central Basin in the Ross Sea.

In the west, the Trunk D Basin is up to 100 km wide and 250 km long and trends at an angle oblique to the Whitmore Mountain Front. The Trunk D Basin correlates with very rough topography with elevation ranging from 400 m above sea level to 900 m below sea level. The topography over the Trunk D Basin may either reflect ice stream processes, as the seafloor topography in the Ross Sea, or possibly recent tectonics. The Bouguer gravity is not consistently positive. The northern half of the basin is characterized by a positive gravity anomaly while the southern half is associated with a gravity negative. The

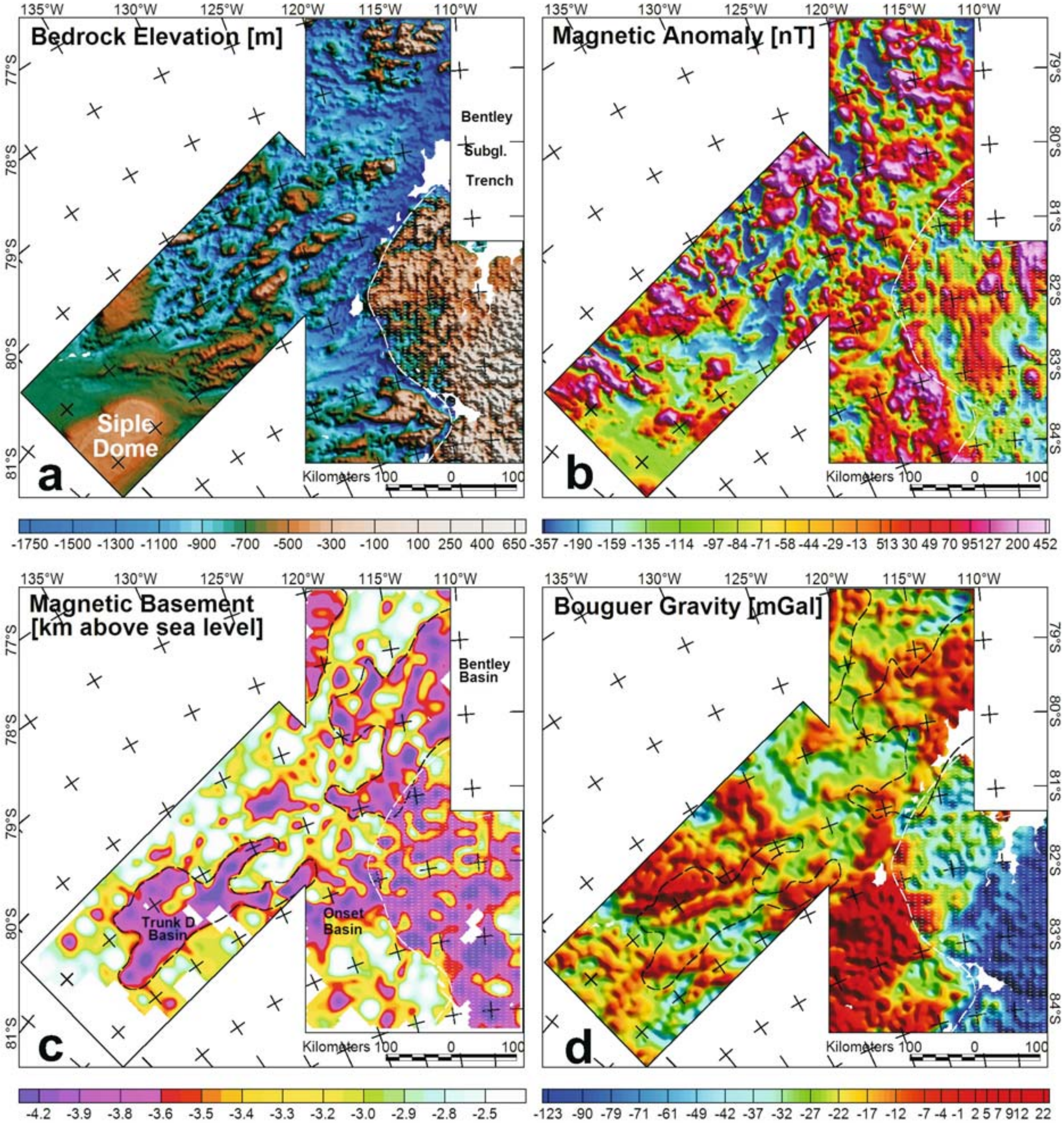

Fig. 3.2-3. Interior Ross Embayment geophysical maps. *White dashed line* shows the boundary between the Whitmore Mountains Block and the Interior Ross Embayment. *Black lines* outline regions of Werner solutions interpreted as sedimentary basins

complex gravity anomaly of this basin resembles the gravity anomaly over the Victoria Land Basin (Late Cretaceous) and the Terror Rift (Cenozoic).

The onset basin lies close to the boundary of the Whitmore Mountains with the Interior Ross Embayment, is 100 km wide and may be the southeastern extension of the Trunk D Basin. The southern margin of this basin correlates well with the basin imaged seismically by Anandakrishnan et al. (1998). The subglacial topography overlying this basin is generally deep and varies smoothly from 900–1 100 m below sea level. This basin is coincident with the northern portion of a major positive Bouguer gravity anomaly.

Conclusions

The unusual positive gravity anomalies of the large Ross Sea basins suggests that identifying the major sedimentary basins within the West Antarctic Rift System cannot be based simply on gravity anomalies. Werner deconvolution of aeromagnetic data can be used to define basement structure and delineate the location and geometry of major sedimentary basins. We identified three basins within the Interior Ross Embayment using magnetic data. These basins are primarily associated with positive Bouguer gravity anomalies and thus we suggest that these basins were probably formed during the Late Cretaceous Gondwana breakup.

Acknowledgments

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